2019-2020 ACRP UNIVERSITY DESIGN COMPETITION

A Cost-effective Approach to Predict Noise Impacts for Non-Towered GA Airports

(January 2020 – April 2020)

Design Challenge: Airport Environmental Interactions Challenges

Team Members:

Graduate Students: Chuyang Yang, Weisi Li

Undergraduate Students: Zachary A. Marshall

Advisor's Name: Dr. John H. Mott

Name of University: Purdue University

PURDUE UNIVERSITY | School of Aviation and Transportation Technology POLYTECHNIC INSTITUTE

1. Executive Summary

Noise pollution is a major, negative externality of airport operations, threatening the health of citizens and growth of aviation. Mitigation of noise pollution is a core goal of managing environmental interactions and inherently aligns with the aim of reducing aviation emissions. As noise pollution adversely affects the operation and expansion of airports by restricting land zoning and flight patterns, procuring precise noise generation and propagation models is imperative (ICAO, 2020). The Federal Aviation Administration (FAA) utilizes the Aviation Environmental Design Tool (AEDT) to assess noise impacts for regulatory compliance and system planning (FAA, 2020). However, non-towered airports lack operations data for advanced noise modelling programs and alternative acoustic sensors are unreliable and unaffordable in recording aircraft noise. To model noise around general aviation (GA) airports, the proposed system estimates flight operations by deploying inexpensive hardware, estimates noise levels by integrating information sources with the Aircraft Noise and Performance (ANP) database, and visualizes noise impacts through Geographic Information System (GIS) software.

The following proposal presents risk, cost, and sustainability assessments and a holistic description of a novel noise modelling system. The design team's background encompasses aviation technology, aerospace engineering, and mechanical engineering technology. Industry and academic experts in airport management, noise consulting, aeronautics, and acoustical engineering were engaged throughout the system design and analysis process.

2. Table of Contents

2.1 Figures

2.2 Tables

3. Background and Problem Statement

Beyond a general annoyance, excessive noise levels induce hearing impairment, stress elevation, and sleep deprivation among residents of communities surrounding airports. Aviation noise pollution, generated primarily by wake turbulence, blade rotation, and fuel combustion, are exacerbated in the high-power, low-altitude takeoff regime. These negative impacts on the local community, where near the airport, affect the operations and expansion of airports, and planning of land use (ICAO, 2020). Aircraft noise is also recognized as a highly technical and complex issue by the Federal Aviation Administration (FAA) (2018). FAA annually sponsored research projects on noise mitigation through the Airport Improvement Program (AIP). The federal government, airports, and related stakeholders work collaboratively to address noise near airports under 14 CFR Part 150 (FAA, 2015). Efforts on minimizing the negative impact of aircraft noise are heavily influenced by the accurate assessment of the geometric distribution of aircraft noise.

The Aviation Environmental Design Tool (AEDT) is a software system that models aircraft noise, emissions, and air quality consequences and provides such information to FAA stakeholders on each of these specific environmental impacts (FAA, 2020a). Aircraft operations and fleet mix data are required when users execute AEDT to compute the noise exposure level (Figure 1); however, those data are not available from non-towered GA airports. Despite several airport operations estimation approaches that have been developed by researchers, the test results showed limitations in accuracy and cost-efficiency of deployment (Muia & Johnson, 2015; Yang et al., 2019). Rather, tracking aircraft through transponder signals and applying noise propagation algorithms to flight paths yield accurate time maps of noise levels around airports. Collected with inexpensive transceiver hardware and visualized with geographic information system software, noise data can be evaluated for compliance with regulatory standards and harnessed for city planning and airport design.

In this report, the proposed technology will be designed according to the following procedures:

(1) Aircraft operation will be estimated based on a 4D trajectory using ADS-B from a low-cost aircraft transponder receiver.

(2) Fleet mix information will be obtained from the publicly available databases from the FAA, and noise level will be computed by referring the aircraft noise and performance (ANP) database from EUROCONTROL.

(3) The noise impacts on the local community near non-towered GA airports will be visualized using a Geographic Information System (GIS).

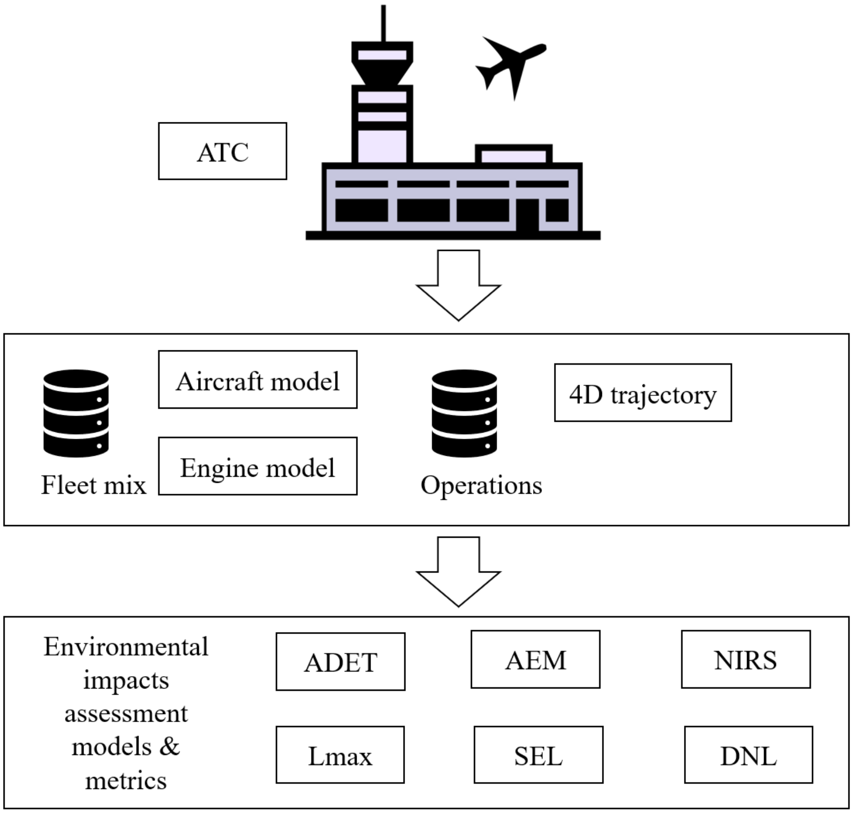

Figure 1. Noise prediction process for towered airports (FAA, 2017a)

4. Summary of Literature Review

4.1 Aircraft Noise and Its Impact

Noise is defined as any unwanted sound and depends on several factors: time of day, length of time, emotional variables, and physical surroundings (Pennsylvania State University, 2020). Despite the fact that there are different sources of noise in and around an airport, the noise produced by aircraft during the Landing and Take-off (LTO) cycle at an airport is measured as the unique noise source in this project (ICAO, 2020).

According to Pennsylvania State University (2020), the scientific-medical community has divided the noise effects on individuals into two general categories of responses:

(1) Psychological Effects. These represent people's psychological reactions to their noise environment and their interference with their daily activities.

(2) Physiological Effects. These represent the effects on the human body's systems such as noise-induced hearing loss.

Since the aircraft noise has a significant impact on the nearby environment, the FAA (2020b) developed four areas to be examined in the consideration of compatible land use around airports.

(1) Impact of aircraft noise. Noise contours are developed to keep incompatible structures, such as residential areas and schools, from being built near airports. Additionally, baselines of noise contours are set to protect people from excessive noise and emissions.

(2) Conflicts between aircraft and tall structures near the airport.

(3) Electronic interference with aviation navigation aids.

(4) Interaction between aircraft and wildlife.

4.2 Models and Metrics used to measure Community Noise Exposure

According to the definition by Pennsylvania State University (2018), 'noise models' are computer programs that can be used to compute environmental impacts caused by various aspects of aircraft and their operations such as fleet mix, flight procedures, runway use, etc., while 'noise metrics' are defined as calculations that express the effect of noise.

FAA's Environmental Policy Teams help develop and ensure that the latest noise impact evaluation tools are used such as the Aviation Environmental Design Tool (AEDT), Area Equivalent Method (AEM), and Noise Integrated Routing System (NIRS) & NIRS Screening Tool (FAA, 2018).

(1) Aviation Environmental Design Tool (AEDT). In order to help the U.S.

government to consider the interdependencies between aircraft-related fuel consumptions, noise, and emissions, AEDT is actively used as software by modeling aircraft four-dimensional (space and time) performance to estimate fuel combustions, emissions, noise, and air quality impacts (FAA, 2019).

(2) Area Equivalent Method (AEM). AEM is a mathematical screening tool for AEDT and a quick way to determine the impact of changes in fleet mix or operations counts as part of noise study (FAA, 2018). As a rule of thumb, a 17% increase in the DNL 65dB contour area is the threshold indicates that further analysis using AEDT is required (FAA, 2018).

(3) Noise Integrated Routing System (NIRS). NIRS is a noise-assessment program designed to provide an analysis of air traffic changes over broad areas. NIRS was first developed to work in conjunction with other Air Traffic modeling systems in 1998 and replaced by AEDT version 2a in 2012 (FAA,2017b). The NIRS Screening Tool (NST) is an application tool that facilitates evaluation of potential noise impacts as a result of changes in airport arrivals and departures above 3,000 feet above ground level (AGL). This tool has been replaced by the Aviation Environmental Screening Tool (AEST), which is currently available only for use by FAA employees (FAA, 2017b).

There are three noise metrics are utilized by the FAA (2020):

(1) A measure of the highest sound level occurring during an individual aircraft overflight (single event). Single events can be measured by Maximum Sound Level (L_{max}) or Sound Exposure Level (SEL),

(2) The single event's maximum level plus its duration,

(3) The cumulative noise levels from multiple flights.

The Equivalent Noise Level (LEQ) is measured by the average sound level over a time period, while the Day-Night Average Sound Level (DNL) is measured over 24 hours with a penalty to operations taking place at night between 10 pm and 7 am (FAA, 2018e).

4.3 Operations estimation methods at non-towered airports

Bernardo (2012) created a set of generic airports in support of a framework for environmental aviation analysis using fleet-mix information such as the total number of operations and types of aircraft. These generic airports can be used to infer noise-specific trends about airports by simply analyzing the generic version, reducing computational demands in early fleet-level airport analysis.

Despite several airport operations estimation approaches that have been developed, the test results in Table 1 showed limitations in the accuracy and cost-efficiency of deployment (Muia & Johnson, 2015; Yang et al., 2019).

Table 1

Basic accuracy and cost information for existing operation estimation methods

Counting Technology[1]	Test Airport	Reported Percentage Error	Cost Per Unit[2]
Sound-Level Meter Acoustic Counter (portable acoustic counter)	KLAF	5% to 99%	$4,800
	KTYQ	8% to 48%	
Security/Trail Camera (portable camera with infrared night vision)	KLAF	54% to 100%	$1,000
	KTYQ	0% to 43%	
Stationary Visual Image Detection (VID) with ADS-B Transponder Receiver (stationary)[3]	KTYQ	10% to 17%	$36,000

Note:

1. This table was retrieved from Yang et al. (2019)
2. The costs are represented as paid for the equipment tested in ACRP report 129 (Muia & Johnson, 2015), and do not include any installation time (except for the leased VID equipment) or data retrieval time.
3. The costs decrease to $31,000 without the ADS-B receiver. This is a lease cost and will vary from airport to airport depending on the airport layout.

A low-cost aircraft operations estimation technology, which consists of a single-board computer (Raspberry Pi), and a USB software-defined radio (SDR), was developed by Mott (2017). In this design, ADS-B signals were collected by the antenna and SDR, processed on the Raspberry Pi, and logged to an SD card, and a heuristic was developed to determine the occurrence of and tabulate aircraft operations, resulting in an error percentage within 10% when compared to FAA operation data (Mott, 2017).

4.4 Regulations

The FAA regulates the maximum noise level emitted from an individual civil aircraft by requiring aircraft to meet noise certification standards, which vary based on maximum noise level requirements by “stage” designation (FAA, 2016). For example, there are four stages identified for civil jet aircraft from Stage 1 (loudest) to Stage 4 (quietest), while there are three stages identified for helicopters from Stage 1 to Stage 3.

FAA rules and regulations are codified in Title 14 of the Code of Federal Regulations (CFR). FAA policies and procedures for compliance with the law which include:

1) 14 CFR Part 36 (Noise Standards: Aircraft Type and Airworthiness Certification). This Part provides information regarding acoustical change limitations, noise limitation based on aircraft type, noise measurement and evaluation, procedures regarding noise limitations, etc. Additionally, it establishes noise certification standards for the design of turbojet and transport category aircraft.
2) 14 CFR Part 150 (Airport Noise Compatibility Planning). This Part describes the procedures, standards, and methods for developing, submitting and reviewing airport noise exposure maps (NEM) and airport noise compatibility programs (NCP). Also, it identifies land uses which normally compatible with different levels of noise exposure and helps airport operators with noise compatibility planning programs.
3) 14 CFR Part 161 (Airport Noise and Access Restrictions). This Part provides requirements and procedures for airport operators implementing Stage 3 aircraft noise and access restrictions. These restrictions follow agreements between airport operators and aircraft operators. It explains details of a requirement related to aircraft operations from Stage 2 to Stage 4. Additionally, it lists procedures for FAA re-evaluation of agreements containing restrictions on Stage 3 aircraft

operations, and aircraft noise and access restrictions affecting Stage 3 aircraft operations imposed by airport operators.

The purpose of the noise certification process is to ensure that the latest available safe and airworthy noise reduction technology is incorporated into aircraft design and noise experienced by communities can be reduced as a reflection offered by those technologies. The FAA works with the international community through ICAO to determine whether new stringent noise standards are needed (FAA, 2016).

5. System Principle and Design

5.1 System Principle

The gaps identified between the current noise prediction model used by the FAA and the required information at non-towered GA airports, along with the development of the aircraft transponder technology and advanced computational power, have presented a unique opportunity to develop a cost-effective approach which would help airport operators to more efficiently assess the noise impact at their respective airports. The proposed cost-effective noise impact prediction approach consists of a hardware system and self-developed algorithms. A low-cost hardware system, combined with an ADS-B antenna, a software-defined radio (SDR), and a single-board computer, was designed to collect ADS-B data from aircraft. The algorithms were developed using the R and GIS software platforms, which include (1) an aircraft trajectory prediction algorithm, (2) an aircraft operations prediction algorithm, and (3) an aircraft noise prediction algorithm.

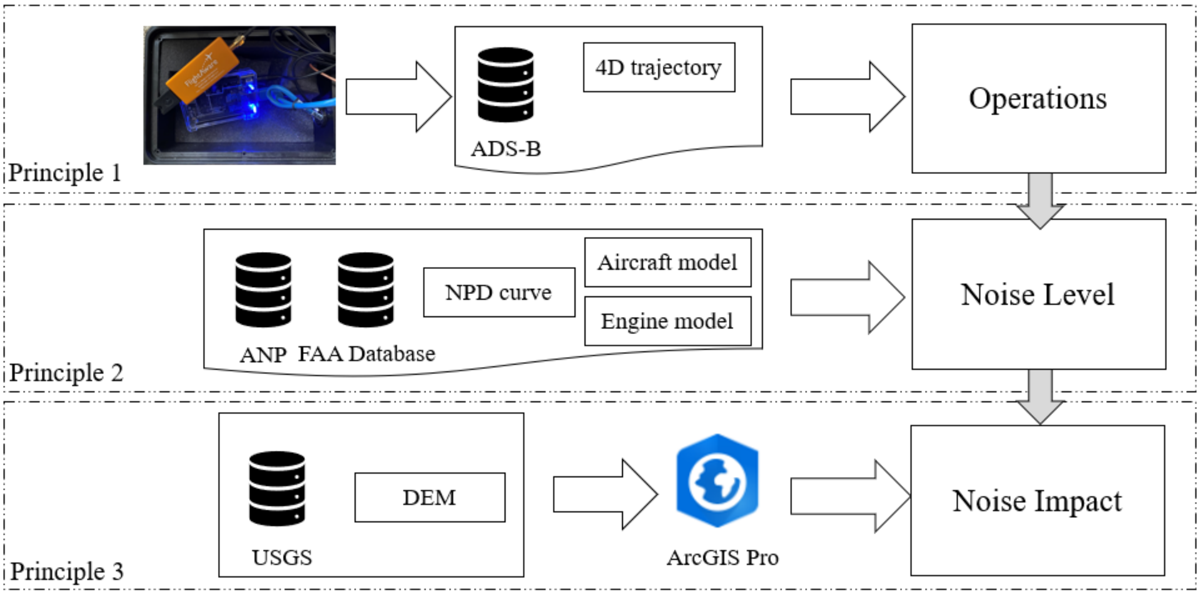

Figure 2. Diagram of the proposed noise prediction approach layout

The design of the proposed noise prediction approach is based on three principles (Figure 2):

(1) Estimation of aircraft operations based on 4D trajectory using ADS-B signals,

(2) Estimation of the noise level of each operation by integrating various publicly available databases, and

(3) Visualization of the noise impact on terrain under the coverage of the LTO cycle at non-towered GA airports.

5.2 System design

Principle 1. Estimation of aircraft operations based on 4D trajectory using ADS-B signals

Aircraft operations data is important to assess the noise impact; however, an accurate flight profile is difficult to obtain from those airports which do not have air traffic control facilities. A low-cost hardware system is used to collect ADS-B data, and an algorithm is developed to estimate aircraft trajectories using ADS-B data.

As shown in Figure 3, the proposed system integrates a GPS receiver, an antenna, and Raspberry Pi built with Dump1090 decoding scripts. The ADS-B data will be collected within a range of 10 nautical miles from the location of hardware deployment and logged to an SD card or to the Cloud in a comma-separated variable (CSV) format.

Figure 3. Hardware photo of the proposed noise prediction approach

The output CSV file contains multiple fields, such as received timestamps, hexid (ICAO identification code), and reported three-dimensional information (attitude, longitude & latitude) as shown in Table 2.

Table 2

The details from received ADS-B data

Name	Description
Timestamps	The time recorded as this ADS-B signal was received by the ADS-B receiver
Hexid	As known as ICAO identification code
Attitude	Reported attitude from aircraft onboard instrument
Longitude	Reported longitude from aircraft GPS instrument
Latitude	Reported latitude from aircraft GPS instrument

Since the proposed approach is intended to predict the noise impact created by the aircraft operated in the Landing and Take-off (LTO) cycle at the airport, the raw dataset will be filtered by altitude and range in terms of the distance between the antenna and aircraft. Then, the first unique ICAO identification code will be selected and recorded as the 'determined Hexid', which will be used to filter the data set again to obtain the ADS-B data that contains only the 'determined Hexid'.

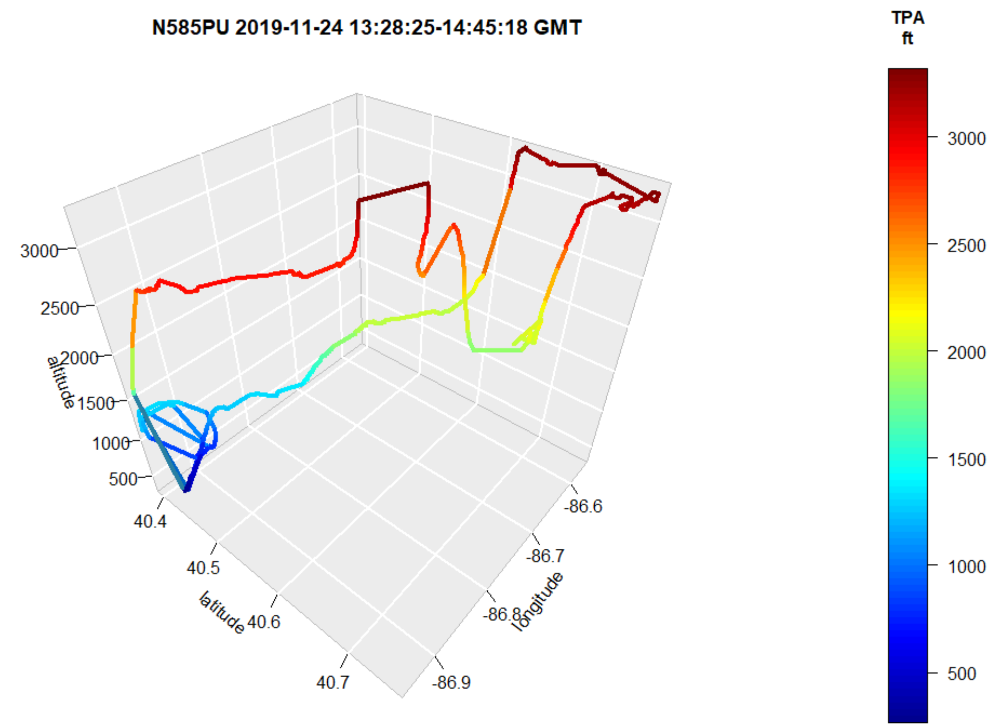

Figure 4. An example of 3D trajectory visualization of a training aircraft N585PU at Purdue University Airport (LAF)

An example of 3D trajectory visualization of a training aircraft N585PU during one LTO cycle (13:28:25-14:45:18 GMT, November 24th, 2019) at the Purdue University Airport (LAF) was obtained as Figure 4, and a heuristic was developed to determine aircraft operations based on the specific interarrival time of each operation.

This process will be executed iteratively until the last unique ICAO identification code in the CSV file is examined. A flow diagram of Principle 1 is presented in Figure 5.

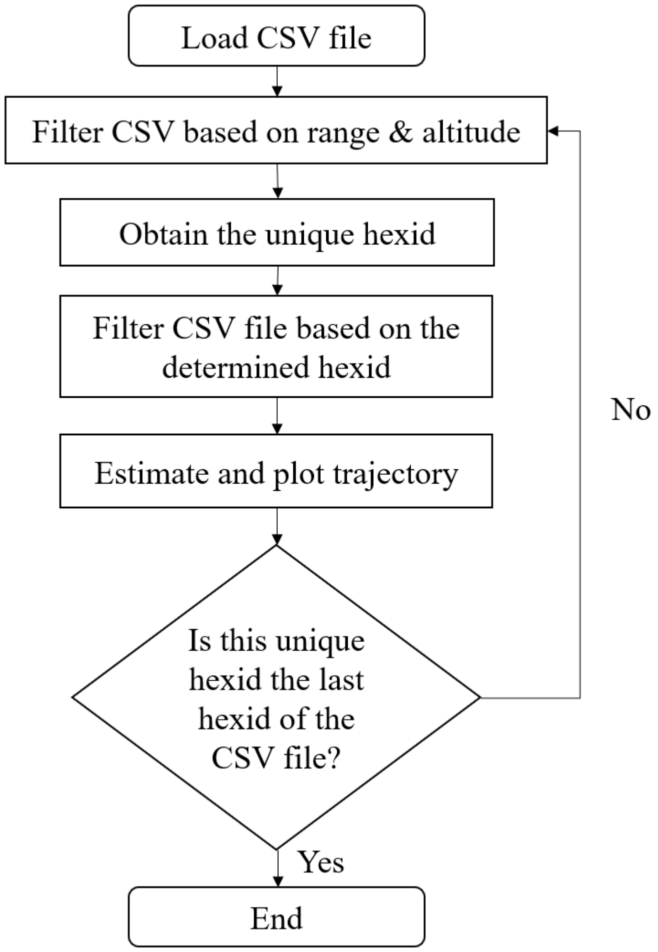

*Figure 5.*Flowchart of estimation of aircraft operations using ADS-B

Principle 2. Estimation of noise level for each operation by integrating publicly available databases

The proposed approach is designed to model airport noise contour using the Aircraft Noise and Performance (ANP) database, which is an online data resource accompanying the ICAO Doc 9911 guidance documents. Since aircraft operation and fleet mix data are required to compute the noise level in Noise-Power-Distance (NPD) data from the ANP database, the proposed approach obtained that required information (Table 3) by integrating several databases from FAA based on the unique ICAO identification code. The referred databases include the Aircraft Registration Master file, Aircraft Reference file by Make/Model/Series, and Engine Reference file, etc. (FAA, 2020).

Table 3.

Partial data obtained from the integrated database

Name	Description	Source
Type Aircraft	1-Glider 2-Balloon 3-Blimp/Dirigible 4-Fixed wing single engine 5-Fixed wing multi engine 6-Rotorcraft 7-Weigh-shift-control 8-Powered Parachute 9-Gyroplane H-Hybrid Lift O=Other	Aircraft Registration Master file
Type Engine	0-None 1-Reciprocating 2-Turbo- prop 3-Turbo-shaft 4-Turbo-jet 5-Turbo-fan 6-Ramjet 7-2 Cycle 8-4 Cycle 9-Unknown 10-Electric 11=Rotary	Aircraft Registration Master file
Model Name	Name of the aircraft model and series	Aircraft Reference file
Engine Model Name	The name of Engine model	Engine Reference file

As shown in Figure 6, Op Mode represents an engine power setting, which can be determined based on the estimated aircraft operation in Principle 1, and NPD_ID represents engine model, which can be determined from the integrated databases using the unique ICAO identification code. Hence, the noise level associated with distance can be determined in the NPD table. A flow diagram of Principle 2 is presented in Figure 7.

NPD_ID	Noise Metric	Op Mode	Power Setting (*)	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft
IO360L	EPNL	A	26.6	78.7	73.6	70.2	66.6	60.3
IO360L	EPNL	A	58.2	85.7	80.6	77.3	73.6	67.4
IO360L	EPNL	D	59.6	88.4	84.3	81.2	77.9	72.1
IO360L	EPNL	D	100.0	90.2	86.3	83.3	79.9	74.2
IO360L	LAmax	A	26.6	71.6	64.2	59.7	55.0	47.7
IO360L	LAmax	A	58.2	78.8	72.2	67.7	62.9	55.2
IO360L	LAmax	D	59.6	82.7	75.6	71.1	66.4	58.9
IO360L	LAmax	D	100.0	84.6	77.8	73.2	68.2	60.4
IO360L	PNLTM	A	26.6	86.6	79.4	74.4	69.1	60.3
IO360L	PNLTM	A	58.2	93.8	86.6	81.6	76.0	67.2
IO360L	PNLTM	D	59.6	97.4	90.6	85.9	80.7	72.3
IO360L	PNLTM	D	100.0	100.2	93.0	87.7	82.2	73.6
IO360L	SEL	A	26.6	73.0	68.7	65.8	63.0	58.6
IO360L	SEL	A	58.2	79.3	75.3	72.7	69.9	65.1
IO360L	SEL	D	59.6	83.5	79.8	77.2	74.4	69.7
IO360L	SEL	D	100.0	84.9	81.4	78.9	76.0	71.2

Figure 6. An example of Cessna 172 from NPD data (EUROCONTROL, 2020)

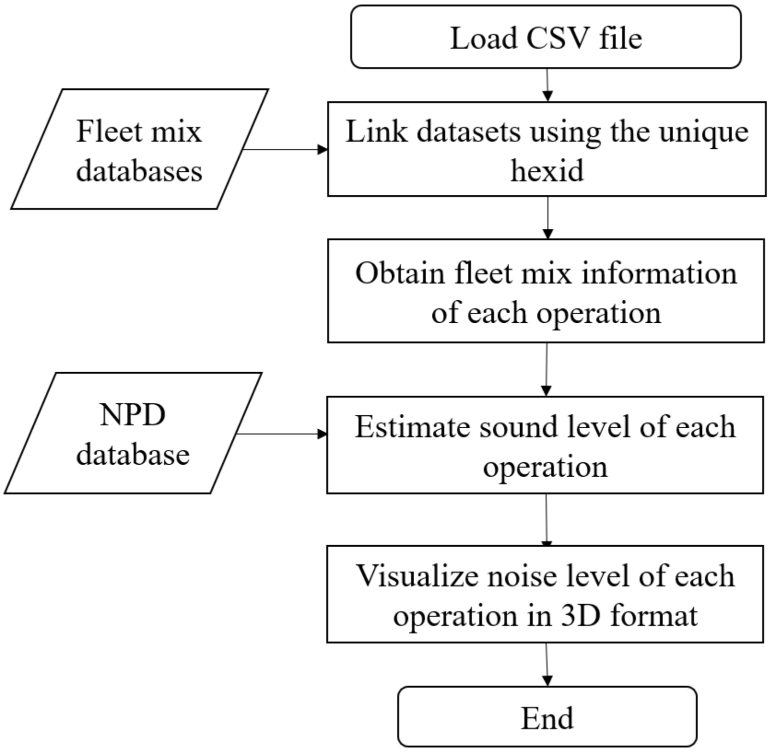

Figure 7. Flowchart of the noise level determination

Principle 3. Estimation of noise impact on territory under the coverage of LTO cycle at non-towered airports

Based on results from Principle 2, aircraft noise impact on the local community will be visualized using ArcGIS Pro, which is a commercial desktop application support data visualization and advanced analysis in both 2D and 3D.

A raster-based elevation model (DEM) is a 3D representation of a terrain's surface crated from a terrain's elevation data. Since the 3D position of the noise source can be obtained from Principle 1, the noise level at a certain point on the terrain's surface can be computed from Principle 2. The estimated noise impacts on the terrain of the community will be computed and visualized on the ArcGIS platform (Figure 8).

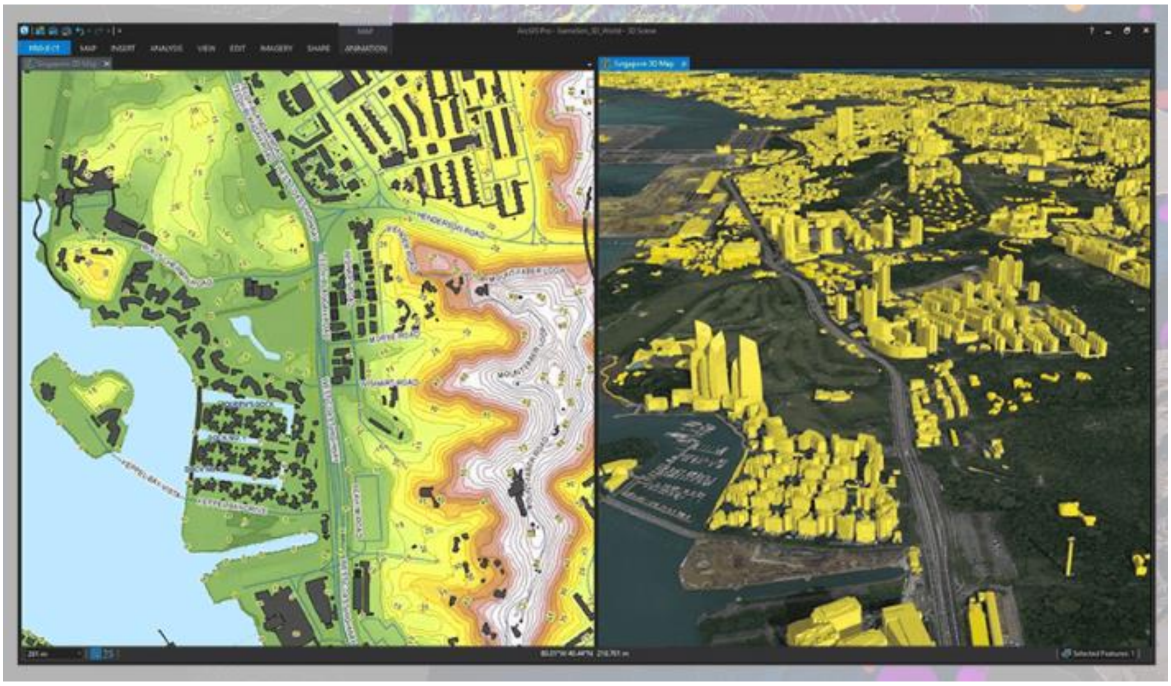

Figure 8. Interface of 2D & 3D visualization of ArcGIS Pro (ESRI, 2020)

6. Safety Risk Assessment

According to MIL-STD-8825, risk is a function of probability and level of severity. FAA AC 150/5200-37 (FAA, 2016a) suggests using a safety matrix to assess risk in the aviation area. The probability and level of severity of each potential hazard are evaluated separately, the product of which is the final risk score. Meanwhile, the probability and severity can be divided into five and four levels respectively. The safety matrix classifies all the potential hazards into four groups based on the final scores: low risk, moderate risk, high risk, and unacceptable risk. The safety matrix used in this report is shown below.

Table 4.

Risk Assessment Matrix

Low Risk: 0-5 Moderate Risk: 6-10 High Risk: 11-15 Unacceptable Risk: 16-20	**Severity**	**Insignificant** No injuries / Low financial loss	**Negligible** Non-reportable injury / minor financial loss	**Moderate** Reportable injury / Moderate damage to property	**Serious** Single death or multiple injuries / high financial loss	**Major** Multiple deaths / significant financial loss
Likelihood	**Level**	**1**	**2**	**3**	**4**	**5**
Rare May occur only in exceptional circumstances	**1**	**1**	**2**	**3**	**4**	**5**
Unlikely Could occur at sometimes	**2**	**2**	**4**	**6**	**8**	**10**
Moderate The event will probably occur at sometimes	**3**	**3**	**6**	**9**	**12**	**15**
Probable Is expected to occur in most circumstances	**4**	**4**	**8**	**12**	**16**	**20**

Based on the assumption: Risk = Likelihood × Severity, Table 4 above illustrates the potential risk assessment via potential situation, likelihood, severity, risk, and possible solutions. As shown in Table 5, since the proposed noise prediction approach has a relatively high degree of flexibility in the implementation and operation stage, most risks can be prevented and mitigated by improving system design and by troubleshooting. Overall, the proposed system exhibits low risk, according to the list of potential assessment.

Table 5.

List of Potential Risk Assessment

Situation	Likelihood	Severity	Risk	Possible Solutions
1 Data link break down	1	1	1	Software engineers troubleshoot the system
2 Algorithm malfunction	1	1	1	Software engineers troubleshoot the system
3 Power outage	2	1	3	Regular maintenance
4 Antenna damage due to outdoor environment	3	1	3	Electronic engineers correct antenna position
5 Data saving failure	3	1	3	Weekly maintenance
6 Human errors including poor maintenance or incorrect operation	3	1	3	Regular training & maintenance

Note. Scores for likelihood, severity, and risk level are evaluated according to Table 4.

7. Cost-Benefit Assessment

The cost and benefit analysis of the proposed system is vital to the viable implementation and practical operation of the system. Indianapolis Executive Airport (TYQ) is used as a case study for the numerical estimation of system costs and benefits. TYQ was chosen as it is non-towered yet facilitates frequent flight operations, and is familiar to the design team due to its proximity to campus.

7.1 Cost Assessment

Costs inherent in system application include framework design and field testing, installation, and maintenance. For each research, development, and implementation phase, the expenses are enumerated in terms of labor, material, and service fees. Labor is required from students, professors, engineers and technicians. Antennas and an ADS-B receiver are needed to detect and transmit records of aircraft operations, while an acoustic sensor may also be procured for validation of noise estimates. The following tables list project costs with the length and location of each development phase, assuming system creation at Purdue University and system deployment to TYQ.

Research and Development Cost at Purdue University (Alpha)

Table 6 presents costs associated with the alpha research and development stage of the noise modelling system in which a prototype device is created. The initial costs include labor and materials for preliminary research and product engineering at Purdue University.

Table 6.

Cost Analysis of the noise prediction technology – Alpha Phase (4 months) – Purdue Univ.

Item	Rate	Quantity	Subtotal	Remarks
Labor				
Student	$25/hr.	120 hrs.	$3,000	3 Students - 40 hrs. each
Faculty	$50/hr.	40 hrs.	$2,000	1 Faculty Advisor - 40 hrs.
Material				
Antenna, ADS-B Receiver			$200	System Design and Device Manufacturing
Subtotal			$5,200	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers, 2016)				

Research and Development Costs (Beta)

Table 7 presents costs associated with the beta research and development stage, including the field testing and continuous improvement of the noise estimation technology. Professional engineers and technicians chiefly account for the phase costs.

Table 7.

Cost Analysis of the noise prediction technology – Beta Phase (6 months) – Purdue Univ.

Item	Rate	Quantity	Subtotal	Remarks
Labor				
Electrical Engineer	$50/hr.	480 hrs.	$24,000	1 worker - 480 hrs.
Mechanical Engineer	$50/hr.	480 hrs.	$24,000	1 worker - 480 hrs.
Material				
Antenna, ADS-B Receiver, Acoustic Sensors			$5,000	Device Testing and System Validation
Subtotal			$53,000	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers, 2016)				

System Installation & Implementation Costs (Initial Investment)

As the system is manufactured, installed, and tested at TYQ, stage costs are driven by technician wages and product material expenses. Table 8 represents the costs associated with the system installation and implementation phase.

Table 8.

Cost Analysis of system installation – 1 month – TYQ

Item	Rate	Quantity	Subtotal	Remarks
Labor				
Electrician	$50/hr.	12 hrs.	$600	1 worker - 12 hrs.
IT Technician	$50/hr.	12 hrs.	$600	1 worker - 12 hrs.
Materials				
Antenna	$50 ea.	1	$50	1090 MHz, 5 dBi Omni-directional Antenna
Raspberry Pi 3	$35 ea.	1 hr.	$35	Hardware
Dump1090	Free.	1 hr.	Free	Mode S Decoder
Micro SD Card	$40 ea.	1 hr.	$40	128 Gb Memory
ADS-B Receiver	$19 ea.	1 hr.	$50	FlightAware Pro Stick Plus USB Software Defined Radio (SDR) Receiver
Subtotal			$1,375	
Note. This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers, 2016)				

System Operation & Maintenance Costs (Recurrent Expenses)

Table 9 represents the costs associated with continuous operation and regular maintenance of the noise estimation system. These costs mainly consist of labor and travel for technical management and support of the system to conduct routine servicing or emergency troubleshooting. From prior tables, the prototype research and development stages are expected to incur $58,200 in expenses. System installation is estimated to cost an additional $1,375. Over an operational period of 10 years at TYQ, the total system cost is projected to be $116, 575.

Table 9.

Cost Analysis of system operation – 1 year – TYQ

Item	Rate	Quantity	Subtotal	Remarks
Service				
Technical Support	$50/day	10 days	$500	Networks
Labor				
Technical Support	$100/day	52 days	$5,200	Technicians
Subtotal			$5,700	Dependent on occurrences of functionality issues

Note.
This table was inspired by Guidance for Preparing Benefit/Cost Analysis (Byers, 2016)

7.2 Benefit Assessment

A noise contour map under the LTO cycle will be estimated and visualized by the proposed noise prediction technology; this map will support airport operators and policymakers in their development of strategies to minimize the negative impacts of aircraft operations on the local community. With improved city and flight planning, community opposition to airport operations may be reduced. For a subsequent rise in general aviation traffic flow, airport services such as fueling, parking, hangaring, aircraft rental, aircraft maintenance, and flight training will facilitate greater airport revenues. Additionally, airport operators and community stakeholders may benefit from these noise predictions by enhanced decision making in compatible land-use zoning in the areas directly adjacent to the airfield.

TYQ serves an average of 93 operations per day and houses 86 based aircraft (AirNav, 2020). As improved city planning and airport management is realized from the proposed noise estimation technology, community members are less likely to resist increases in the peak frequencies or overall volumes of aircraft operations. For just a unit percentage increase in annual airport operations, TYQ's fixed-base operator, First Wing Jet Center, is poised for relatively modest financial gain. Assuming that each additional aircraft operation at TYQ generates an average of $50 in revenue, the aggregate annual benefit is projected to be $17,000. Over the first 10 years of system implementation and operation, the noise modelling system is financially favorable to airport operators, as shown in Table 10. Boasting a benefit to cost ratio with 1.458, the project offers presumed benefits outweighing estimated costs for the case study of the proposed noise estimation approach at TYQ.

Table 10.

Benefit vs. Cost Analysis – 10 years - TYQ

Item	Subtotal	Qty	Total	Remark
Cost				
Development, Testing, & Installation	$59,575	1 period	$59,575	Table 6 &7 & 8
Operation & Maintenance	$5,700 / year .	10 years	$57,000	Table 9
Total Cost:			$116,575	
Benefit				
Airfield Services	$50 / operation	10 years	$170,000	340 additional operations per year
Total Benefit:			$170,000	
Benefit to Cost Ratio			1.456	Benefit outweighs cost

8. Industry Interaction

The team had formal and informal conversations with two professors in aviation technology area, two researchers in aircraft noise prediction area and two practitioners work with aircraft noise prediction for non-towered GA airports:

1) Purdue University Professor: Dr. Mary E. Johnson

2) Georgia Institute of Technology Senior Graduate Researcher: Ameya Behere

3) Purdue University Postdoctoral Researcher: Dr. Yiming Wang

4) Huntingburg Regional Airport Manager: Travis McQueen

5) Butler Fairman & Seufert Inc Executive Vice President: Paul A. Shaffer, P.E.

6) University of Nebraska at Omaha Assistant Professor: Dr. Chenyu Huang

In interviews with Dr. Johnson, she suggested the team should interact with the real-world practitioners to find more applicable information. For example, interviews with non-towered GA airport managers and operators were suggested to learn from their experiences in aircraft noise prediction and identify their needs. Additionally, on-site training of AEDT was encouraged to help the team find evidence of the gap identified in the previous section of this report.

During the Transportation Research Board (TRB) Annual Meeting 2020, the team members had an informal conversation with Ph. D. candidate Ameya Behere from the Georgia Institute of Technology. Ameya indicated that there is a gap when using AEDT to predict the noise impact for non-towered airports since the aircraft operations and fleet mix information are not available.

The design team also had a talk with Dr. Yiming Wang, a postdoctoral researcher in the School of Mechanical Engineering at Purdue University. Dr. Wang works as a research assistant for the Aviation Sustainability Center (ASCENT) under the FAA, and has experience in modeling aircraft noise propagation. Dr. Wang explained the details of how AEDT predicts aircraft noise based on operational data and fleet mix data, while it is difficult to obtain this information when the airport does not have an air traffic control facility. Additionally, Dr. Wang pointed out that the prediction model in AEDT still has room to be improved.

Since the proposed approach is intended to be applied to non-towered GA airports, the team member interviewed with several non-towered GA airport managers and industry experts during the 2020 Purdue Road School Conference. In the interview with Travis McQueen, he indicated that he did not use any noise prediction tools because of the limited number of operations at the Huntingburg Regional Airport, however, a cost-effective noise prediction technology would be significantly helpful to non-towered GA airports and stakeholders to evaluate the noise impact.

When a team member talked with Paul Shaffer, vice president of Bulter Fariman & Seufert Inc. Mr. Shaffer indicated that his team worked with Michigan City Airport, a non-towered GA airport in Indiana, to predict the aircraft noise impact using AEDT. Since Mr. Shaffer's team was unable to access the aircraft operations and fleet mix data through air traffic control facilities, they conducted a rational inference by manually recording the percentage of the operations and types of aircraft. Hence, an approximate estimation of noise impact on Michigan City Airport can be generated from AEDT.

During the interview with Dr. Chenyu Huang, Dr. Huang pointed out the proposed approach would significantly help the decision-making process of airport expansion and land planning by visualizing the noise impact of non-towered airports from a geospatial perspective. Furthermore, Dr. Huang also mentioned since there is are limited prescribed approach procedures under Visual Flight Rules (VFR) for non-towered GA airports, the airport operators and managers will also benefit from the noise contour map by figuring out the aggregate profile of aircraft operations at those airports.

9. Projected Impact of Design

9.1 How This Project Meets ACRP Goals

Assessing noise impact and emission impact is part of airport management and planning with the goal of "successfully mitigate/diminish local concerns for airport development" (ACRP, 2009, p.17). ACRP also listed the new tools and approaches that can help reduce noise at airports as the focused challenges under the category of Airport Environmental Interactions Challenges. The FAA uses AEDT to assess the noise level based on aircraft operations and fleet mix information, while this information is not available from non-towered GA airports. The proposed cost-effective noise prediction approach will bridge the gap between aircraft operation data and noise prediction, help minimize the negative impacts on the community, and support decision-making in airport expansion and compatible land use planning.

9.2 Sustainability Assessment

The FAA adopts “EONS” (economic vitality, operational efficiency, natural resources, and social responsibility) to describe airport sustainability (FAA, 2017). The proposed cost-effective noise prediction approach is designed to support non-towered GA airports’ noise reduction actions by estimating aircraft operations, fleet mix, and noise level. Airport and stakeholders can benefit from the proposed design from operational, economic, environmental, and social perspectives.

Operational Impact

The proposed noise prediction approach has many potential impacts on airport operations. Using this system, airport operators and managers will be able to access relatively accurate aircraft contour and fleet mix information, which are usually unavailable for those airports that do not have ATC facilities. For example, since there is no standard VFR approach procedure, the proposed approach would help non-towered airport operators and managers to conduct a geospatial analysis of the noise contour map.

Economic Impact

An accurate prediction of noise impact will significantly benefit the design and implementation of noise abatement procedures in terms of the economic cost. For example, since the time duration of the aircraft noise contour can be obtained from this proposed technology and one of the most common noise abatement procedures is to reschedule arrival and departure times at non-towered airports (Postorino & Mantecchini, 2016; Filippone, 2014), the noise impacts on local residents can be minimized and complaints can be avoided by rescheduling the flight plan. Also, the proposed cost-effective noise prediction approach will help the decision-making process for airport expansion and compatible land use planning by visualizing the aggregate noise impact on non-towered GA airports.

Environmental Impact

Aircraft noise often has negative impacts on a community's health in terms of the total psychological and physiological well-being of its members. A cost-effective noise prediction approach can significantly help the development of noise abatement actions. Additionally, since noise and emissions are highly related, actions on reducing noise can change its emissions. In this proposed approach, aircraft emissions can be predicted using obtained operations and fleet mix information. Such information would assist decision-making in the planning of compatible land use and airport expansion; hence, the environmental impacts on the community will be minimized.

Social Impact

A local airport benefits a community by increasing convenience and help the local economy, successful implementation of the proposed system will help airport operators and decision-makers to minimize the negative impacts on the community. Hence, the prediction results of aircraft noise impacts will lead to help the decision-making in airport expansion and compatible land use planning, which can help to provide more jobs and economic benefits to the community.

10. Conclusion

In this design project, the proposed cost-effective noise prediction approach for non-towered GA airports is presented for the topic “New tools and approaches to help reduce noise at airports”, which is under the sub-category of Airport Environmental Interactions Challenges of ACRP University Design Competition for addressing airport needs. By deploying a low-cost hardware system at non-towered GA airports, aircraft ADS-B data will be collected to estimate operations. The fleet mix information can be also obtained from various public databases and be further used to predict aircraft noise under the LTO cycle in the airport. Finally. the noise impacts on the terrain will be visualized using ArcGIS platform.

Details of the principles of this system, the risk assessment, the cost-benefit assessment and sustainability assessment are also presented in this report. The results suggest that the airport managers and stakeholders will benefit from the noise abatement procedures, which could be supported and improved by the implementation of the proposed cost-effective noise prediction approach for non-towered GA airports. Recording and analyzing noise pollution data at general aviation (GA) airports through the proposed noise modelling technology would drastically address this pervasive consequence of aircraft operations and perpetual concern of airport communities.

Appendix A: List of Complete Contact Information

Faculty Advisor:

John H. Mott, Ph.D.

School of Aviation and Transportation Technology

Purdue University

jhmott@purdue.edu

Students:

Chuyang Yang

School of Aviation and Transportation Technology

Purdue University

yang1481@purdue.edu

Weisi Li

School of Engineering Technology

Purdue University

li3150@purdue.edu

Zachary A. Marshall

School of Aeronautics and Astronautics

Purdue University

zmarsha@purdue.edu

Appendix B: Description of the University

About the University:

Purdue University, located in West Lafayette, Indiana, is a public research university. As a vast laboratory for discovery, Purdue has been well-known not only for science, technology, engineering, and math programs, but also for our imagination, ingenuity, and innovation. It's a place where those who seek an education come to make their ideas real - especially when those transformative discoveries lead to scientific, technological, social, or humanitarian impact.

Founded in 1869 in, the university proudly serves its state as well as the nation and the world. Academically, Purdue's role as a major research institution is supported by top-ranking disciplines in aviation, pharmacy, business, engineering, and agriculture. With embracing the diversity of cultures, Purdue community has more than 39,000 students from all 50 states and 130 countries. Add about 950 student organizations and Big Ten Boilermaker athletics, and people get a college atmosphere that's without rival.

School of Aviation and Transportation Technology Mission Statement:

Economic forecasts suggest that a steady increase in traveling passenger and air cargo requirements will fuel a dramatic expansion of the aviation industry, and require a complete restructure of the existing air transportation system architecture. This industry growth is generating a wide range of leadership opportunities in the aviation industry for individuals who possess aviation and aerospace management skills such as operational analysis, safety systems development, project management, systems integration, environmental sustainability, and related interdisciplinary skills.

Purdue University’s School of Aviation and Transportation Technology, one of six departments and schools in the Purdue Polytechnic Institute, is recognized worldwide as a leader in aviation education. All seven of Purdue’s Aviation and Transportation Technology undergraduate majors are world-class educational programs. The aviation and aerospace industry is in the midst of a technological sea change. The School of Aviation and Transportation Technology emphasizes on improving students’ skills such as operational analysis, safety systems development, and environmental sustainability. The programs in the School of Aviation and Transportation Technology are focused on making sense of the changes and helping plan for aviation’s future. Our research centers provide many opportunities to make an impact through research and problem solving. Pursuing a degree in aviation at Purdue University will assist students in striving towards their occupational dream. The school is continually looking at ways for students to reach their academic goals faster.

Appendix C: Description of Non-University Partners Involved in the Project

Not Applicable.

Appendix E: Evaluation of the Educational Experience Provided by the Project

Students (Answer were discussed by all team members)

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes, this competition provided a unique learning experience for the design team. Requiring multidisciplinary collaboration, industry engagement, and project management, this project offered an appreciated opportunity to apply skills to an interesting and important real-world challenge. Participation in this competition instilled stringent time management, adaptive workflow distribution, and effective interpersonal communication, allowing design team members to grow in both academic and professional dimensions. This early exposure to the exciting area of research of aviation noise mitigation induced greater interest in airport management among design team members. Report writing and professional interviews are specific areas of scholastic development that were honed during the system design and documentation process. Throughout this process, design team members continuously enhanced skills that will form the foundation of our future careers in aviation and aerospace management.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

One challenge was the team lost opportunities to contact industry and academia experts due to the outbreak of pandemic COVID-19 in the U.S., but the team still received enough professional inputs from experts in several national conferences such as the Transportation Research Board Annual Meeting and the Purdue Road School Annual Conference during the time between January and March.

Another challenge was working under the pandemic COVID-19, which means the team had to work from home, following guidance issued by the federal and state government. The team completed this project on time by working cooperatively through E-mail and cellphones.

3. Describe the process you or your team used for developing your hypothesis.

The proposed design aims to develop a cost-effective noise prediction approach for non-towered GA airports. The preliminary stage of hypothesizing involved general research into FAA and ACRP initiatives. Multiple brainstorming group sessions using non-traditional ideation techniques produced a condense list of prospective topics. Consultation of our faculty advisor resulted in the determination of noise prediction at non-towered airports. Interactions with academia and industry experts were conducted during several national conference meeting to help the team identify the gap of the interested topic. From information and concepts learned while performing a literature review, all team members discussed, pivoted upon, and ultimately agreed on a design hypothesis for this project. After generating the means of the hypothesis, the technical feasibility and financial viability of the proposed idea were improved and iterated through interviews with industrial and academic experts.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

The participation by industry in the project was highly meaningful and very conducive to accelerated learning. The team prioritized performing plenty of face-to-face interviews with a diverse cross-section of professionals in the aviation sustainability and aircraft noise fields as the functionality of our system in practice was of paramount importance. After the outbreak of the COVID-19 at the middle of March, the team could not access industry and academic experts due to the social distance policy and guidance issued by the local government. Overall, those interactions gave us a thorough understanding of airport environmental interaction, while we readily applied to make our design more suited to airports' needs while under their cost restrictions. Industry interaction also effectively conveyed the current status of applications of noise prediction technology at U.S. non-towered GA airports in a manner not easily replicated inside a classroom setting. Feedbacks on cost-benefit and risk-safety assessments were also invaluable in driving our team project development and personal learning experiences.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

The project overall has been a learning experience in every aspect from the gathering of information to the design of our system on the technical side and writing of the report. While long hours and effort were devoted to this project, all team members are grateful for the hard and soft skills gleaned from this competition that will directly translate into success for our academic and professional careers.

Faculty

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

The team assembled for this competition was a diverse one, in that it consisted of students from both different cultural and different educational backgrounds. The students were enrolled in three different schools at our university, and comprised a mix of graduate students and undergraduates. The students learned to overcome differences in their individual knowledge of the technical details of the project, as well as communication barriers both internal to the team and external with regard to the various stakeholders. I believe substantial learning occurred not only in terms of the technical aspects of noise modeling, technology integration, and cost-benefit analysis, but also as a result of overcoming the challenges I have described here.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Yes; this project was completed in a graduate-level independent study course.

3. What challenges did the students face and overcome?

One of the primary associated with the project was that of reviewing prior work on noise modeling and understanding the limitations of those models and how technology that we have developed and been improving in conjunction with FAA PEGASAS Project 29 might be applied to mitigate problems associated with those limitations. Other challenges were related to communication among the internal team members and external stakeholders, as described in (1). I think this competition, more so than any others with which I have been associated, helps student improve both communication and project management skills. I have been pleased to be able to see such improvement on the part of each student inv0olved in this year's competition.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Yes; this is my second year of advising a team in the competition. I believe the competition provides an opportunity for the participating students to apply theoretical concepts they acquire in our undergraduate and graduate programs to the solution of practical problems, and work with industry and other faculty as they endeavor to create those potential solutions. The skills students gain by participating will serve them well as they graduate and move to positions in industry. In addition, the competition provides an opportunity for both graduate and undergraduate involvement. This is an area of research interest of mine, and I have modeled by research center, A^{3}IR-CORE, after the concept. See:

Mott, J. H. (2014). A^{3}IR-CORE at Purdue University: An innovative partnership between faculty, students, and industry. *The Journal of Aviation/Aerospace Education & Research, 24*(1), 26–40. doi: https://doi.org/10.15394/jaaer.2014.1607 for more information.

5. Are there changes to the competition that you would suggest for future years?

It is my hope that the dropping of the requirement for hard copies of the submission package is extended in perpetuity. Electronic submission is far more convenient, and especially so if we continue working with distributed project teams.

Appendix F: Reference

Bernardo, E. J. (2012). Development and Assessment of Generic Airports for Fleet-Level Noise Modeling. *Partnership for Air Transportation Noise and Emissions Reduction (PARTNER): 9th Annual Joseph A. Hartman Student Paper Competition.* Retrieved from http://web.mit.edu/aeroastro/partner/reports/hartman/bernardo-13.pdf

ESRI. (2020). *ArcGIS Pro: Next-generation Desktop GIS.* Retrieved from https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

EUROCONTROL. (2020). *ANP database.* Retrieved from https://www.aircraftnoisemodel.org/data/aircraft

Federal Aviation Administration. (2015). *Fact Sheet – The FAA Airport Noise Program.* Retrieved from https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=18114

Federal Aviation Administration. (2016). *Details in FAA Noise Levels, Stages, and Phaseouts.* Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/airport_aircraft_noise_issues/levels/

Federal Aviation Administration. (2017a). *Aviation Environmental Design Tool (AEDT) Technical Manual version2d.* Retrieved from https://aedt.faa.gov/documents/aedt2d_techmanual.pdf

Federal Aviation Administration. (2017b). *Noise Integrated Routing System (NIRS) & NIRS Screening Tool (NST).* Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/nirs_ nst/

Federal Aviation Administration. (2018a). *Aircraft Noise Issues: Aircraft and Airport Noise.* Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/airport_aircraft_noise_issues/

Federal Aviation Administration. (2018b). *AEM: Area Equivalent Method (Version 2c SP2).* Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/aem_model/media/aem_2c_sp2_users_guide.pdf

Federal Aviation Administration. (2018c). *Environmental Analysis Tools and Guidance.* Retrieved from https://www.faa.gov/air_traffic/environmental_issues/environmental_tetam/

Federal Aviation Administration. (2018d). *Report to Congress: Nation Plan of Integrated Airport Systems (NPIAS): 2019-2023.* Retrieved from https://www.faa.gov/airports/planning_capacity/npias/reports/media/NPIAS-Report-2019-2023-Narrative.pdf

Federal Aviation Administration. (2018e). *Fundamentals of Noise and Sound.* Retrieved from https://www.faa.gov/regulations_policies/policy_guidance/noise/basics/

Federal Aviation Administration. (2020a). *Aircraft Registry: Releasable Aircraft Database Download.* Retrieved from https://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download/

Federal Aviation Administration. (2020b). *Land Use Compatibility and Airports.* Retrieved from https://www.faa.gov/about/office_org/headquarters_offices/apl/noise_emissions/planning_toolkit/media/III.B.pdf

Filippone, A. (2014). Aircraft Noise Prediction, *Progress in Aerospace Sciences, 68,* 27-63, https://doi.org/10.1016/j.paerosci.2014.02.001

Flightradar24. (2020). Retrieved from https://www.flightradar24.com/data/airports/laf

International Civil Aviation Organization. (2020a). *Aircraft Noise: Balanced Approach to Aircraft Noise Management.* Retrieved from https://www.icao.int/environmental-protection/Pages/noise.aspx

International Civil Aviation Organization. (2020a). *Local Air Quality Technology Standards.* Retrieved from https://www.icao.int/environmental-protection/Pages/LAQ_TechnologyStandards.aspx

Kryter, K. D. (1982). Community Annoyance from Aircraft and Ground Vehicle Noise. *Journal of Acoustical Society of America, 72(4),* October 1982. Retrieved from https://asa.scitation.org/doi/10.1121/1.388332

Muia, M. J., & Johnson, M.E. (2015). *Evaluating Methods for Counting Aircraft Operations at Non-Towered Airports.* Transportation Research Board. Doi: 10.17226/22182

Mott, J. H. (2017). *Measurement of Airport Operations Using a Low-Cost Transponder Data Receiver and Collection Unit.* [Doctoral dissertation, Purdue University]. Purdue e-Pubs.

Postorino, M. N., & Mantecchini, L. (2016). A Systematic Approach to Assess the Effectiveness of Airport Noise Mitigation Strategies, *Journal of Air Transport* Management, 50, 71-82. https://doi.org/10.1016/j.jairtraman.2015.10.004

Yang, C., Mott, J. H., Hardin, B., Zehr, S., & Bullock, D. M. (2019). Technology Assessment to Improve Operations Counts at Non-Towered Airports, *Transportation Research Record: Journal of the Transportation Research Board, 2673 (3),* pp.44-50, https: // doi.org/10.1177/0361198119835804