NASA/TM–20210014096

Acoustic Flight Simulator Architecture, Noise Training Aid Manual, and Its Training Benefits

Anna C. Trujillo
Langley Research Center, Hampton, Virginia

Daniel R. Hill
Analytical Mechanics Associates, Hampton, Virginia

October 2021

NASA STI Program...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI Program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collection of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI Program, see the following:

- Access the NASA STI program home page at `http://www.sti.nasa.gov`

- E-mail your question to `help@sti.nasa.gov`

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM–20210014096

Acoustic Flight Simulator Architecture, Noise Training Aid Manual, and Its Training Benefits

Anna C. Trujillo
Langley Research Center, Hampton, Virginia

Daniel R. Hill
Analytical Mechanics Associates, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

October 2021

Acknowledgments

Special thanks to Dr. Eric Greenwood, Assistant Professor at Penn State, who developed the algorithm to calculate the predicted ground noise footprint. The authors would also like to thank those that helped us exhibit the acoustic flight simulator at various forums. In particular, HAI Fly Neighborly and DOT Volpe, especially Juliet Page and Amanda Rapoza, for allowing us to share their exhibit booth at HAI Heli-Expo 2019 and 2020; Gregory Harbert, Wyle Labs at NASA Ames Research Center, for his help at VFS's 75th Annual Forum and Technology Display; and Kyle Pascioni and Andrew Lind, NASA Langley Research Center, for their help on the noise score and at HAI Heli-Expo 2020.

This work was funded by NASA's Advanced Air Vehicles Program Revolutionary Vertical Lift Technologies Project under the eVTOL Noise, Safety and Comfort subproject, Source Noise and Response.

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

Abstract

The Revolutionary Vertical Lift Technology project at NASA is researching source noise and response to reduce the noise impact of vertical takeoff and landing aircraft. To aid in this effort to address community noise, Dr. Eric Greenwood has developed real-time helicopter noise modeling that uses noise hemispheres generated from measured acoustic data as a basis for informing predictions the ground noise footprint of a particular helicopter model. This report describes a depiction of the predicted ground noise footprint and related information on how to reduce the ground noise footprint. Additionally, it details how to use the acoustic flight simulator and its associated programs. Also included are the results from a brief survey asking potential users about what they thought about the noise training aid aspect of the acoustic flight simulator and whether the predicted ground noise footprint display would be useful in learning about how to decrease noise. In summary, potential users have indicated that the noise training aid would be beneficial in learning how their vehicle's state affects noise.

Contents

Nomenclature

γ_e	=	effective flight path angle (radians)
$\hat{n}_a$	=	inertial tip path plane normal vector
μ	=	advance ratio
Ω	=	main rotor rotation speed (radians/second)
ρ	=	air density (kilograms/meter^2)
$\vec{a}$	=	acceleration (meters/second^2)
$\vec{v}$	=	inertial frame velocity (meters/second)
A	=	area of the rotor (meters^2)
C_T	=	thrust coefficient
h	=	altitude (feet)
$heading$	=	heading (radians)
L	=	A-weighted sound pressure level (dBA)
lat	=	latitude (radians)
lon	=	longitude (radians)
R	=	main rotor radius (meters)
T	=	main rotor thrust (Newtons)
t	=	time (seconds)
V	=	horizontal velocity (meters/second)
V_z	=	vertical velocity (meters/second)
dBA	=	A-weighted decibel

1 Introduction

The Revolutionary Vertical Lift Technology project, which is under NASA's Advanced Air Vehicles program, is addressing source noise and response in order to reduce vertical takeoff and landing (VTOL) aircraft noise impact [1]. With the development of the urban air mobility (UAM) concept [2–4], the effects of VTOL aircraft noise on communities is a growing concern. In order to address community noise, Dr. Eric Greenwood has developed real-time helicopter noise modeling that predicts the ground noise footprint of a particular helicopter model [5, 6]. Current models that the noise prediction algorithm incorporates include the Bell 407B (the current vehicle model used in the acoustic flight simulator) and Airbus AS350 with additional helicopter model development underway for several light civil helicopters that were flown in the 2017 NASA/FAA noise test program [7], which includes the Sikorsky S-76D, Bell 205 "Huey," and Leonardo AW139.

The next logical step is to make this information useful to the vehicle operator. Thus, this report describes a depiction of the predicted ground noise footprint and related information on how to reduce the ground noise footprint in addition to the operation of the tool displaying the predicted ground noise footprint. The initial methodology was to develop a noise training aid incorporated in an acoustic flight simulator that pilots could use during simulated flight that indicated the predicted real-time noise footprint on the ground dependent on vehicle states. A training aid was initially chosen because it is independent of vehicle cockpit layout, a preliminary concept for a display was developed in [6], and it is a natural precursor to an in-flight display which will be highly dependent on the vehicle cockpit equipage.

This report documents the acoustic flight simulator which includes the noise training aid. The acoustic flight simulator consists of three modules: (i) a commercially-available flight simulator (§4); (ii) the algorithm that calculates the ground noise footprint (§5); and (iii) the noise training aid displaying of the predicted ground noise footprint that incorporates the noise algorithm (§6). Also included are associated programs to define a flight path (§7), define noise sensitive locations (§8), and convert externally recorded flight data to a format the acoustic flight simulator could replay (§9). Lastly, results from a survey asking potential users about their thoughts on the noise training aide aspect of the acoustic flight simulator are detailed in §10.

2 Installation Instructions

The noise training aid requires the user supplied X-Plane 11 [8] in addition to the noise training aid modules. The required noise training aid modules are the noise server application and the noise training aid. Optional modules include defining a flight path and noise sensitive locations, and the ability to read a predefined flight path from a comma delineated file. Please ensure that X-Plane 11 and any associated helicopter plugins, such as the Dreamfoil Creations Bell 407 model [9] mentioned in §4, have been installed. For an accurate predicted ground noise footprint, please use the Dreamfoil Creations Bell 407 model; otherwise, the noise predictions will not be accurate.

The noise training aid software bundle comes in a self-contained zip archive. It is installed by the user simply unzipping it into a location of choice on the resident computer. Please make a note of that location. Then, to install the X-Plane plugin:

1. Locate the `X-Plane_Plugins` folder under `[unzipped file location]`▸`RVLT_Noise`▸`X-Plane_Plugins`

2. Copy the folder `xpcPlugin` into the X-Plane plugins directory, `[X-Plane 11 Home]`▸`Resources`▸`plugins`. Note the X-Plane 11 home directory is typically under `C:`▸`X-Plane 11` for computers using a Microsoft Windows operating system.

3 Starting the Acoustic Flight Simulator

To start the noise training aid, the three components that make up the acoustic flight simulator must be started. First, start X-Plane 11 with the Dreamfoil Creations Bell 407 as the vehicle model. See §4 for details about the flight simulator. Second, start the noise server application by double clicking on `RunNoiseServerApp.bat`, which is located in the directory where the noise training aid software bundle was unzipped (in the `RVLT_Noise` folder). Additional information about the noise server application is described in §5.1. Last, start the noise training aid by double clicking on `RunNoiseTrainingAid.bat`, also located in the directory where the noise training aid software bundle was unzipped. Additional information about the noise training aid its associated ground noise footprint display can be found in §6.

4 Flight Simulator

X-Plane 11 [8] (X-Plane) is used for the flight simulator with the Bell 407 model available from Dreamfoil Creations at `store.xplane.org` [9]. X-Plane provides the helicopter's attitude and orientation, velocities, main rotor rotation speed (Ω), and main rotor thrust (T) to the Noise Algorithm (§5). Table 1 details the information provided by X-Plane. The developers use a Puma Pro Flight Trainer [10] for the control inceptor.

Table 1: X-Plane supplied information used in the noise algorithm. Units are those needed for the noise algorithm detailed in Noise Algorithm (§5).

Parameter	Symbol	Units
Latitude		decimal degrees
Longitude		decimal degrees
Altitude		ft, mean sea level (MSL)
Heading		radians
Roll		radians
Pitch		radians
Horizontal Velocity	V	meters per second (m/s)
Vertical Velocity	V_z	m/s
Main Rotor Rotation Speed	Ω	radians/s
Main Rotor Thrust	T	Newtons

X-Plane is run on a desktop using Windows 10, 16 GB RAM, and an nVidia graphics card. The acoustic flight simulator noise training aid software bundle requires at most 200 MB of hard drive space to install. X-Plane 11 system requirements can be found at `https://x-plane.helpscoutdocs.com/article/16-x-plane-11-system-requirements` [11]. Initially the flight simulator computer was separate from the ground noise footprint display computer; therefore, when using one computer to run X-Plane and another computer to run the acoustic flight simulator, a crossover cable can be employed to pass data from the flight simulator to the noise algorithm and hence the noise footprint display.

5 Noise Algorithm

Greenwood's FRAME-QS (Fundamental Rotorcraft Acoustic Modeling from Experiments – Quasi-Static acoustic mapping) noise algorithm [5] provides data for the predicted noise footprint. FRAME-QS determines the appropriate acoustic sphere to use based on the helicopter's physical characteristics and the data from the simulator (described in Flight Simulator (§4)). These data include measured orientation of the helicopter [6]. FRAME-QS also uses effective flight path angle (γ_e), which is calculated by

$$\sin \gamma_e = \frac{\vec{v} \cdot \hat{n}_a}{V} \quad \text{(from Ref. [12])} \tag{1}$$

where V is longitudinal velocity (available from the simulator), $\vec{v}$ is the inertial frame velocity (derived from the simulator velocity vector (V and V_z) and heading, pitch, and roll), and $\hat{n}_a$ is the inertial tip path plane normal vector, which is related to inertial acceleration. Therefore,

$$\hat{n}_a(t) = \frac{\vec{a}(t)}{|\vec{a}(t)|} \tag{2}$$

where acceleration (a) is calculated from changes in velocity (V and V_z). Also needed are advance ratio (μ) and thrust coefficient (C_T). Advance ratio is a function of the free-stream velocity vector (V_∞) and main rotor rotation speed (Ω)—both provided from the simulator—in addition to the main rotor radius (R),

$$\mu = \frac{V_\infty}{\Omega R} \tag{3}$$

The thrust coefficient uses main rotor thrust (T) and main rotor rotation speed, all provided from the simulator, in addition to the main rotor radius, area of the rotor, and air density (ρ),

$$C_T = \frac{T}{\rho A \Omega^2 R^2} \tag{4}$$

Once the appropriate sphere is determined, the maximum noise is assumed to be directly underneath the vehicle for this implementation. While accurate in many cases, this assumption may not be correct for cases of blade vortex interaction (BVI) [13, 14]. A flat-earth model is also assumed, which may further affect the accuracy of the predicted ground noise footprint. Helicopter altitude is taken into consideration to set the noise level on the ground by attenuating the noise level by 6 dBA for each doubling of distance (Eq. 5).

$$\Delta\text{Level} = 20 \log\left({}^{1}\!/\!{}_{2}\right) = -6.06 \text{ dBA} \tag{5}$$

The noise level underneath the helicopter projected onto the ground in addition to the distance where the noise level is at an annoyance threshold (also projected onto the ground) and the helicopter altitude are used to define the predicted ground noise footprint contour (§6.1).

5.1 Noise Server Application

In order for the predicted ground noise footprint display to acquire the data mentioned above, the `RunNoiseServerApp.bat` needs to be started, which is located in the directory where the noise training aid software bundle was unzipped (in the 🗀 `RVLT_Noise` folder). Double click on `RunNoiseServerApp.bat` and once started, the ServerApp window in Figure 1 appears. The predicted ground noise footprint will display in the noise training application display once the noise field model has completed loading, which is indicated on the noise server application with "Completed loading Noise field model," and X-Plane is outputting a vehicle location. Table 2 details the menus and buttons on the ServerApp.

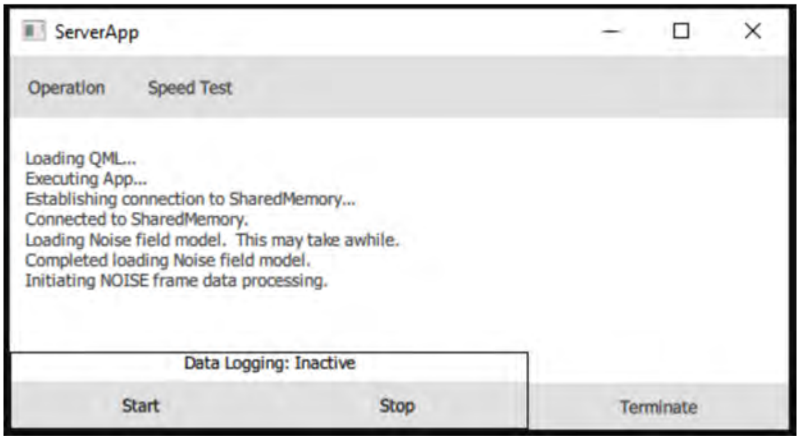


Figure 1: Noise server application.

Table 2: ServerApp menus and buttons.

Menu or Button	Action
Operation > Pause	Pauses the server application which results in the noise footprint not updating.
Operation > Resume	Reactivates the server application from its paused mode.
Speed Test > Run Test	Special case setup; therefore, not currently active.
Speed Test > Log Results	Special case setup; therefore, not currently active. (Reports duration of speed test and number of noise fields generated in that time.)
Start	Start writing debugging data to the file `NoiseData_NoiseDataDump_<DATE>_<TIME>.log`.
Stop	Stops writing debugging data.
Terminate	Closes the ServerApp window.

6 Noise Training Aid

As mentioned in Noise Algorithm (§5), the ground noise footprint display uses Greenwood's FRAME-QS noise algorithm to provide data for the predicted noise footprint. The information is shown on a display programmed in general using Qt®[1], in particular using QtXML version 5.12 [15, 16]. QtXML was chosen because it is an easy to use cross-platform application framework that has a map plug-in, QtLocation version 5.15 [17].

The noise training aid display is shown Figure 2. The display is intended to aid pilots with learning how to minimize ground noise footprint; therefore, the information provided consists primarily of a background map, the predicted ground noise footprint, a pitch and bank ladder, and four tapes—longitudinal acceleration, airspeed, altitude, and vertical velocity. Other improvements such as the tape ribbons and noise level were added because of feedback obtained from potential users at various exhibitions (e.g., HAI (Helicopter Association International) Heli-Expo 2019 and 2020, Vertical Flight Society's (VFS) 75th Annual Forum and Technology Display, and EAA (Experimental Aircraft Association) AirVenture Oshkosh 2019). Details regarding improvements made after feedback from the above mentioned exhibitions is in [18].

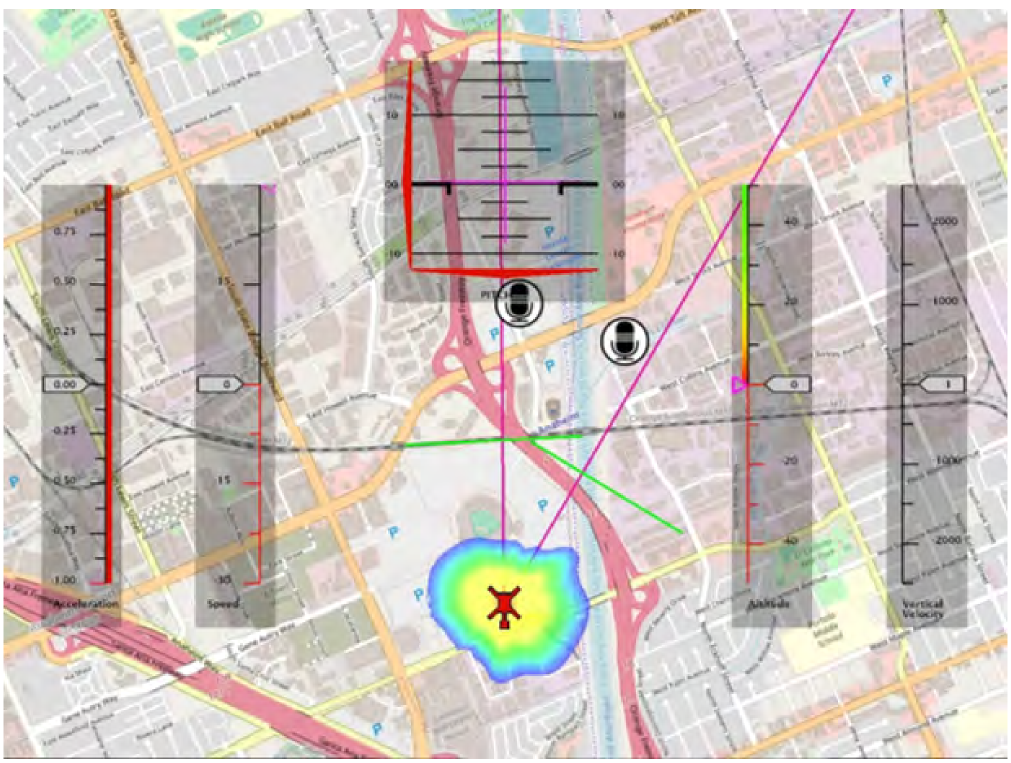


Figure 2: Noise training aid display.

[1]Qt is a registered trademark of The Qt Company Ltd. and its subsidiaries.

6.1 Ground Noise Footprint Display

The noise footprint radiates away from the helicopter icon out to the annoyance threshold. The default annoyance threshold is 65 dBA (A-weighted decibel of the overall sound pressure level). The 65 dBA level is chosen as the default annoyance threshold because it is a common threshold for transportation noise as it is comparable to daytime background noise levels of suburban neighborhoods and is described as a moderate noise level [19, 20]. The noise footprint color scheme from loudest to lowest dBA is reddish-orange, yellow, green, blue, and dark blue indicating the annoyance threshold. See §6.4 for an example of the color scale. The color palette was chosen so that there is minimal conflict with the alerting colors [21]. The default noise level for the reddish-orange color is ≥110 dBA which is described as almost painful [20].

The noise footprint is calculated along every 5° radiating out from the vehicle center to where the annoyance threshold is reached with the helicopter icon's color matching the noise level color below the helicopter, which is typically the loudest noise level. The noise level linearly decreases from the position of the loudest noise point out to the annoyance threshold boundary along each radial because terrain is currently not taken into consideration and noise typically attenuates by 6 dBA for each doubling of distance as mentioned in §5 and Eq. 5. For this current instantiation of the predicted ground noise footprint as mentioned in §5, the loudest location is assumed to be underneath the vehicle, which may not always be true (e.g., for blade vortex interactions). Therefore, the developers are looking into methods to increase the accuracy of the predicted ground noise footprint by pinpointing the loudest location.

6.2 Vehicle States Tapes and Ladders

There are four tapes—longitudinal acceleration (acceleration), airspeed (speed), altitude, and vertical velocity (also known as vertical speed)—and a pitch and roll ladder (Figure 2). Pitch, acceleration, and altitude are displayed because these parameters directly affect the noise generated. Speed and vertical velocity were also included because these are common pilot control parameters and they are directly related to acceleration and altitude respectively.

Any values outside the maximum and minimum maneuvering limits of acceleration, speed, altitude, vertical velocity, and pitch for a particular helicopter model are represented by red on the tapes and pitch ladder. Table 3 indicates the maneuvering limits of the Bell 407 [22–24] as an example.

Indications of vehicle states needed to minimize the predicted ground noise footprint are shown on the ribbons on the outside left of the tapes and on the outside left and bottom of the ladder. The values to minimize noise were calculated by sampling what the noise level would be if that particular variable changed to that point on the tape; for example, determining what the noise value underneath the vehicle would be if the altitude changed from the current altitude to current altitude plus ten feet with the other vehicle states remaining the same.

The ribbons use the same color coding as the noise footprint (Figure 3). For

Table 3: Bell 407 maneuvering limits.

Parameter	Limits
Acceleration	-1.0 – 3.5 g-force
Speed	0 – 140 knots
Altitude	0 – 18,690 ft
Vertical Velocity	±2,000 ft/min
Pitch	-30° – 50°

the bank and pitch ladder, two possible implementations were developed: (i) using a U-shape where the pitch ribbon is shown on both sides of the ladder (Figure 4a) and (ii) using an L-shape where the pitch ribbon is shown only on the left side of the ladder (Figure 4b). The current default setting is the L-shape (Figure 4b).

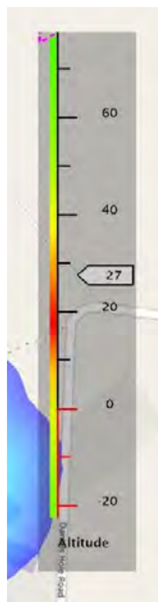
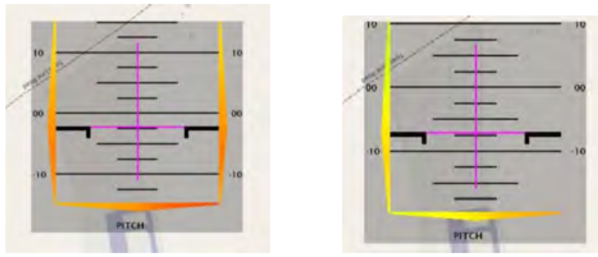


Figure 3: Tape ribbon indicating the vehicle state needed to minimize predicted ground noise footprint. This example is for altitude. The current altitude is 27 feet and the ribbon indicates that the noise beneath the helicopter will increase if altitude is decreased (red) to 20 feet and the noise will decrease if the altitude is increased (yellow at approximately 40 feet and green at approximately 60 feet).



(a) U-shaped ladder ribbon.

(b) L-shaped ladder ribbon.

Figure 4: Bank and pitch ladder ribbons indicating attitude needed to minimize predicted ground noise footprint. In Figure 4b, an increase in pitch to approximately 10 degrees or a bank to the left will decrease the noise (to green or light yellow respectively).

6.3 Map

The map is supplied by OpenStreetMap™[2] [25] and Qt has a plugin for OpenStreetMap [17] for easy integration. In order to accurately display the map, there must be an internet connection. The map is synchronized to the flight via latitude and longitude data from the simulator. The noise footprint is also scaled to the map based on the map scale. The map is oriented track up.

6.4 Map Scales

A legend in the lower left corner indicates the map scale (Figure 5). The map scale can be changed via a mouse scroll wheel or on a touchpad using an up and down two finger gesture. Additionally, a scale indicating the current endpoints of the noise threshold values was also added (Figure 5).

Figure 5: Map scaling and noise threshold scaling values.

[2]OpenStreetMap is a trademark of the OpenStreetMap Foundation, and is used with their permission. This project is not endorsed by or affiliated with the OpenStreetMap Foundation.

6.5 Changing Noise Threshold Levels

Tour businesses that operate in quiet areas, such as national parks, suggested that the annoyance level should be lower in these regions because the overall noise level is typically very low. Therefore, an option was implemented to vary both noise footprint endpoints via a dialog box (Figure 6). This is done by clicking on Replay/Record > Configure Noise Field, which will display the dialog box Configure the Noise Field ... (Figure 6). When the noise threshold levels are changed, the noise scale on the map scales (§6.4) will reflect the new noise scales once Save is clicked. Table 4 details the Configure the Noise Field... dialog box options.

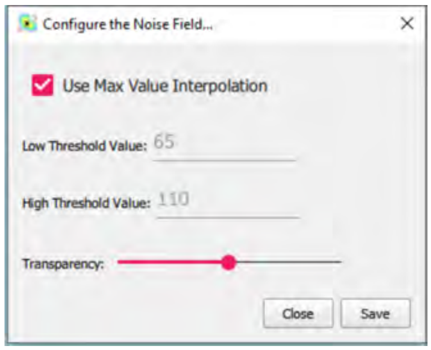


Figure 6: Dialog box to change noise threshold values.

Table 4: Configure the Noise Field... dialog window buttons.

Button	**Action**
Use Max Value Interpolation	Smoothly interpolates the values between the "High Threshold Value" and "Low Threshold Value." If not checked, color coding will always be from red to yellow to green to blue regardless of the noise reported under the vehicle.
Low Threshold Value: 65	Low noise threshold value (in dBA). Default recommended value is 65 dBA.
High Threshold Value: 110	High noise threshold value (in dBA). Default recommended value is 110 dBA.
Transparency:	Transparency level of the predicted ground noise footprint on the display. Default recommended value is 50.
Close	Closes the dialog box without saving.
Save	Saves the values and closes the dialog box.

6.6 Route

A route can be shown on the ground noise footprint display. The route is in magenta (see Figure 2). The path is rendered using an `XML` file. An example section of the route is shown in Listing 1. Notice that the number of legs must be one less than the number of waypoints. The location of the waypoints are in decimal degrees latitude and longitude. For the legs, the start id waypoint number must be the same as the previous end waypoint number for the path to be contiguous except for the first leg. The lateral and vertical constraints are for noise scoring purposes and currently cannot be easily modified. A noise scoring penalty will be accrued if the vehicle is more than plus or minus the defined values laterally or vertically. See §6.8 for further details regarding noise scoring.

Listing 1: Example XML route listing.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- This document contains the route consisting of waypoints that
<!-- form legs.-->
<Flight>
  <Route name="UF36fromCL86to15CA" wrapAround="false">
    <Waypoint id="0" name="Wpt00">
      <Location lat="37.385495" lon="-121.972459"/>
        </Waypoint>
        <Waypoint id="1" name="Wpt01">
          <Location lat="37.39369085" lon="-122.0056955"/>
        </Waypoint>
        <Waypoint id="2" name="Wpt02">
          <Location lat="37.38127998" lon="-122.0316538"/>
        </Waypoint>
        <Waypoint id="3" name="Wpt03">
          <Location lat="37.42592817" lon="-122.1384746"/>
        </Waypoint>
        <Leg id="0" start="0" stop="1">
          <LateralConstraint value="-1.0" unit="ft"/>
          <VerticalConstraint value="500" unit="ft"/>
        </Leg>
        <Leg id="1" start="1" stop="2">
          <LateralConstraint value="-1.0" unit="ft"/>
          <VerticalConstraint value="500" unit="ft"/>
        </Leg>
        <Leg id="2" start="2" stop="3">
          <LateralConstraint value="-1.0" unit="ft"/>
          <VerticalConstraint value="500" unit="ft"/>
        </Leg>
  </Route>
</Flight>
```

The route can be generated by running `RunDefineFltPath.bat` located in the 🗁`RVLT_Nose` folder and this application is detailed in §7. The route file can then be loaded via menus in the acoustic flight simulator (see §6.9.3).

6.7 Noise Sensitive Areas

Noise sensitive areas can also be shown on the ground noise footprint display. These noise sensitive areas are represented by the microphone symbol as seen in Figure 2. The symbol placement is rendered using an `XML` file. An example section of the route is shown in Listing 2. As before, the location of the sensors are in decimal degrees latitude and longitude.

Listing 2: Example XML noise sensitive areas listing.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- This document contains a list of sensors that can be loaded
<!-- into the Acoustic Flight Simulator. -->
<Sensor id="101">
  <Location lat="33.8077778" lon="-117.8769444" alt="0.00"/>
</Sensor>
<Sensor id="102">
  <Location lat="33.822778" lon="-117.89722" alt="0.00"/>
</Sensor >
<Sensor id="103">
  <Location lat="33.819722" lon="-117.862222" alt="0.00"/>
</Sensor>
<Sensor id="104">
  <Location lat="33.804722" lon="-117.873056" alt="0.00"/>
</Sensor>
```

The noise sensitive area locations can by specified running `RunSelectNoiseSensitiveLox.bat` located in the 🗀`RVLT_Noise` folder as described in §8. The noise sensitive areas file can then be loaded via menus in the acoustic flight simulator (see §6.9.3).

6.8 Noise Level Scoring

The noise level readout is a cumulative measure of noise for both the flight and over the noise sensitive areas. For the flight, the noise level below the vehicle, which is typically the loudest, is summed for the flight. At the noise sensitive area locations, the noise level is summed if it is greater than the lower threshold noise level. The general equation for the noise summation is

$$L_{AE} = 10\log_{10}\int_{t_1}^{t_2} 10^{\frac{L_a(t)}{10}} \approx 10\log_{10}\sum_{n=0}^{n} 10^{\frac{L_a}{10}} \tag{6}$$

where L_{AE} is the A-weighted overall sound pressure level in dBA, t is time, and L_a is the A-weighted sound pressure level at that moment in dBA.

The noise is calculated once the vehicle passes beyond the "start" gate location and ends when it crosses the "stop" gate location as detailed in Listing 3. As with the other `XML` files, the latitude and longitude are in decimal degrees.

Listing 3: Example XML gate listing.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<!-- This document contains a list of gates that start
<!-- and stop the noise calculations. -->
<Flight>
  <GateList>
        <Gate role="start">
          <Location lat="33.804414" lon="-117.884559"/>
          <Location lat="33.801969" lon="-117.8767769"/>
        </Gate>
        <Gate role="stop">
          <Location lat="33.802518" lon="-117.879039"/>
          <Location lat="33.796889" lon="-117.874231"/>
        </Gate>
  </GateList>
</Flight>
```

A digital display of the current noise level scoring can be toggled on and off by pressing Flight » Show Data. Details are available in §6.9.2 .

6.9 Noise Training Aid Application

To start the noise training aid, double click on `RunNoiseTrainingAid.bat` in the `RVLT_Noise` folder. Once started, the Noise Training Aid window in Figure 7 appears. Click on XPlane » Disconnect and then XPlane » Connect to ensure the application is communicating with the noise server application (§5.1) and X-Plane. The background map should automatically populate from X-Plane data with the current vehicle location.

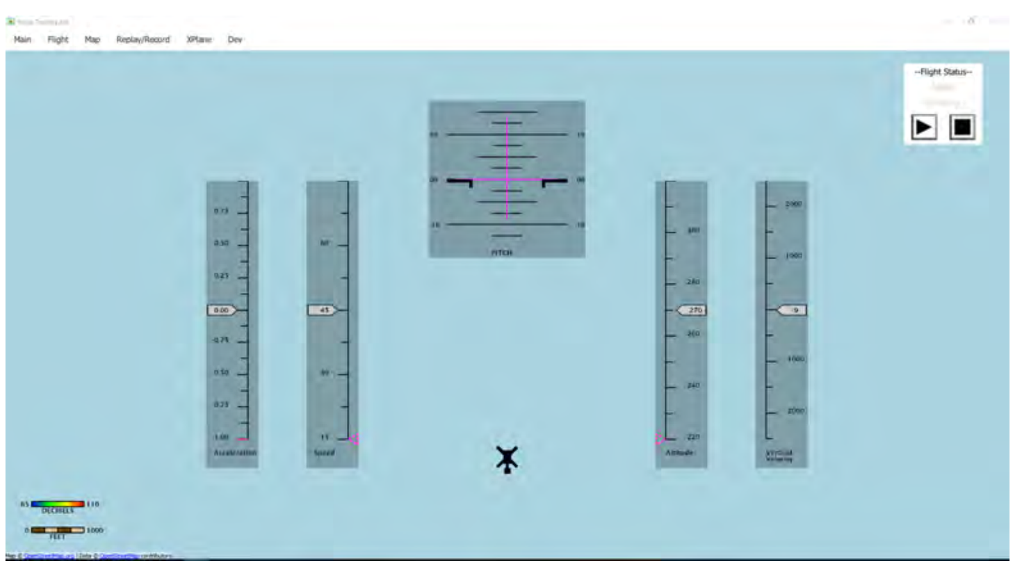


Figure 7: Noise training aid start screen.

6.9.1 Main Menu

In the Noise Training Aid main menu, Main > Exit will exit the Noise Training Aid.

6.9.2 Flight Menu

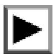
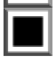
Noise Training Aid flight menu is detailed in Table 5.

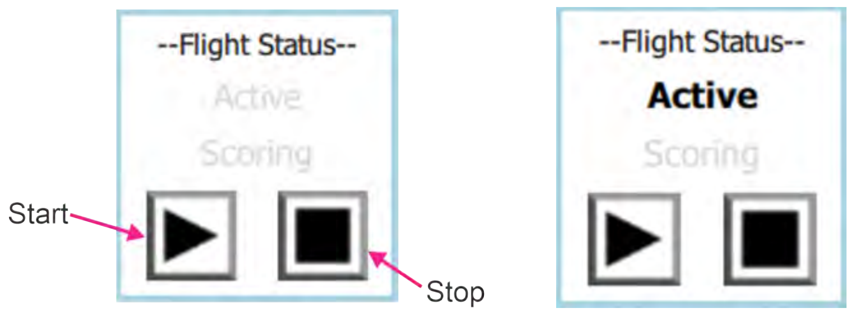
Table 5: Noise Training Aid flight menu.

Menu or Button	Action
Flight > Load Flight	Brings up a dialog to choose a flight XML file. To load a flight, simply navigate to the appropriate 🗀 `XML Folder` and choose the appropriate `<FLIGHT>.xml` file (file that has a `<Flight>` tag). The route will then be displayed on the noise training aid display with a magenta line between waypoints and microphone symbols if noise sensitive areas were defined (see Figure 2).
Flight > Show Flight Controls	Toggles the flight status window (See Flight Status Window).
Flight > Show Data	Toggles a window that indicates the noise score, upcoming waypoint if applicable, and percent progress through the route. See Show Data Window.
Flight > Start	Starts data recording. Also see Flight Status Window.
Flight > Stop	Stops data recording. Also see Flight Status Window.
Flight > Export	Exports the flight to `TestFlight_<DATE>_<TIME>.db`. This file contains information about the flight just flown that can be used for Replay (see §6.9.4). The fields in the database are simulation frames by timestamp, noise field and noise guidance by timestamp, embedded noise sensitive locations, route information (i.e., waypoints and legs), and scoring parameters.
Flight > Export Scored	This file contains information about the flight just flown with noise information recorded between the start and stop gates. This file can be used for Replay (see §6.9.4). The fields in the database are the same as mentioned in Flight > Export.
Flight > Reset	This erases the current memory for the active flight. This includes any record of simulation frames, noise frames, scoring data, and route progress. It does not clear the flight configuration; it essentially resets a flight to start again.

Flight Status Window The flight status window (Figure 8) has some of the same functionality of the Flight > Start and Flight > Stop (Table 5). Table 6 and Figure 8 detail the functionality of the buttons on the –Flight Status– window. This window appears in the upper right of the screen and cannot be moved.

Table 6: –Flight Status– window buttons.

Button	Action
	Starts data recording. Recording is active as indicated in Figure 8b.
	Stops data recording.



(a) Inactive. (b) Active.

Figure 8: Flight status window for data recording.

Show Data Window Flight > Show Data toggles the noise score window shown in Figure 9. This window shows the cumulative noise score, next waypoint name and percent progress through the route if applicable. This window is in the upper left side of the screen and cannot be moved.

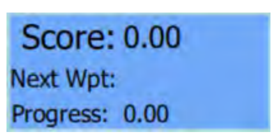


Figure 9: Noise score window toggled by Flight > Show Data.

6.9.3 Map Menu

Noise Training Aid map menu is detailed in Table 7.

Table 7: Noise Training Aid map menu.

Menu	Action
Map > Load Route	Brings up a dialog to choose a route XML file. To load a flight, simply navigate to the appropriate 🗀 `XML Folder` and choose the appropriate `<ROUTE>.xml` file (file that has a `<Route>` tag). The route will then be displayed on the noise training aid display with a magenta line between waypoints (see Figure 2).
Map > Load Sensors	Brings up a dialog to choose a sensor location XML file. To load the sensor locations, simply navigate to the appropriate 🗀 `XML Folder` and choose the appropriate `<SENSOR>.xml` file (file that has a `<Sensor>` tag). The sensors will then be displayed on the noise training aid display using microphone symbols (see Figure 2).
Map > Clear All	Clears the route and noise sensitive locations from the display.
Map > Clear Route	Clears the route from the display.
Map > Clear Sensors	Clears the noise sensitive locations from the display.
Map > Locations	Choose and display pre-chosen destinations.

6.9.4 Replay/Record Menu

Noise Training Aid replay/record menu is detailed in Table 8. Note that a flight (Flight > Start) is a scored data run that is not necessarily being recorded to a database file. The user has to choose to export the data at that point to do so (Flight > Export or Flight > Export Scored). Recording with the record system does not account for any scoring (Replay/Record > Record Flight); it is strictly about recording simulation and noise frames from start to finish. So in summary, Flight > Start is for noise scoring analysis and Replay/Record > Record Flight is for "free flight" with no scores.

Record Flight The Record System dialog box is show in Figure 10 and the buttons are detailed in Table 9. When "OK" is pressed, the Record Run... control window appears (see View Record Controls).

Replay Flight Replay System window is shown in Figure 11 and the buttons are detailed in Table 10.

View Record Controls Replay/Record > View Record Controls displays the Record Run... controls box shown in Figure 12 with button details in Table 11. This box can be moved out of the way to other parts of the display. It can also be expanded to display the full elapsed time field by using a mouse to drag the right side of the window.

View Replay Controls Replay/Record > View Replay Controls displays the Replay Run... dialog box shown in Figure 13 and the buttons are detailed in

Table 8: Noise Training Aid replay/record menu.

Menu	Action
Replay/Record » Record Flight	Brings up the Record System dialog. Details about this dialog is in Record Flight.
Replay/Record » Replay Flight	Brings up the Replay System dialog. Details about this dialog is in Replay Flight.
Replay/Record » View Record Controls	Brings up the Record Run... dialog box, which is detailed in View Record Controls. This box can be moved out of the way to other parts of the display.
Replay/Record » View Replay Controls	Brings up the Replay Run... dialog box, is detailed in View Replay Controls. This box can be moved out of the way to other parts of the display.
Replay/Record » Configure Noise Field	Displays the Configure Noise Field... dialog box detailed in §6.5.

Table 12. This box can be moved to other parts of the screen.

6.9.5 XPlane Menu

Noise Training Aid XPlane menu is detailed in Table 13.

Configure XPlane IP Address The Configure XPlane IP Address... dialog box is shown in Figure 14 and the buttons are detailed in Table 14.

7 Define Flight Path Application

A route can be generated by running `RunDefineFltPath.bat` in the 🗀`RVLT_Noise` folder, which will open the MainWindow dialog box (Figure 15). The buttons are described in Table 15.

At least two coordinates need to be entered. After two coordinates are entered, a window appears asking if another waypoint needs to be entered. If "Yes" is clicked, then Figure 15 reappears. If "No" is clicked, then a dialog asking the name to save the `XML` file appears (see §7.2).

7.1 Define Flight Path Coordinate Using Latitude and Longitude

Figure 17 shows the window for inputting a waypoint using latitude and longitude. The coordinates can be entered using either decimal degrees (e.g., 37.38127998; left side under "Decimal Latitude and Longitude") or degrees:minutes:seconds (e.g., 37° 22' 52.6074''; right side under "Degrees Minutes Seconds Latitude" and "Degrees Minutes Seconds Longitude"). Suggested websites are provided to look up known waypoints via AirNav.com for decimal degrees and iFlightPlanner Aviation Charts

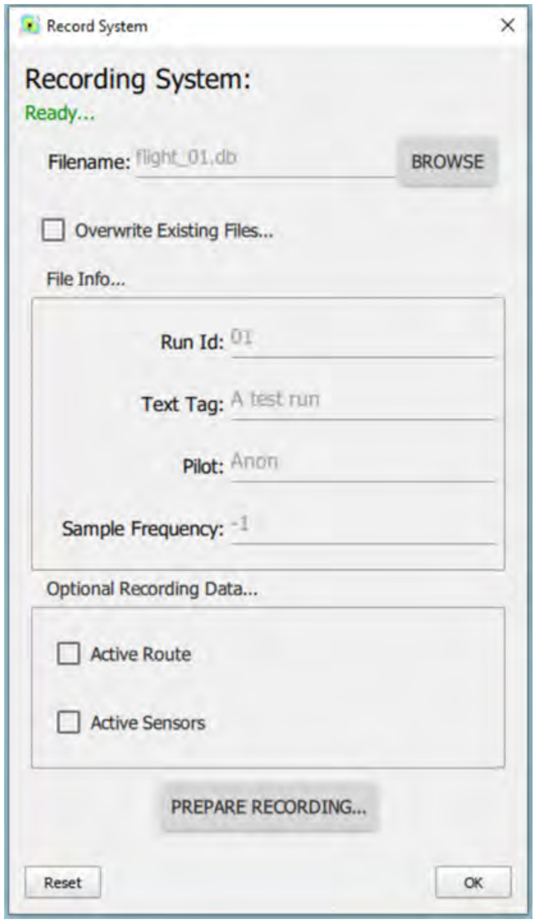


Figure 10: Record system dialog box.

for degrees:minutes:seconds. A name must be entered for the waypoint and then hit the `Tab` key. Once all the information has been entered either the "Submit Decimal Lat/Lon" or "Submit DMS Lat/Lon" button will become active. To save the coordinates, press the active button. To cancel the input, press "Cancel" and the MainWindow (Figure 15 and §7) will be displayed.

7.2 Save Flight Path Coordinates

In order to save the flight path, the dialog shown in Figure 18 comes up. The default location for saving files is in 🗀`Resources/Flights`. "Save" will save the `*.XML` file and "Cancel" will end the program without saving the flight path.

8 Define Noise Sensitive Areas Application

The noise sensitive area locations can by specified running `RunSelectNoiseSensitiveLox.bat` in the 🗀`RVLT_Noise` folder, which will open a DefineNoiseSensitiveLox window (Figure 19). The buttons are detailed in Table 16.

Table 9: Record System window buttons.

Button	Action
Filename: flight_01.db BROWSE	BROWSE brings up a file window dialog box where a previous or new database file (`*.db`) can be specified. Once the file is named, it will show in the Filename: window
Overwrite Existing Files...	Overwrite the file if it already exists; otherwise the new file will be created if it does not already exist. If the file exists and "Overwrite" is not checked, the system will throw an error.
Run Id: 01	Input a run identification number. Default is "01."
Text Tag: A test run	Input a text tag. Default text is "A test run."
Pilot: Anon	Enter pilot's name. Default is "Anon."
Sample Frequency: -1	Change the sample frequency in Hz. The default of "-1" collects data at the fastest rate possible.
Active Route	Embeds the route information from the route (see Listing 1 in §6.6) into the database by creating tables for legs ("legData"), waypoints ("waypointData"), and route information ("routeInfo").
Active Sensors	Embeds the noise sensitive location information (see Listing 2 in §6.7) into the database by creating tables for sensor information ("sensorInfo") and sensor data ("sensorData").
Reset	Clears all the Record System dialog inputs.
OK	Closes this dialog and brings up the Record Run dialog box as detailed in View Record Controls.

8.1 Define Noise Sensitive Locations Using Latitude and Longitude

Figure 20 shows the dialog for inputting a noise sensitive location in using latitude and longitude. The coordinates can be entered using either decimal degrees (e.g., 37.38127998; left side under "Decimal Latitude and Longitude") or degrees:minutes:seconds (e.g., 37° 22' 52.6074''; right side under "Degrees Minutes Seconds Latitude/Longitude"). After naming the noise sensitive location, press `Tab`. Once all the information has been entered either the "Submit Decimal Lat/Lon" or "Submit DMS Lat/Lon" button will become active. To save the coordinates, press the active button. To cancel the input, press "Cancel" and the MainWindow (Figure 19 and §8) will be displayed.

8.2 Save Noise Sensitive Coordinates

Once all the noise sensitive locations have been inputted, Figure 21 appears asking for a route `XML` file where the data is to be saved. Note, the data must be saved to a preexisting route file.

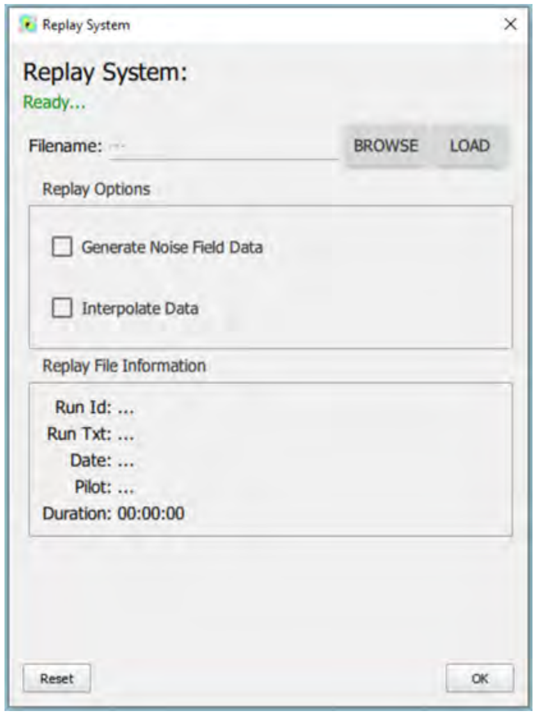


Figure 11: Replay system dialog box.

Table 10: Replay System window buttons.

Button	Action
Filename: BROWSE LOAD	BROWSE brings up a file window dialog box where a previous database file (*.db) can be chosen. Once the file is selected, it will show in the Filename: window. Then click on LOAD to load the file into memory. Once loaded the status changes from "Ready..." to "Replay load successful!" and the lower box under "Replay File Information" provides the user with information regarding that run—run ID, run text, date, pilot, and duration of the flight—if available.
Generate Noise Field Data	Click to see the predicted ground noise footprint.
Interpolate Data	Click to smooth the data for the predicted ground noise footprint.
Reset	Clears all the inputs in the Replay System.
OK	Closes this dialog and brings up the Record Run dialog box as detailed in View Replay Controls.

9 Converting Outside Recorded Data for Replay

Externally generated database (*.db) or comma delineated (*.csv) files from actual flights can be converted into a database for use in the acoustic flight simulator. Open

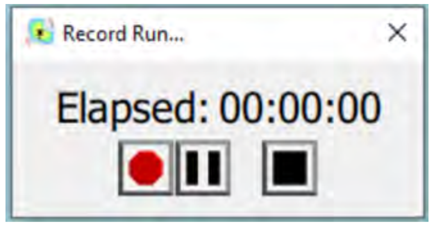
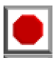
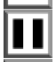
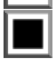


Figure 12: Record run dialog box.

Table 11: Record Run... window buttons.

Button	Action
	Starts the recording of the run.
	Pauses the recording of the run.
	Stops the recording of the run.

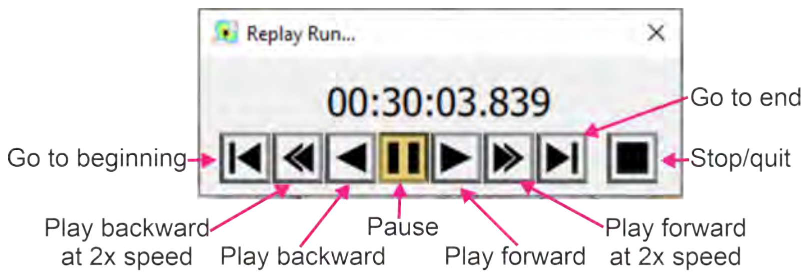
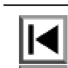
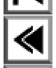
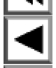
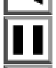
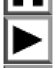
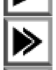
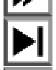
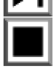


Figure 13: Replay controls.

Table 12: Replay System window buttons.

Button	Action
	Go to the beginning of the replay file.
	Plays the replay of the run backwards at 2x speed.
	Plays the replay of the run backwards.
	Pauses the replaying of the run.
	Starts the replay of the run.
	Plays the replay of the run at 2x speed.
	Go to the end of the replay file.
	Stops the replaying of the run and closes this window.

`RunFltDataManip.bat` in the `RVLT_Noise` folder and choose whether to convert a database or csv file (Figure 22). Clicking on "DB file" will allow a database file to be converted (see §9.1) while clicking on "CSV file" will allow a csv file to be converted (see §9.2). "Cancel" will close the program.

Table 13: Noise Training Aid XPlane menu.

Menu	Action
XPlane » Connect	Connects the Noise Training Aid to the server application (and thus to X-Plane 11).
XPlane » Disconnect	Disconnects the Noise Training Aid to the server application.
XPlane » Set Port Id	Brings up the Configure XPlane IP Address... dialog box detailed in Configure XPlane IP Address.

9.1 Conversion of Database Files

To convert a database file, click on "Browse" which will open up a dialog to choose a `*.db` file. Navigate to the appropriate `DB` folder and in order to choose the `*.db` file. Clicking on "OK" will then bring up the screen to match the data (§9.3) and "Cancel" will close the program.

9.2 Conversion of CSV Data

To convert a CSV file, click on "Browse" which will open up a dialog to choose a `*.csv` file. Navigate to the appropriate `CSV` folder and in order to choose the `*.csv` file. Clicking on "OK" will then bring up the screen to match the data (§9.3) and "Cancel" will close the program.

9.3 Matching Data

The flight data from the external file needs to be matched to the data needed by the acoustic flight simulator. This is done through the interface shown in Figure 25. First locate the database table that was read in via §9.1 or converted to a database file via §9.2 and then click on "Select." This will activate the simTime field. Click on the "v" and choose the variable for simTime and then click on "Select." Repeat this for Latitude, Longitude, and Altitude. These variables are required for the acoustic flight simulator and cannot be calculated from other fields.

Then choose the appropriate fields for Heading, Indicated Airspeed, Groundspeed, and Vertical Velocity. If the groundspeed is in knots, please click on "KNOTS?" so that the values can be converted to meters per second. These four variables can be calculated from the Required Data previously entered with fairly accurate calculations. In particular, heading will be calculated from the course between two points (Eq. 7 from [26]):

$$\begin{aligned} heading = \operatorname{mod}\Big(&\operatorname{atan2}\big(\sin(lon1 - lon2) * \cos(lat2), \\ &\cos(lat1) * \sin(lat2) - \\ &\sin(lat1) * \cos(lat2) * \cos(lon1 - lon2)\big), 2\pi\Big) \end{aligned} \tag{7}$$

where $lat1$ and $lat2$ are the starting and ending latitude respectively, and $lon1$ and $lon2$ are the starting and ending longitudes respectively. If either indicated airspeed

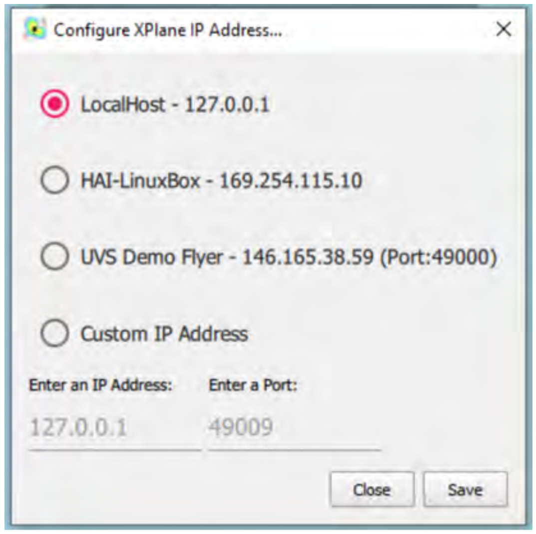
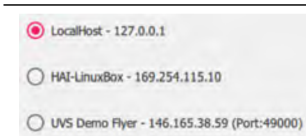


Figure 14: Configure XPlane IP Address... dialog.

Table 14: Configure XPlane IP Address window buttons.

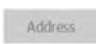
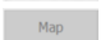
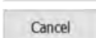
Button	**Action**
	Click on “LocalHost - 127.0.0.1.”
	Click only if there is a custom IP address that needs to be used. If clicked, “Enter an IP Address:” and “Enter a Port:” becomes active.
	Specific IP address to use. Only active if “Custom IP Address” is clicked.
	Specific port to use. Only active if “Custom IP Address” is clicked.
	Closes the dialog box.
	Saves changes and closes the dialog box.

or groundspeed is not available, then both will be set to the same value; however, if neither is available, then indicated airspeed and groundspeed are calculated using the haversine formula for distance [26] and the difference between the associated timestamps (i.e., simTime). If vertical velocity is not available, it will be calculated by a simple derivative of the difference in altitude divided by the associated timestamps.

If data is not available for Pitch, Roll, Thrust, and Rotor Speed, then an estimation of these values will be calculated but the accuracy of the predicted ground

Figure 15: DefineFltPath initial menu.

Table 15: Define flight path dialog window buttons.

Button	Action
	Enter a flight path coordinate using latitude and longitude (see §7.1 on page 20).
	Not currently implemented.
	Not currently implemented.
	Asks about quitting the define flight path program (Figure 16). Press “OK” to quit the program or press “No” to return to the define flight path initial menu (Figure 15).

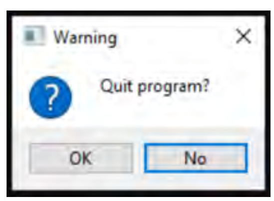


Figure 16: Define flight path “Quit” program question.

noise footprint will be *greatly* affected. If the external thrust values are in pounds, please click on “LBS?” to convert those values to Newtons and if the rotor speed is in rotations per minute, please click on “RPM?” to convert those values to radians per second.

Lastly, indicate the column with air density if available. If not, the standard formula

$$\rho = \begin{cases} \rho_0 * (1 - 6.8755856 * 10^{-6} * h)^{5.2558797} & \text{if } h < 36,089.24 \text{ ft}, \\ \rho_{Tr} e^{(-4.806346*10^{-5}(h-36089.24))} & \text{otherwise} \end{cases} \tag{8}$$

will be used where $\rho_0 = 1.2250 \text{ kg/m}^3$, $\rho_{Tr} = 0.2970756 * \rho_0$, and h is the vehicle

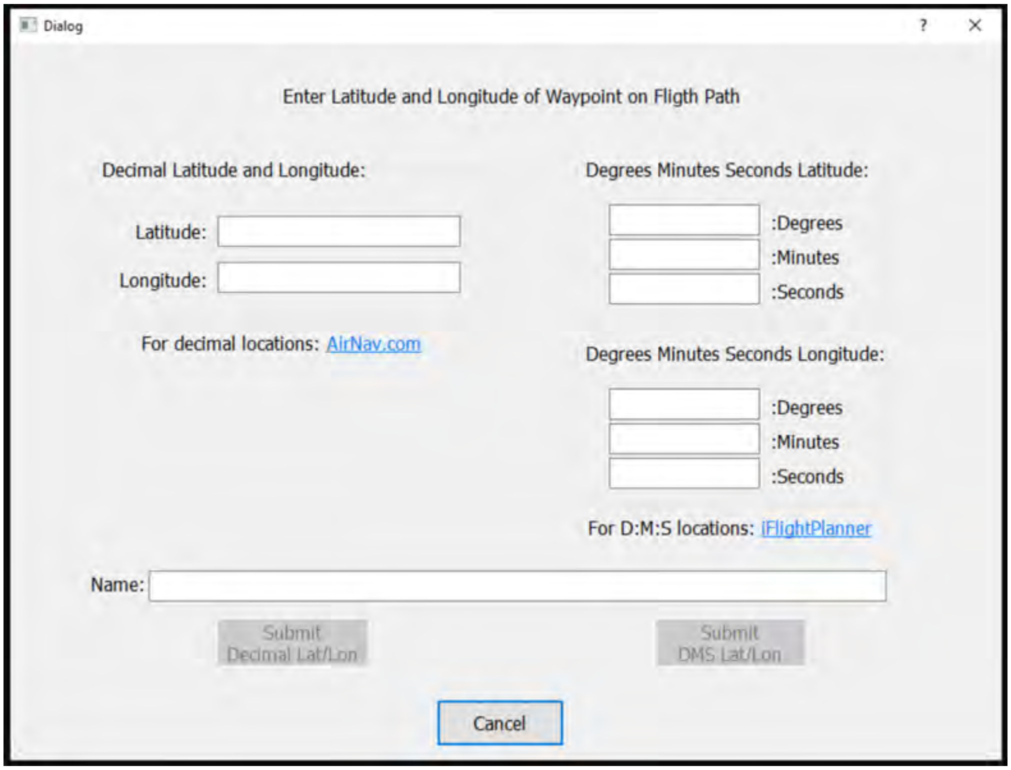


Figure 17: Inputting a flight path coordinate using latitude and longitude.

Figure 18: Saving a flight path.

altitude in feet [26].

Clicking on “Submit” will allow the database file to be saved (§9.4), “Reset” will reset all the fields in this form, and “Cancel” will close the program.

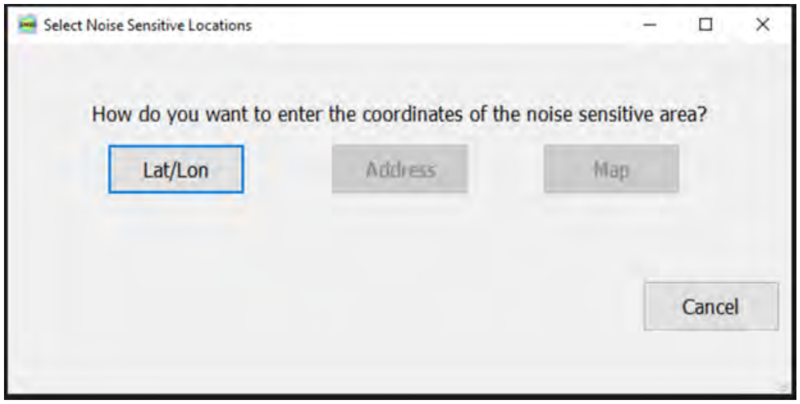


Figure 19: Input noise sensitive area by latitude and longitude or address.

Table 16: Define noise sensitive locations dialog window buttons.

Button	Action
Lat/Lon	Enter a noise sensitive location using latitude and longitude (see §8.1).
Address	Not currently implemented.
Map	Not currently implemented.
Cancel	Asks about quitting the define noise sensitive location program. Press "OK" to quit the program or press "No" to return to the define noise sensitive location initial menu (Figure 19).

9.4 Saving Database File

In order to save the converted outside record to a database file, the dialog shown in Figure 26 comes up. The default location for saving files in 🗀`Resources/Flights`. "Save" will save the `*.db` file and "Cancel" will end the program without saving the flight path.

10 Survey

A quick survey was conducted while at one of the exhibitions asking potential users about what they thought about the acoustic flight simulator and whether the predicted ground noise footprint display would be useful in learning about how to decrease noise [27]. The actual survey questions are shown in Appendix A.

Data was analyzed using IBM® SPSS®[3] Statistics 26 (version 26.0.0.1) [28–31]. Significance was set at $p \leq 0.05$. Note that the number of subjects ($N = 7$) was extremely small but all were current helicopter pilots.

[3]IBM and SPSS are trademarks of International Business Machines Corporation, registered in many jurisdictions worldwide.

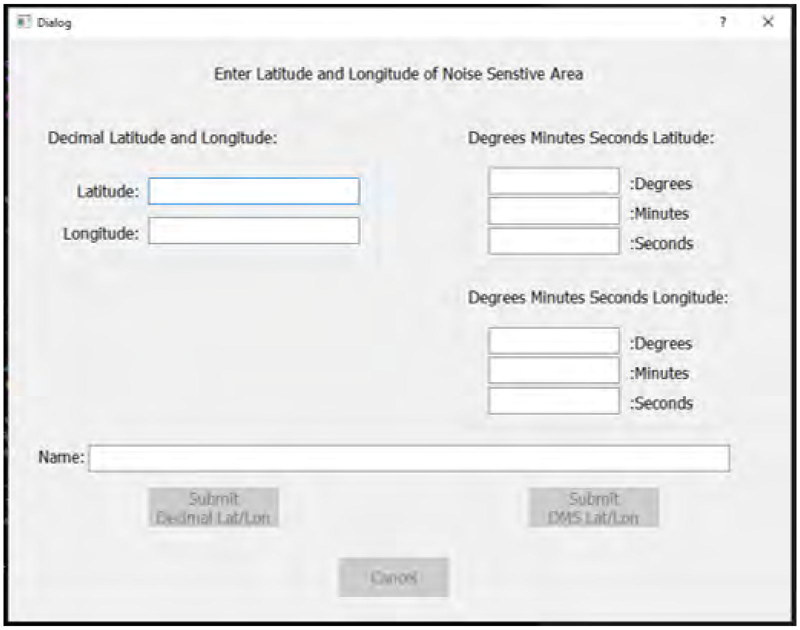


Figure 20: Input noise sensitive area by degrees or degrees, minutes, seconds latitude and longitude.

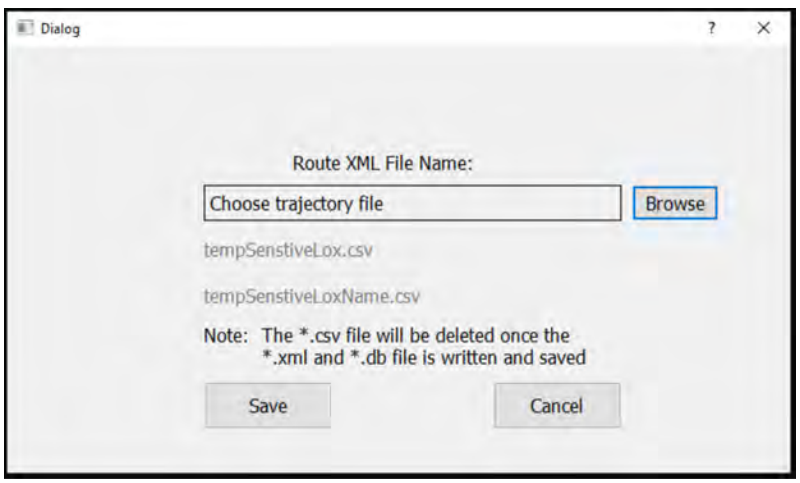


Figure 21: Save noise sensitive locations dialog.

10.1 Usefulness of Noise Training Aid Display

Respondents thought that the ribbons were useful in learning how to minimize noise $\left(\chi^2(2, N = 7) = 8.857, p \leq 0.02\right)$ and in learning how their vehicle's state affects noise $\left(\chi^2(2, N = 7) = 8.857, p \leq 0.02\right)$ whereas the footprint itself was not significant (Figure 27 and Figure 28, respectively). As can be seen in Figure 27b and Figure 28b, the vast majority of the respondents felt that the ribbons would be "Helpful" and these results are supported from comments obtained at another exhibition. Overall, respondents indicated that the noise training aid display would

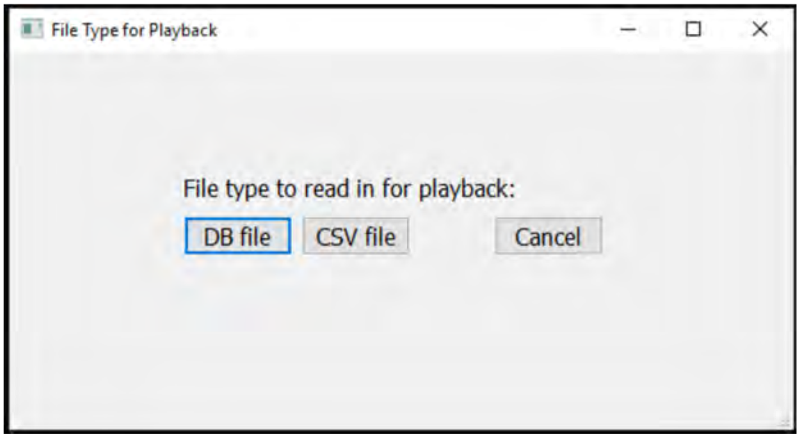


Figure 22: Saving a flight path.

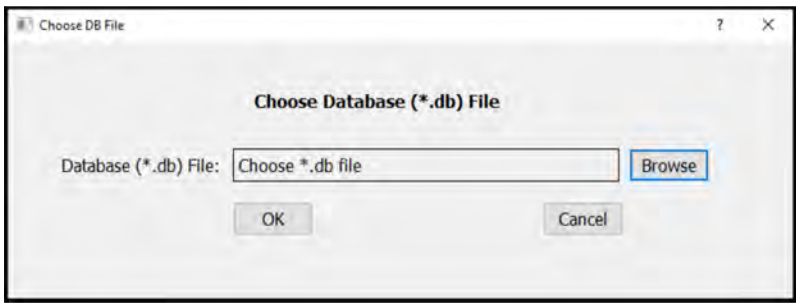


Figure 23: Specifying a database file to convert into a replay file.

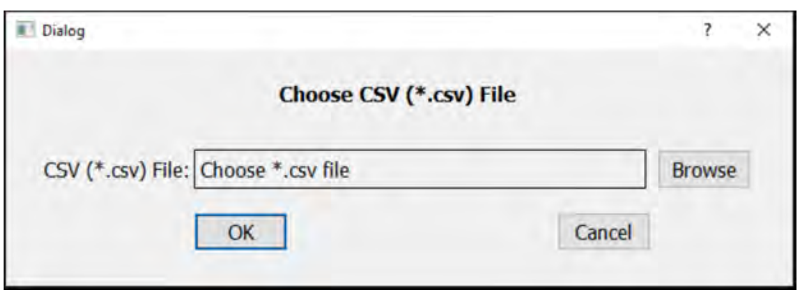


Figure 24: Specifying a comma delineated (CSV) file to convert into a replay file.

be useful for learning how to minimize noise and learning how the vehicle's state affects noise $\left(\text{both } \chi^2(2, N = 7) = 8.857, p \leq 0.02; \text{Figure 29}\right)$. This was most likely driven by the helpfulness of the ribbons as detailed above.

10.2 Preferred Method to Decrease Noise

Because information is provided via the ribbons on the tapes, respondents were asked to rate what their preferred method of decreasing noise would be. As can be seen in

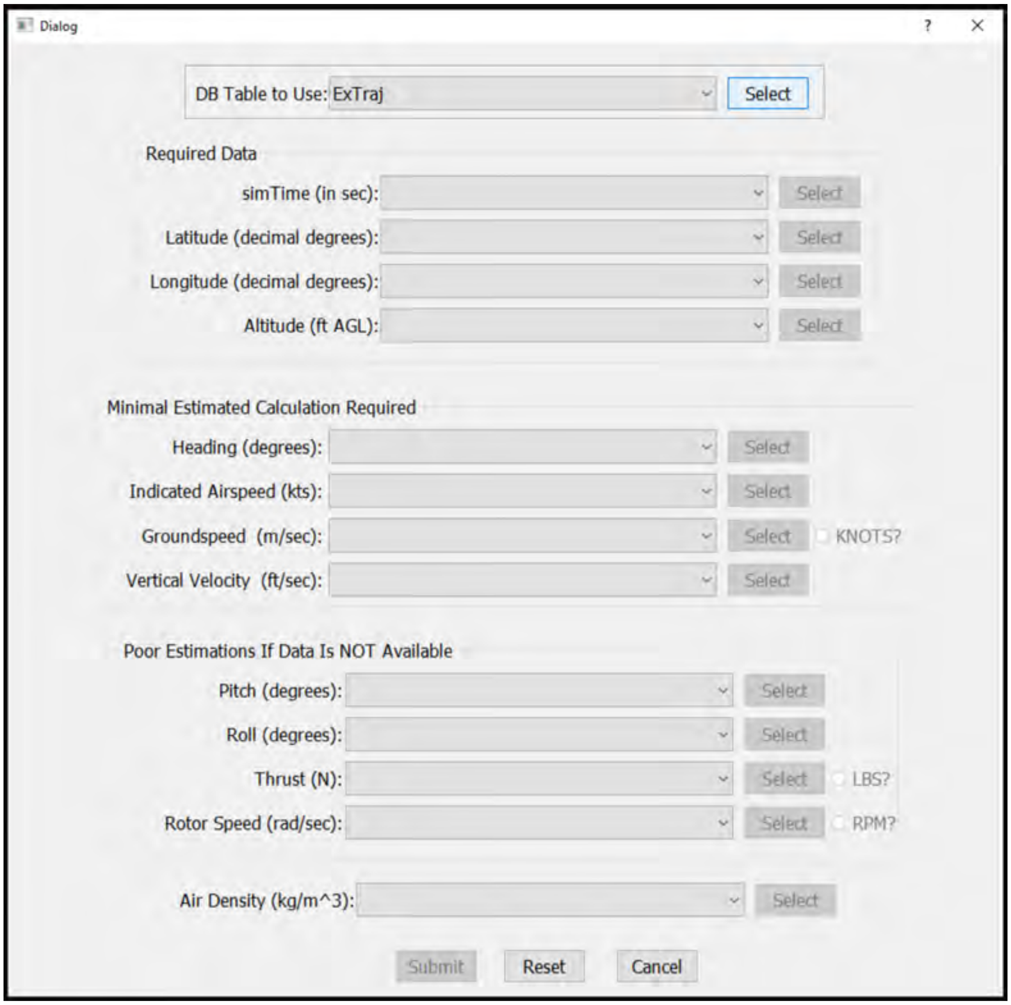


Figure 25: Choosing file contents for conversion into a replay file.

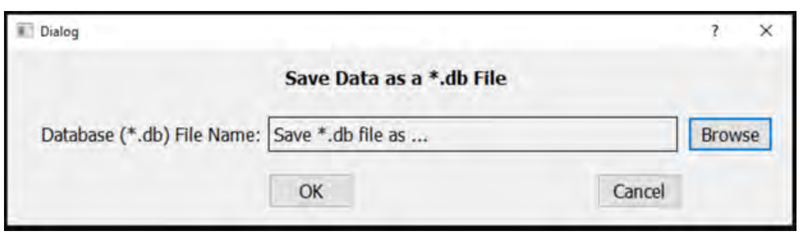
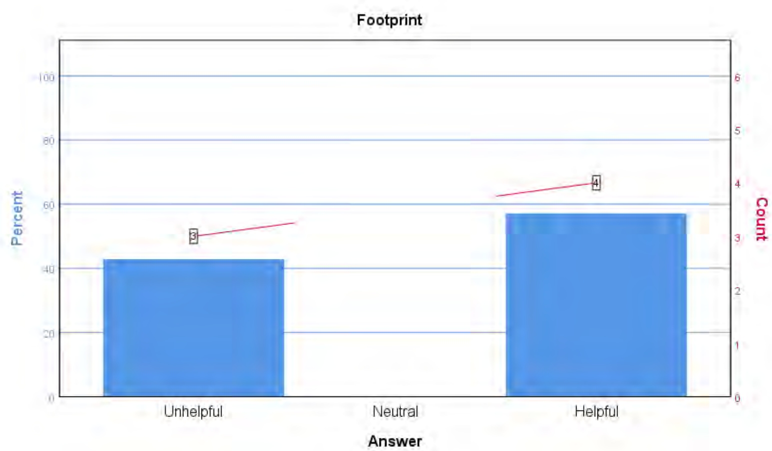


Figure 26: Choosing file to save external flight data to.

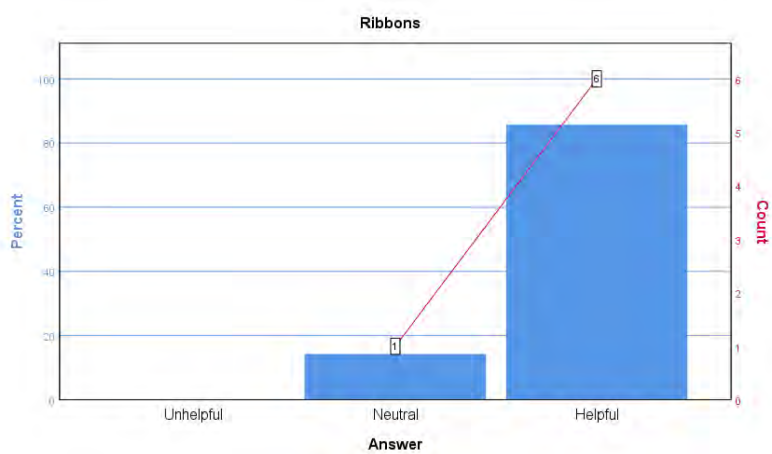
Figure 30, most respondents indicated that they would prefer to change altitude and bank angle and these were significantly different from acceleration $\left(\chi^2(3, N = 28) = 12.673, p \leq 0.01\right)$. This is most likely because increasing altitude increases safety and it is fairly easy to turn away from a noise sensitive area. As for acceleration being the least preferred, this information is typically not shown on the instrument panel and pilots typically do not control their vehicle using this parameter. Furthermore, some pilots mentioned that they automatically limit acceleration if they have passengers because passenger comfort is more important than any reason to perform a high acceleration maneuver unless safety is a factor.

10.3 Concern About Noise During Flight

Respondents did indicate that they were concerned about noise during flight (Figure 31) although this was not significant and this data was taken at a booth stressing the importance of noise during flight. Pilots, in general, did comment that they were primarily focused on safety during flight with their next concern being their flight path. Noise levels were lower on the priority list during flight.

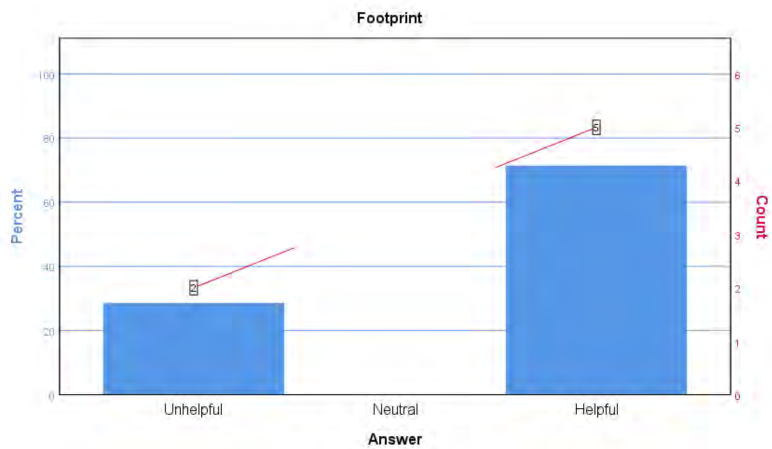


(a) Footprint helpfulness.

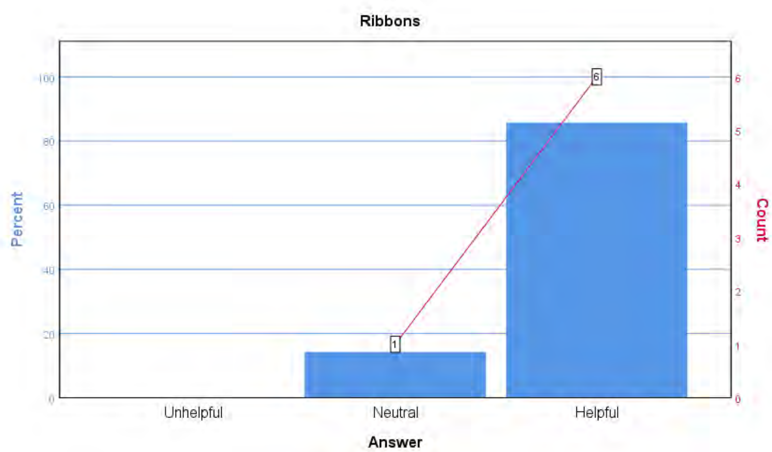


(b) Ribbon helpfulness.

Figure 27: How helpful do you think the noise [footprint,ribbons] would be in helping to learn to minimize noise?

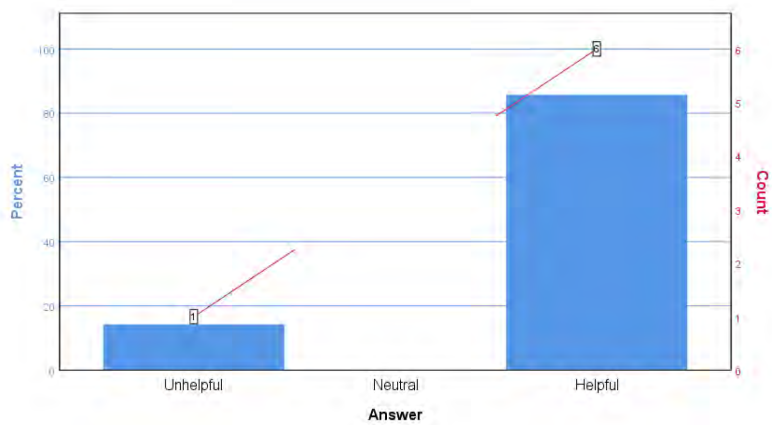


(a) Footprint helpfulness.

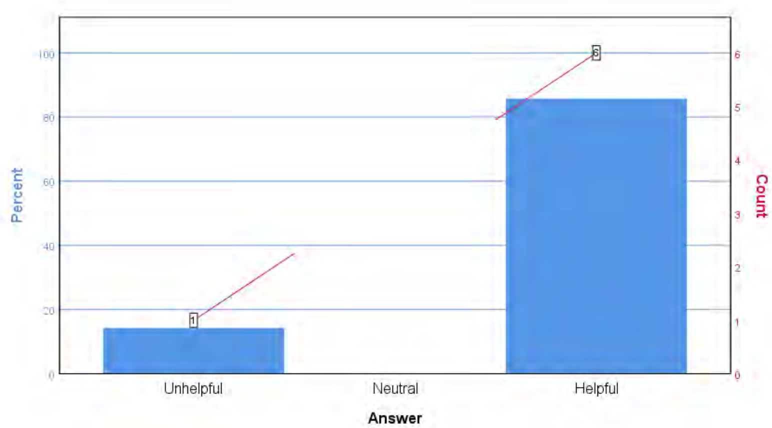


(b) Ribbon helpfulness.

Figure 28: How helpful do you think the noise [footprint,ribbons] would be in helping to learn how vehicle attitude affects noise?



(a) Overall, how helpful do you think the noise display would be in helping you learn how to minimize you noise during flight?



(b) Overall, how helpful do you think the noise display would be in helping you learn how your vehicle attitude affects noise?

Figure 29: Overall helpfulness of the display.

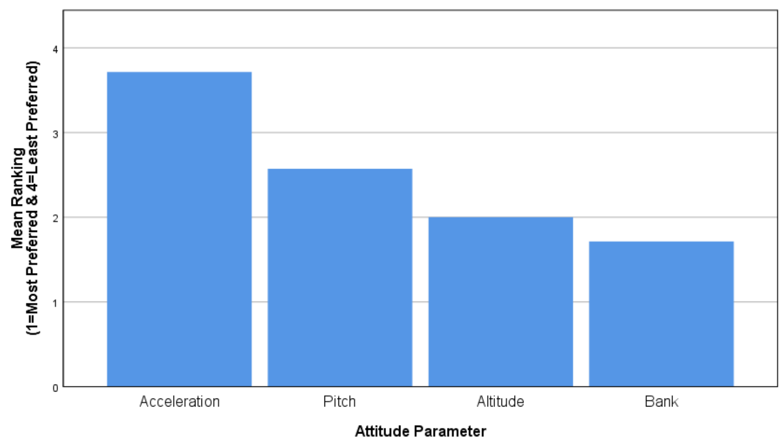


Figure 30: Average rankings to the question “[p]lease rank order your preferred method for decreasing noise from 1 = most preferred to 4 = least preferred”.

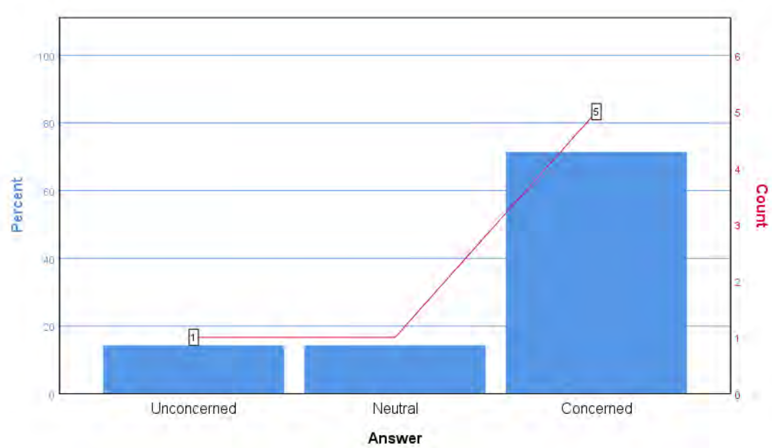


Figure 31: How concerned are you regarding the noise you generate during a flight?

11 Summary

The Revolutionary Vertical Lift Technology project is addressing source noise and response in order to reduce vertical takeoff and landing aircraft noise impact. The effects of the generated noise from these aircraft on communities is a growing concern and in order to address community noise, a real-time helicopter noise modeling technique was developed. This report detailed the acoustic flight simulator which depicts the predicted ground noise footprint. This report also provides a user manual for the acoustic flight simulator and its associated programs. Furthermore, results from a survey asking potential users about the noise training aid aspect of the acoustic flight simulator were detailed.

In summary, the acoustic flight simulator paired with X-Plane 11 and a control inceptor is able to accurately depict the potential ground noise footprint of a vehicle. Associated programs included with the acoustic flight simulator are able to record flights from the simulator and replay flights recorded from both the acoustic flight simulator and by other means. Potential users have indicated that the noise training aid aspect of the acoustic flight simulator would be beneficial in learning how their vehicle's state affects noise. Furthermore, the ribbons may be the most useful for this learning process. Currently, the authors are conducting beta testing in order to more firmly stabilize the code with the ultimate goal of providing a publicly releasable version of the acoustic flight simulator.

References

1. Susan A. Gorton. NASA's approach to eVTOL noise modeling and technology solutions. Slide deck at National Academies, 2018. URL https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/D7E1123405EB87BF6DD3DC5D341F31725EAC82116D35.

2. Kevin Antcliff, Siena Whiteside, Lee W. Kohlman, and Christopher Silva. *Baseline Assumptions and Future Research Areas for Urban Air Mobility Vehicles*. American Institute of Aeronautics and Astronautics, 2019. doi: 10.2514/6.2019-0528. URL https://arc.aiaa.org/doi/abs/10.2514/6.2019-0528.

3. Parimal Kopardekar. Enabling autonomous flight and operations in the national airspace. NASA Technical Report Server, 2019. URL https://ntrs.nasa.gov/api/citations/20190030729/downloads/20190030729.pdf.

4. Parimal Kopardekar. Urban air mobility (UAM). NASA Technical Report Server, 2020. URL https://ntrs.nasa.gov/api/citations/20200000618/downloads/20200000618.pdf.

5. Eric Greenwood and Robert Rau. A maneuvering flight noise model for helicopter mission planning. *Journal of the American Helicopter Society*, 65(2):10, April 2020. doi: 10.4050/JAHS.65.022007. URL https://doi.org/10.4050/JAHS.65.022007.

6. Eric Greenwood. Real time helicopter noise modeling for pilot community noise awareness. In *Noise-Con 2017*, page 9, June 2017. URL https://www.researchgate.net/publication/318725929_Real_Time_Helicopter_Noise_Modeling_for_Pilot_Community_Noise_Awareness.

7. M. E. Watts, Eric Greenwood, C. D. Smith, and J. H. Stephenson. Noise abatement flight test data report. Technical Report NASA-TM-220264, NASA Langley Research Center, March 2019.

8. X-Plane. X-Plane 11. Website, 2020. URL https://www.x-plane.com/.

9. Dreamfoil. Bell 407 XP11. Website, 2019. URL https://store.x-plane.org/Bell-407-XP11_p_620.html.

10. Puma. Pro flight trainer. Website, 2019. URL https://www.pro-flight-trainer.com/pages/our-story.

11. X-Plane. X-Plane 11 system requirements. Website, 2020. URL https://x-plane.helpscoutdocs.com/article/16-x-plane-11-system-requirements.

12. G Gopalan. *Quasi-Static Acoustic Mapping of Helicopter Blade-Vortex Interaction Noise*. Ph.D. thesis, University of Maryland, 2004.

13. Eric Greenwood. Helicopter flight procedures for community noise reduction. In *American Helicopter Society 73rd Annual Forum*, page 14. VFS, May 2017. URL https://ntrs.nasa.gov/api/citations/20170005476/downloads/20170005476.pdf.

14. Kyle A. Pascioni, Eric Greenwood, Michael E. Watts, Charles D. Smith, and James H. Stephenson. Medium-sized helicopter noise abatement flight test data report. NASA Technical Report Server Report No. NASA/TM-20210011459, 2021. URL https://ntrs.nasa.gov/api/citations/20210011459/downloads/NASA-TM-20210011459FINAL.pdf.

15. The Qt Company. Qt. Website, 2019. URL https://www.qt.io/.

16. The Qt Company. QtXML. Website, 2019. URL https://doc.qt.io/qt-5/qtxml-index.html.

17. The Qt Company. Qt location open street map plugin. Website, 2019. URL https://doc.qt.io/qt-5/location-plugin-osm.html.

18. Anna C. Trujillo. Helicopter noise footprint depiction during simulated flight for training. In Neville Stanton, editor, *Advances in Human Factors in Transportation: Proceedings of the AHFE 2020 International Conference on Human Factors in Transportation, July 16-20, 2020, Virtual*, volume 1212 of *Advances in Intelligent Systems and Computing (AISC)*, chapter 70, pages 554–561. Springer International Publishing, 16-20 July 2020. doi: 10.1007/978-3-030-50943-9_70. URL https://doi.org/10.1007/978-3-030-50943-9_70.

19. noisehelp.com. Noise level chart. Website, 2019. URL https://www.noisehelp.com/noise-level-chart.html. Accessed May 2019.

20. boomspeaker.com. Noise level chart: Decibel levels of common sounds with examples. Website, 2019. URL https://boomspeaker.com/noise-level-chart-db-level-chart/. Accessed May 2019, last updated 5 May 2019.

21. U.S. Department of Transportation. Title 14: Aeronautics and space. In FAA, editor, *Electronic Code of Federal Regulations*, chapter I, Subchapter C, §29.1322. U.S. Government Printing Office, 24 May 2019. URL https://www.ecfr.gov/cgi-bin/text-idx?SID=380f6ca85a33dd825a5147edea123fac&mc=true&node=se14.1.29_11322&rgn=div8. Accessed 29 May 2019, page last edited 24 May 2019.

22. *Bell 407 Model: Rotorcraft Flight Manual (BHT-407-FM-1)*. Bell Helicopter, revision 4 edition, 2005. URL https://www.maunaloahelicopters.edu/library/Rotorcraft_Flight_Manuals/Bell_Helicopter/407.pdf. Accessed 29 May 2019.

23. U.S. Department of Transportation. Title 14: Aeronautics and space. In FAA, editor, *Electronic Code of Federal Regulations*, chapter I, Subchapter C, §27.337. U.S. Government Printing Office, 24 May 2019. URL https://www.ecfr.gov/cgi-bin/text-idx?SID=e12deadde770afd8f3541dafa53b074e&mc=true&node=se14.1.27_1337&rgn=div8. Accessed 29 May 2019, page last edited 24 May 2019.

24. Wikipedia.org. Bell 407. Website, 2019. URL https://en.wikipedia.org/wiki/Bell_407. Accessed 29 May 2019, page last edited 8 May 2019.

25. OpenStreetMap Foundation. OpenStreetMap. Website, 2019. URL https://www.openstreetmap.org.

26. Ed Williams. Aviation formulary v1.47. Website, 2021. URL https://edwilliams.org/avform147.htm.

27. Anna C. Trujillo and Daniel R. Hill. Acoustic flight simulator for noise training. In *Proceedings of the 77th Annual Forum*, page 12. The Vertical Flight Society, 11-13 May 2021.

28. *IBM SPSS Statistics Base 26*. IBM, 2020. URL https://www.ibm.com/support/pages/ibm-spss-statistics-26-documentation#en.

29. *IBM SPSS Advanced Statistics Base 26*. IBM, 2020. URL https://www.ibm.com/support/pages/ibm-spss-statistics-26-documentation#en.

30. *IBM SPSS Statistics 26 Command Syntax Reference*. IBM, 2020. URL https://www.ibm.com/support/pages/ibm-spss-statistics-26-documentation#en.

31. *GPL Reference Guide for IBM SPSS Statistics*. IBM, 2020. URL https://www.ibm.com/support/pages/ibm-spss-statistics-26-documentation#en.

Appendix A

Survey Questions

Questions asked via computer survey at an exhibition. Survey respondents had to be current helicopter pilots.

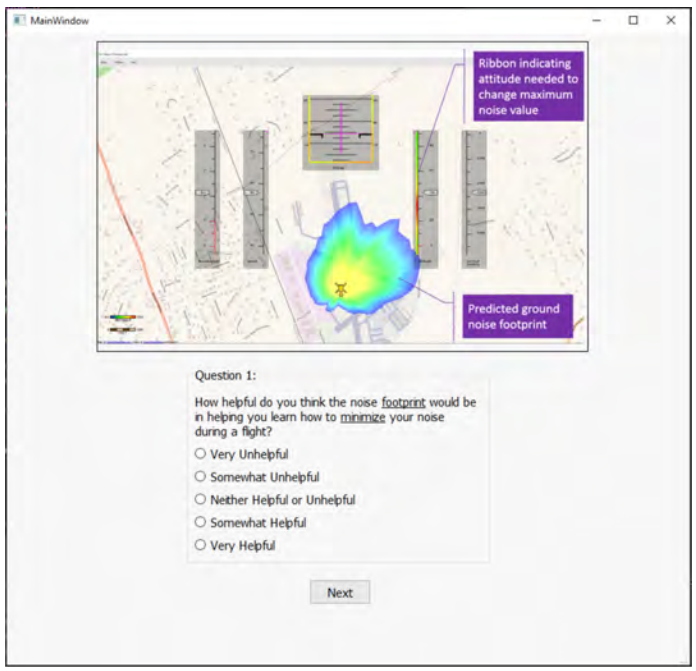


Figure A32: Question 1 – How helpful do you think the noise footprint would be in helping you learn how to minimize your noise during a flight?

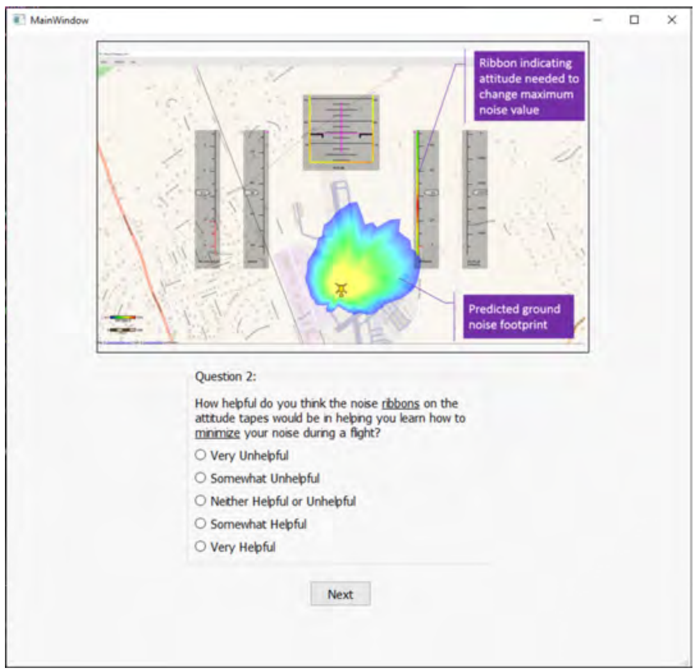


Figure A33: Question 2 – How helpful do you think the noise <u>ribbons</u> on the attitude tapes would be in helping you learn how to <u>minimize</u> your noise during a flight?

Figure A34: Question 3 – How helpful do you think the noise <u>footprint</u> would be in helping you learn how your vehicle <u>attitude</u> (bank, pitch, altitude, etc.) affects noise?

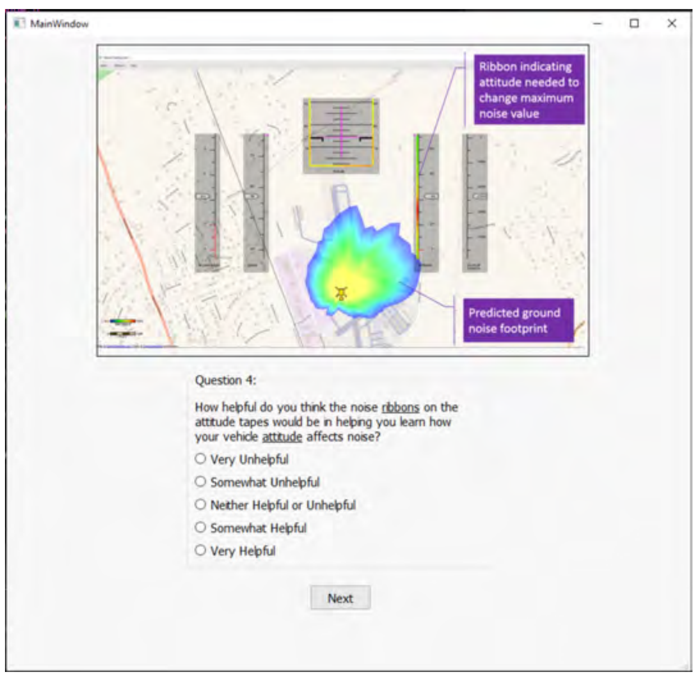


Figure A35: Question 4 – How helpful do you think the noise <u>ribbons</u> on the attitude tapes would be in helping you learn how your vehicle <u>attitude</u> affects noise?

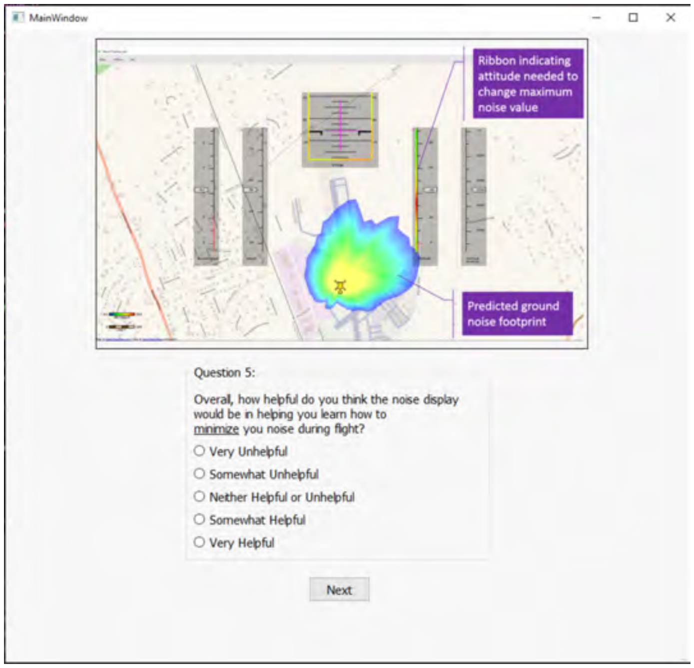


Figure A36: Question 5 – How helpful do you think the noise display would be in helping you learn how to <u>minimize</u> your noise during flight?

Figure A37: Question 6 – Overall, how helpful do you think the noise display would be in helping you learn how your vehicle <u>attitude</u> affects noise?

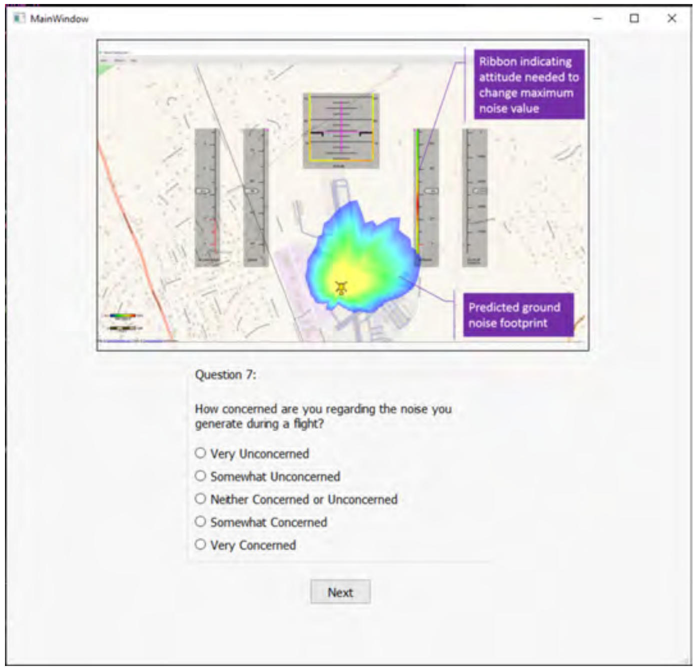


Figure A38: Question 7 – How concerned are you regarding the noise you generate during a flight?

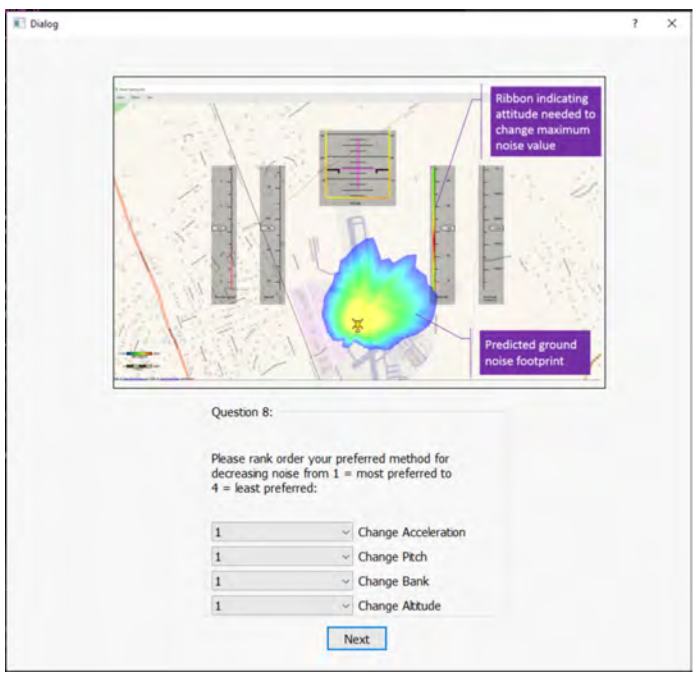


Figure A39: Question 8 – Please rank order your preferred method for decreasing noise from 1 = most preferred to 4 = least preferred.

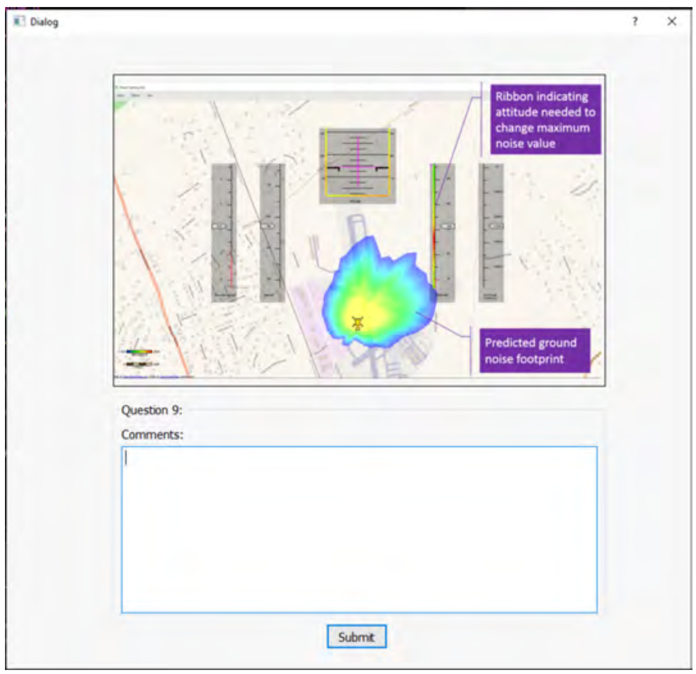


Figure A40: Question 9 – Comments.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704–0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
01-10-2021	Technical Memorandum	

4. TITLE AND SUBTITLE
Acoustic Flight Simulator Architecture, Noise Training Aid Manual, and Its Training Benefits

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Trujillo, Anna C.; Hill, Daniel R.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, Virginia 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TM–20210014096

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category 53
Availability: NASA STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES
An electronic version can be found at http://ntrs.nasa.gov.

14. ABSTRACT
The Revolutionary Vertical Lift Technology project at NASA is researching source noise and response to reduce the noise impact of vertical takeoff and landing aircraft. To aid in this effort to address community noise, Dr. Eric Greenwood has developed real-time helicopter noise modeling that uses noise hemispheres generated from measured acoustic data as a basis for informing predictions the ground noise footprint of a particular helicopter model. This report describes a depiction of the predicted ground noise footprint and related information on how to reduce the ground noise footprint. Additionally, it details how to use the acoustic flight simulator and its associated programs. Also included are the results from a brief survey asking potential users about what they thought about the noise training aid aspect of the acoustic flight simulator and whether the predicted ground noise footprint display would be useful in learning about how to decrease noise. In summary, potential users have indicated that the noise training aid would be beneficial in learning how their vehicle's state affects noise.

15. SUBJECT TERMS
noise, display, flight path replay

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	50	STI Information Desk (help@sti.nasa.gov)
					19b. TELEPHONE NUMBER (Include area code)
					(757) 864-9658