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Development of Fly Neighborly helicopter model specific operational noise abatement guidance from acoustic flight test data

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ABSTRACT

Helicopter model-specific noise abatement guidance has been developed based on acoustic test data acquired by NASA, FAA and Volpe in support of the Helicopter Association International (HAI)'s Fly Neighborly Program. This higher fidelity material was developed to supplement previous training programs based on pilot and operator feedback. The manner of presentation allows pilots to readily interpret the directional noise emission of their vehicle at different operating conditions. Flight path, airspeed, approach descent rate, and deceleration rate can be assessed to optimize flight patterns both during the pre-flight planning stage and in real time during flight operations in response to local conditions and events. The resultant sound directivity would be displayed as colored noise exposure contours overlaid onto a map of the area in the vicinity of the helicopter. New Fly Neighborly training modules have been developed utilizing directional operational noise plots based on Volpe's Advanced Acoustic Model (AAM) modeling with empirical sound sphere data from dedicated US Government helicopter flight tests. This paper will describe the acoustic analyses and will present the updated noise guidance for the AS350, AS365, AW139, Bell 205, Bell 206, Bell 407, R-44, R-66 and S-76D helicopters.

1. INTRODUCTION

The Fly Neighborly (FN) program was initiated by the Helicopter Association International (HAI) in the early 1980s and continues to be supported by numerous private and public partners including the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). The program is intended to be a holistic approach to reducing helicopter noise impacts on the community and includes both a noise abatement flight procedure element (https://www.rotor.org/initiatives/fly-neighborly) and a community engagement and outreach component (Mittelman *et al.,* 2020). Responses from pilots and operators taking live wide-area operational noise (Page *et al.,* 2019) training classes conducted during HeliExpo 2020, indicated a desire to have more granular directivity information to support targeted noise abatement efforts and reduce impacts on specific critical community areas. Using acoustic data from a recent series of US

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Government helicopter acoustic flight tests (Watts, *et al.,* 2019; Pascioni *et al.,* 2020) and expanding on prior wide-area operational noise (Op Noise) recommendations (Stephenson *et al.,* 2020), an analysis was conducted to develop directional fidelity and produce actionable directivity noise abatement guidance for nine specific helicopter models including the R-44, R-66, AS350, AS365, AW139, B205, B206, B407 and S-76D.

Directional Op Noise graphics were developed as a visual means of communicating to pilots the noise received on the ground towards the right, center and left side of the helicopter. Analyses using the empirical 3D spectral noise spheres using the Volpe Advanced Acoustic Model (AAM) (Page *et al.,* 2020) were conducted to determine the noise levels and blade vortex interaction (BVI) occurrence at an array of receptors divided into wedges, for a range of flight conditions for each helicopter model. These results were then distilled and compared with the empirical and observational auditory noise records for consistency. The analysis methods and results will be described in more detail in Section 2.

Finally, a set of nine helicopter model-specific training programs was developed with the directional Op Noise graphics as the centerpiece. The training program reviews and builds upon the 2020 wide-area Op Noise training (which is also helicopter model-specific), and includes the following key objectives:

- Understanding the wide-area Op Noise plot that shows BVI noise versus approach condition
- Knowledge of the recommendations for wide-area approach noise abatement, including additional recommendations for rate-of-descent constrained flight operations
- Knowledge of directional (left-center-right) BVI noise characteristics and noise abatement guidance
- Understanding how the noise abatement guidance can be used in routing approaches for improved FN operations
- Listening to aural comparisons of noise abatement and high BVI-noise approaches

A description of the training course content, testing of the educational methods employed and FN course implementation plans are described in Section 3.

2. METHODS

2.1 Flight Tests and Data

A series of flight test campaigns were conducted jointly by NASA, the FAA, Volpe and the US Army in order to acquire data about vehicle source noise for research purposes and with the intent of developing Fly Neighborly noise abatement procedures for reducing impacts of helicopter operations on communities. These tests included nine different helicopters and were conducted at Eglin Air Force Base Test Range C62, FL (2017), Amedee Army Airfield, CA (2017) and Coyle Field, NJ (2019). The flight test arrangement for Coyle Field is shown in Figure 1, and while the specifics of the microphone array and other equipment was adapted for each test site location, the general arrangement was similar. In addition to the acoustic instrumentation, trained observers were positioned at locations approximately ±200, ±600 and/or ±1200 feet lateral to the flight track and created observational field logs.

The acoustic testing covered the flight envelope of the vehicles. Testing spanned a range of speeds and flight path angles for level flight, approach and departure. Additional decelerating approach conditions were also tested. In-field auditory techniques (Page *et al.,* 2019) were utilized to develop noise abatement procedures, which were flown and verified on subsequent test days. In field processing utilized the Acoustic Repropagation Technique (Page *et al.,* 2020), a capability provided as part of the AAM suite, to generate 3D noise spheres from acoustic measurement and vehicle positional data. One sphere was created for each viable flight pass for which the vehicle was on condition, the instrumentation was operational, and signal to noise requirements were met. These noise spheres were reviewed, compared with field logs and down-selected. For the Bell 407 helicopter, resources were available to process the measurement data to include additional, on-condition data points (thereby increasing geometric sphere coverage), tailor and fine-tune signal-to-noise ratio (SNR) settings for each microphone and run combination and to increase confidence by aggregating noise spheres via an averaging process for comparable flight conditions.

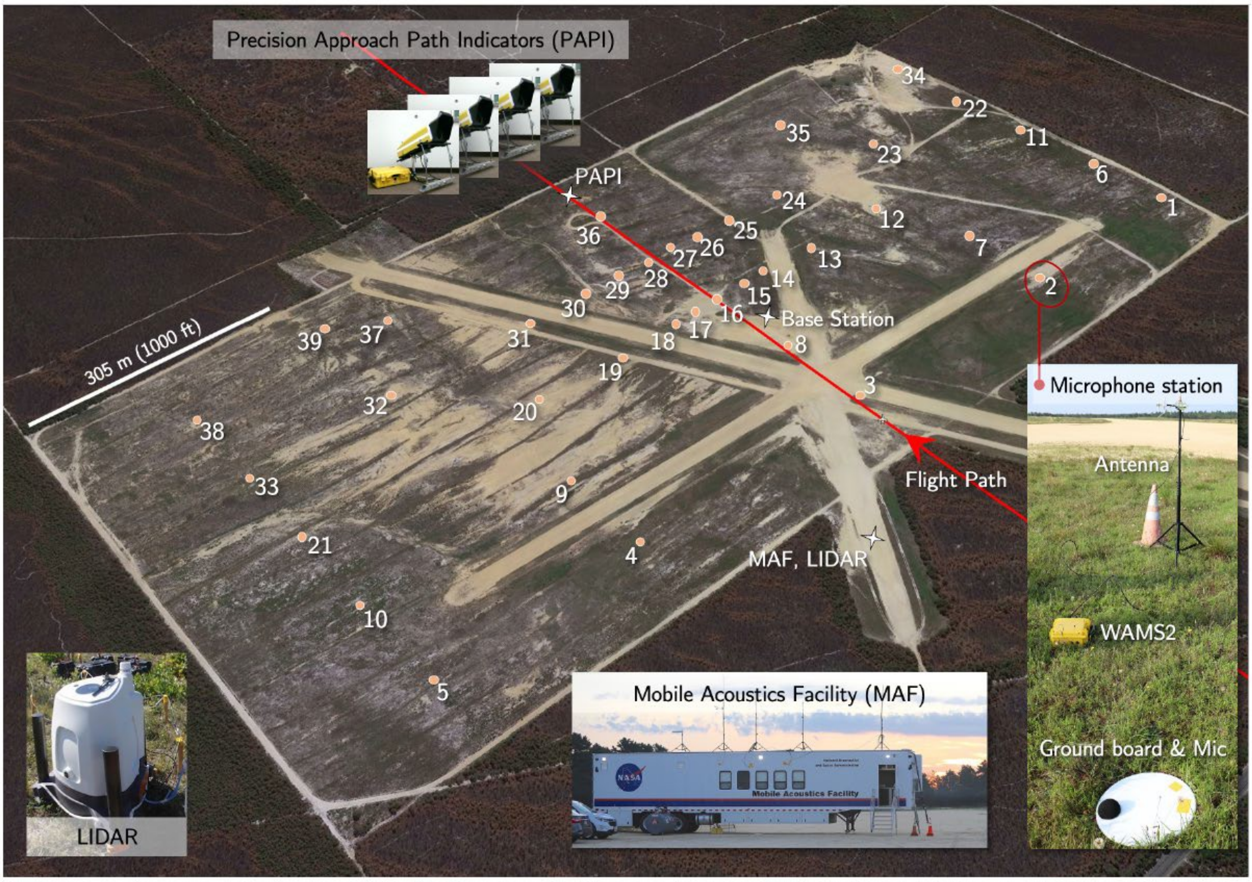

Figure 1. Helicopter flight test arrangement at Coyle Field displaying microphone locations and supporting test equipment with the nominal flight path (red). (Source: NASA)

2.2 Acoustic Data Processing

AAM is a simulation tool that propagates noise from a defined flight trajectory (position, flight condition, geometric orientation etc.) using 3D spectral acoustic spheres (Figure 2) to points of interest or a grid of receptors. The sound at the receivers, which is available as 1/3 octave band time histories or as specific integrated metrics, can be post-processed and assessed to determine the prevalence and intensity of BVI noise.

2.3 Flight Geometry of the Wedges

The AAM analysis utilized empirical noise spheres created in the field during the aforementioned flight tests. These noise spheres where generated using idealized trajectories and projected to the noise as spectral time histories onto the ground at an array of 18 virtual microphone locations across the flight path, 1900 ft from the modeled landing location. Nominally, six microphones were identified for the left side, center and right side of the flight path.

Noise emission geometry is independent of aircraft location along the flight path. Relative changes in noise levels between differing constant flight conditions at these 18 receptor locations are representative at any location along the flight path with equivalent geometrical relationships. Hence, the single line of receptors at 1900 ft from the modeled landing location provided noise information anywhere in triangular ground areas converging on the landing point. These triangular areas were termed left, center and right wedges for subsequent use in Op Noise training. An example overlay of these wedges on a flight path over a relatively densely populated area is shown in Figure 3.

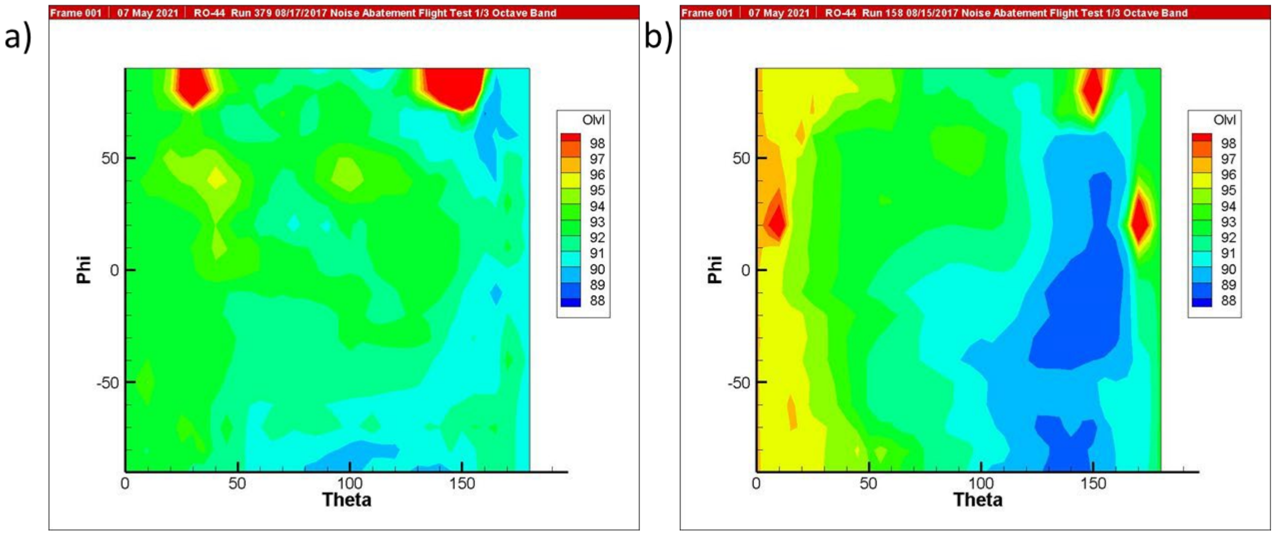

Figure 2. R-44 noise spheres displaying the unweighted overall noise levels for a) 65 knot, 500 fpm and b) 80 knot 1000 fpm descent cases. The polar angle theta is 0° at the nose and 180°at the tail of the aircraft. The azimuth angle phi is negative to port, 0° below, and positive to starboard.

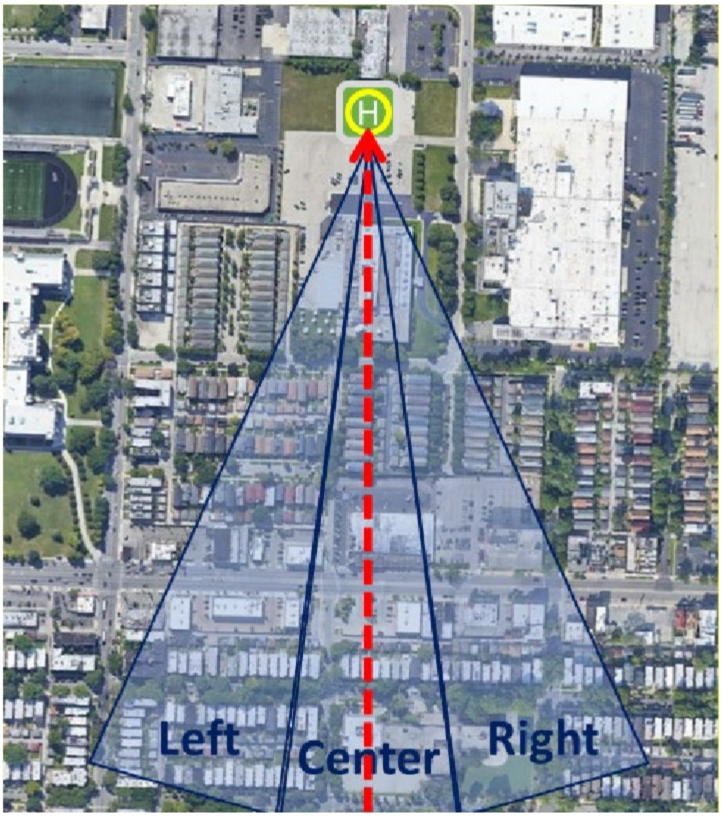

Figure 3. Example illustration of modeled flight path with left, center, and right wedges

2.4 Development and use of Empirical Noise Spheres

Using AAM, the noise spheres developed in the field were processed each night after the flights concluded. The analysis used nominal ART settings (signal-to-noise ratio, range before and after the array, and local environmental conditions), and relied on field logs based on real time monitoring, to identify and remove any measurement data anomalies. The flight testing explicitly gathered data from repeat passes at the same flight conditions. These data were then post-processed and averaged when the associated flight tracking data indicated that as-flown trajectories were on-condition within the range utilized for sphere de-propagation. In the event that there were multiple spheres for assigned conditions that could not be averaged, sphere quality was assessed (minimizing prevalence of unsteady anomalies and consistency with the auditory field logs) and one sphere was selected for use in the Fly Neighborly analysis.

2.5 Metric Analysis at the Left-Center-Right Points of Interest

In the rotorcraft research community, the BVI-SPL metric is typically used to quantify BVI impacts. The BVI condition tends to increase noise in the higher frequencies which substantially contribute to A-weighted levels. BVI-SPL is an unweighted summation of spectral data across one-third octave bands, typically containing frequencies from the 5th to the 60th main rotor harmonic. The advantage of this metric is that it isolates and quantifies the main rotor (MR) BVI and is generally uncontaminated by loading and thickness noise and other effects which typically dominate the lower main rotor harmonics. This concept is shown by the example below for the Bell 412, developed by the authors (Page 2016).

Prior to continuing use of the BVI-SPL metric, as defined above, a sensitivity study was conducted to investigate potential modifications that could enhance the metric's use as an evaluator of BVI noise. Specifically, A-weighted and C-weighted versions were evaluated, and the start frequency was increased to include only the 10th harmonic and higher and the 20th harmonic and higher. All of these variants were evaluated for possible benefits in further quantifying BVI noise, however no clear-cut advantages were identified over the initial formulation; which was therefore retained for all subsequent analyses.

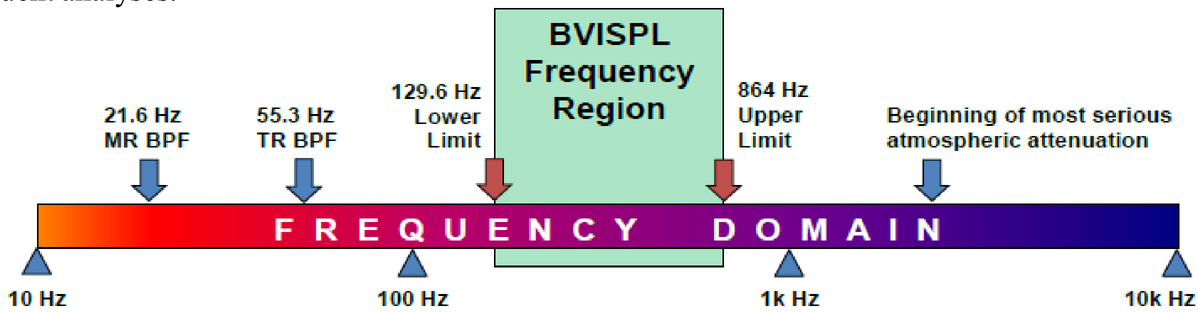

Figure 4. Bell 412 / CH-146 Spectral Content and BVI-SPL Range (Page 2016).

The AAM predicted spectral time histories, at the 18-microphone array, were post-processed and the maximum Blade Vortex Interaction Sound Pressure Level (BVI-SPLmax) for each time history were computed. These spectral time histories were then averaged over the microphones within each of the three wedges (left-center-right). BVI-SPLmax was chosen for this analysis as the spectral range (including the 5th to the 60th harmonic of the main rotor) is representative of BVI presence in the signal and effectively identifies the existence of BVI noise in a manner that agrees with the flight test auditory field logs. BVI-SPL has also been used in the past to assess the existence of BVI, including for the development of the wide-area Op Noise representations (Pascioni *et al.,* 2020).

For some of the helicopter models – particularly those with high lateral roll-offs of BVI noise – one outer microphone was dropped from the left and right averages in order to better represent left-center- right BVI noise characteristics for Fly Neighborly pilot training purposes. The primary objective was not comparability between helicopter models, but rather comparability between left, center and right BVI noise characteristics for a given helicopter model to support effective noise abatement guidance for flight operations.

3. RESULTS

3.1 Directional Op Noise Plot and Presentation for Operators

The resultant directional Op Noise plot, which includes left, center and right components, was developed for use in Fly Neighborly training. An example of the R-44 directional Op Noise, combined with the wide-area Op Noise, is provided in Figure 4, which serves as the centerpiece for the newly developed Fly Neighborly training course. The speaker icon indicates interactive listenable course content for the right center and left sides of the flight path. The ear icons on the red/yellow wide-area heat map show the corresponding locations in the operational regions for BVI avoidance (the red contour) and the primary R-44 wide- area noise abatement guidance (the green box) and alternative noise abatement guidance for rate-of- descent constrained flight operations (the blue box) that can be listened to for the left, center and right side.

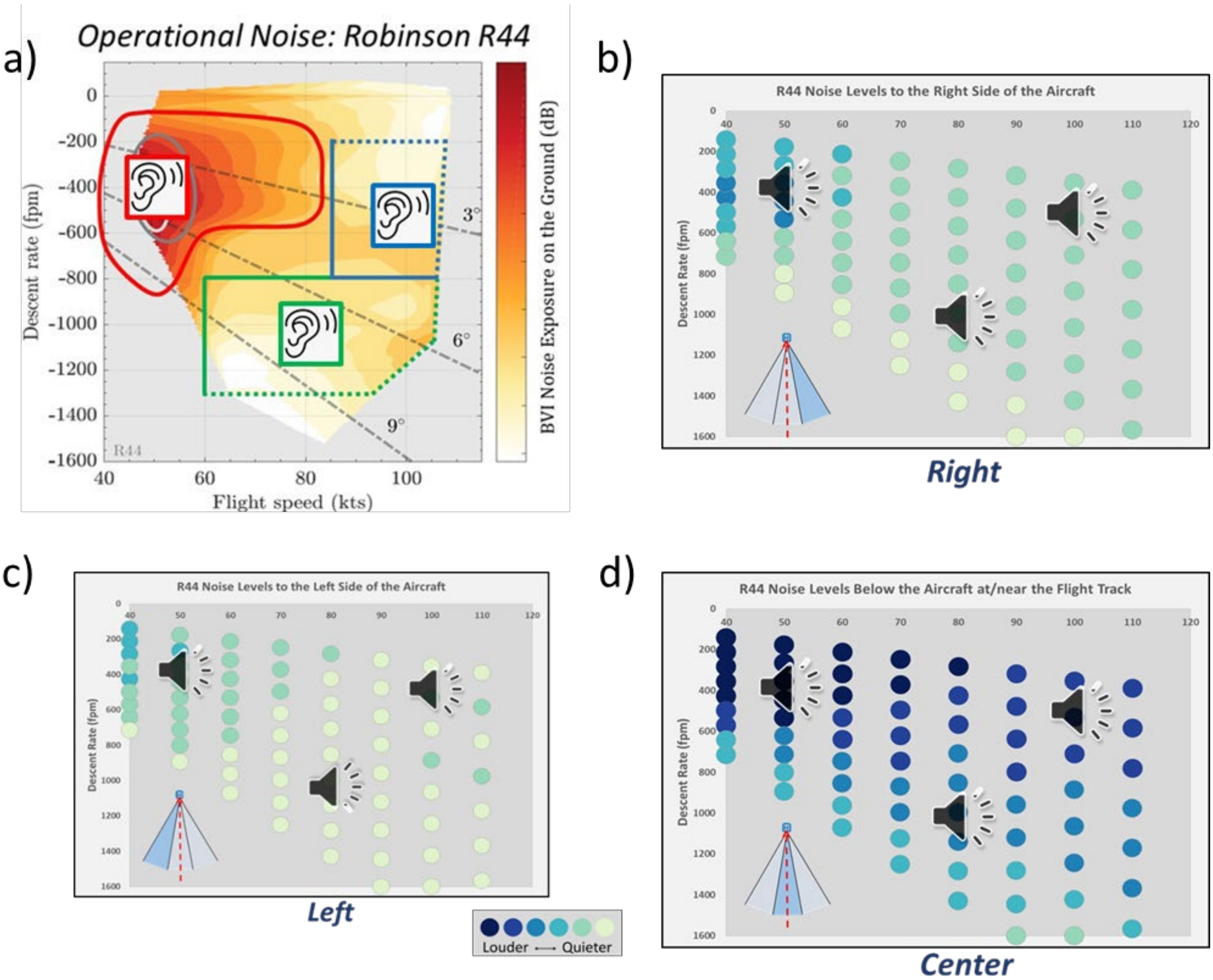

Figure 5. The R-44 Op Noise diagram used in Fly Neighborly training, consisting of the (a) wide-area Op Noise and directional Op Noise plots for the (b) right (c) left and (d) center. The speaker icon indicates listenable sounds /interactive media content. The ear icon reflects the portion of the Op Noise diagram corresponding to the sounds.

The choice of the color and display schemes for the directional Op Noise (Figure 5 b, c, d) was deliberate in order to differentiate it at a glance from the wide-area Op Noise plot (Figure 5a) for several reasons:

- The wide-area Op Noise was developed using the projection of sound from the lower portions of a noise sphere onto a ground plane with a duration adjustment based on speed; this reflects multiple directivity angles, each linked to a specific slant range geometry (sphere to ground plane).
- The directional Op Noise was developed by simulating noise over microphones on a lateral array with duration effects inherently included. Additionally, directional angles may reflect different slant range effects depending on the individual flight path angle geometry with respect to the lateral array.
- The wide-area and directional Op Noise plots represent different metrics and calculation procedures and are not intended for quantitative comparisons by the user.
- “Red contours” versus “Blue dots” plots provide effective communication nomenclature and means for discrimination between the two styles of plots for Fly Neighborly training.
- The dots on the directional Op Noise plots are intended to visually convey BVI noise trends with airspeed and/or rate-of-descent as well as facilitate left-center-right comparisons between specific flight conditions in individual locations. In contrast, the gradient contours on

the wide-area Op Noise are reflective of and intended to be interpreted as generalized trends over the wider ground areas.

- The final directional Op Noise visualization style was developed and refined over several months in response to feedback from written materials and live presentation provided to pilots, operators, helicopter noise researchers and the HAI Fly Neighborly working group.

An initial examination of the left, center and right plots in Figure 5 indicates that significant benefits for noise abatement can be achieved if approach routes can be defined so as to keep noise sensitive areas to the "far" left or right side of the flight path. The greatest level of noise abatement overall occurred when keeping noise sensitive areas to the left side of the flight path. Similar results were obtained for all of the helicopter models included in the left-center-right analyses.

Further examination of the left, center and right wedge results in Figure 5 shows consistent trends with airspeed and rate-of-descent for all three directivities. For the R44 helicopter, increasing airspeed and/or increasing rate-of-descent results in reduced BVI noise emissions for all directivities. However, some helicopter models exhibited opposing BVI noise trends between the center and one or more sides, particularly for increasing rate-of-descent. These opposing trends present opportunities for trade-offs between center or right and left side BVI noise with beneficial implications for specific operational situations and specific sensitive receivers.

3.2 Next Steps

The FN directional Op Noise training programs will be presented live using a webinar format during the summer of 2021 and feedback garnered from pilots and operators will be used to further adapt the training. There are also plans to develop an online, on-demand version of the directional Op Noise curriculum and make it available publicly to pilots and operators. The FN program also strongly endorses and recommends that operators engage in proactive outreach to the communities in which they operate. The FN program includes materials under the iFlyQuiet program that can be used to facilitate such communications.

4. REFERENCES

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