FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Quantifying uncertainties in predicting aircraft noise in real-world situations

Project 40 – Purdue Part

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Motivation

- Desire for enhanced capabilities to better support environmental impact studies at national and international levels
- There are gaps in understanding the uncertainties for predicting aircraft noise in the current FAA modeling tools
- Need to increase the Research Readiness Level (RRL) of noise emission and propagation capabilities for possible future use in FAA noise tools

Objectives

- Quantify uncertainties of both numerical model and field data for predicting aircraft noise in real world situations
- Validate current and new FAA noise modeling capabilities

Approach

- Review and analyze field data that are influenced by (i) the meteorological conditions, (ii) the effect of high-speed source motion
- Identify sets of field data for specific propagation scenarios to validate the enhanced modeling capabilities
- Estimate an overall uncertainty in predicting aircraft noise based on the input information on source, propagation path and receiver.

Schedule / Status

- **Previous work and findings (Purdue)**
  - Review and analyze the field measurement data obtained from Discover/AQ dataset.
  - Investigate Doppler's effect due to source motion
  - Quantify the uncertainties due to ground effects
- **Current Work (Purdue)**
  - Examine the Discover/AQ dataset for uncertainties due to the effect of source motion
  - Assess the overall uncertainties in noise predictions of fly-over aircraft
  - Quantify the uncertainties due to ground effects (continue)

See the poster presentation for the PSU work

Outcomes and Practical Applications

- **Outcomes**
  - Identify and analyze measurement data from Discover/AQ dataset: Level flight paths
  - Validation of existing propagation models with available experimental databases.
  - Establish the uncertainties in the prediction models.
  - Reports and codes
- **Practical applications**
  - Improvements to AEDT
  - Better impact assessment of aircraft noise
  - Work useful for noise modeling of both current fleet and future generation of propulsion systems

Research Tasks

- **Penn State**
  - See the Poster presentation
- **Purdue**
  - Study the combined effect of source motion, atmospheric and terrain profiles on the propagation of aircraft noise
  - Examine the uncertainty in predicting the aircraft noise by the current AEDT model
  - Investigate the effect of terrain profile, ground impedance and microphone placement on noise measurements

Status of databases: Discover/AQ dataset

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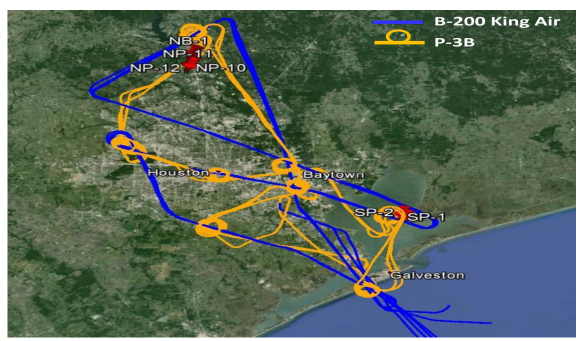
- A set of acoustic, atmospheric and aircraft location data measured in September 2013 by NASA and Volpe (in support of FAA) in the vicinity of Houston, Texas.
- Lockheed P-3B Orion and Beechcraft B-200 Super King Air.
- Flight path: Level & spiral flight paths

Site Data
- Site location
- 1/3 octave SPL

On Board Data
- Aircraft GPS location including rolling angle etc.
- Acoustic data

Atmospheric Profiles:
- Temperature
- Humidity
- Wind speed
- Pressure

NASA P-3B in a typical mission configuration layout during a check flight. (Photo Credit: NASA)



Examples of Different Event Types during the Houston DISCOVER-AQ Flight test (Graphic Credit: NASA)

One of the measurement sites (Graphic Credit: NASA)

Updated Schedule and Status

Aug. 2018: In liaison with PSU, the Purdue research team starts working on the project

October 2018: Fall 2018 ASCENT advisory committee meeting – Purdue: project presentation; PSU: poster presentation

Nov. 2018: Analysis of BANOERAC dataset (work in coordination with PSU) if needed.

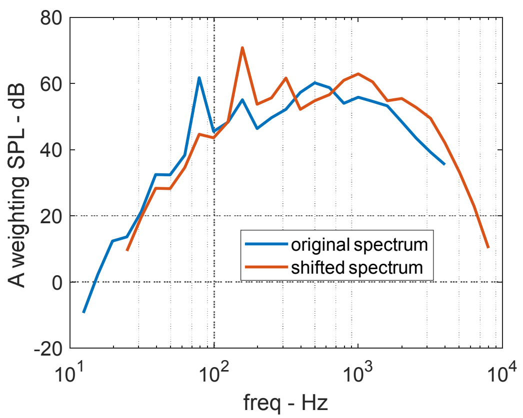
Dec. 2018: First Technical Report

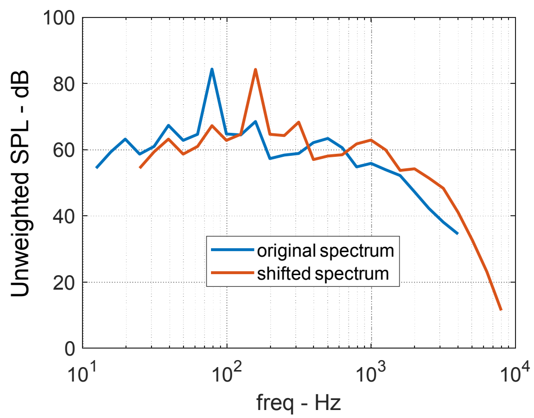
Jan. 2019: Underway – Liaison to obtain the Silence(R) dataset (Dr. Sparrow of PSU takes the lead)

Feb. 2019: Preparation for Spring 2019 ASCENT advisory committee meeting

Overview:

Doppler's shift and A-weighting





Original A-weighted level = 62 dB

Shifted A-weighted level = 66 dB

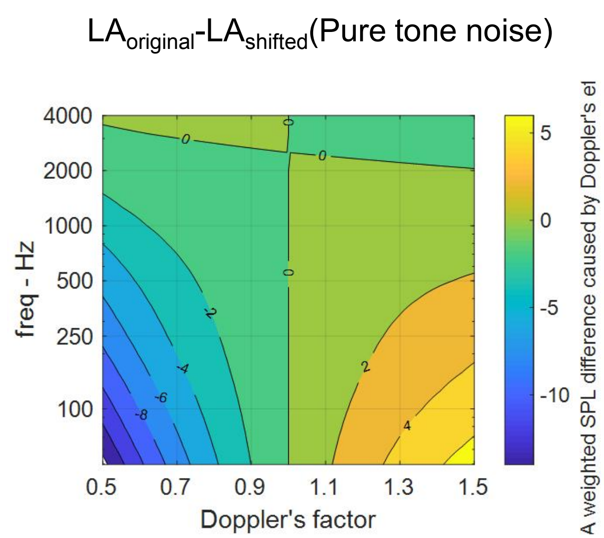
Doppler effect:

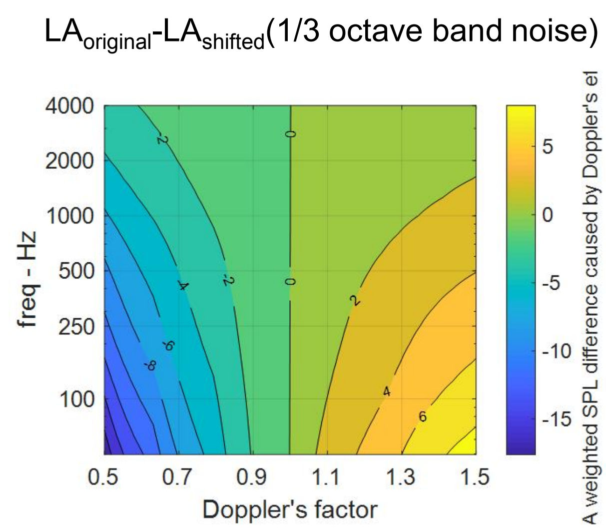
- Increase or decrease the absolute sound pressure level: $20\log_{10} D^2$
- Apparent shift in the source frequency (Doppler shift): $f_{shifted} = D \cdot f_{original}$

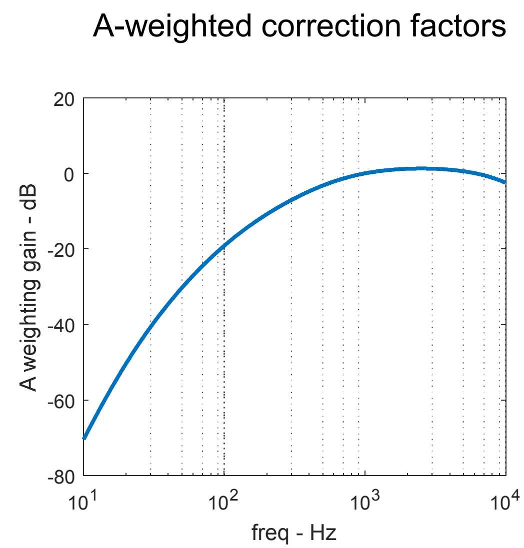
What are the consequences of the frequency shift?

- A weighted SPL increased/decrease
- Air absorption
- Ground reflection and line-of-sight blockage effects

Effect of frequency shifts on pure tone and third-octave band noise



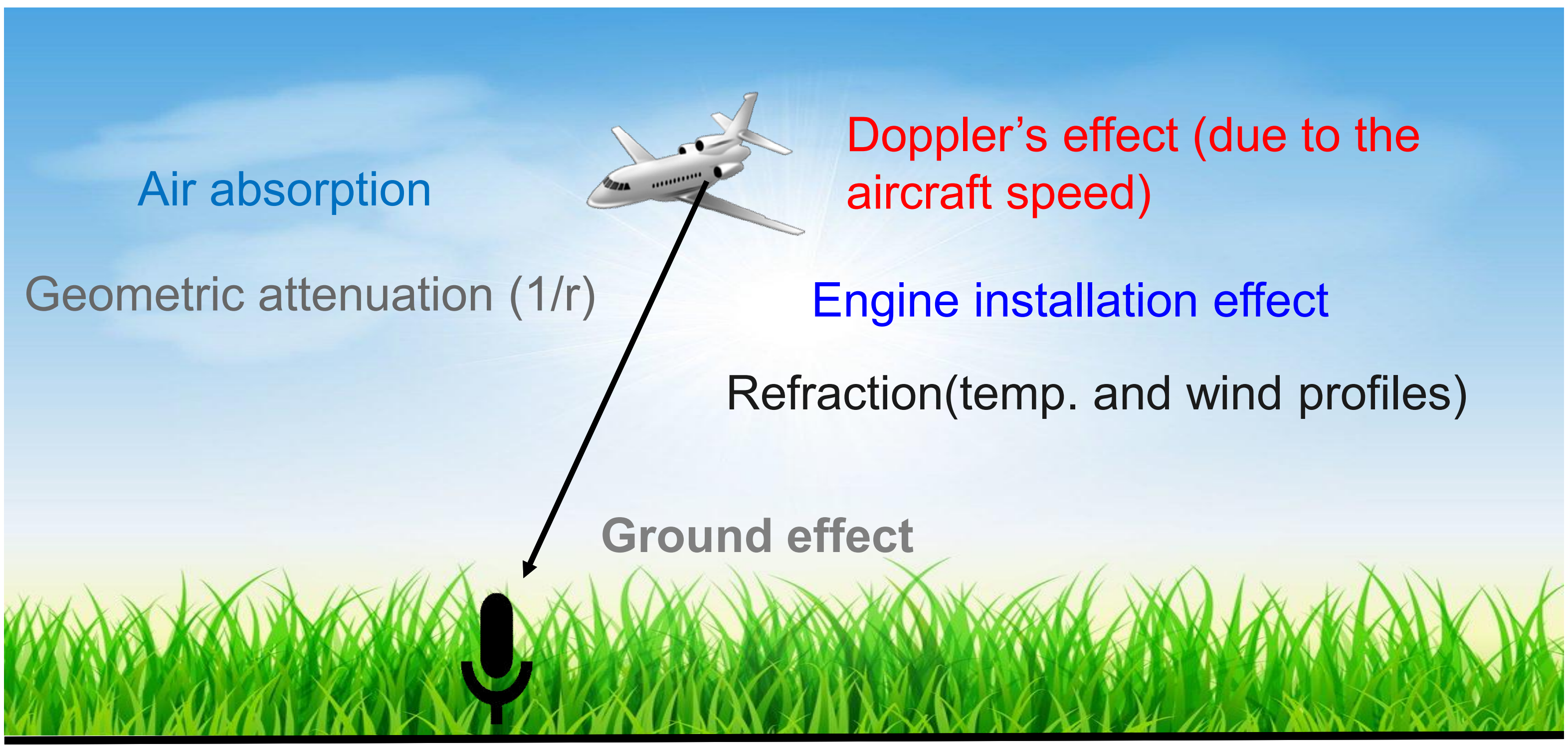




- Low frequency noise is more sensitive to the shifting.
- The influence of shifting to pure tone noise is less than that to 1/3 octave band noise.
- Strictly speaking, the shape of the spectrum, air absorption, ground effect and any frequency dependent effects could all influence the results

Propagation Model

Propagation factors	Dependent Parameters	AEDT model	Theoretical model
(a)Divergence effect	Propagation distance	NPD	$1/R$
(b)Air absorption	Dist., temp., humidity, freq. and pressure	User defined model	$\alpha(f,T,rh,pr)\cdot R$
(c)Refraction	Wind speed/temp profiles and dist.	Lateral attenuation	Ray tracing or wave equation model
(d)Doppler effect	Aircraft speed, receiver location	Only partially Included	$f = D\cdot f_0, \quad p = D^2 p_0$
(e)Ground effects	Ground properties, Freq., elevation angle and R	Lateral attenuation	$p = \frac{e^{ikR_1}}{4\pi R_1} + [R_p + (1-R_p)F(w)]\frac{e^{ikR_2}}{4\pi R_2}$



Ground effect

Discussion of NPD curves

Propagation factors	AEDT model
(a) Divergence effect	NPD curve
(b) Air absorption	ARP5534
(c) Refraction	Lateral attenuation
(d) Doppler effect	Partially included in NPD
(e) Ground effects	Lateral attenuation

NPD curve (interpolate with power and distance)

↓

- Air absorption
- Lateral att.
- Noise fraction
- Directivity factor
- Thrust reverser

Correction with desired atmospheric profile and aircraft location data

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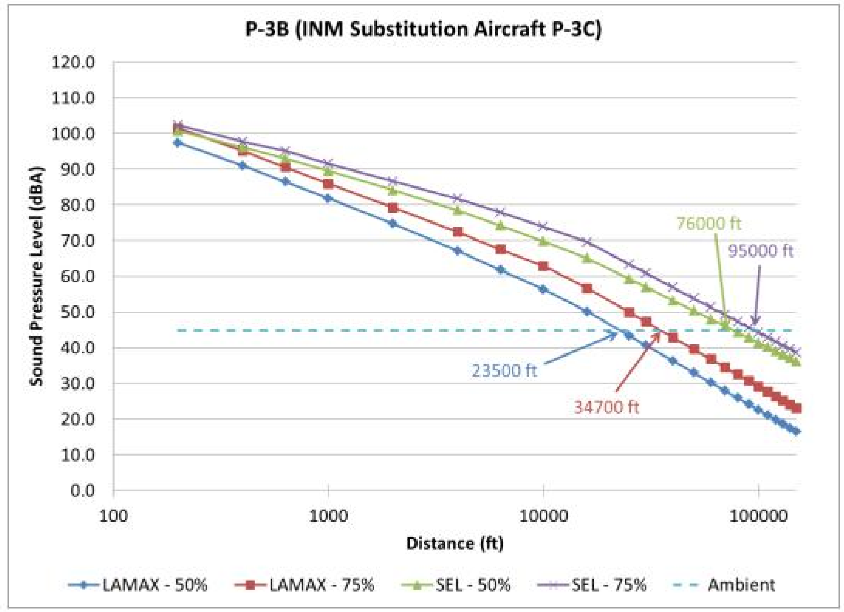
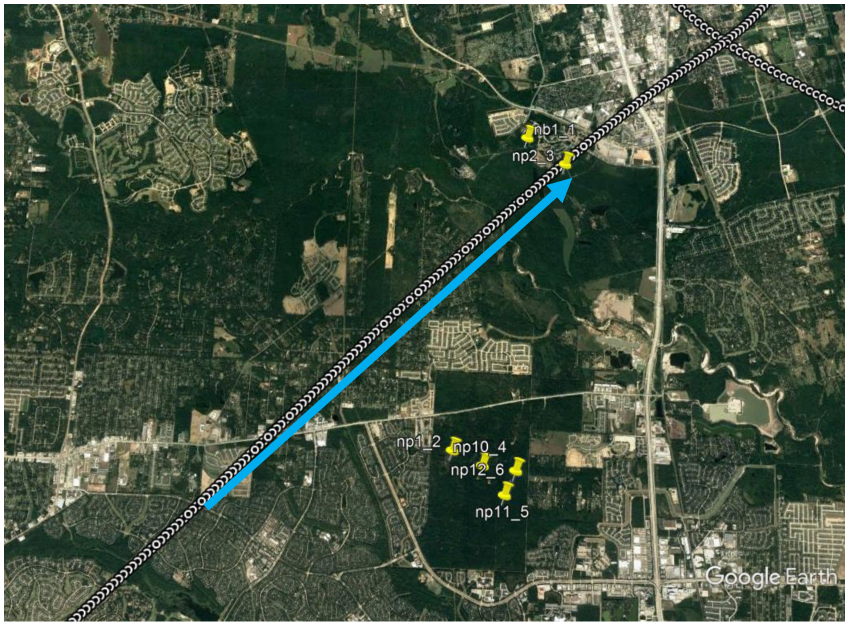
Required noise level (SEL or $L_{A,max}$)

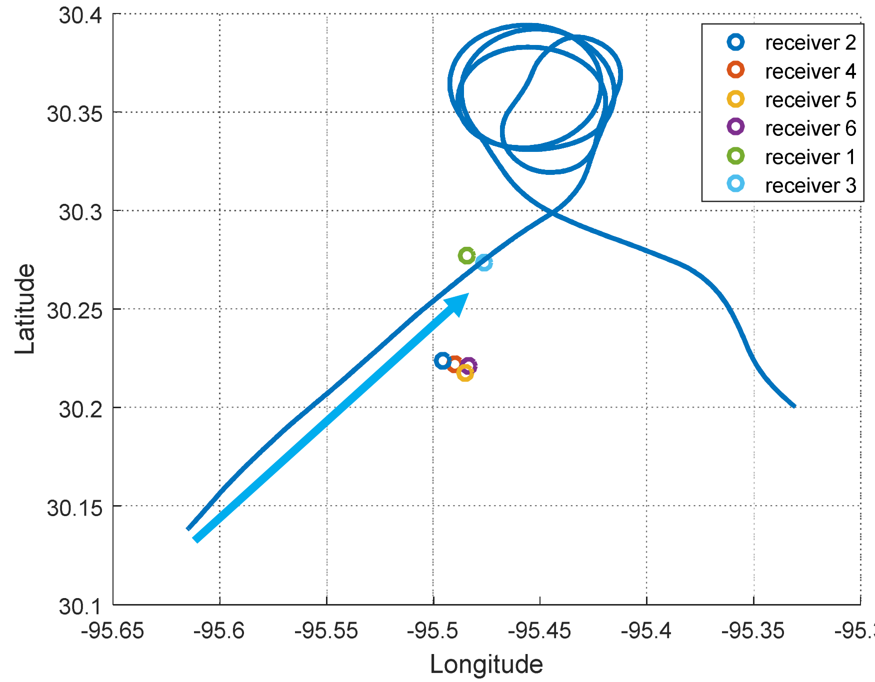
Noise Power Distance curve of P-3B



- NPD curve derived with the guideline documented in SAE-AIR-1845
- Often provided by manufacturers based on measurement data

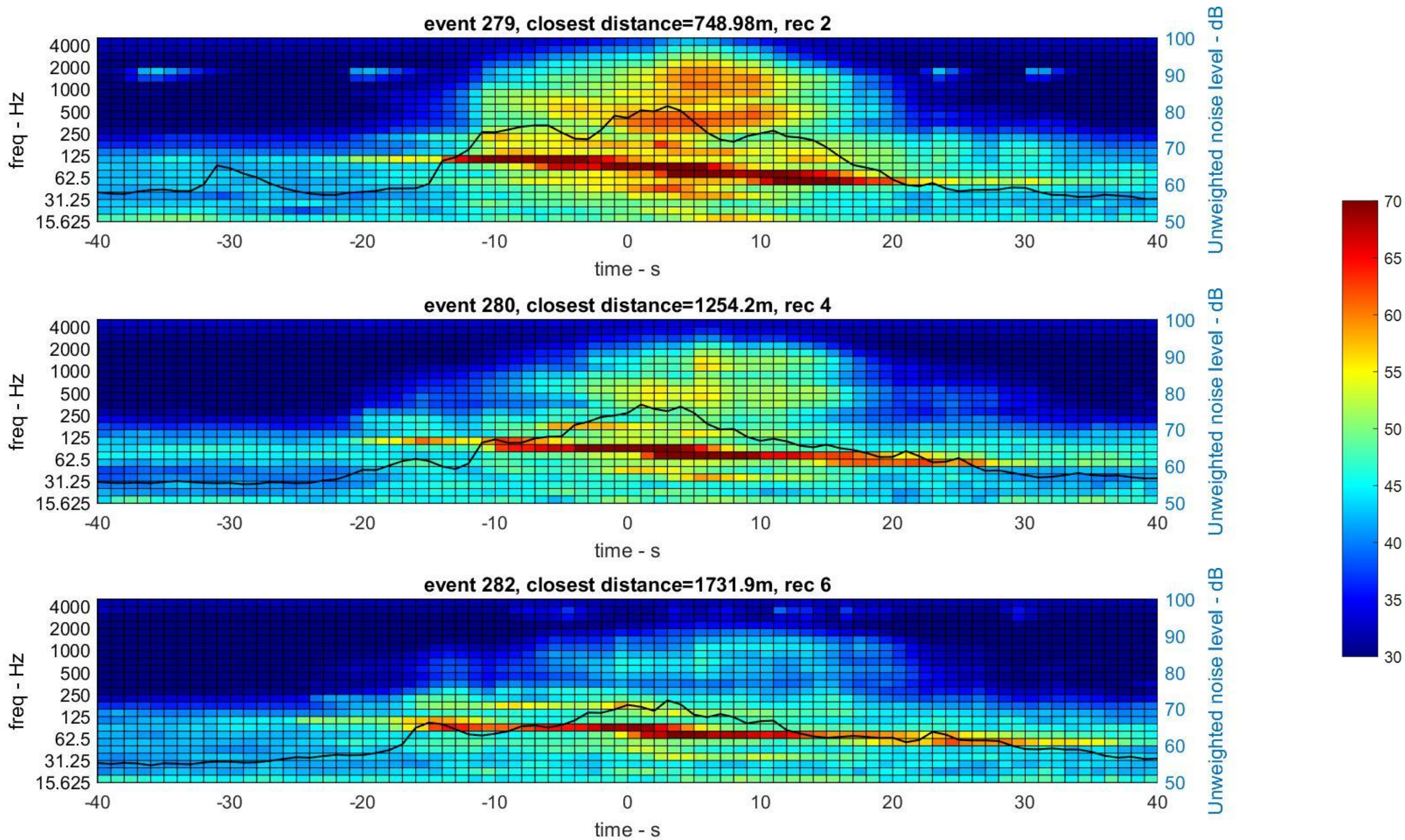
Level flights in DISCOVER-AQ datasets





- **Six receivers near the flight path in various forested areas**
- **P3B Orion at level flight (at about 300 m height) with constant power settings**
- **Aircraft speed of about 71 m/s or 138 knots (comparable with NPD ref. speed)**

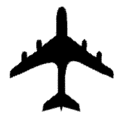
Typical measured data for the level flights



- The aircraft noise could be seen clearly from these typical datasets.
- The sound exposure level and maximum value could be calculated with the data.
- Aircraft Noise was 10 dB higher than the background level levels

Source subtraction method for the sound exposure level

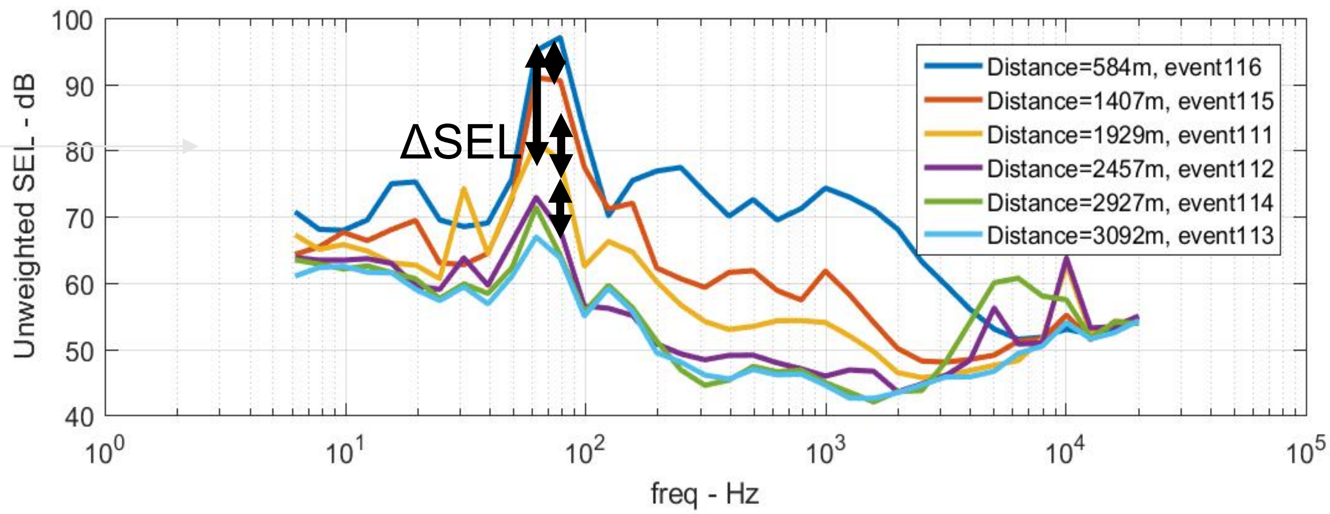
What to compare:



Receiver A SEL_A ← Δd → Receiver B SEL_B

SEL = SEL_{source} - $Att_{propagation}$

$$\Delta SEL(\Delta d) = SEL_A - SEL_B = \Delta Att(\Delta d)$$



- The source effect can be minimized by analyzing simultaneous measurements at different locations.
- The difference between the sound pressure levels measured at two receiver points is dominated by the propagation effect.
- The directivity of source could influence the analysis but it should be small at long distances.

Summary

- Work underway to quantify uncertainties via available data
  - DISCOVER/AQ dataset is used to examine the possible uncertainties on the predictions of en-route aircraft noise
  - Investigate the uncertainties of the AEDT prediction model with the measured noise data
  - Improve the noise propagation capabilities for use in FAA noise tools

- Key challenges/barriers
  - Just beginning to understand uncertainty in aircraft noise sources and the Doppler effect of an en-route aircraft. Lots more to do
  - Would like to identify additional industrial partners who can provide supporting data or expertise
  - Funding uncertainty on the project impacts on the ongoing work

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- National Aviation University, Ukraine: Sasha Zaporozhets
- Industry partners: Mark Cheng and Rachel Min (Vancouver Airport Authority); Nico van Oosten (ANOTEC)