FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Quantifying uncertainties in predicting aircraft noise in real-world situations

Project 40

Lead investigators: Vic Sparrow, Phil Morris [Penn State] & Kai Ming Li [Purdue]
Project manager: Hua (Bill) He, FAA

October 22, 2019
Alexandria, VA

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project 40 through FAA Award Numbers 13-C-AJFE-PSU and 13-C-AJFE-PU under the supervision of Dr. Hua He. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA.

ASCENT
AVIATION SUSTAINABILITY CENTER

Motivation

- Need to increase the Research Readiness Level (RRL) of noise emission and propagation capabilities for possible future use in FAA noise tools
- Quantifying noise requires accounting for both a complex environment and model input/output uncertainties
- Need an integrated approach to account for uncertainties in accurately modeling of the aircraft state and resulting noise (source), atmospheric and meteorological conditions (propagation) and ground impedance and terrain profile (receiver)
- Want enhanced capabilities to better support new aircraft entering service and environmental impact studies

Objectives

- Quantify uncertainties of both numerical model and field data for predicting aircraft noise in real world situations
  - Establish overall uncertainty based on input information
- 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

Status of databases

Dataset	Key feature	Status	Date Acquired
Discover/AQ Acoustics	Propeller aircraft	In ASCENT	Dec. 2015
Vancouver Airport	Terminal area noise	In ASCENT	Aug. 2016
BANOERAC	Jet aircraft en-route	In ASCENT	Dec. 2017
SILENCE(R)	Careful A321 measurements	Waiting on Airbus	In process

- Discover/AQ now being used extensively at Purdue.
- BANOERAC now being used extensively at Penn State.
- SILENCE(R) data pledged by Airbus for use in Project 40.

Schedule and Status

Project was turned back on in June 2019. Thank you!

Penn State

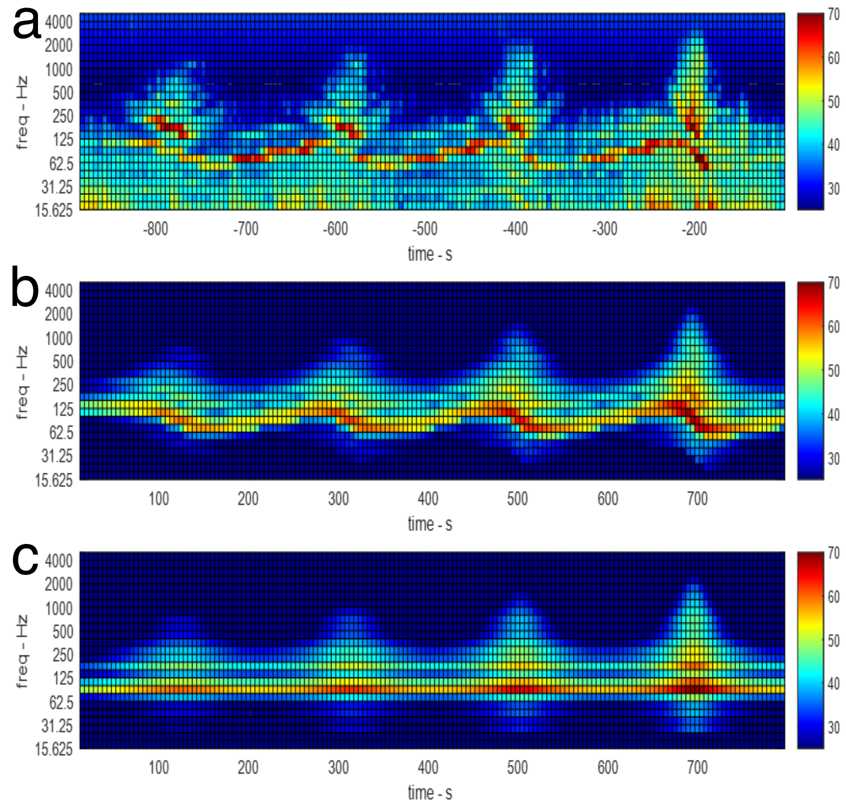
- Identify role of directivity in received levels on the ground for common subsonic airliners
- Assess relative importance of source versus propagation, accounting for uncertainties
- Develop source models including intensity, directivity, and sensitivity of noise to changes in aircraft state

Purdue

- Identify appropriate datasets that have variations in measured noise levels for comparable flight routes and flight patterns
- Estimate the possible uncertainties in AEDT due to the ground and Doppler effects
- Study the Doppler effect due to source motion on the apparent ground impedance

Recent Accomplishments (Purdue)

- Predict sound pressure levels in time histories for all frequency bands.
- Overall agreement is good.
- Doppler's effect can be seen clearly in the spectral data.
- Doppler's effect on A weighted noise level is studied in detail.



Spectral Analyses

(a) Measurement;
(b/c) Predictions with/without inclusion of the Doppler effect

Issues identified

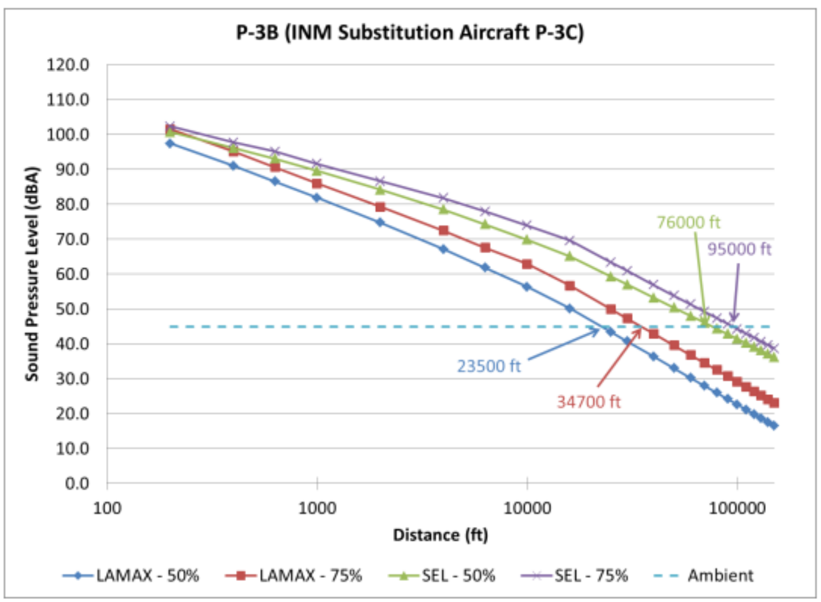
- Unable to separate source uncertainty from the propagation uncertainty.
- Uncertainties in source power are larger than the variations of propagation effects in many cases. This means that the uncertainties in source power cannot be ignored
- Adjustments are needed for comparing the AEDT model with point-to-point measured data.

Uncertainties in AEDT

Corrections

NPD curve (interpolate with power and distance) → • Air absorption • Lateral → Required noise level (SEL or max noise)

Noise Power Distance curve of P-3B (P-3C)



- **Air absorption effect corrected using P-3B Orion's spectrum and atmospheric data.**
- **Lateral Att. using sideline distances and elevation angles.**

Possible uncertainities in AEDT

- **Doppler effect**
- **Ground effect**

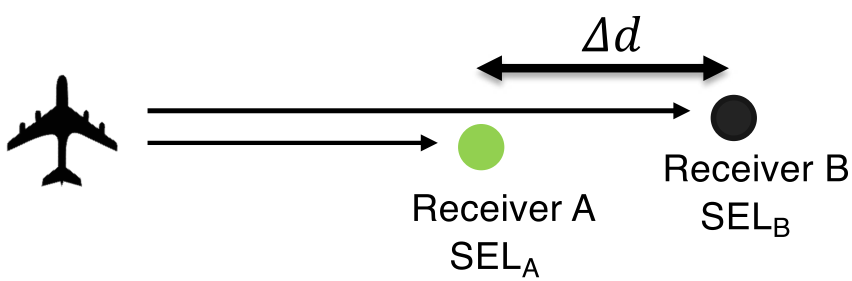
Level flight and subtraction of sound exposure levels

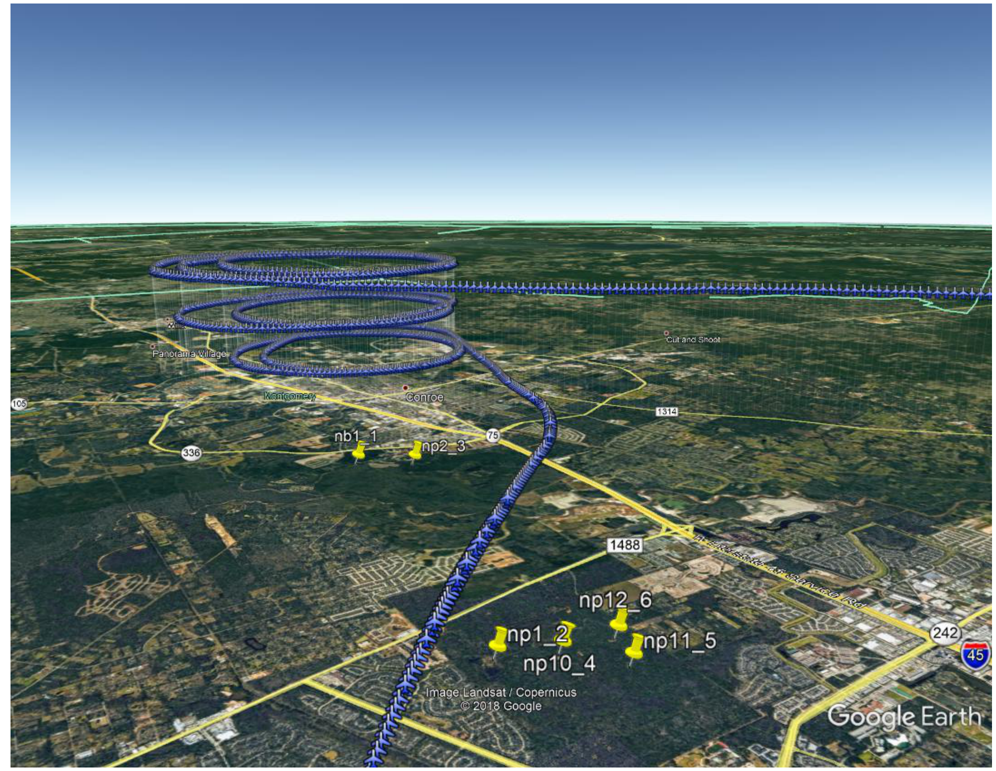
SEL in the model:

$$SEL = SEL_{no\ propagation} - Att_{propagation}$$

What to compare:

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





- The simultaneous noise levels were due to the same noise source – P3B Orion.
- The difference between the noise levels at the two receivers is due to the propagation effect.
- There are 6 receivers in a group, then there will be 15 ΔSEL to use.
- The directivity of source could influence the analysis but it should be small at long distances.

Activity for the current year (Purdue)

- Focus on the propagation effects instead of both propagation and source modeling.
- Use method of subtraction to analyze propagation effect. To minimize influence of source uncertainties.

Steps to analyze Discover-AQ dataset

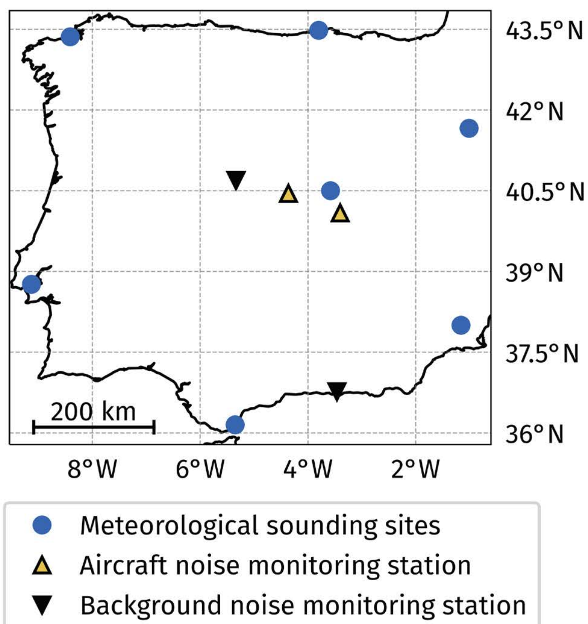
1. Identify appropriate datasets for analysis based on signal/noise ratio, path similarity, etc.
2. Use subtraction method to minimize source uncertainties
3. Use sound exposure level (top 10 dB exposure level) to analyze propagation factors.
4. Compare propagation effects in DISCOVER-AQ data with those obtained from AEDT and theoretical model.

Purdue Summary

- Work underway to quantify uncertainties via available data
  - Comparison of the measured SEL for the level flight data taken from Discover-AQ dataset with the predictions according to AEDT and the ray model
  - Comparison of NPD in AEDT database with that calculated by the ray model (including the Doppler effect)

BANOERAC (Background noise level and noise levels from en-route aircraft)

BANOERAC measurement sites

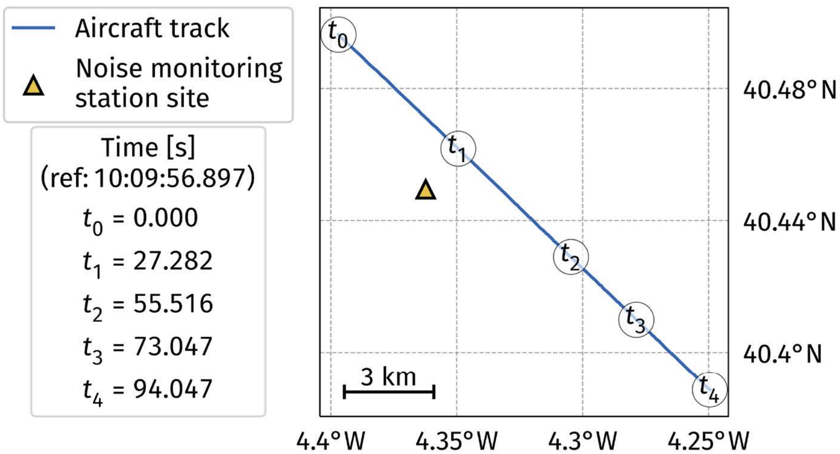


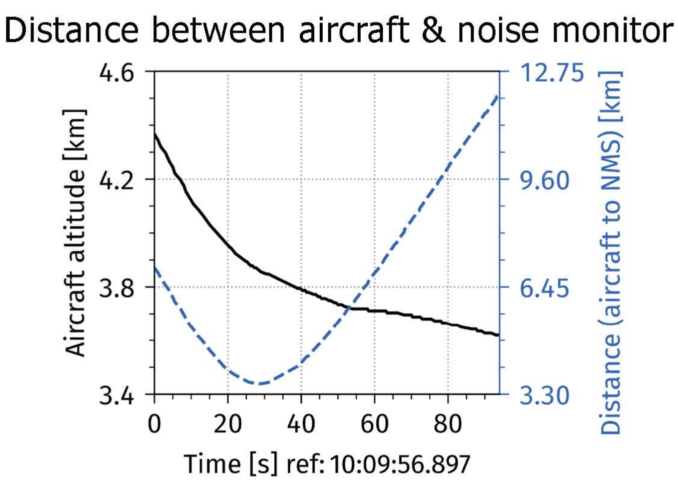
- Dataset obtained from ANOTEC Consulting, S.L. (contracted by European Aviation Safety Agency).
- En-route **aircraft noise measurement** data along with **GPS tracking data** and meteorological data.
- Data from meteorological sounding stations won't be useful (far away). Limited data from the ground meteorological stations (same location as noise monitors) available.
- Data obtained on 20 days spread over the period of 6 months (February - July 2009).
- ~1000 aircraft events (~500 claimed to be "clean").

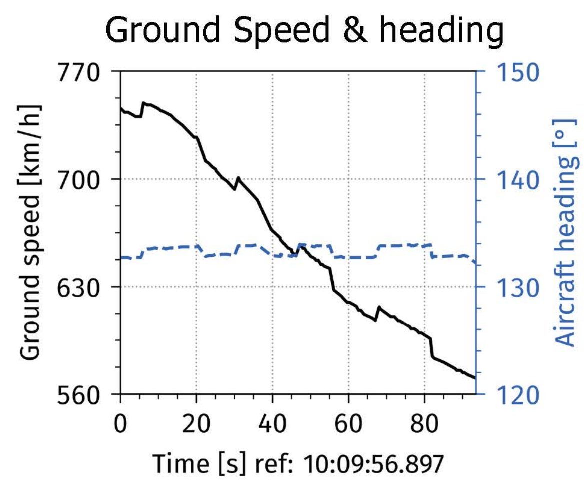
Up next: A preliminary investigation of one of the events from the dataset

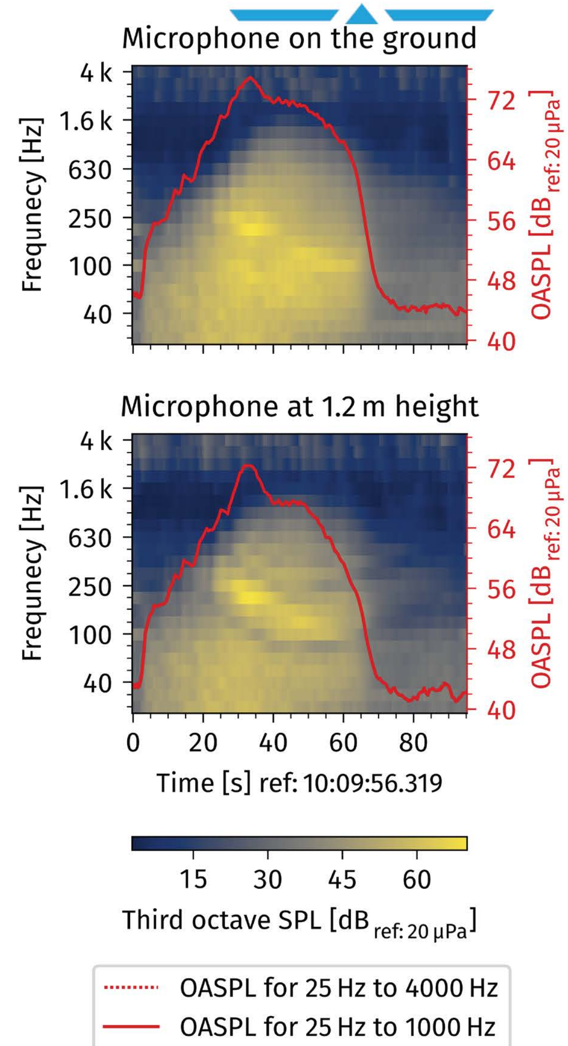
The event (Aircraft model: 757-200)

Aircraft track



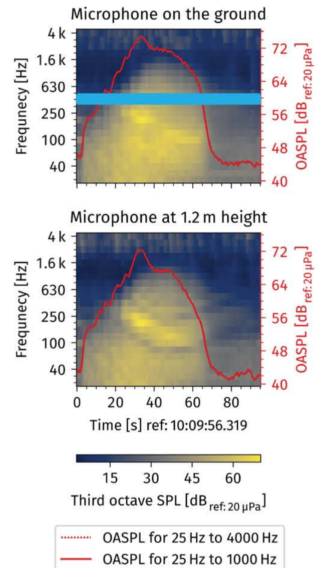




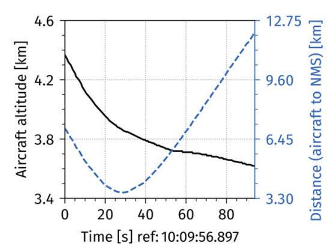


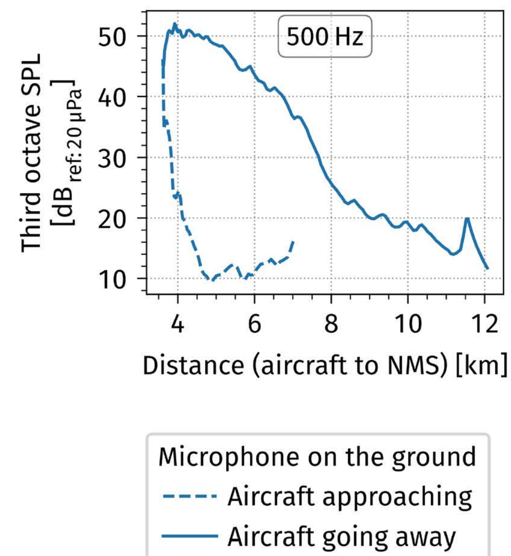
Noise levels as a function of the distance between aircraft and noise monitor

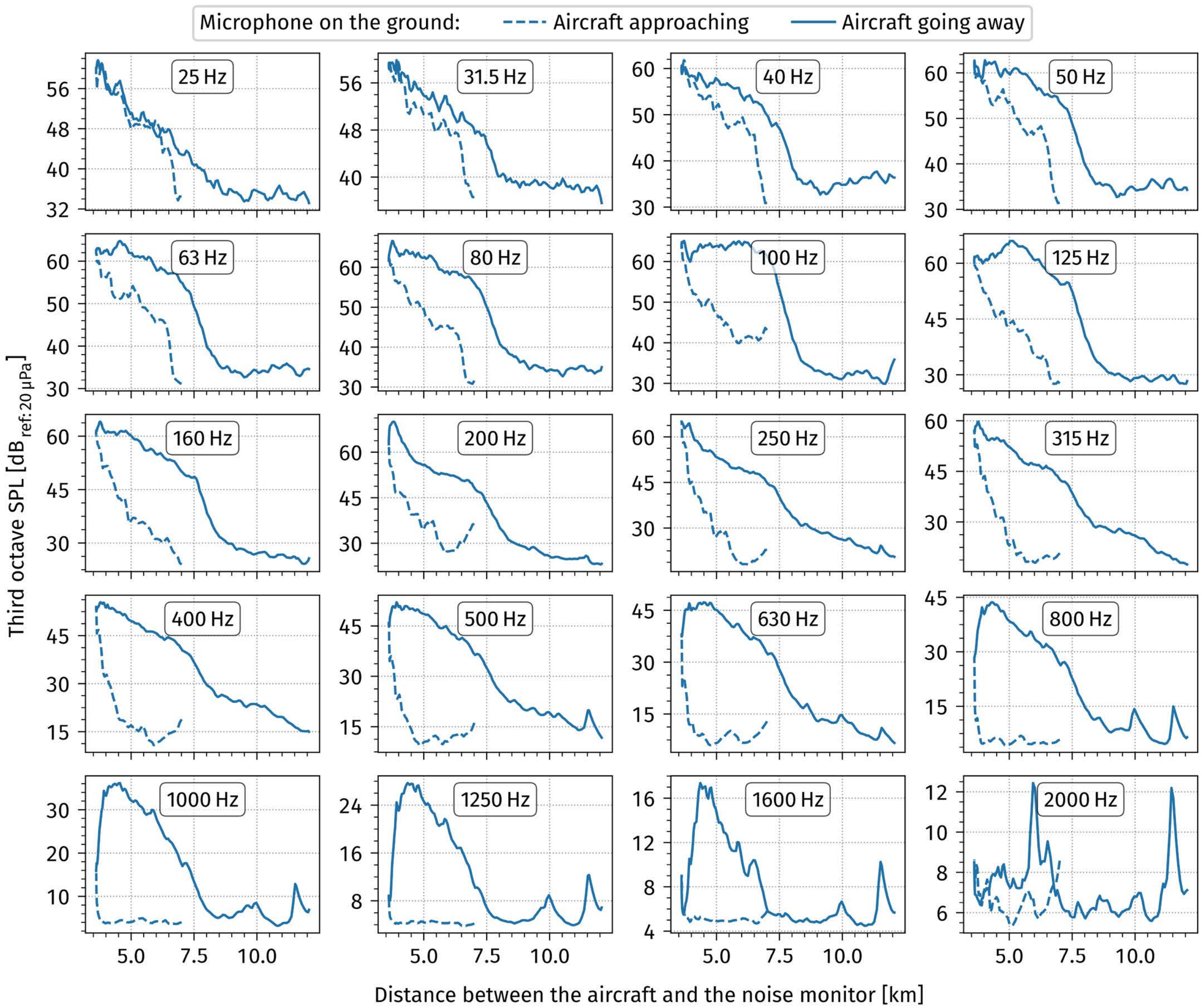
Time history of third octave levels at the noise monitors.



Time history of distance between the aircraft and the noise monitors



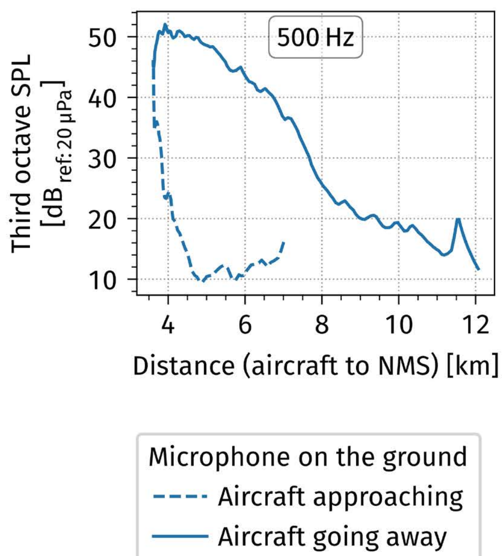




Overall trend:

lower levels when the aircraft is **approaching** the noise monitor (vs. aircraft going away).

Why is the noise level lower when the aircraft is approaching the noise monitor?



Candidate factors that could explain the difference in levels for the same distance:

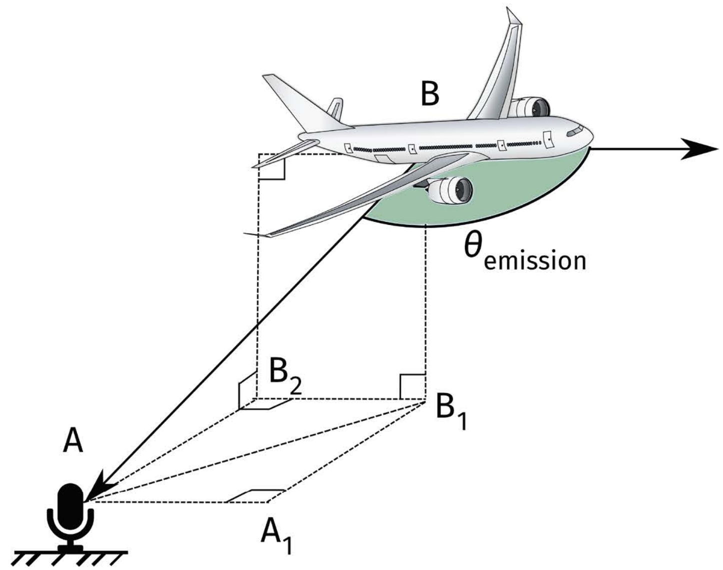
- Convective amplification
- Aircraft directivity

Convective amplification
(Effect of source motion on the received level)

Convective amplification =

$$-40\log\left(1 - M\cos\left(\theta_{emission}\right)\right)$$

- Need airspeed to calculate the Mach number but the available data is for groundspeed (data for the wind velocity not available).
- Typical wind velocities at 4 km altitude could be as high as 100 km/hr. Considering 3 different cases (no wind, aircraft flying downwind, aircraft flying upwind).



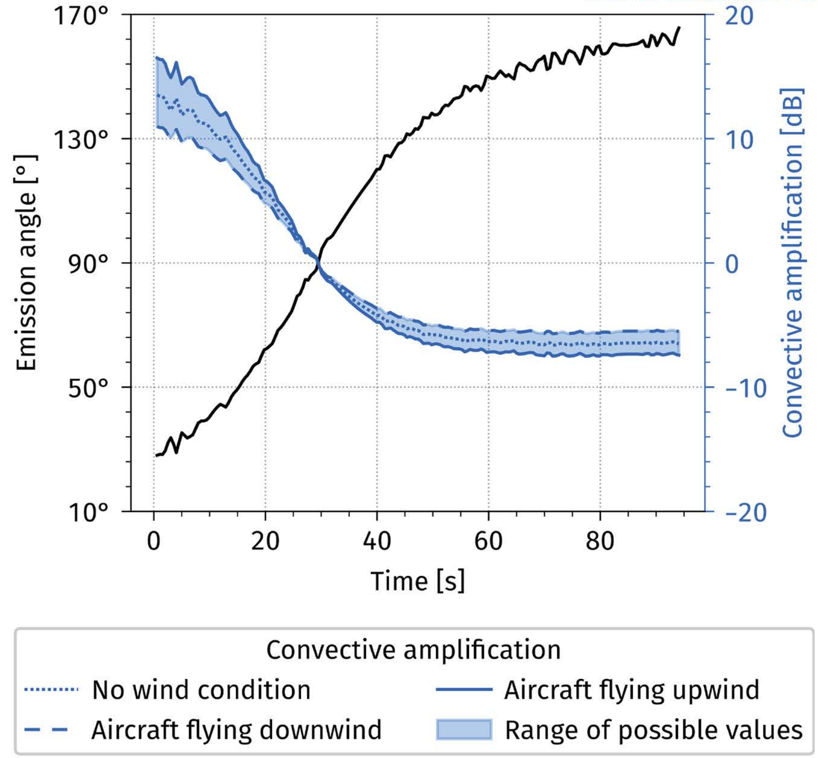
Convective amplification

Convective amplification =

$$-40\log\left(1 - M\cos\left(\theta_{emission}\right)\right)$$

Three cases shown:

1. Aircraft flying downwind
2. Aircraft flying upwind
3. No wind condition



Not knowing the exact wind velocity can make a difference as high as 6 dB!
Assuming no wind condition for the preliminary analysis.

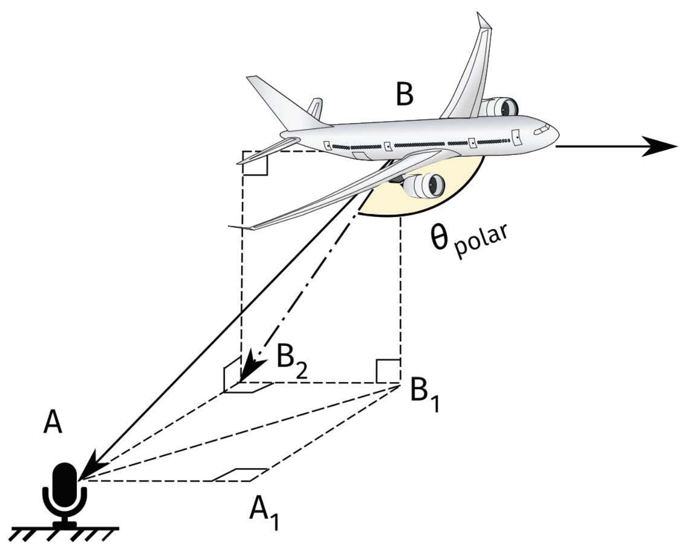
Sources of aircraft noise

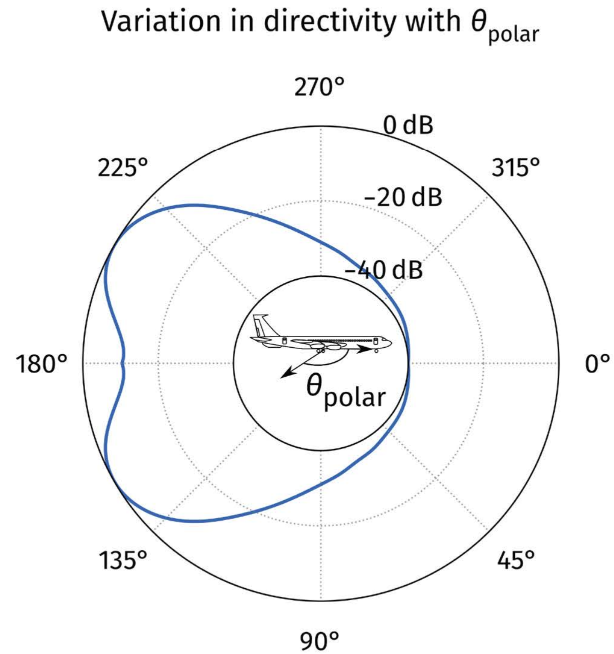
- Jet noise
- Fan and turbine noise
- Combustion chamber noise
- Airframe noise

Assumption for the preliminary analysis

For the event under consideration, it would be fair to assume that jet noise would be the dominant source and hence the overall noise directivity will closely resemble the jet noise directivity.

Jet noise directivity

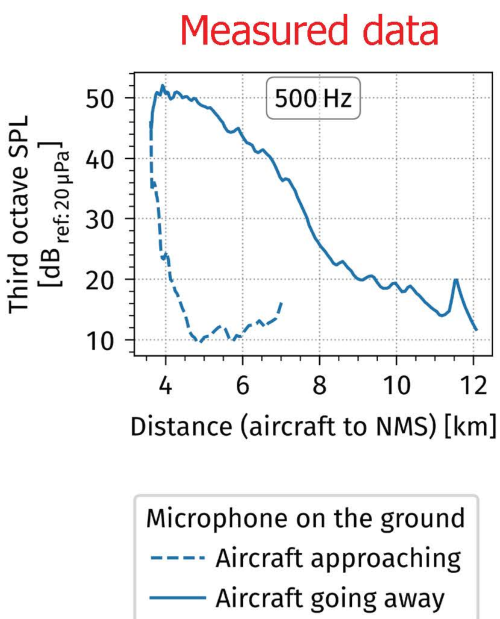


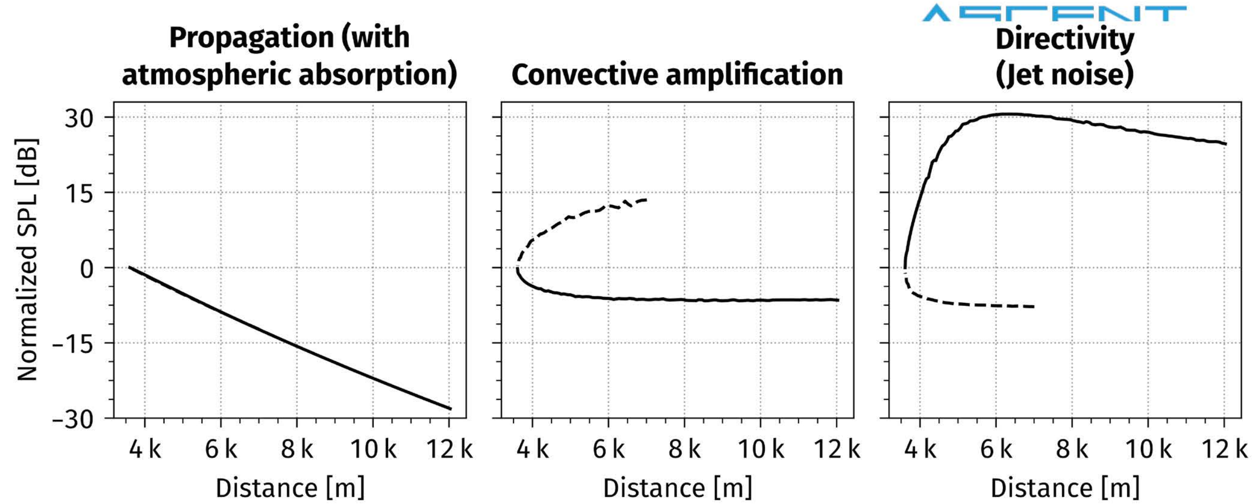


IMPORTANT NOTE:

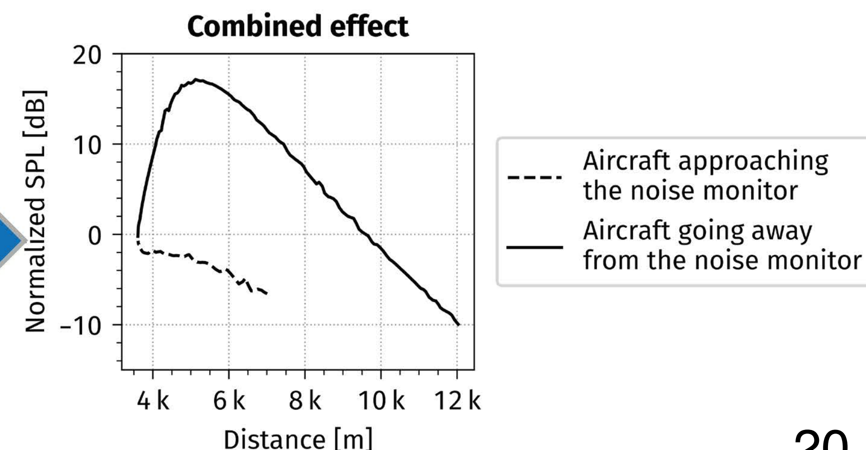
This is a typical directivity pattern for jet noise (the exact pattern for the aircraft under consideration might be slightly different – depending on the normalized jet velocity and the type of jet).

Acoustic propagation + Convective amplification + Jet noise directivity





Approaching a qualitative agreement



Penn State Summary

- To accurately predict aircraft noise, it is necessary to account for both the convective amplification and the noise directivity.
- Source levels and directivity as a function of frequency are needed to explain the details of the received noise levels.
- Need detailed information about aircraft state to predict absolute noise levels.

- Not shown here: We are working more closely with Georgia Tech on ASCENT Project 43 to develop improved noise source models.

Overall Status

- Project 40 lives again!
- Next steps:
  - Purdue: linking Discover/AQ Acoustics data to AEDT predictions and NPD database
  - Penn State: looking more closely at effects of aircraft state and propagation on received noise levels
- Key challenges/barriers
  - Just beginning to understand uncertainty in aircraft noise sources. Lots more to do. Collaborations with Georgia Tech on Project 43 will help meet this challenge.
  - It is not easy to find additional industrial partners who can provide supporting data or expertise for this topic

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Participants

- Penn State: Victor Sparrow, Phillip Morris, Harshal Patankar, Stephen Willoughby
- Purdue: Kai Ming Li, Yiming Wang
- FAA: Bill He
- Volpe: Eric Boeker, Juliet Page
- National Aviation University, Ukraine: Sasha Zaporozhets
- Industry partners: Mark Cheng and Rachel Min (Vancouver Airport Authority); Nico van Oosten (ANOTEC); Pierre Lempereur (Airbus)