The Advanced Acoustic Model and Three Dimensional Noise Sources

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Wyle Laboratories

Aviation Noise Impacts Roadmap Meeting
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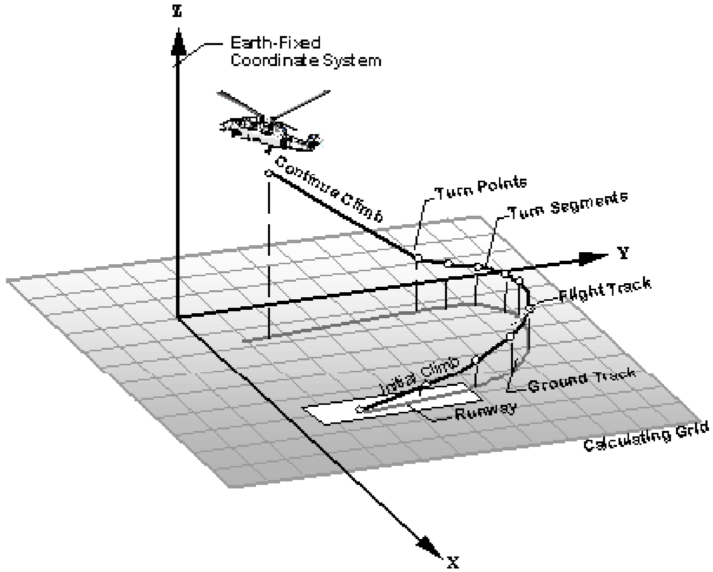
Aircraft Noise Modeling



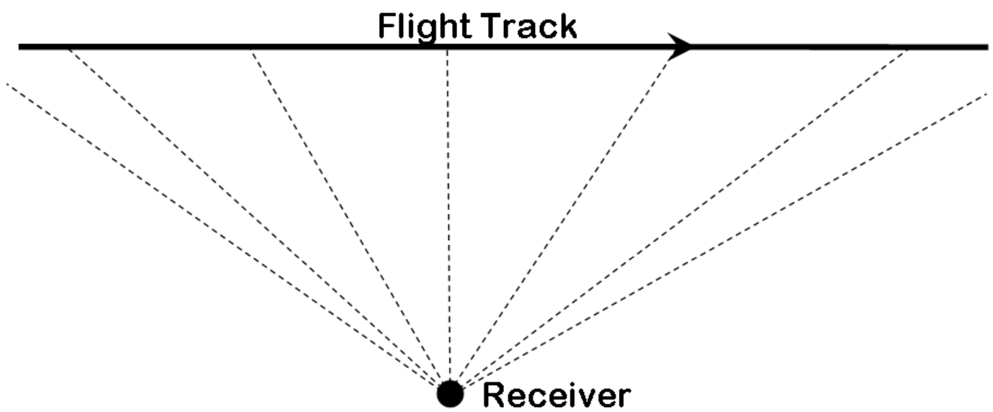
Sound propagates from each point on the flight path to each point on the ground

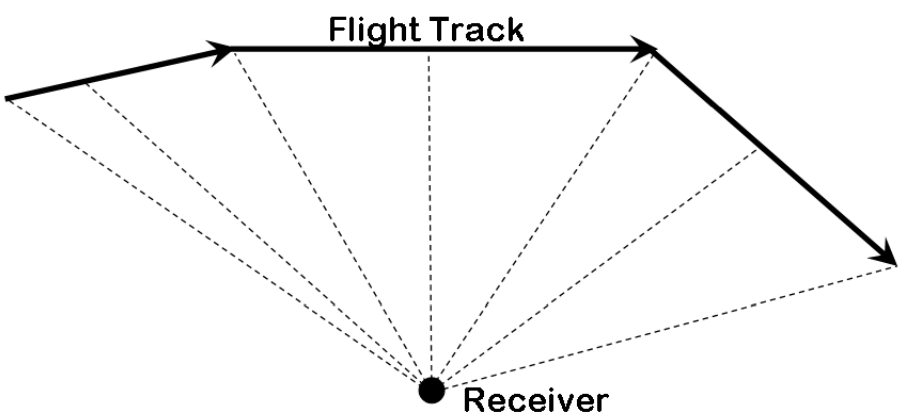
$$L(r) = L(r_0) + A_{spread} + A_{atm} + A_{weath} + A_{grnd} + A_{topo} + A_{nonlin}$$

where

A_{spread} = geometrical spreading, generally $1/r^2$
A_{atm} = atmospheric absorption of sound,
A_{grnd} = finite impedance ground effect
A_{topo} = propagation effects due to non-flat ground; includes shielding
A_{weath} = propagation effects due to atmospheric gradients
A_{nonlin} = nonlinear propagation effects

Integrated Models (NOISEMAP, INM)





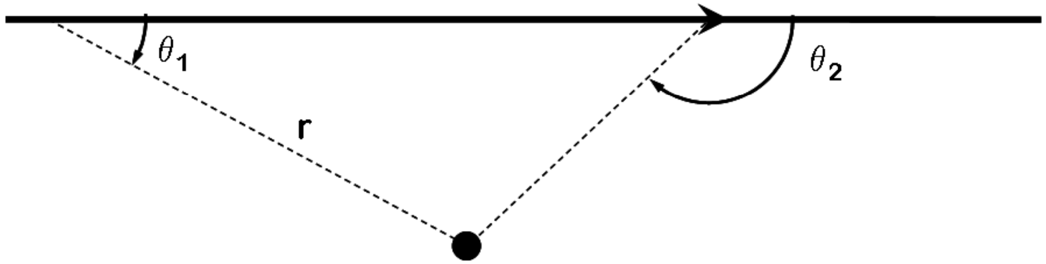
Integrate noise along a full straight track

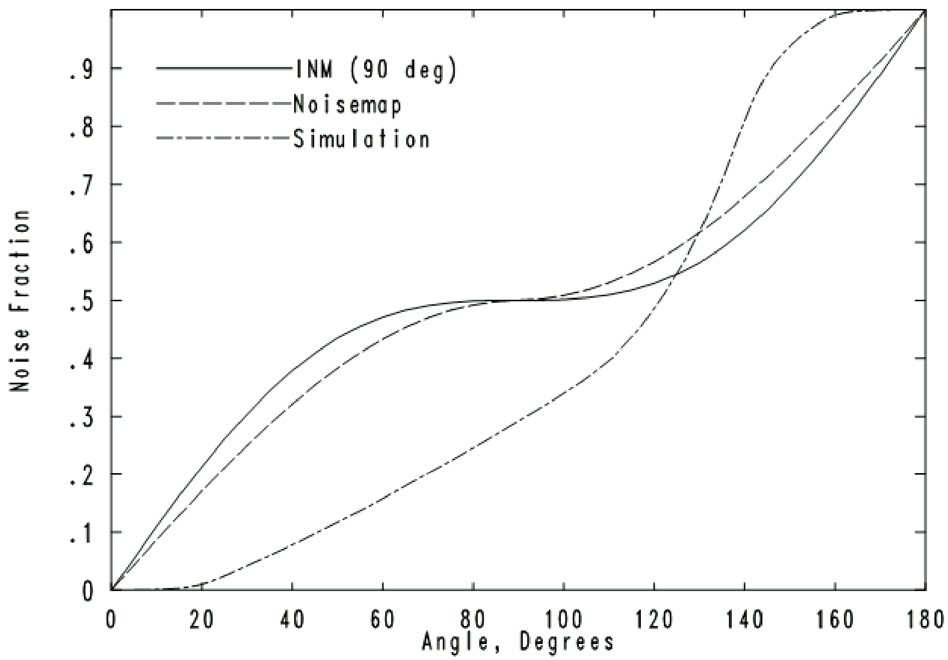
- **Measured in flight test, usually at 1000 ft**
- **Extrapolated to other distances by various methods**
- **SEL data base**

Complex tracks broken into segments

- **SEL from data base**
- **Adjust by noise fraction**
- **NF derived from simple (power law) propagation model**

Noise Fraction





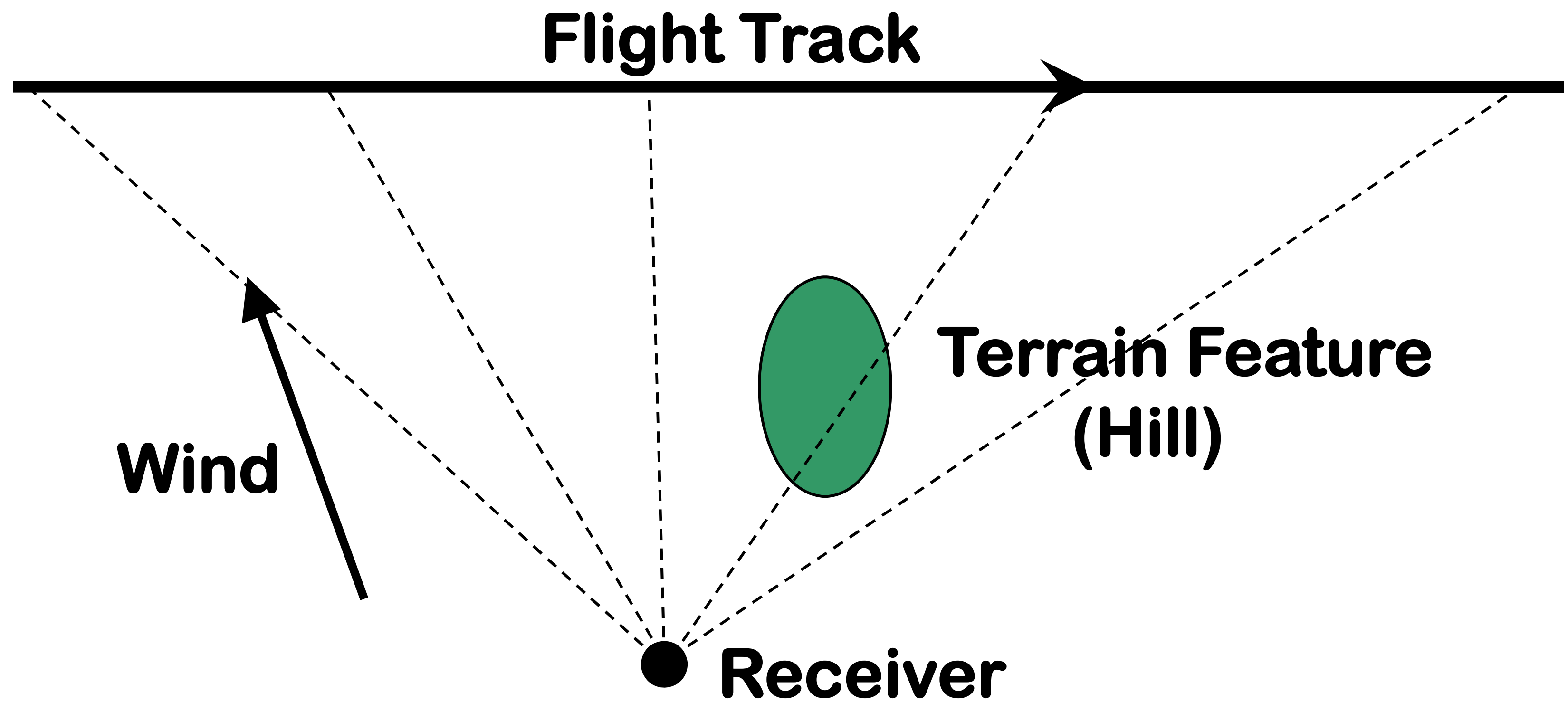
Noise Fraction: INM vs F-16C Simulation

NF computed analytically, using omnidirectional source, $1/r^3$ or $1/r^4$ propagation

NF does not always agree with time history integration of a real source

Integrated Model Limitations

Complex (non-isotropic) Situations



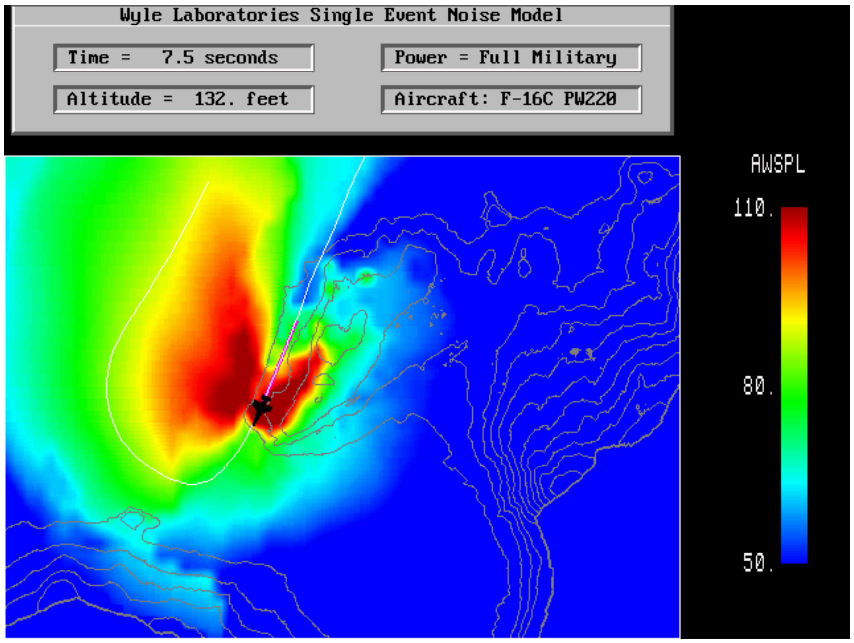
Can't define standard noise fraction

Advanced Acoustic Model

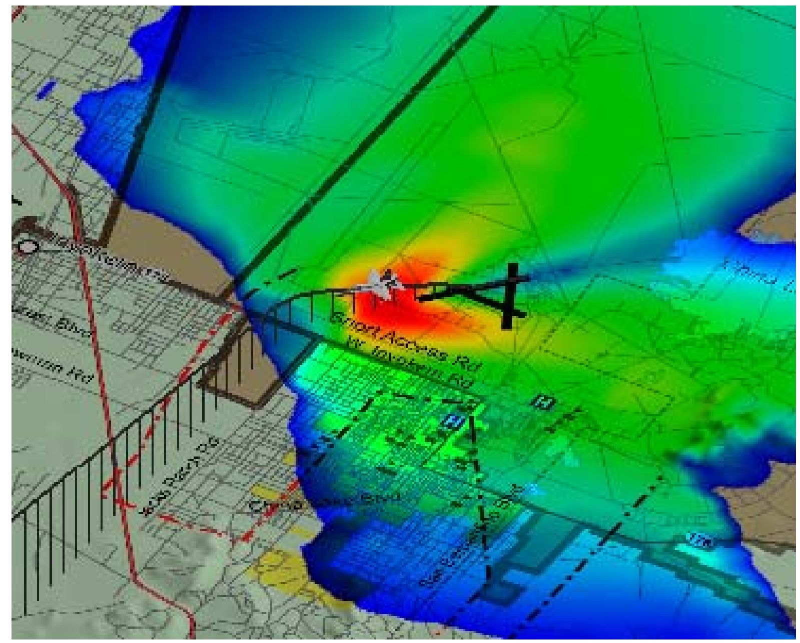
- Noise simulation model developed under SERDP Project WP-1304
- Roots are in:
  - Wyle/AFRL NoiseMap Simulation model
  - Wyle/NASA Rotorcraft Noise Model
- Computes spectral time histories of noise at specific points or on a grid
- Accounts for true propagation from each point
  - Terrain
  - Atmospheric gradients
  - Nonlinear effects

Noise Rendering/Presentation

- Contours – compatible with NMAP, INM, NMPlot
- Color renderings of noise footprints



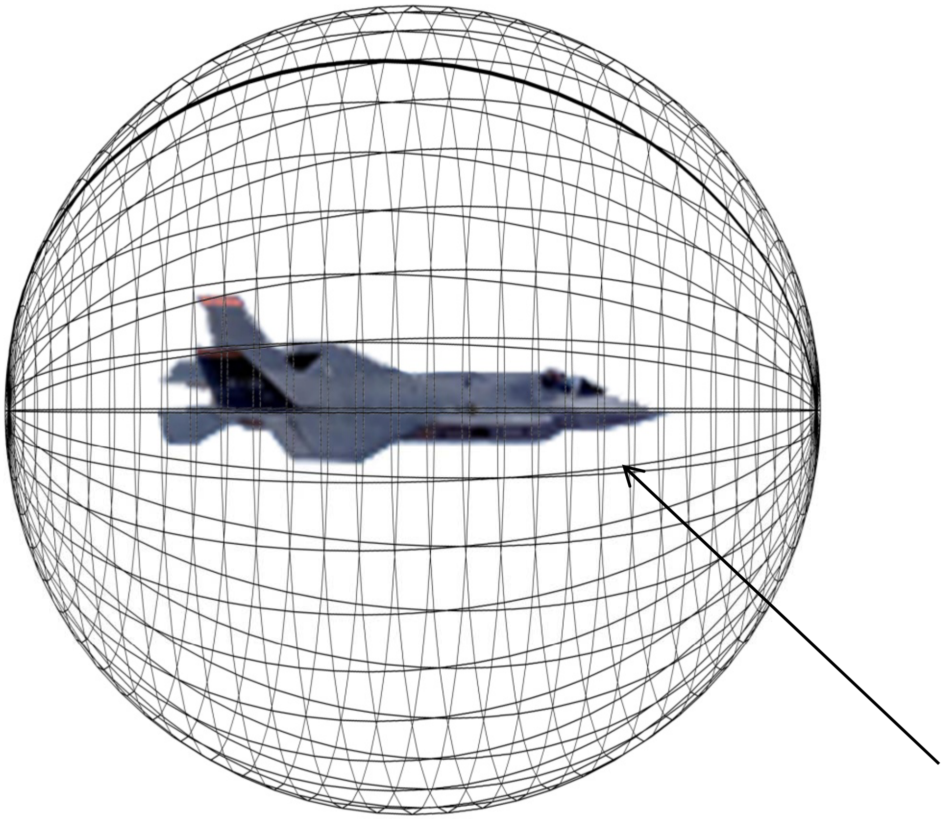
2-D



3-D

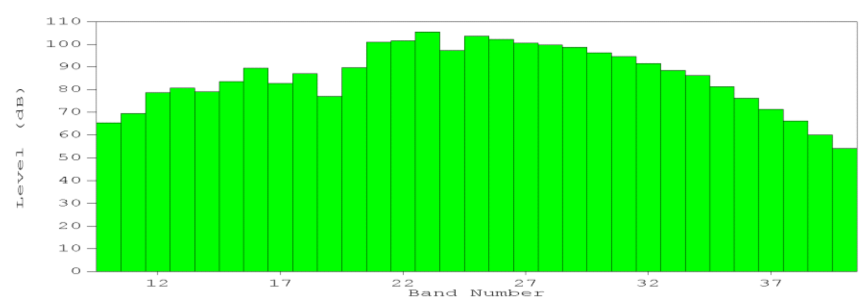
- Animations – for analysis and outreach

3-D Sources: Noise Sphere

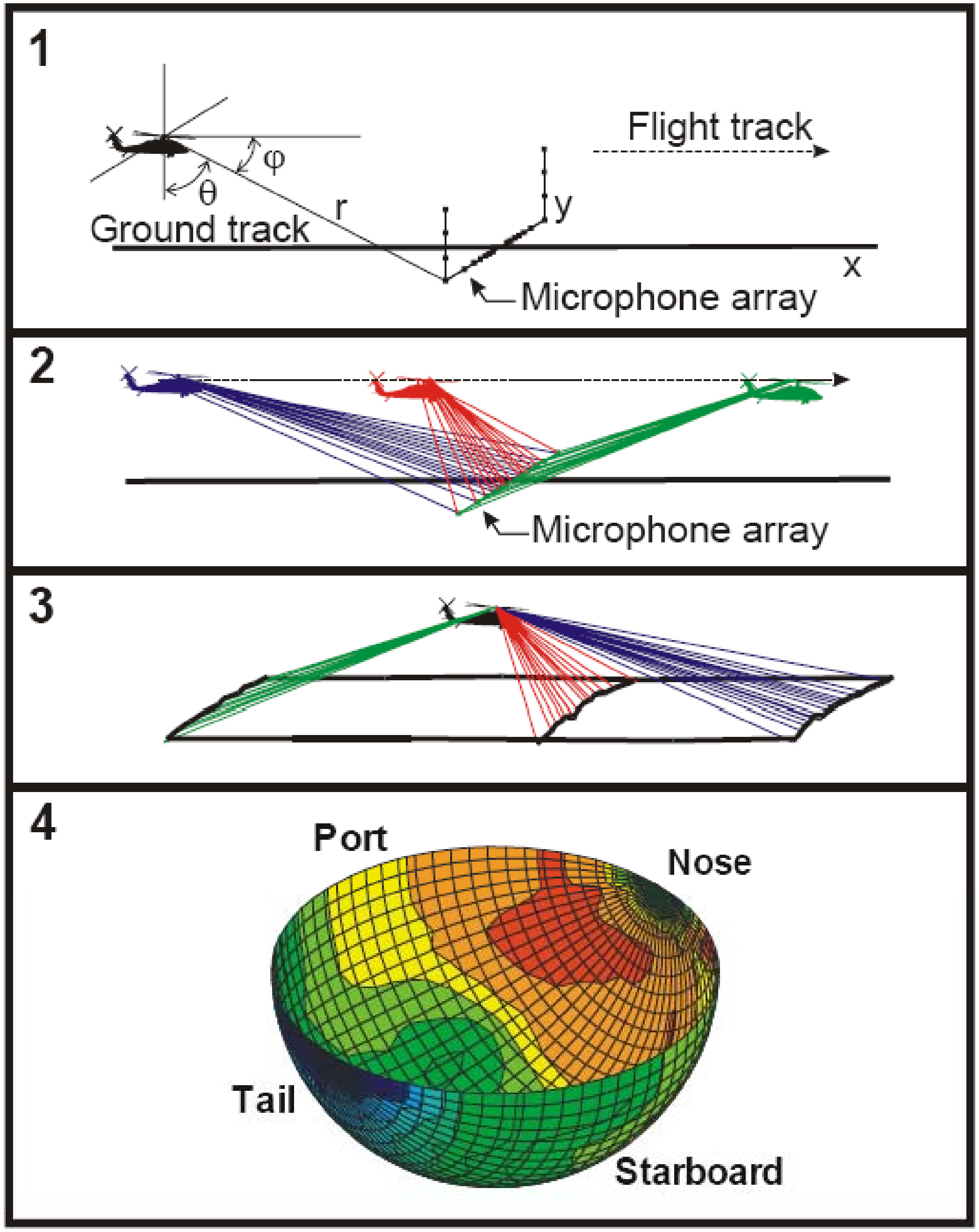


Fore-aft angle θ
Roll angle φ

- Need spectral emission as a function of direction
- Need relationship with and between operating states
- Set of noise spheres at various power



Acoustic Re-propagation Technique (ART)



- Fly aircraft past a microphone array
  - Through a hoop would be ideal
  - Settle for ground and elevated (tower) mics
- Record noise
- Run model “backwards”
- Normalize to a noise sphere

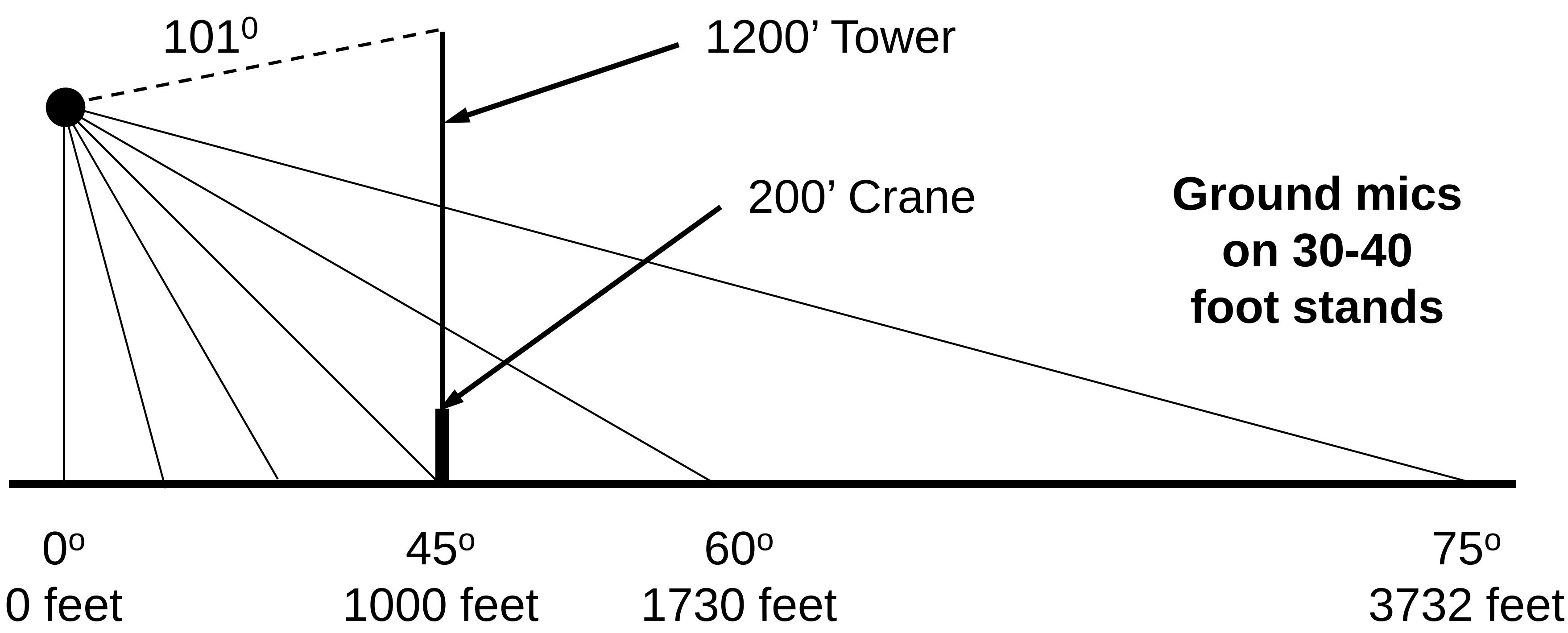
Flight Test Setup – Elevated Microphones

Aircraft

Microphones suspended from cranes and on ground between

USAF (AFRL) is building the Aeroacoustic Research Complex, with permanent tall towers

Lateral Microphone Geometry: φ

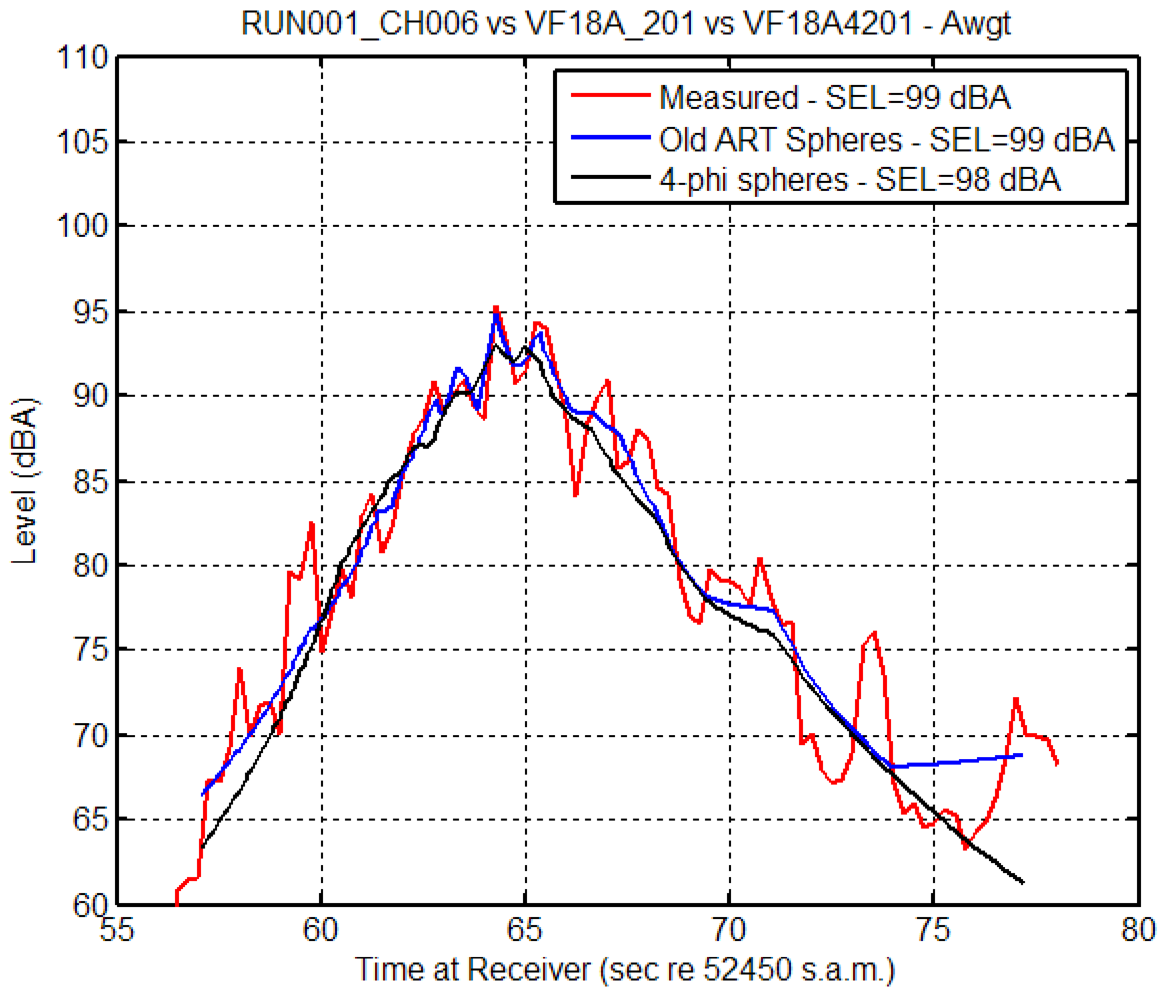


Ground Array, 15º Angular Spacing. Crane and Tower Shown

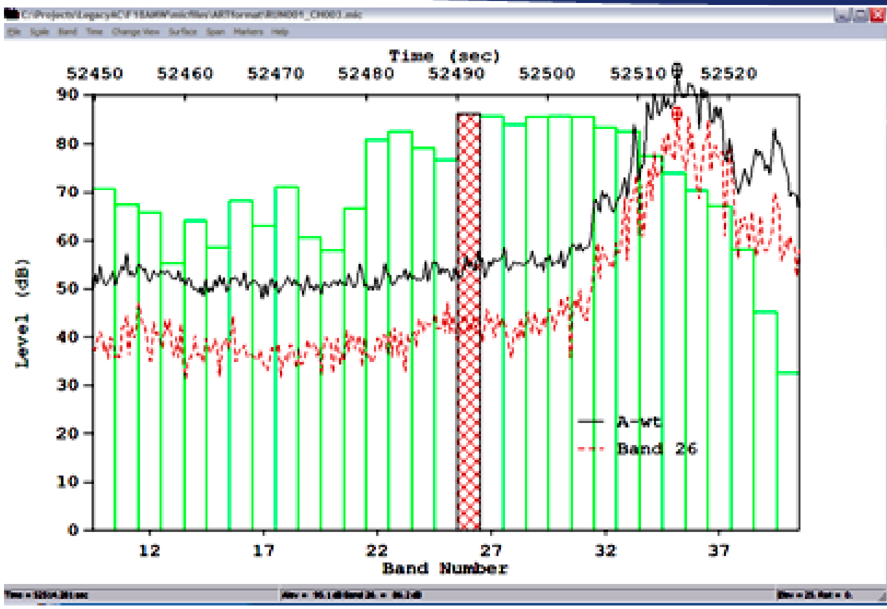
- 1200 foot tower gets past horizontal, up to 101 degrees
- 200 foot crane reaches 51 degrees
- 300 foot crane (not shown) reaches 55 degrees
- Passes at 250 ft with 300 ft cranes to get 90 degrees

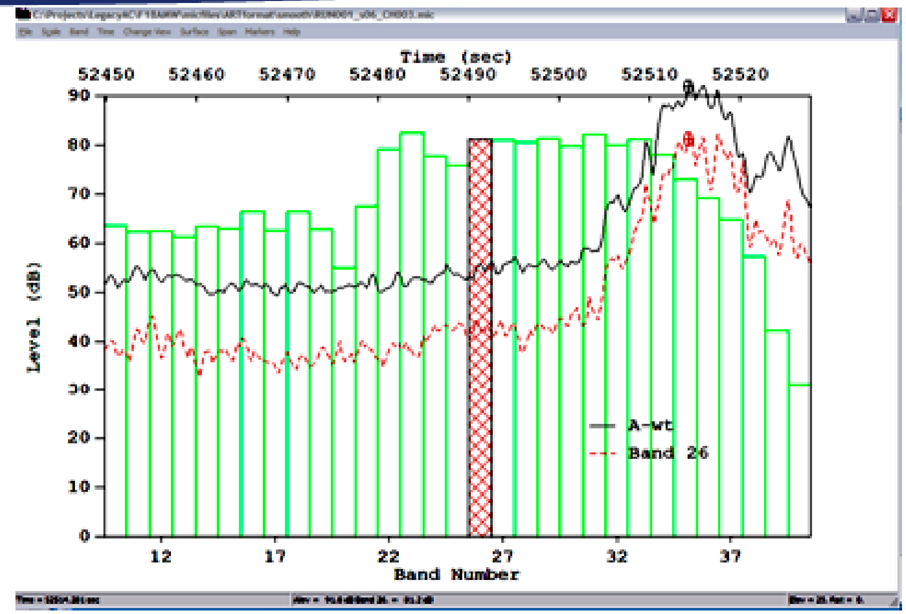
Processing Flight Data to Spheres

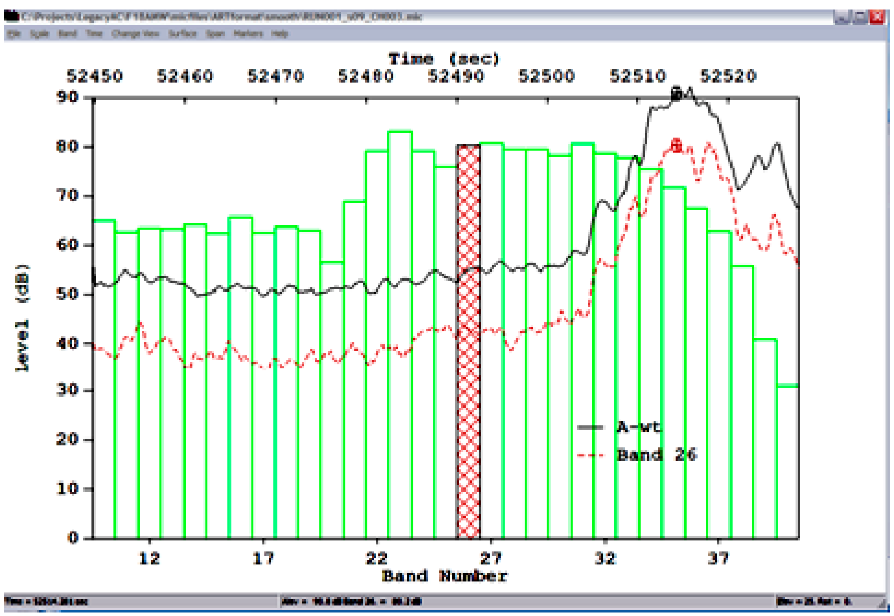
Need to smooth raw data

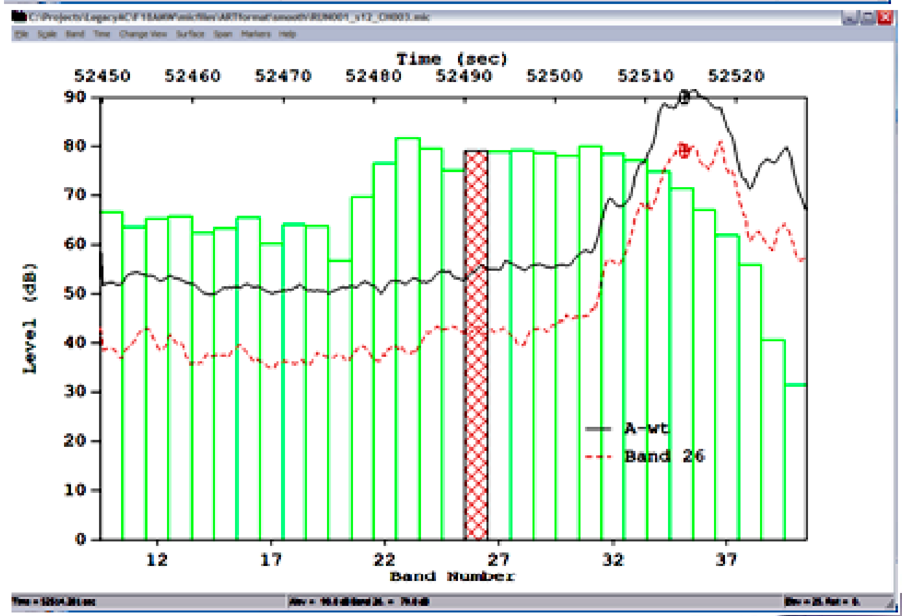


Multiple Applications of Smoothing Filter



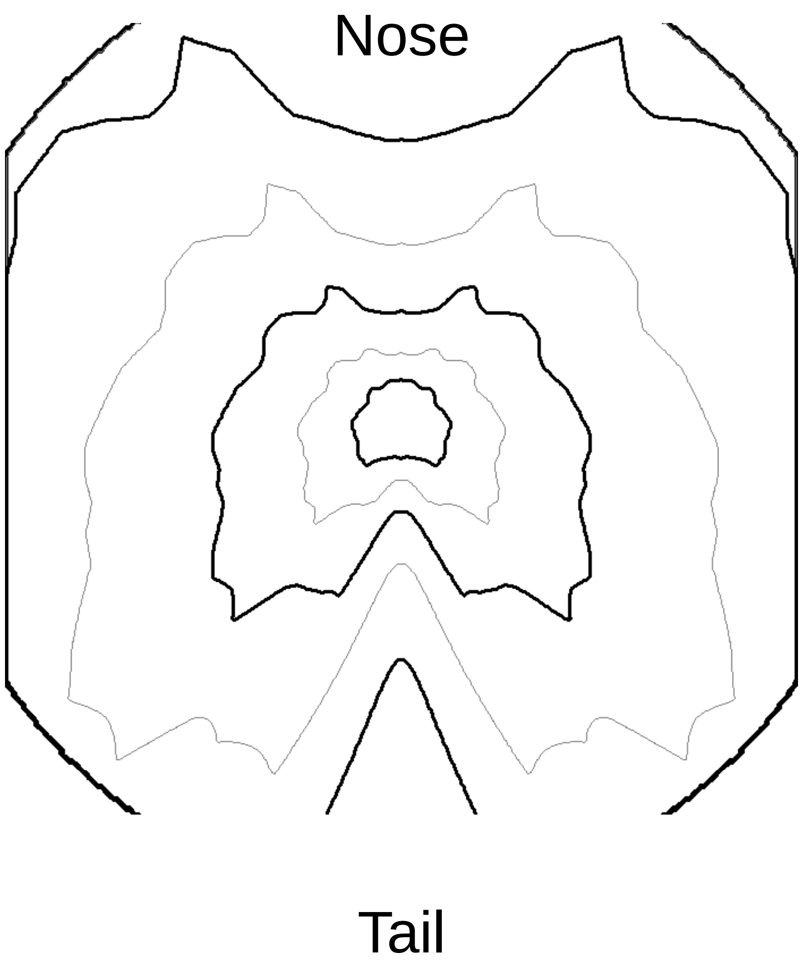




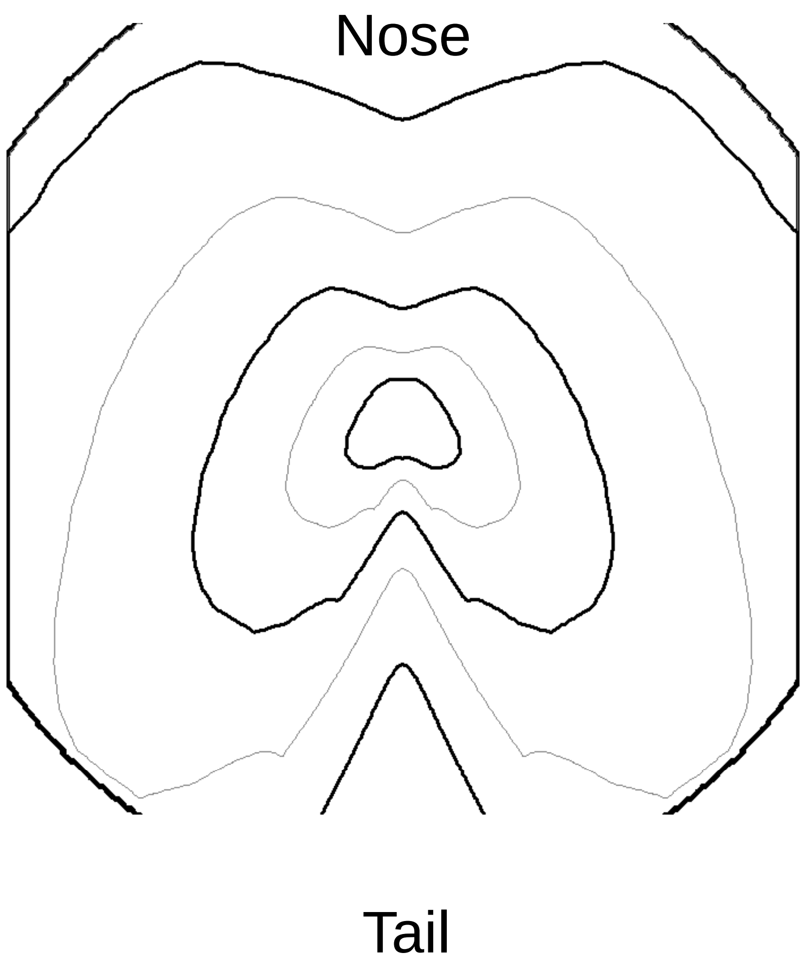


Effect of Smoothing Data

Directivity from Raw data



Directivity from Smoothed Data



Source Database – From 3-D Tests

Rotorcraft

- AH-1W
- BE206
- BO105
- CH46E
- CH53E
- CH146 (BE412)
- MV22B
- SH60B
- TH57B
- XV-15

Fixed wing

- **AV-8B**
- **F-35**
- **F-22**
- **F-15 PW220**
- **F-16 PW220**
- **F-16 GE100**
- **F-18 A+**
- **F-18 PSU synthesized**
- **B767-400**

More are needed, and are being obtained by:

- Penn State models
- Legacy project

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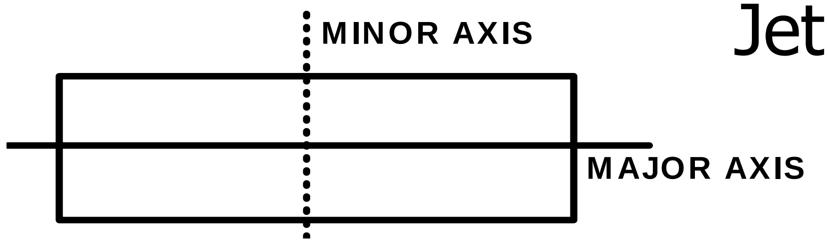
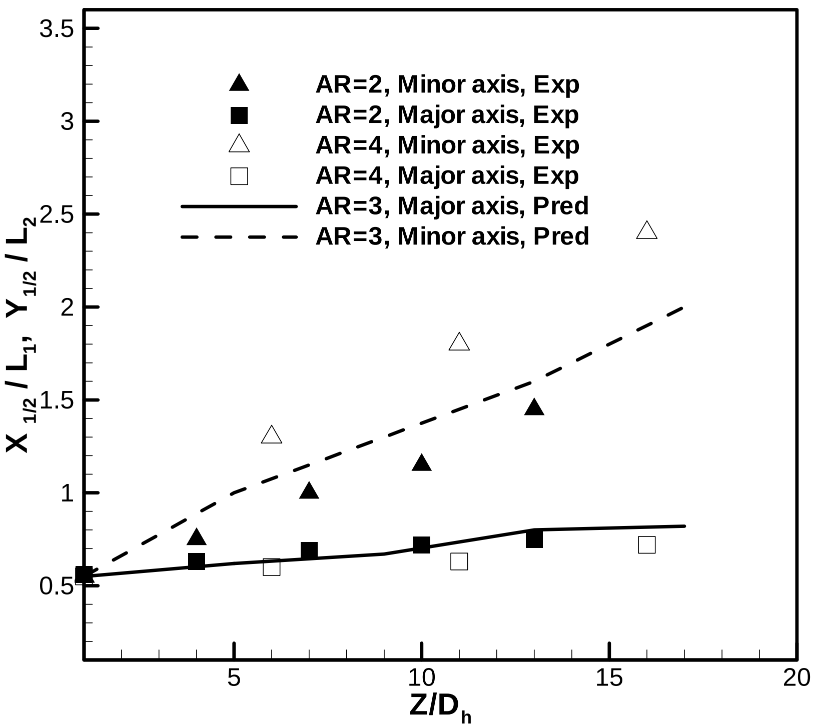
Penn State Noise Models

- Part of SERDP WP-1304
  - Laboratory model tests of nozzle shapes, twin engine configurations, hot/cold jets
  - Numeric simulation of model shapes, vectored thrust
- Use to extrapolate/interpolate flight test measurements
  - Reduce necessary number of measurements
  - Analytic support of empirical spheres
- Full prediction via extension of SAE ARP-876, "Gas Turbine Jet Exhaust Noise Prediction"

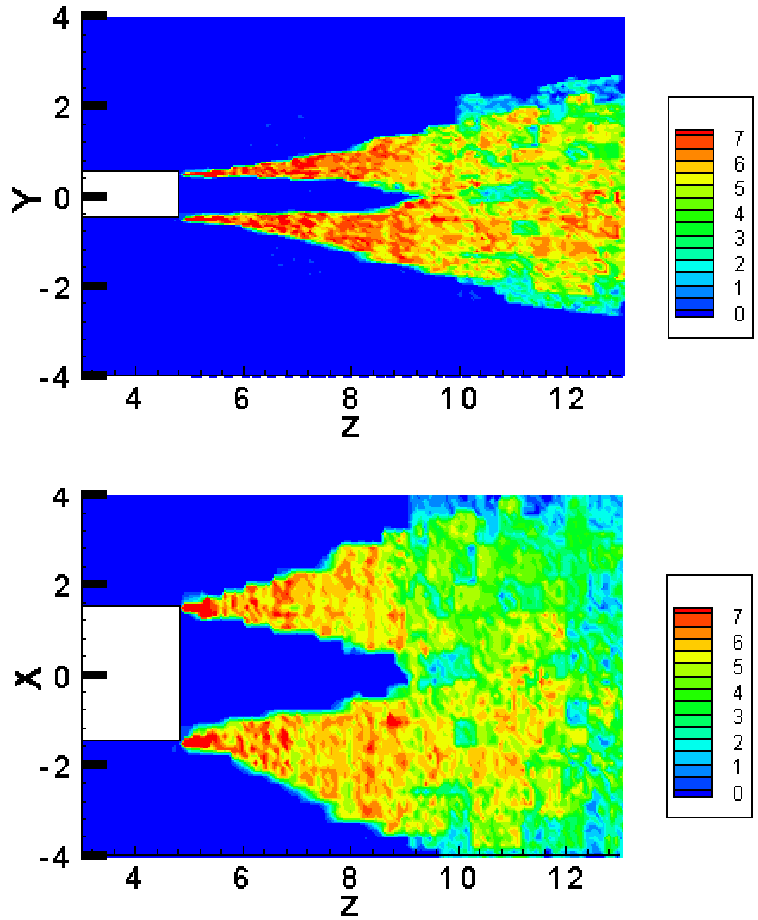
Rectangular Jet Nozzle



Jet spreads differently in two planes



Jet half-width



Minor

Major

Vorticity magnitude contours

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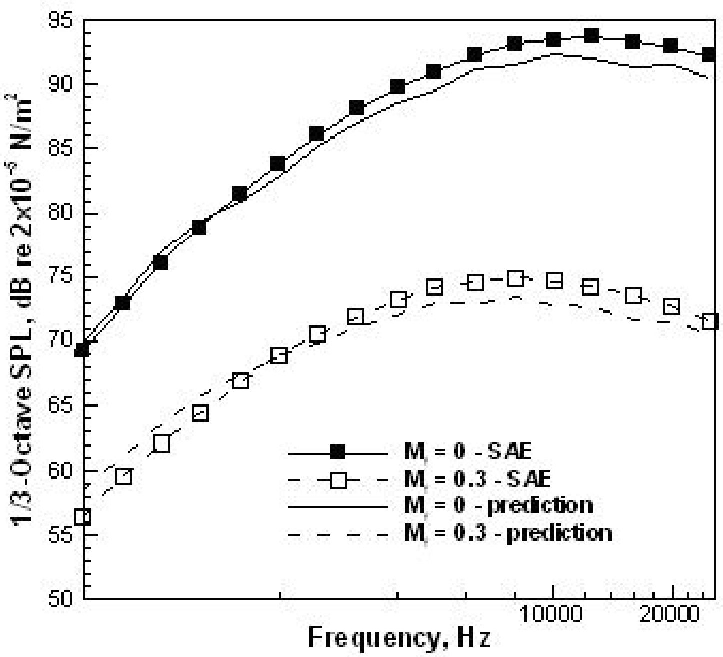
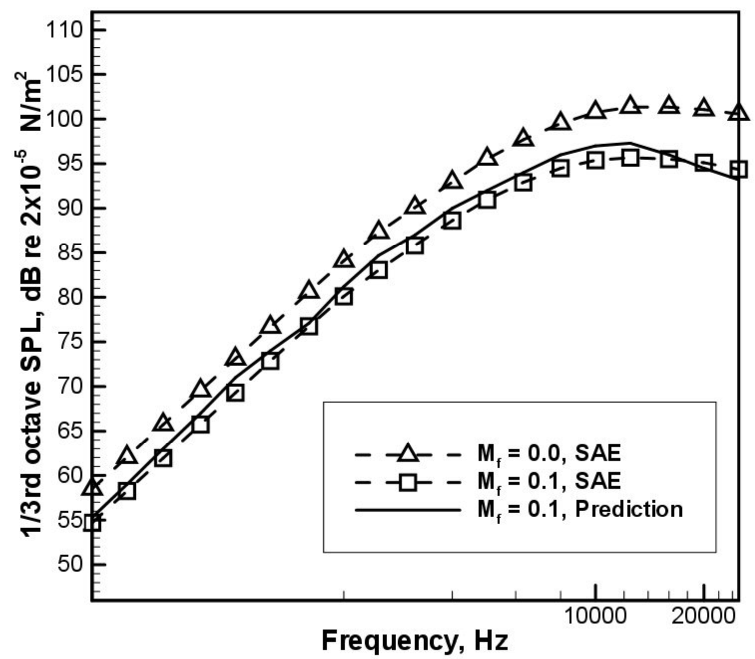
Forward Flight Effect

Velocity Ratio = 0.3

Velocity Ratio = 0.1

$$\theta = 30^0$$





Significant Reduction in Peak Noise with Forward Flight

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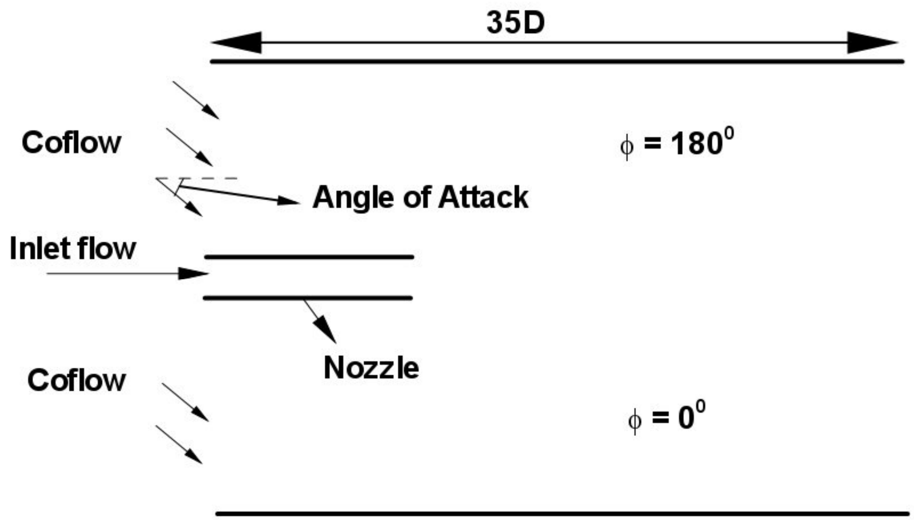
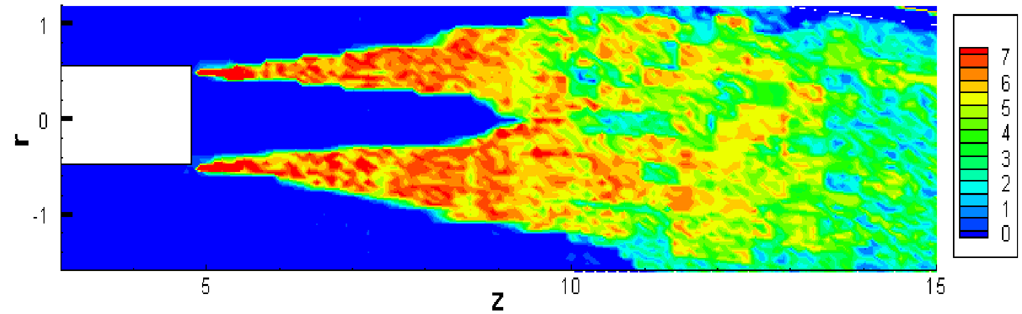
Flight at an Angle of Attack

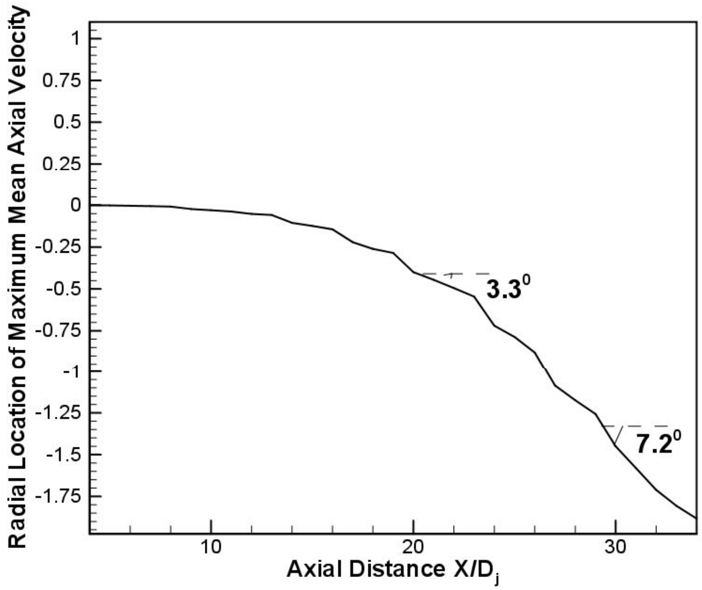
$M_J = 0.9, M_f = 0.1, Re = 2 \times 10^5, AOA = 30^0$



Computational domain schematic



Vorticity magnitude



Centerline velocity

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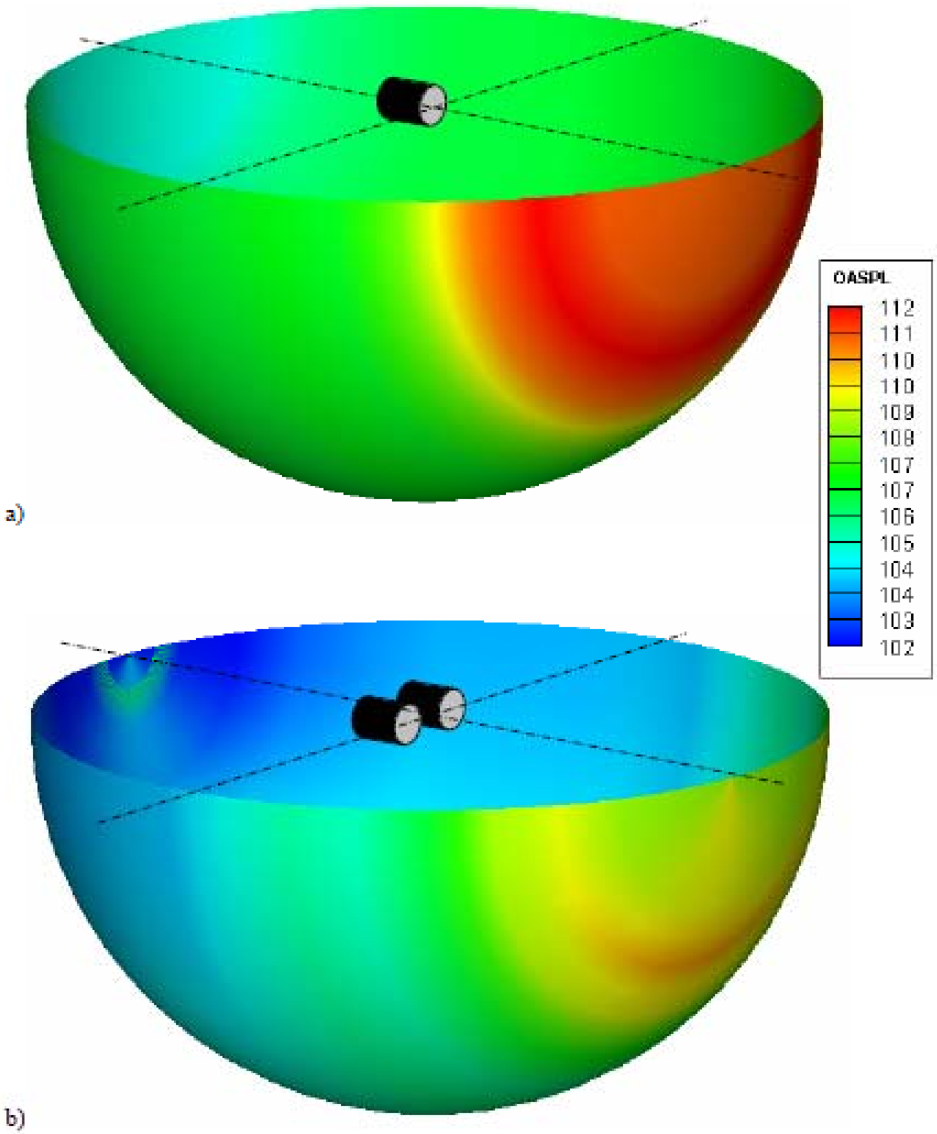
SAE ARP-876 Prediction Extension



Single engine + 3 dB
- Lateral directivity ignored

Twin engine model
- Use directly
- Apply directivity to measured under-track noise

Legacy Project – Flight Test Database

Develop spheres from existing AFRL flight test data

- 1000 foot AGL level runs
- Microphones centerline and +/- 1000 feet laterally
- Original 1/3 octave band and tracking data
- Process data using single- or three-slice ART
- Obtain axisymmetric noise sphere
- Use Penn State models for lateral directivity of side-by-side twins and non-round exhausts

Legacy Project - Noisefile

File of in-flight of SEL, L_{Amax}, etc., and spectra

Static runup data: spectra at 250 foot radius

- In-flight levels and spectrum from Noisefile
- Fore-aft directivity:
  - Static runup data not directly suitable - forward flight effects not included
  - Use nominal directivity from 3-D spheres for similar aircraft
- Run in AAM, match SEL to Noisefile SEL
- PSU ARP 876 for lateral directivity of twins

Similar process for INM aircraft, if needed, using NPD and spectral classes

Summary

- Advanced Acoustic Model (AAM) is time step simulation model
  - Computes complete noise time histories
  - Physically correct propagation infrastructure
  - Amenable to state of the art propagation models
- Requires 3-D noise source spheres
  - Flight test measurement procedure is defined, and being formalized through standards process
  - Direct 3-D measurements for 10 rotorcraft, 8 military fixed wing aircraft, one modern airliner
  - Procedure to prepare spheres from flight test data with limited microphone arrays
  - Procedure to prepare nominal spheres from Noisefile and INM databases