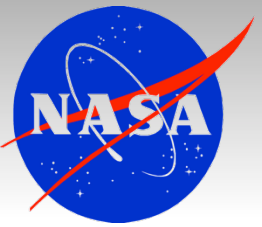



# Jet Noise Ground Effects

Steven A. E. Miller

The National Aeronautics and Space Administration
Langley Research Center

NASA Technical Working Group
April 12th 2012

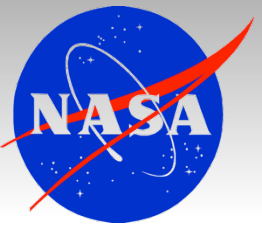
# Acknowledgements

Dr. J. H. Miles (NASA)

Dr. E. Greenwood (NASA)

Many discussions with colleagues

NASA Fundamental Aeronautics Program
Supersonics Project




# Outline

- Introduction and Motivation
- Experiment of Dr. J. H. Miles
- Acoustic Analogy
  - Preliminary free-field predictions
  - Preliminary ground effect predictions
- Summary and Future Research

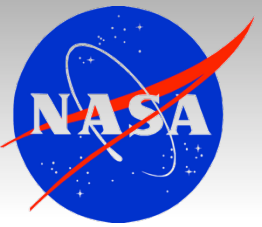
# Introduction and Motivation

- Fundamental questions about jet fluid dynamics

  *discover fundamental physics*

- Jet noise is an annoyance and causes:
  - Hearing loss
  - Sonic fatigue
  - Rocket engine component failure
  - Psychological effects
  - Etc.

- Jet propulsion and aerospace vehicles
  - Jet noise scattered by airframe, runway, aircraft carrier, launch facilities, etc.
- Why ground effects?
  - Green's function associated with ground effects is relatively simple
  - Simple to test method before trying complicated geometry
  - Excellent experimental dataset by Dr. Miles (NASA)




# EXPERIMENTAL SUMMARY

Miles, J. H., “Analysis of Ground Reflection of Jet Noise Obtained with Various Microphone Arrays Over an Asphalt Surface,” NASA TM X-71696, 1975.

# Experimental Summary (Miles 1975)

- Convergent nozzle
- $D$ = 0.3302 m (13 in.)
- Nozzle height
  $N_h$ = 3.89 m (12.75 ft)
- Asphalt ground surface
- $T_\infty$ = 288.9 K
- Microphone observer angle
  $\psi$ = 145 deg
- Microphones distances
  $R/D$ = 23.08, 46.15, and 69.23
- Microphone heights
  $M_h$ = 0.0061, 1.52, and 3.89 m
- SPL, 1/3 octave band, lossless

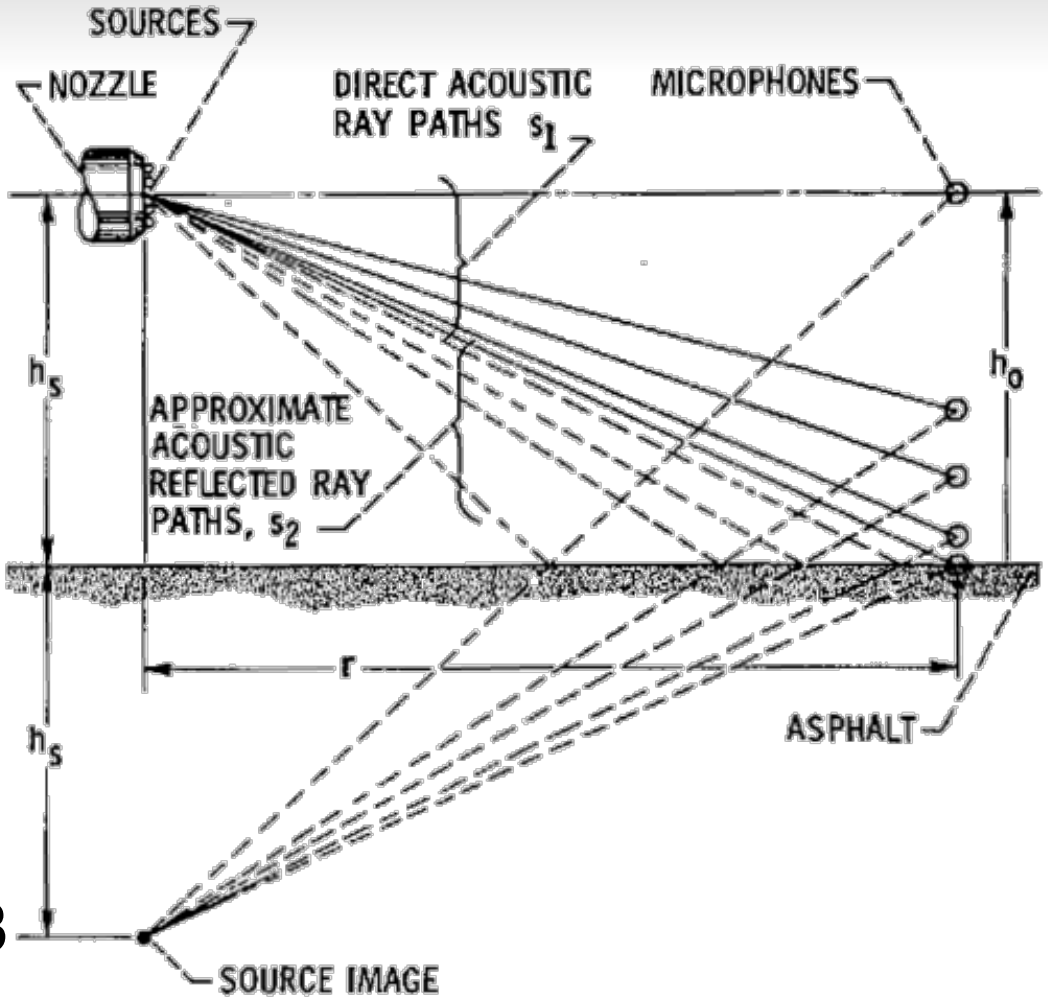
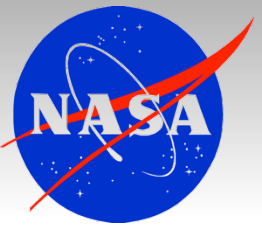



Figure 1. – Schematic of nozzle and microphone geometry relative to asphalt surface.

Miles, J. H., "Analysis of Ground Reflection of Jet Noise Obtained with Various Microphone Arrays Over an Asphalt Surface," NASA TM X-71696, 1975.




# ACOUSTIC ANALOGY

Definition (10/18/11): The rearrangement of the governing equations into a left hand side operator and a right hand side equivalent source.

# Modeling Goals

- Goals
  - In the form of an acoustic analogy
  - $0.05 < M < 5.00$
  - $1.00 < TTR < 5.00$
  - $M_\infty \geq 0$
  - Separate source from propagation
  - Axisymmetric and three-dimensional
  - Near-field and far-field
  - Auto- and cross-spectra
  - Source maps
  - *And more…*
- Implement in RISN: RANS Integration for Shock Noise
  - Just a tool –> *discover physics*

Feedback Welcome!

# Acoustic Analogy: Mixing Noise

$$S(\underline{x},\omega)=\rho_\infty^2 c_\infty^4 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \left\{ \pi_g^{0*}(\underline{x},\underline{y},\omega)\pi_g^{0}(\underline{x},\underline{y},\omega)A_s^2 + \sum_{n=1}^{3}\sum_{m=1}^{3} \pi_g^{n*}(\underline{x},\underline{y},\omega)\pi_g^{m}(\underline{x},\underline{y},\omega)B_s^2 \right\}$$

$$\times \frac{2c_\infty^2\pi^{3/2} l_x l_y l_z \tau_s z^2}{c_\infty^2 z^2 + \left(c_\infty z + u z_1 + v z_2 + w z_3\right)^2 \tau_s^2 \omega^2} \exp\left[\frac{-\left(l_x^2 z_1^2 + l_y^2 z_2^2 + l_z^2 z_3^2\right)\omega^2}{4c_\infty^2 z^2}\right] d\underline{y}$$

where,

$A_s = A_s(g_a, \underline{q}, \pi_g^n, M_\infty)$

$B_s = B_s(g_a, \underline{q}, \pi_g^n, M_\infty)$

$g_a$ = Adjoint Green's Function of Fourier Transformed Convective Wave Equation

$\underline{q} = \underline{\mathrm{q}}(\rho, \underline{u}, p, K, \varepsilon)$

$\pi_g^n$ =Periodic vector Green's Function of the LEE about $g_a$

Miller Mixing Noise Acoustic Analogy Model 6 Revision 8, 03/08/2012

*This analogy attempts to address all requirements except near-field and cross-spectra.*

# Informing the Equivalent Sources

- Required to inform the equivalent sources of the acoustic analogy
  - Empirical / semi-empirical (CoJet)
  - Large Eddy Simulation (LES) / Unsteady Simulation
  - Steady RANS with two-equation turbulence model
  - Other?
- For now, use steady RANS (FUN3D or Wind-US) Turbulent integral scales of length, time, and velocity,

$$\tau = c_\tau K / \varepsilon$$

$$l_i = c_{li} K^{3/2} / \varepsilon$$

$$u_i = c_{ui} \sqrt{2K/3}$$

*Note: Exact same coefficients used for all predictions!*

# Green's Function and Scattering

- Free-Field
  - Convective wave eq.
- Ground Reflection
  - Method of images
- Arbitrary Geometry
  - $g_a$ from numerical scattering code such as
    - Fast Scattering Code (FSC)
    - BEM
    - FastBEM
    - Diffraction Integral Method 2 (DIM2, MIT/NASA)

Green's Mill

January 15th 2007

http://en.wikipedia.org/wiki/File:Green%27s_windmill.jpg

# Ground Impedance Model

Green's function of Helmholtz equation about an infinite flat surface (ground),

$$g_a = \frac{\exp\left[\frac{i\omega}{c_\infty}\sqrt{\left(x_1-y_1\right)^2+\left(x_2-y_2-N_h\right)^2+\left(x_3-y_3\right)^2}\right]}{4\pi\sqrt{\left(x_1-y_1\right)^2+\left(x_2-y_2-N_h\right)^2+\left(x_3-y_3\right)^2}} - Z_c \frac{\exp\left[\frac{i\omega}{c_\infty}\sqrt{\left(x_1-y_1\right)^2+\left(x_2+y_2+N_h\right)^2+\left(x_3-y_3\right)^2}\right]}{4\pi\sqrt{\left(x_1-y_1\right)^2+\left(x_2+y_2+N_h\right)^2+\left(x_3-y_3\right)^2}}$$

where $Z_c$ is the normal surface impedance,

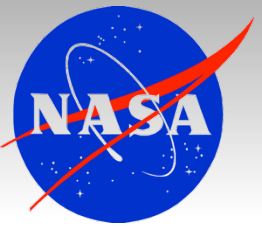
$$Z_c = 1 + 0.0571\left(\rho_\infty f / R_s\right)^{-0.754} + i0.087\left(\rho_\infty f / R_s\right)^{-0.732}$$

Delany, M. E. and Bazley, E. N., "Acoustical Properties of Fibrous Absorbent Materials," Applied Acoustics, Vol. 3, 1970, pp. 105–116.

and $R_s$ is the flow resistivity, and for the experiments we are examining,

$$R_s \cong 27000 \text{ kPa s / m}^2$$

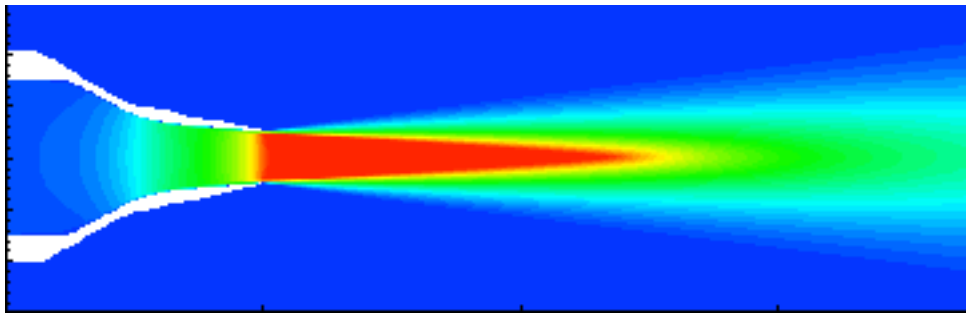
Attenborough, K. and Ver, I. L., "Sound-Absorbing Materials and Sound Absorbers in Noise and Vibration Control Engineering: Principles and Applications," John Wiley & Sons Inc., Hoboken, N.J. USA, 2nd ed., 2007.

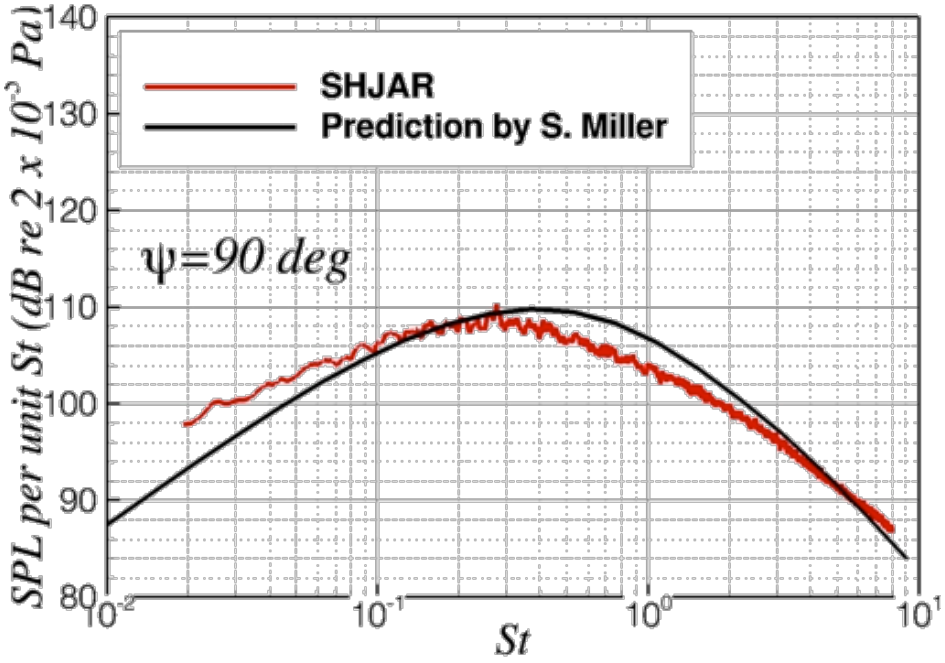


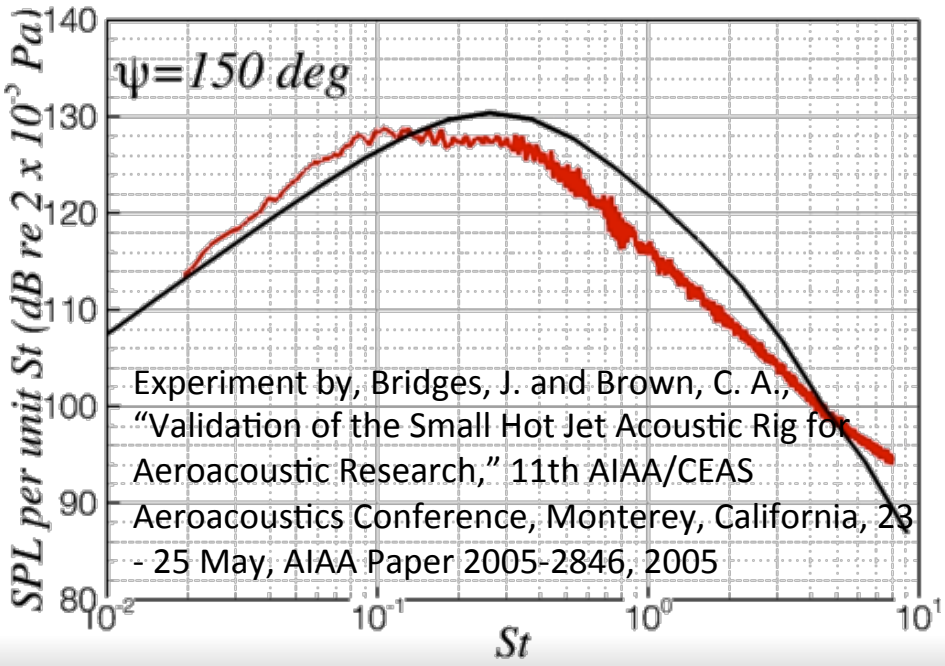

# PRELIMINARY FREE JET PREDICTIONS

# Mixing Noise Free-Field

- SMC000 nozzle
- Convergent nozzle
- Free jet
- $M_d = 1.00$
- $M_j = 1.00$
- $TTR = 3.20$
- $R/D = 100$
- $D = 0.0508\ m\ (2\ in.)$



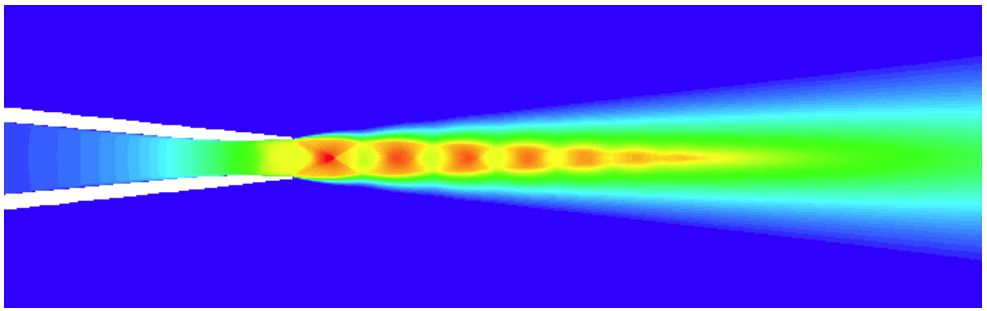


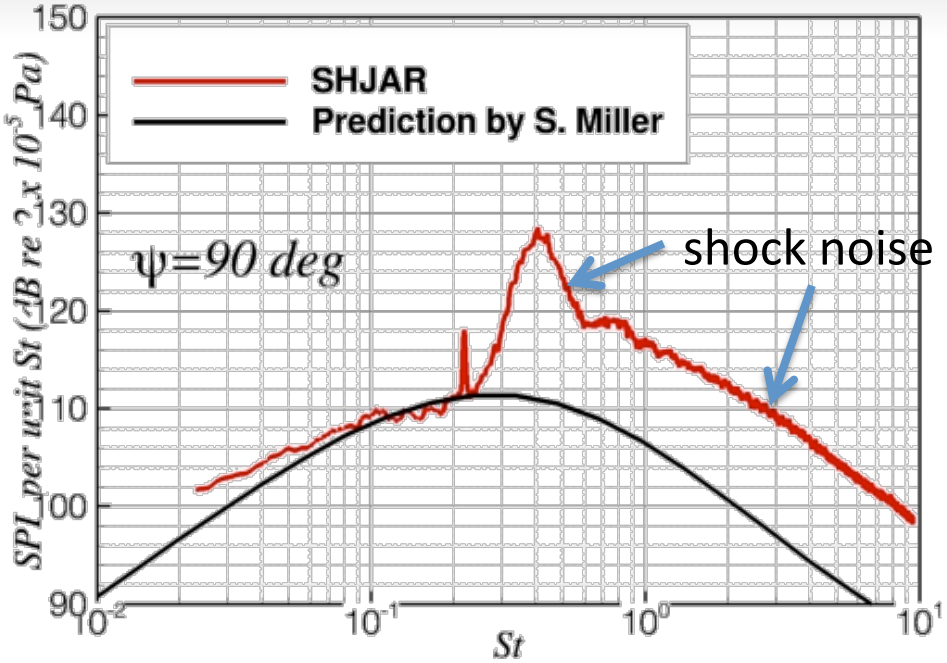



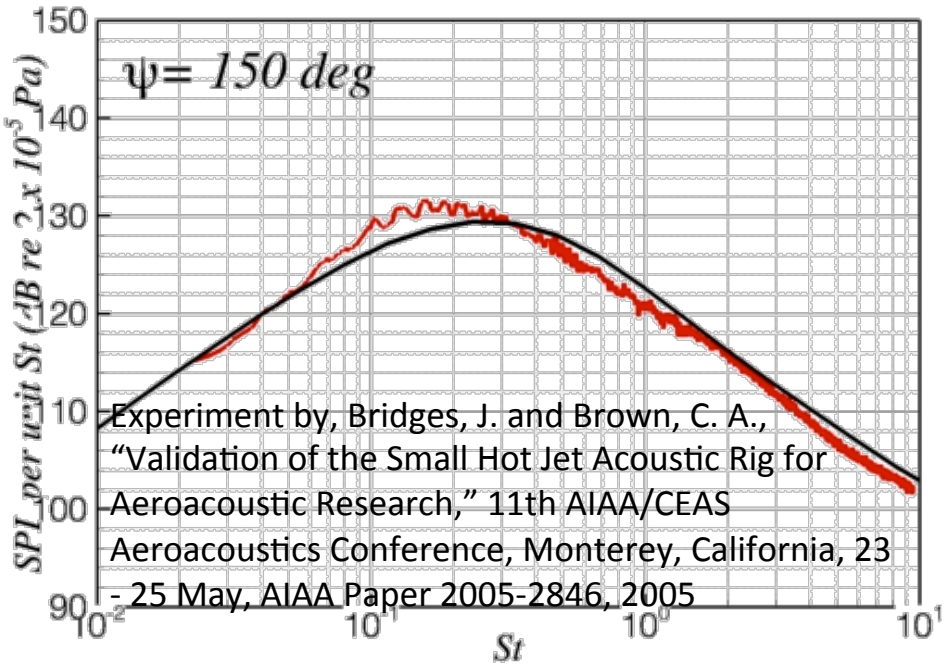

Experiment by, Bridges, J. and Brown, C. A., "Validation of the Small Hot Jet Acoustic Rig for Aeroacoustic Research," 11th AIAA/CEAS Aeroacoustics Conference, Monterey, California, 23 - 25 May, AIAA Paper 2005-2846, 2005

# Mixing Noise Free-Field

- SMC016 nozzle
- 'C-D' nozzle
- Free jet
- $M_d = 1.50$
- $M_j = 1.734$
- $TTR = 1.00$
- $R/D = 100$
- $D = 0.0508\ m\ (2\ in.)$



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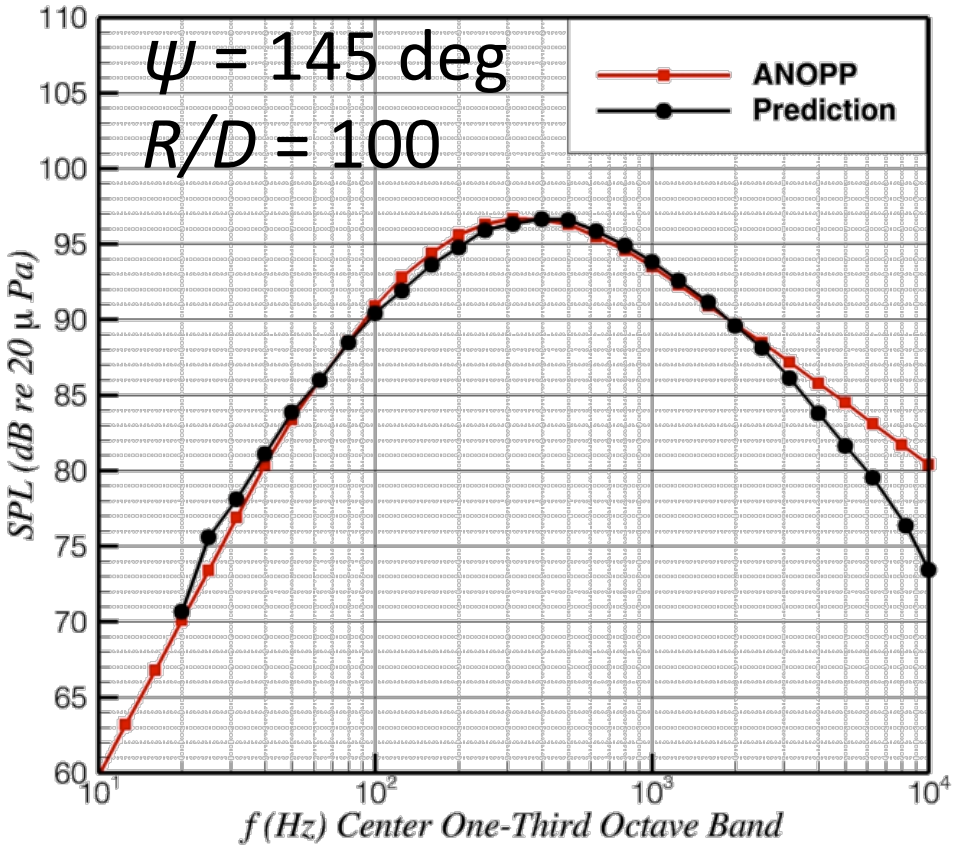
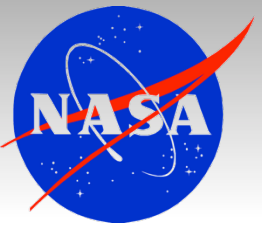
# Comparison with ANOPP

- Operating conditions are those of the experiment by Miles
  - $M_d = 1.00$
  - $M_j = 0.95$
  - $TTR = 1.00$
  - $D = 0.3302$ *m (*13 *in.)*
- Discrepancy at high freq.
  - *Not* a propagation problem
  - Source model problem
  - Attack issue this summer




ANOPP by Zorumski, W. E., "Aircraft Noise Prediction Program. Theoretical Manual. Parts 1 and 2," NASA TM 83199, 1982.

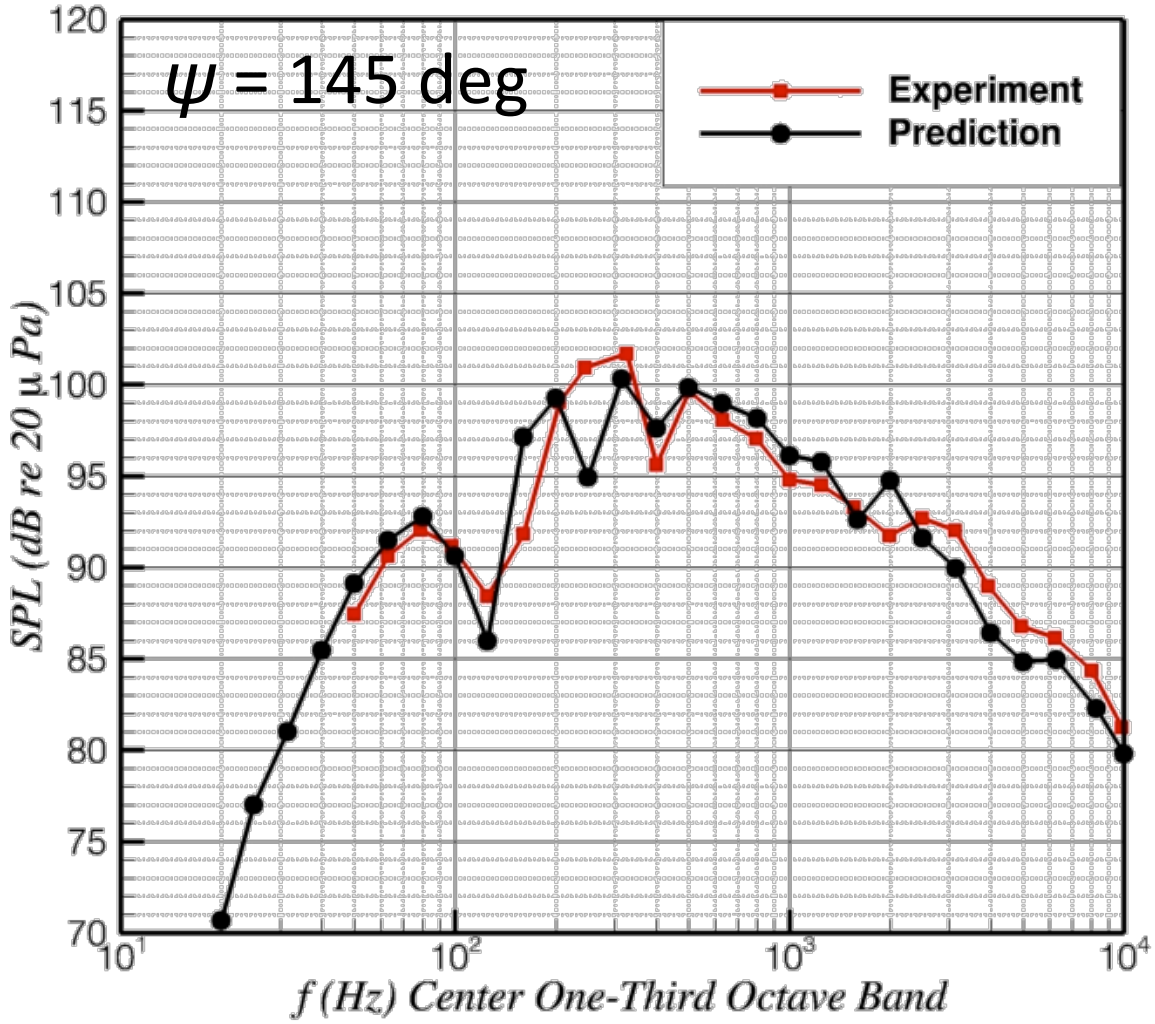



# PRELIMINARY JET PREDICTIONS NEAR AN INFINITE FLAT SURFACE (JET NOISE GROUND EFFECTS)

# Miller Mixing Noise Acoustic Analogy and Ground Effects

$M_d = 1.00$, $M_j = 0.95$, $TTR = 1.00$, $D = 0.3302\ m$ (13 *in.*)

$R/D = 69$ and Microphone Height = 3.89 *m*



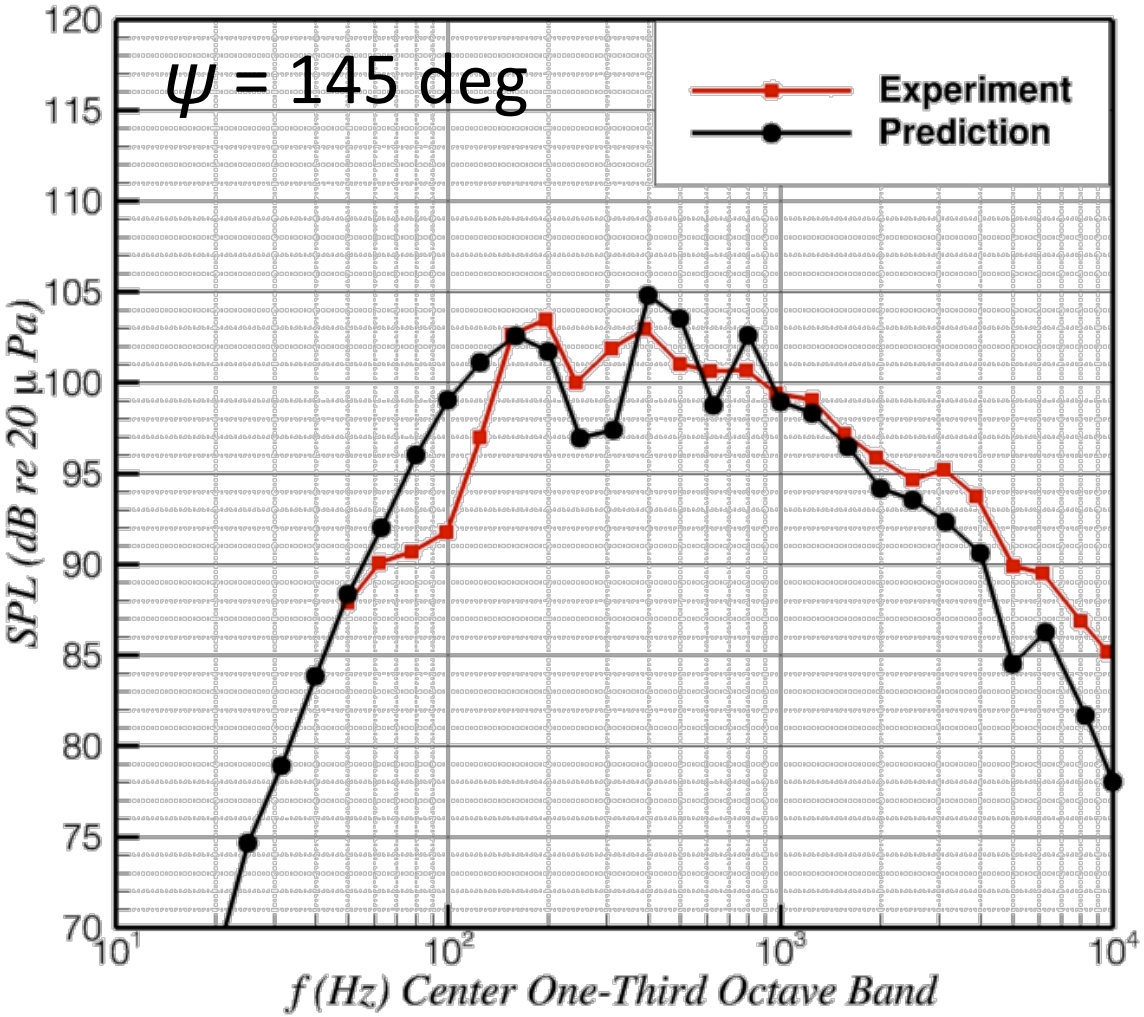

Prediction by Miller, S. A. E. Mixing Noise Acoustic Analogy Model 6 Revision 8, 03/08/2012.

Experiment by Miles, J. H., "Analysis of Ground Reflection of Jet Noise Obtained with Various Microphone Arrays over an Asphalt Surface," NASA Technical Memorandum X-71696, 1975.

# Miller Mixing Noise Acoustic Analogy and Ground Effects

$M_d = 1.00$, $M_j = 0.95$, $TTR = 1.00$, $D = 0.3302\ m$ (13 *in.*)

$R/D = 46$ and Microphone Height = 3.89 *m*

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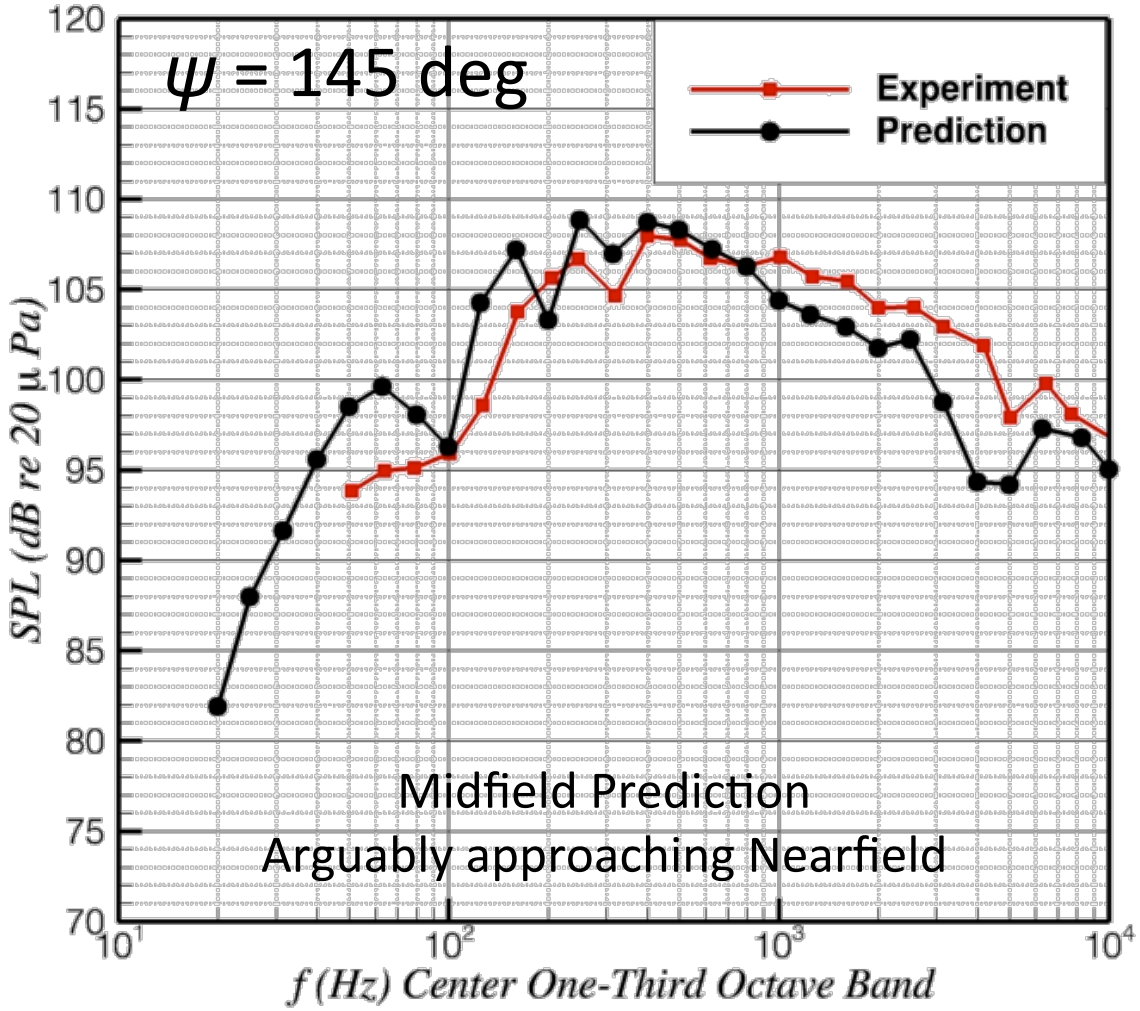
# Miller Mixing Noise Acoustic Analogy and Ground Effects

$M_d = 1.00$, $M_j = 0.95$, $TTR = 1.00$, $D = 0.3302\ m$ (13 *in.*)

$R/D = 23$ and Microphone Height = 1.52 *m*

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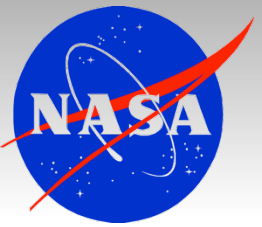
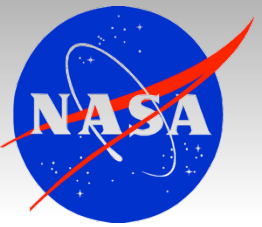


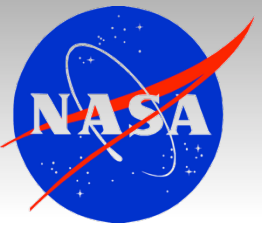

# Summary and Future Research

- Preliminary assessment of jet noise about a scattering surface (ground)
- Additional research required
  - Source and propagation modeling development
  - Additional validation cases
- Many other exciting ideas coming along!
  - "The Scaling of BBSAN with Increasing Temperature," AIAA Aeroacoustics 2012
  - Assessment of mixing noise acoustic analogy, AIAA Aeroacoustics 2013



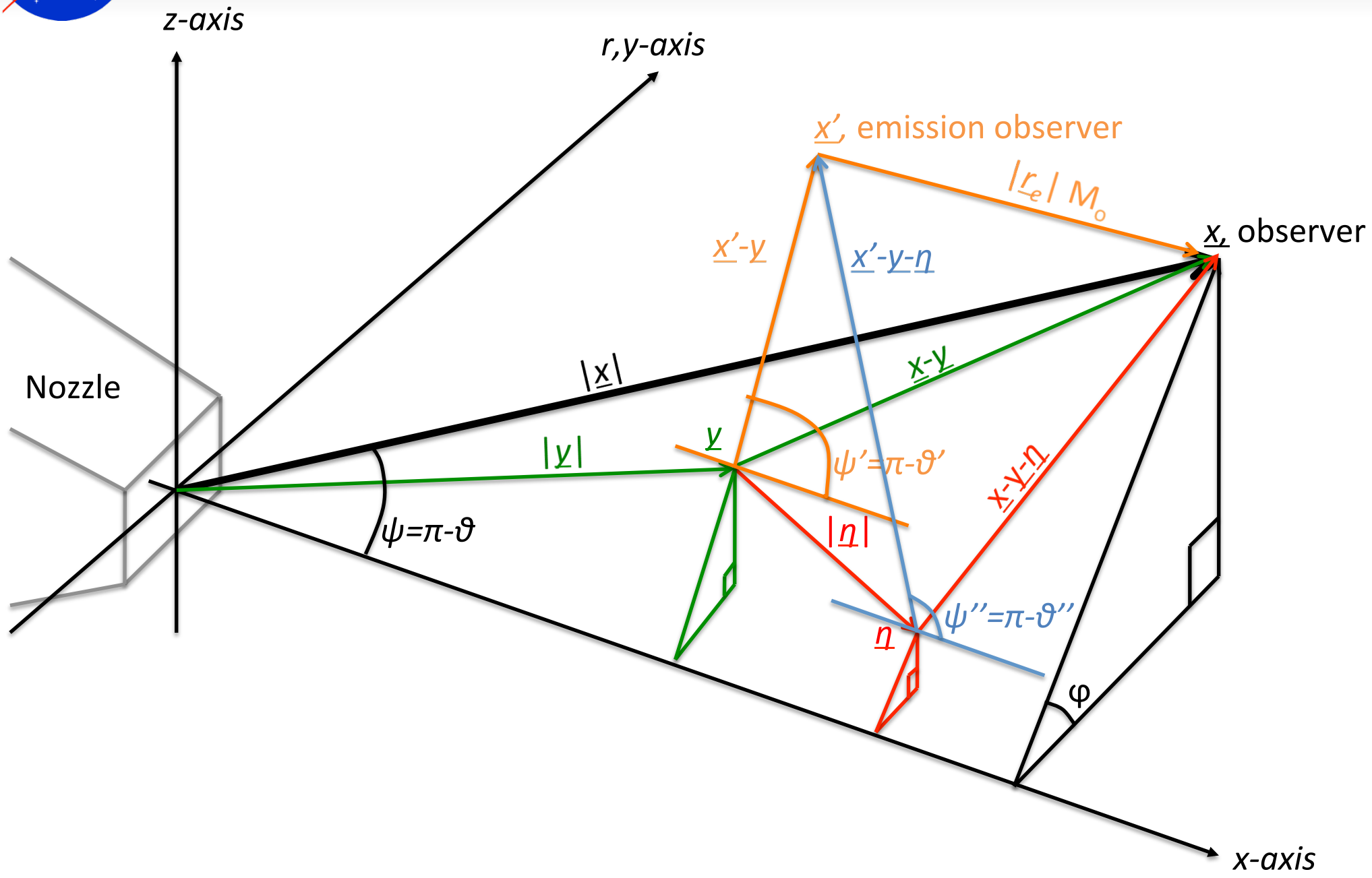

# QUESTIONS

Contact
s.miller@nasa.gov



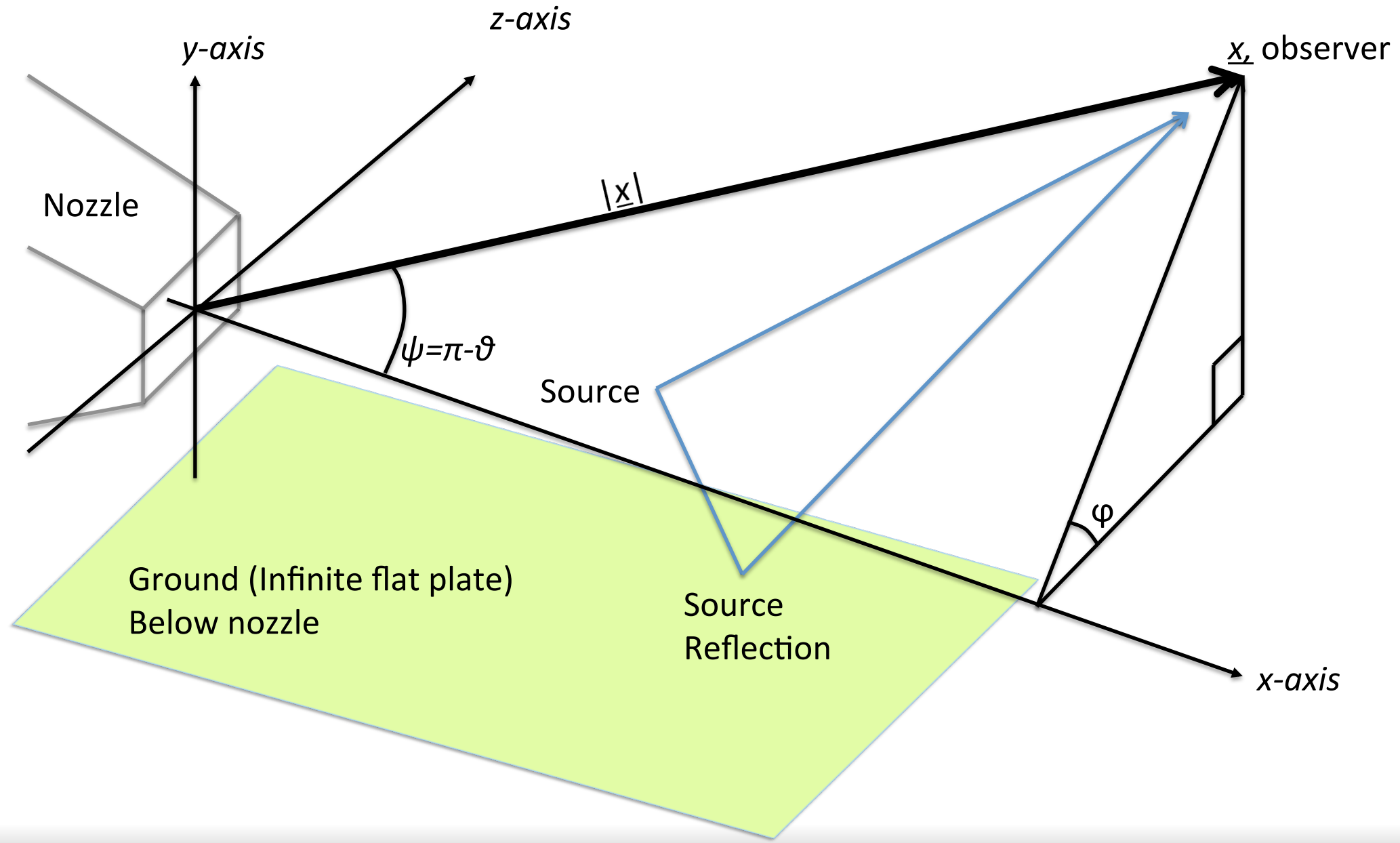

# EXTRA SLIDES

# RISN Coordinate System



# Example Ground Effects Calculation

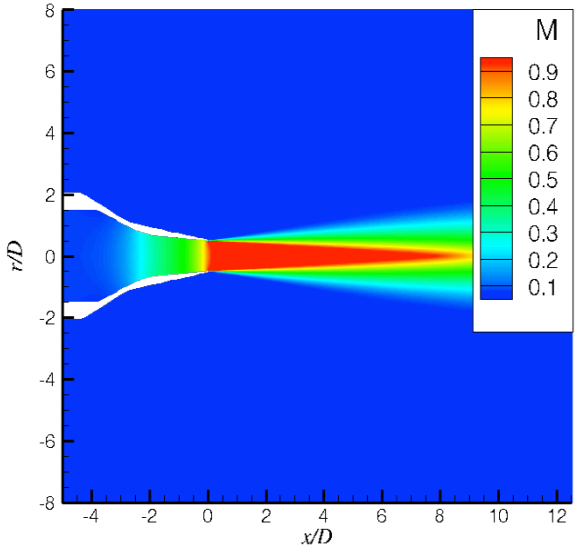
Governed by the Helmholtz Green's function of the infinite flat plate.



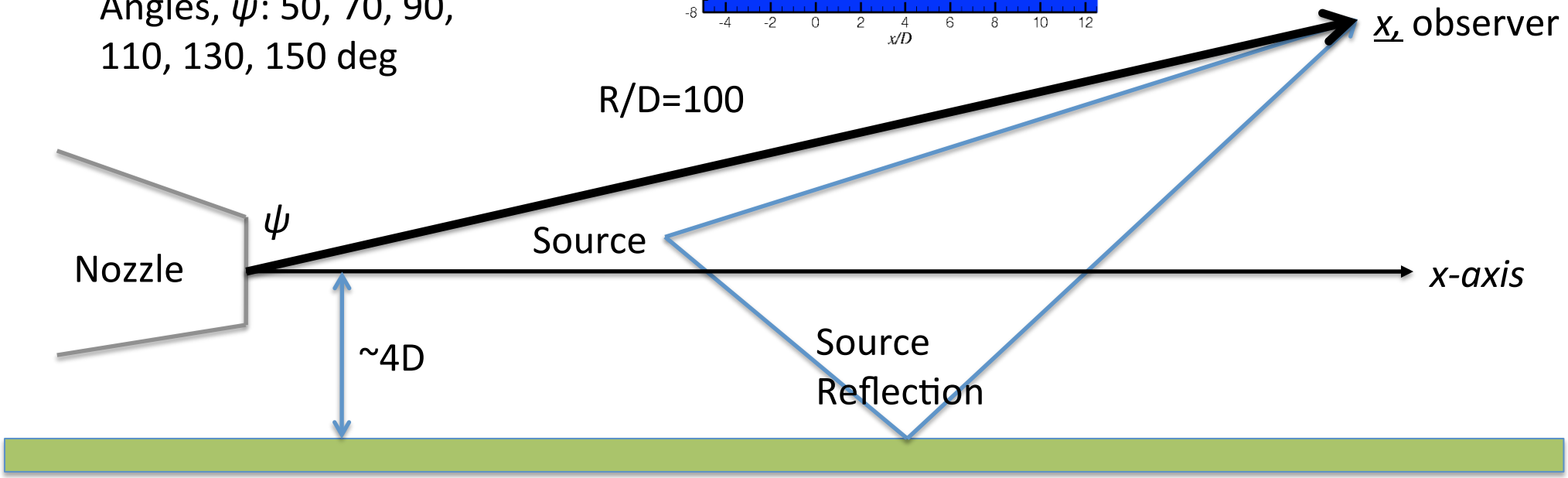
# Example Ground Effects Calculation

Md = 1.00
Mj = 1.00
TTR = 3.20
R/D=100

Microphones on a polar arc
Angles, $\psi$: 50, 70, 90,
110, 130, 150 deg




Fun3D
Flow-field
(does not include ground)

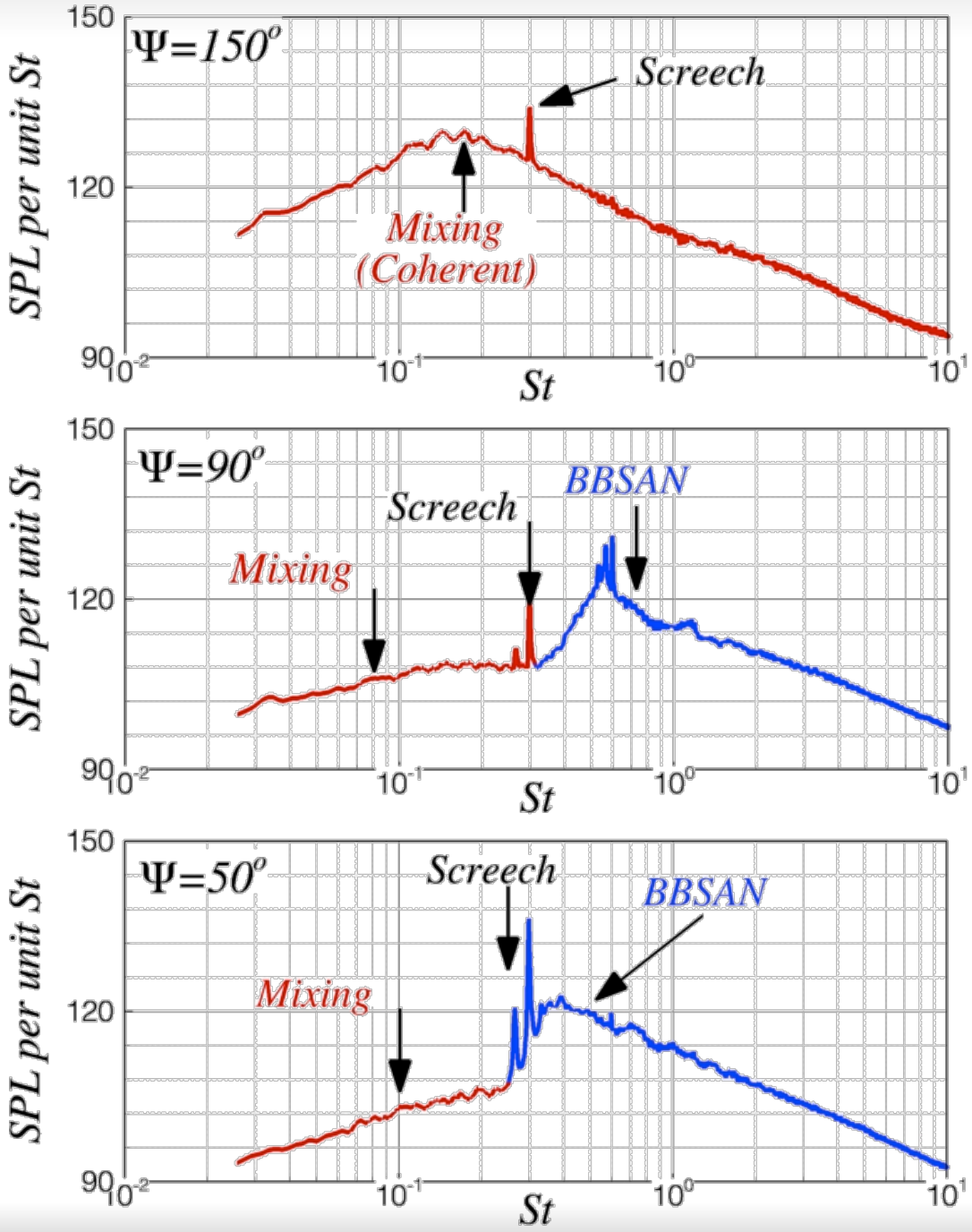



Ground (Infinite flat plate)

*This drawing is 2D but the calculation is 3D.*

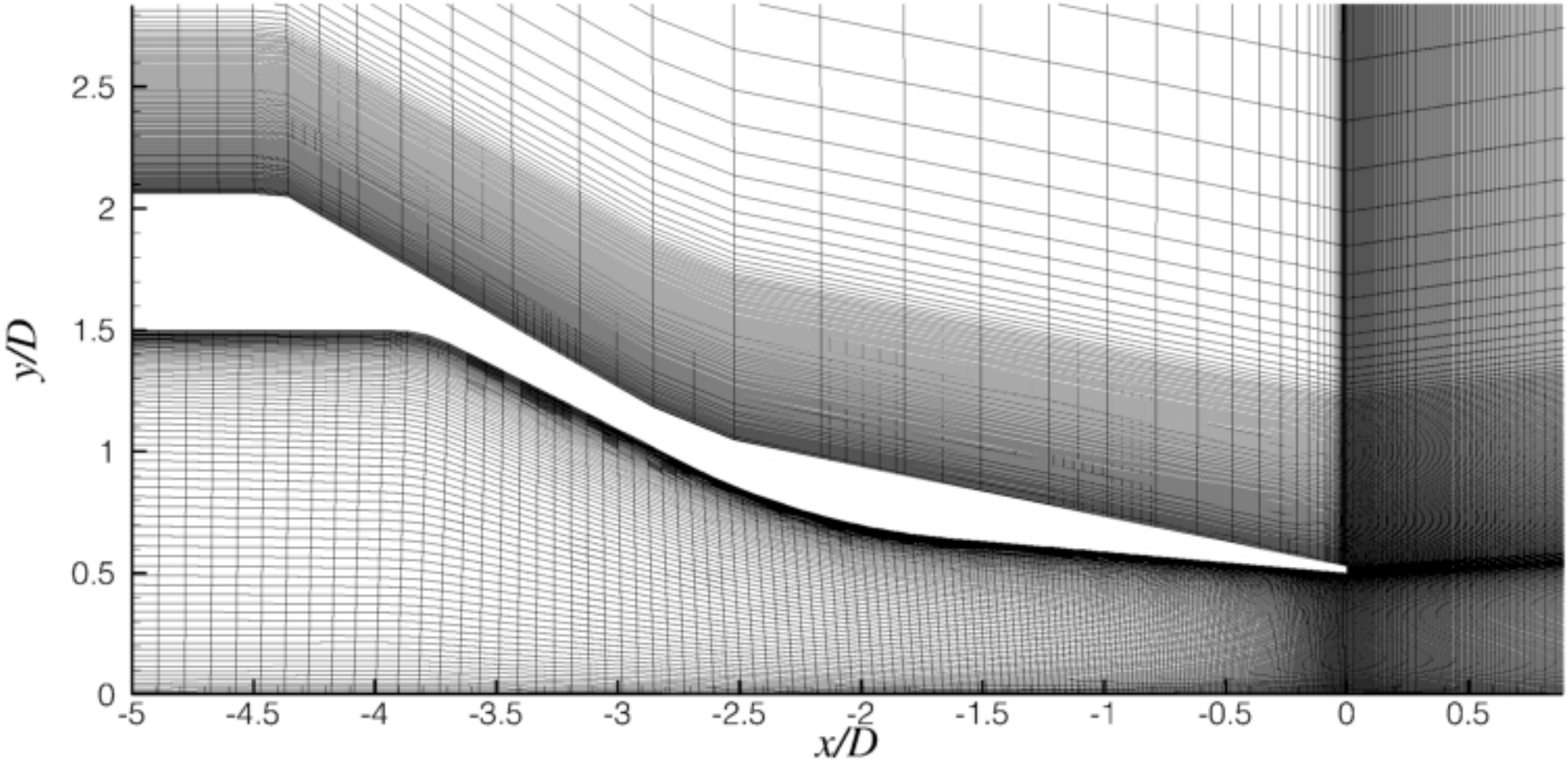
# Jet Noise Sources and Spectra

- Mixing
- Shock-Associated
- Not including:
  - Fine-scale
  - Large-scale
  - Self- and shear-noise
  - Convective amplification
  - Etc…



# Computational Domain

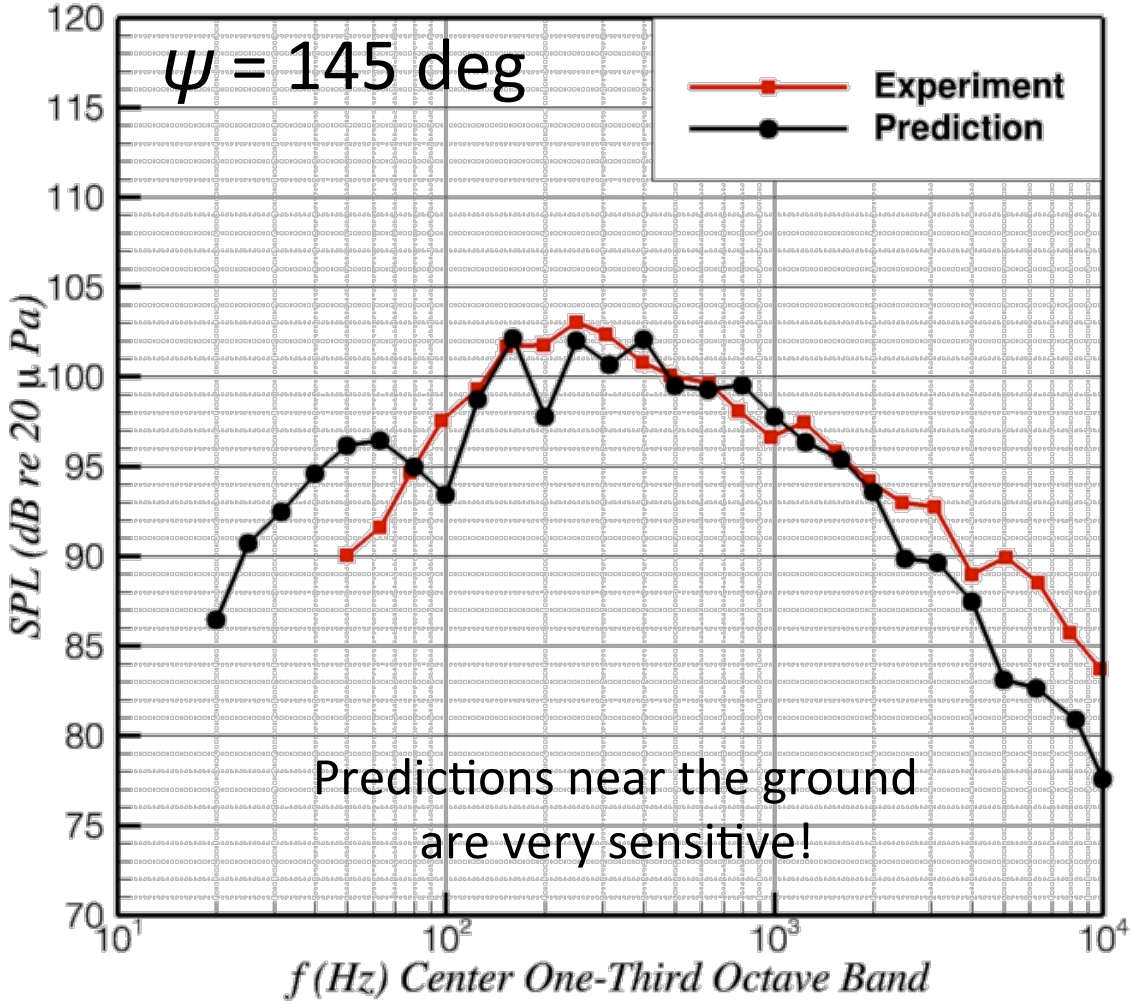
- 205,251 grid points
- 204,000 elements



# Miller Mixing Noise Acoustic Analogy and Ground Effects

$M_d = 1.00$, $M_j = 0.95$, $TTR = 1.00$, $D = 0.3302\ m$ (13 *in.*)

$R/D = 69$ and Microphone Height = $0.0061\ m$

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