Characterization of Jet Induced Sidewall Pressures

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Final Report of SFW Cabin Noise Element

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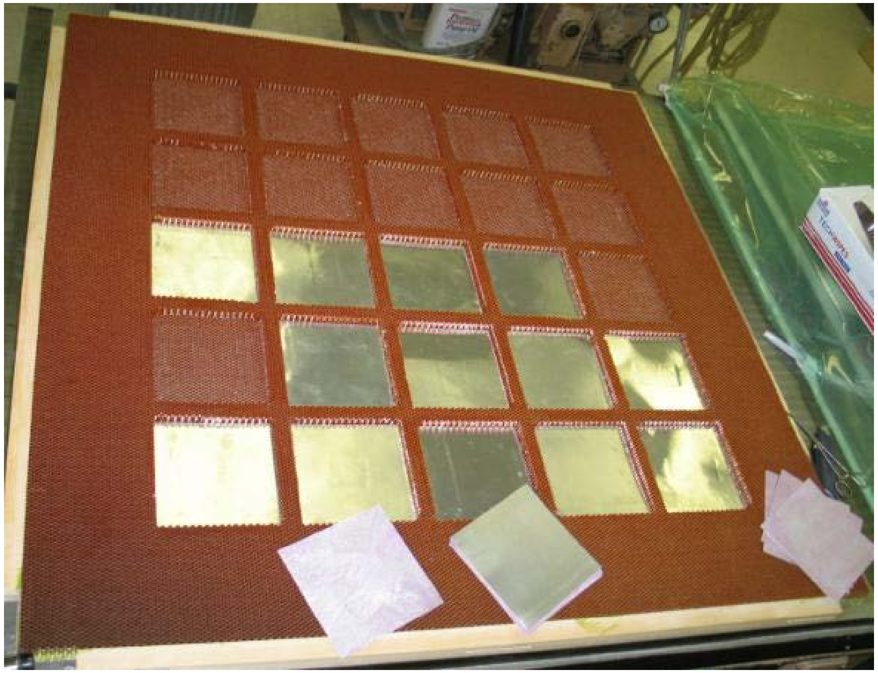
Outline

- Why Jet Noise is important to Cabin Noise
- Miller’s extension of Ribner’s two point correlation
- Palumbo/Miller extension of Harper-Bourne
- Results
- Concluding remarks

Path to Jet Noise Requirements

- Development of recessed/reinforced honeycomb composite
  - One patent awarded, another in process
  - INCE best paper award
  - Boeing interest



Optimization is necessary to fully realize potential of design

Path to Jet Noise Requirements

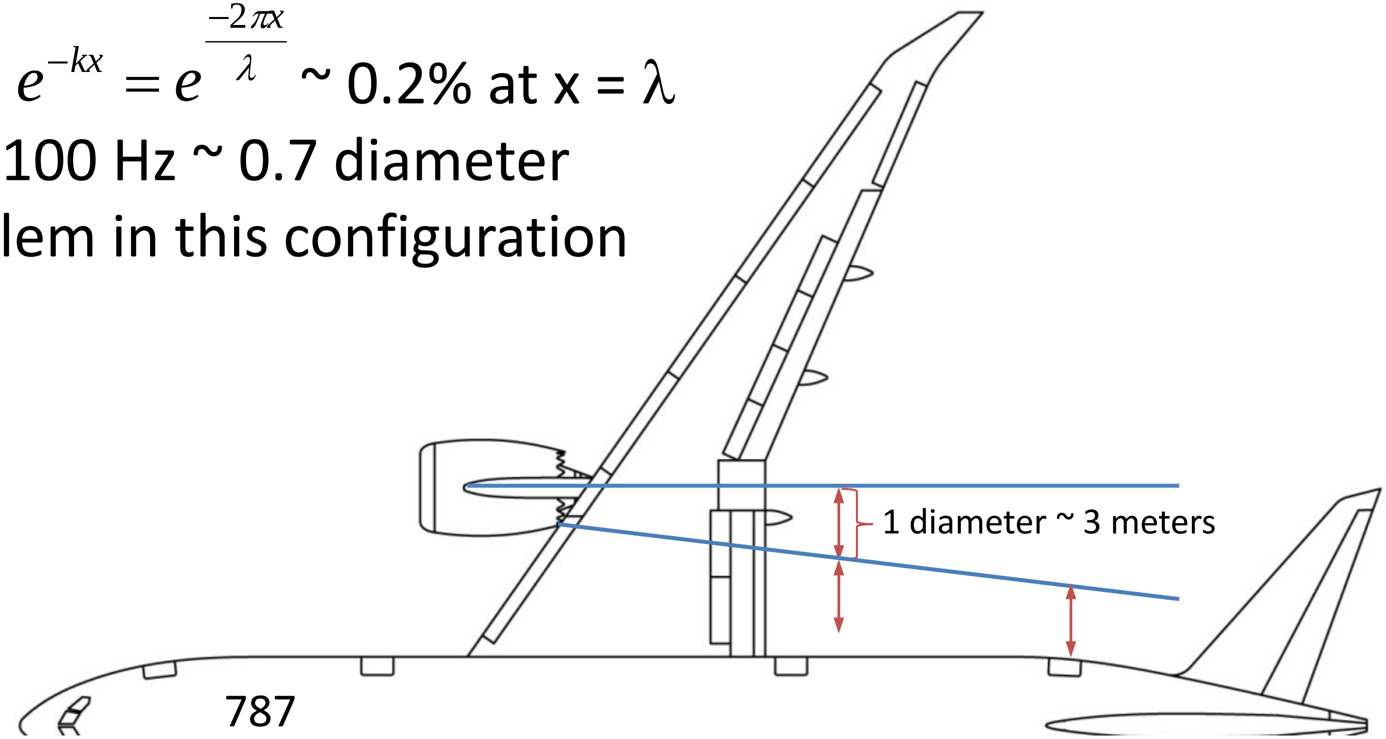
- Optimal design of structure requires accurate noise source models of sidewall cross spectra
  - Three sources were identified for characterization: TBL, Jet and Open Rotor
  - TBL completed in 2011
  - Jet noise milestone due in 2012
  - Open Rotor work will not be done

Summary of TBL Findings

- Flight test raised more questions then it answered
- Estimate 7-8 dB uncertainty in noise radiation estimates based on measurements and theory
- 3 papers published in JSV

Aircraft Sidewall in Jet Near Field

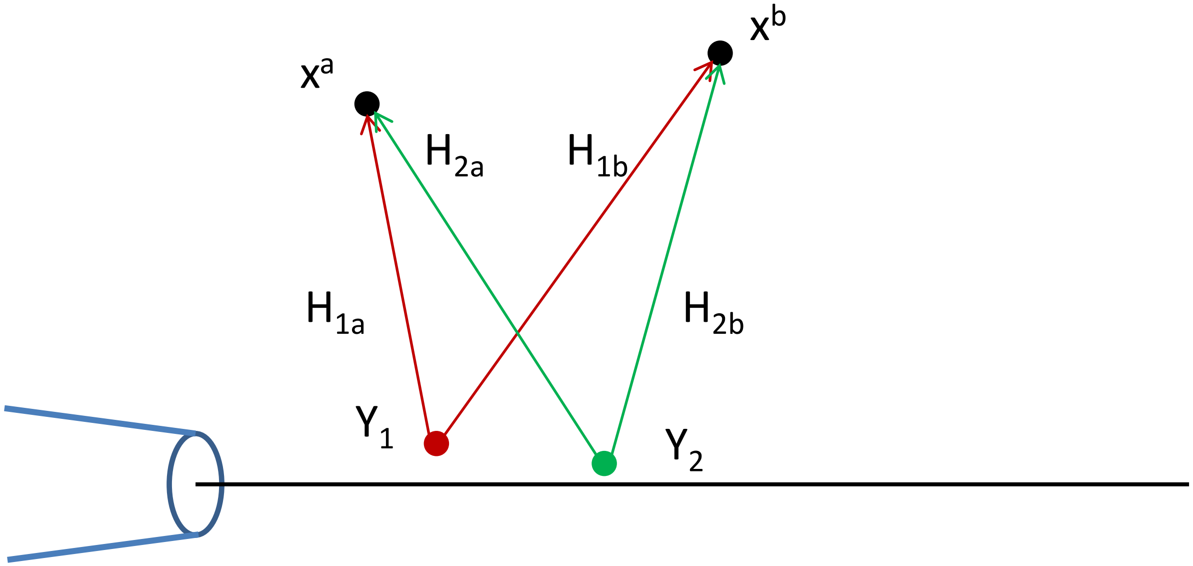
- Negates some far field simplifications.
- Is evanescent field problematic?
  - decays like $e^{-kx} = e^{\frac{-2\pi x}{\lambda}}$ ~ 0.2% at x = λ
  - λ ~ 2 m @ 100 Hz ~ 0.7 diameter
  - Not a problem in this configuration



Relevant Jet Noise Models

- Nearly all jet noise models predict auto power spectrum in far field
- Ribner’s model predicts far field correlation
  - Might be adaptable to near field
  - Has several limitations
- Harper-Bourne’s model predicts near field cross power.
  - Requires an extensive experimental data set

Two Approaches



Miller/Ribner: Extend Ribner's two-point correlation theory using RANS solution and modern acoustic analogies.

Palumbo/Miller: Define source after Harper-Bourne and cross spectra in jet after Corcos and Leib. Propagate cross spectra to observers through analytically defined H.

Theory of Two-Point Correlations of Jet Noise, Herbert S. Ribner, 1976

- Far field approximation (radiation, geometry)
- No source convection, refraction or scattering
- Observer locations are equidistant
- Zero time delay between reception of signals
- Homogeneous, isotropic turbulence
- Exponential shape factor an oversimplification
- Source region non-compact and incoherent

Source Definition Solution Simplification Correlation Model

Ribner’s Self Noise Prediction (Eq. 24)

$$R_{se}\left(\vec{x}^{a},\vec{x}^{b},\tau\right)=\underbrace{H\left(\vec{x}^{a},\vec{x}^{b}\right)}_{\text{propagation}}\int_{jet}\underbrace{G_{yy}\left(\vec{Y}\right)}_{\text{power}}\underbrace{e^{-2\omega_{f}\left|\tau+\Delta\right|}}_{\text{correlation}}d^{3}\vec{Y}$$

where

R_{se} is correlation of acoustic pressure between equidistant points x^a and x^b at delay τ.
Y is the midpoint between two acoustic sources in the jet.
H is the transfer function of acoustic power between Y and x^a,x^b.
G_{yy} is the acoustic power at Y.
Δ is the time delay between the two acoustic sources at Y.

- Shear noise term has a similar form.

Extension of Prof. Ribner’s Theory

$$\underbrace{G_{xy,\text{self}}(\vec{x}_1,\vec{x}_2,\omega)}_{\text{Cross-Spectra Self Noise}} = \int_{jet} \underbrace{H(\vec{x}_1,\vec{x}_2,\vec{q})}_{\text{propagation}} \underbrace{G(\vec{x}_1,\vec{x}_2,\vec{q},\omega)}_{\text{power}} \underbrace{C(\vec{x}_1,\vec{x}_2,\vec{q},\omega)}_{\text{correlation}} d\vec{y}$$

where

q are the field-variables from a steady RANS solution
ω is the radial frequency
x_1 *and* x_2 are the observer locations

- Improvements: Modern source model, arbitrary observer placement, and freestream effects
- Require steady RANS solution and experimental validation
- Shear noise term has similar form
- Assumptions
  - Far-field
  - Statistical model of turbulent velocity covariance
  - Compact source
  - Isotropic turbulence

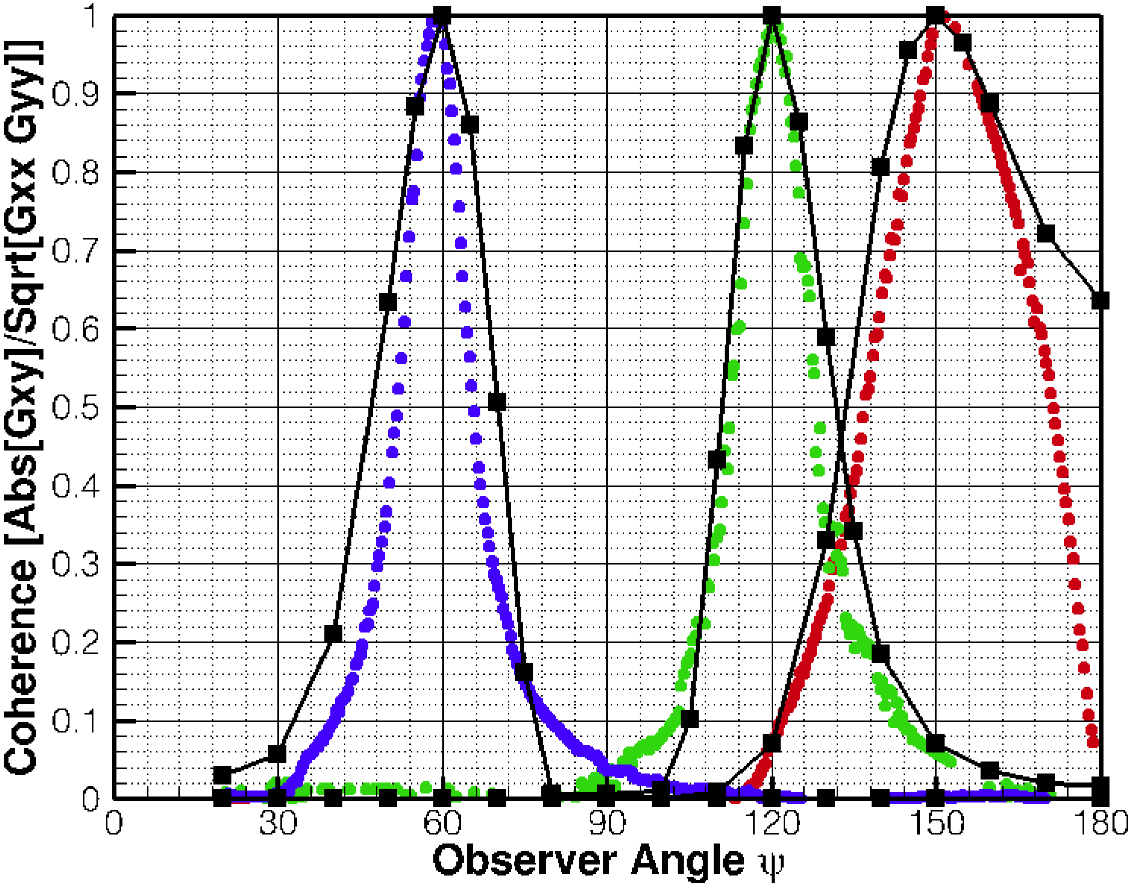
Prediction of Miller/Ribner to Experiment of Maestrello

Modified Ribner Model:

$M_d = 1$
$M_j = 1$
$TTR = 3.20$
$D = 0.0508$ m
$R/D = 100$

Experiment by Maestrello:

$M_d = 1$
$M_j = 0.75$
$TTR = 1.00$
$D = 0.0254$ m
$R/D = 169$



Experiment: Maestrello, L., "Two-Point Correlations of Sound Pressure in the Far-Field of a Jet: Experiment," NASA TM X-72835, April 1976.

Harper-Bourne - Predicting the Jet Near-Field Noise of Combat Aircraft (2001)

- Semi-empirical
- Entropy noise assumed negligible
- Fixed frame of reference
- Self noise acoustically compact
- Observer located at *r* > jet diameter
- Directivity and decay length taken as constant along jet axis

Harper-Bourne, M., "Predicting the Jet Near-Field Noise of Combat Aircraft," RTO AVT Symposium on Ageing Mechanisms and Control: Part A – Developments in Comp. Aero. & Hydro. Acous., Manchester, UK Oct. 8-11, 2001.

Harper-Bourne Cross Spectrum Prediction (Eq. 12)

$$G_{ab}\left(\vec{x}^{a},\vec{x}^{b},\omega\right)=\underbrace{G_{90}(\omega)}_{\text{power}}\int_{y}\underbrace{G_{yy}(y,\omega)}_{\text{power}}\underbrace{H\left(y,\vec{x}^{a},\vec{x}^{b},\omega\right)}_{\text{propagation \& correlation}}dy$$

$$H\left(y,\vec{x}^{a},\vec{x}^{b},\omega\right)=D\left(y,\vec{x}^{a},\vec{x}^{b},\omega\right)C_{A}\left(y,\vec{x}^{a},\vec{x}^{b},\omega\right)\frac{e^{-ik_{a}\left|\vec{x}^{a}-\vec{x}^{b}\right|}}{\left|\vec{x}^{a}\right|\left|\vec{x}^{b}\right|}$$

Where

G_{ab} is the cross spectrum of the pressures at x^a and x^b.
G_{90} is the power spectrum perpendicular to the jet axis
G_{yy} is the power in the jet at source location y
H is the transfer function that includes propagation and correlation
D is the cross power directivity
C_A is the cross power convective amplification
k_a is the wavenumber in air

- ➢ Correlation information is embedded in experimentally determined D and C_A.

Palumbo/Miller
Jet Cross Spectrum

$$G_{12}(y_1, y_2, \omega) = (G_r(y_1, \omega) G_r(y_2, \omega))^{1/2} e^{-|y_2 - y_1| / L} e^{-ik_j (y_2 - y_1)}$$

$$G_r(y, \omega) = G_{90}(\omega) G_{yy}(y, \omega) D_j^{\,2}$$

$$L = c_l D_j \left(1 - Exp\left[-c_s l_s St / D_j\right]\right) / St$$

Where

G_{12} is the cross spectrum in the jet
G_r is the power term relative to location y
L is the coherence length in the jet (after Morris and Boluriaan)
k_j is the wavenumber in the jet
D_j is the jet diameter
St is the Strouhal number
$c_l = 7.16\ \pi$, $c_s = 0.75$, $l_s = 0.2$

- L and k_j should, most likely, be functions of jet axis position.

*From Morris and Boluriaan, "The Prediction of Jet Noise from CFD Data," AIAA Paper 2004-2977, 2004.

Palumbo/Miller Observer Cross Spectrum

$$G_{ab}(\vec{x}^{a},\vec{x}^{b},\omega)=\int \underbrace{H(y_1,\vec{x}^{a},\omega)}_{\text{propagation}}\underbrace{G_{12}(y_1,y_2,\omega)}_{\text{power \& correlation}}\underbrace{H(y_2,\vec{x}^{b},\omega)^{*}}_{\text{propagation}}d^{2}y$$

$$H(y,\vec{x},\omega)=D(\theta_o)C_A(\theta_o)\frac{e^{-ik_a r_o}}{4\pi r_o}$$

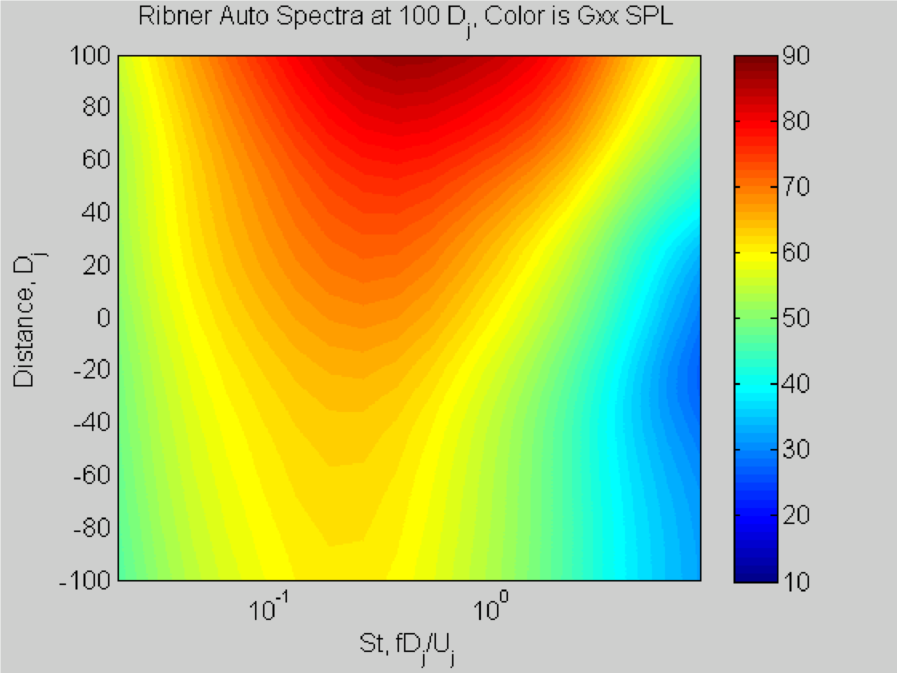
Where

Θ_0 is the angle from the jet axis to the observer
D is the directivity
C_A is the convective amplification
k_a is the wavenumber in air
r_0 is the distance from the source to the observer

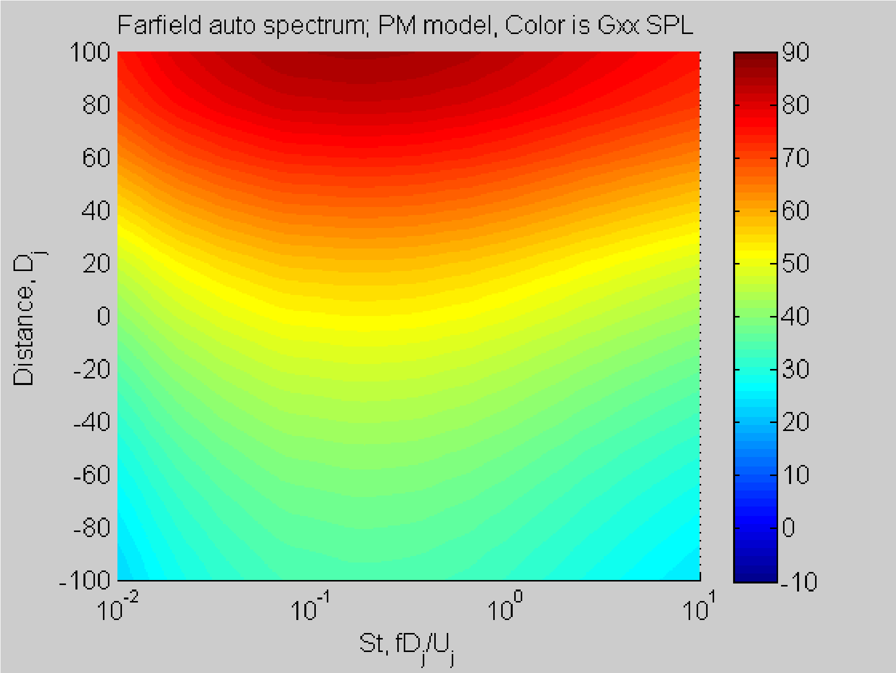
Inherits limitations of Harper-Bourne model.
D and C_A should be function of jet axis position.

Far Field Auto Spectrum

Miller/Ribner, y_2 = 100D



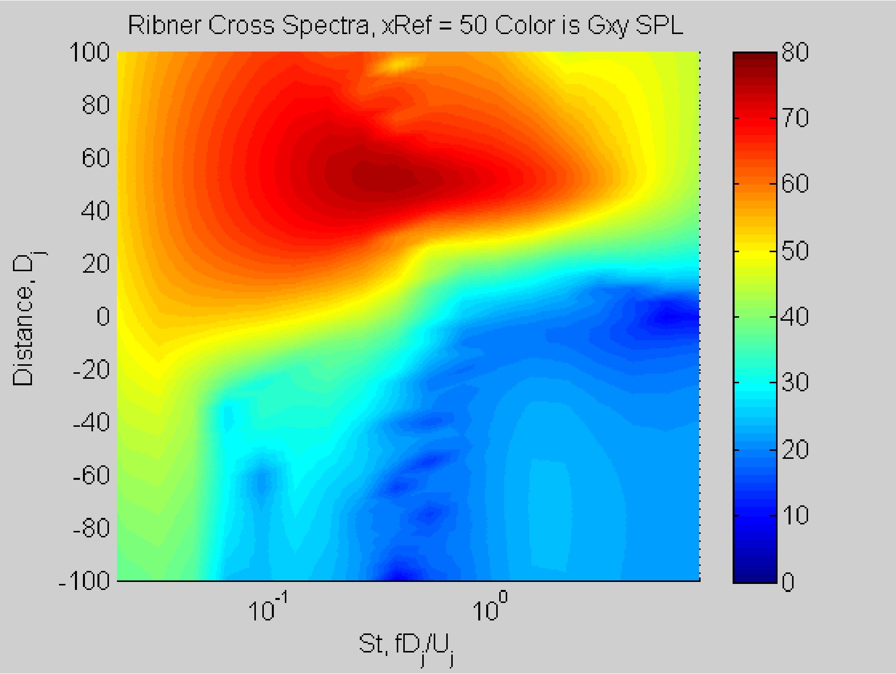
Palumbo/Miller , y_2 = 100D



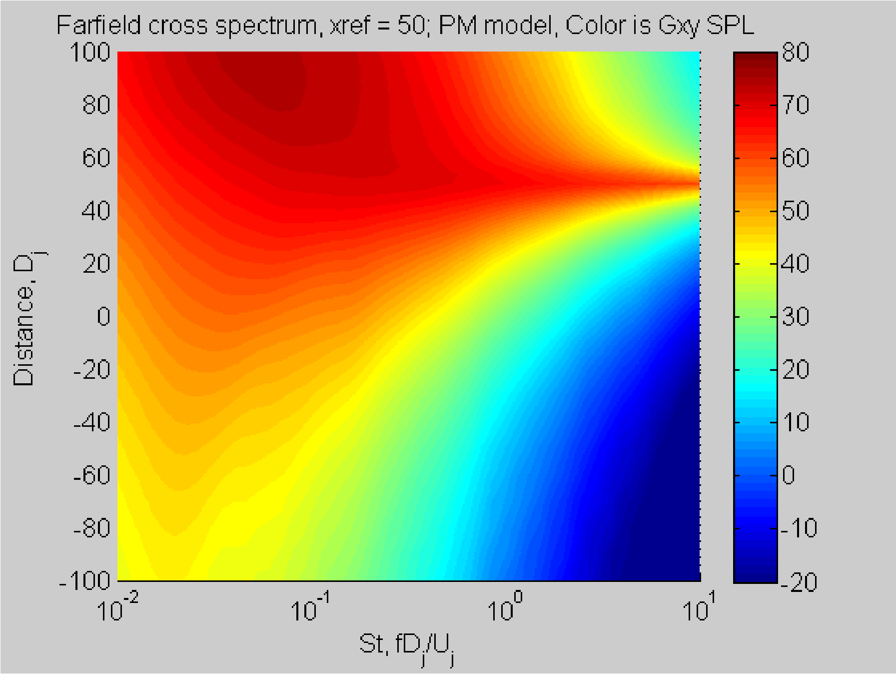
Palumbo/Miller (PM) auto spectrum levels are broader and peak at lower frequency.
The autopower in in PM model decays faster towards upstream direction

Far Field Cross Spectra

Miller/Ribner , y_2 = 100D



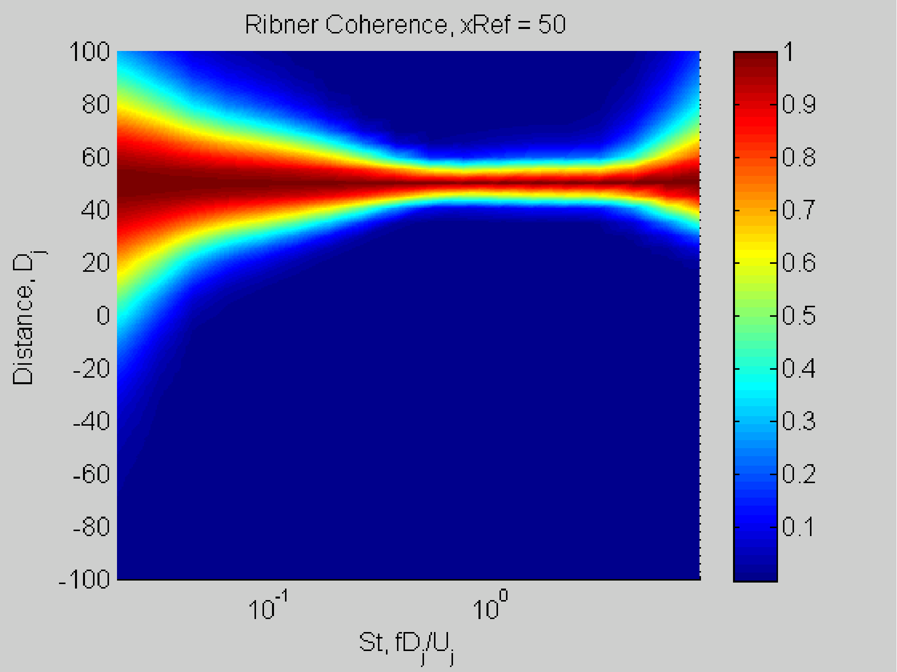
Palumbo/Miller , y_2 = 100D



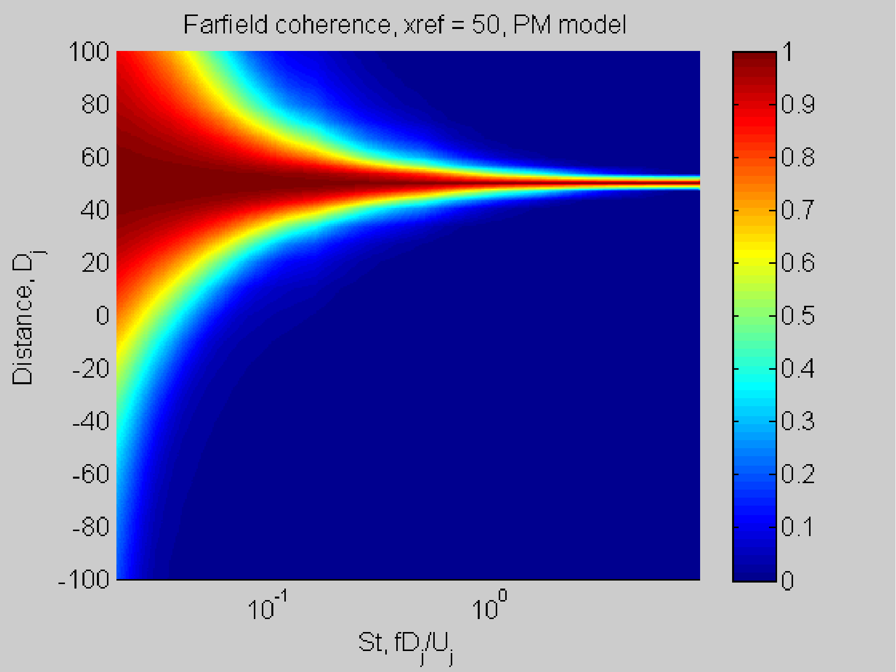
The PM model's peak in cross power occurs at a lower frequency and further downstream.

Far Field Coherence

Miller/Ribner , y_2 = 100 D



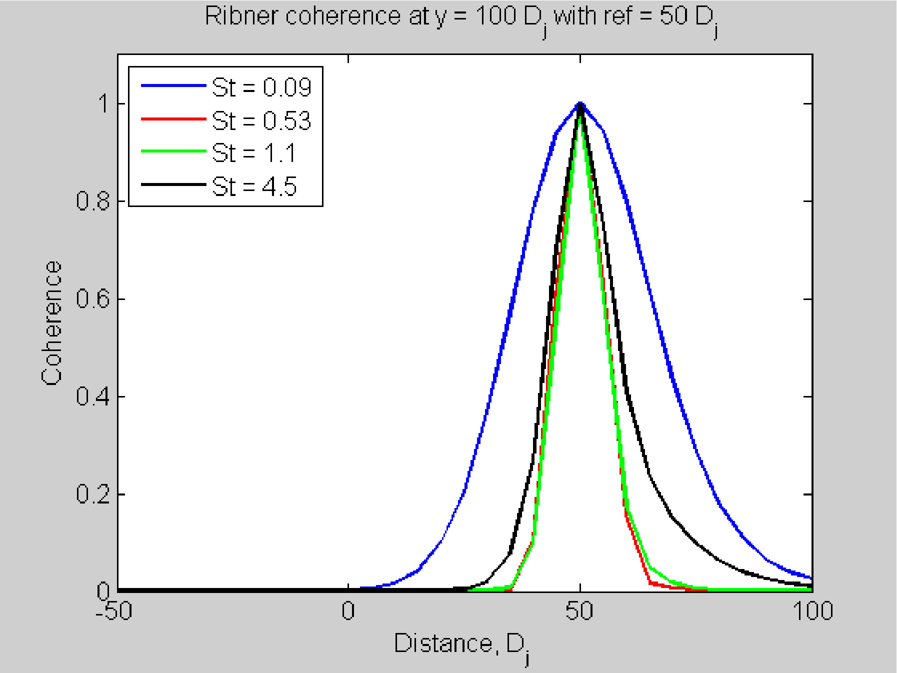
Palumbo/Miller , y_2 = 100 D



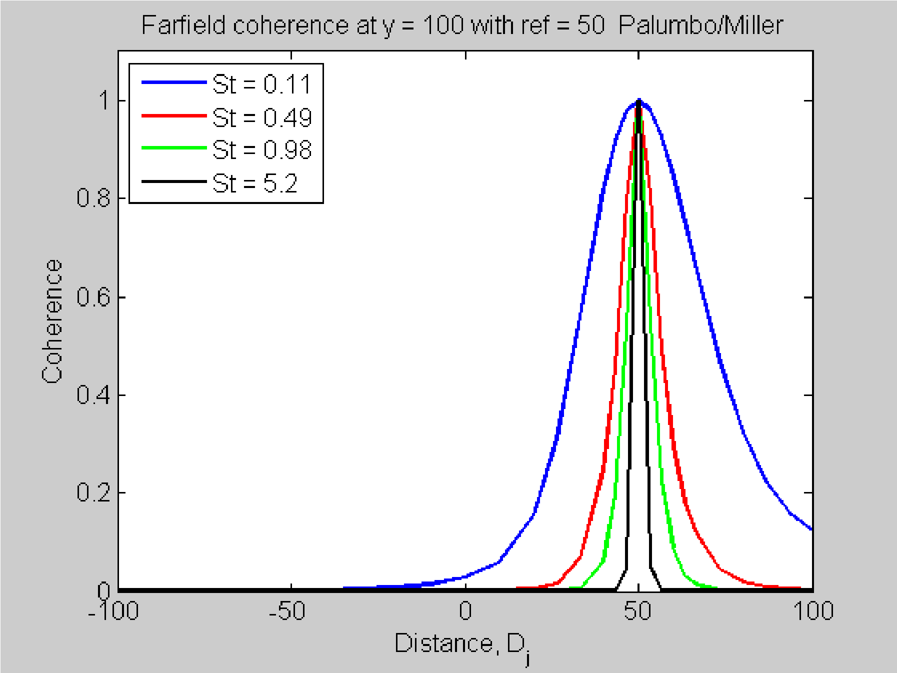
Shape of coherence is similar.

Far Field Coherence Cross Sections

Miller/Ribner , y_2 = 100 *D*



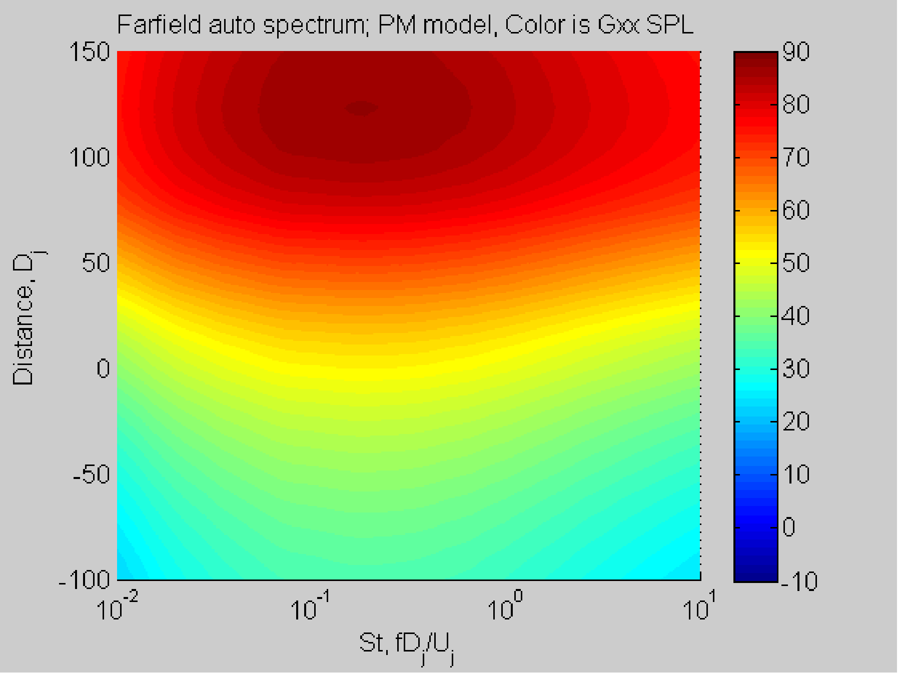
Palumbo/Miller , y_2 = 100 *D*



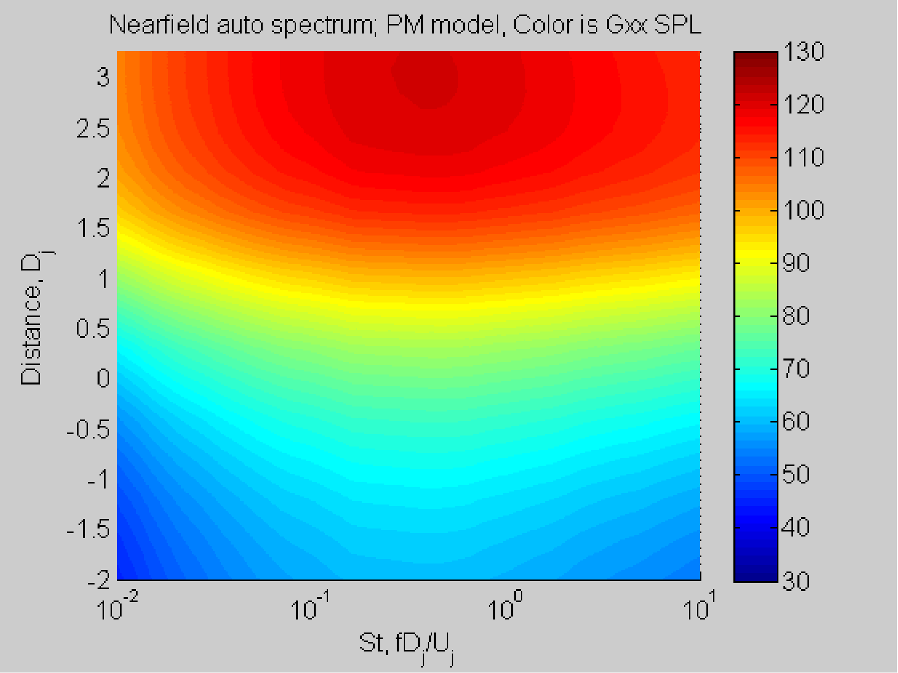
Shape of coherence similar at lowest frequency. Palumbo/Miller narrows quickly

Auto Spectrum: Far vs. Near Fields

Far Field, y_2=100 *D*



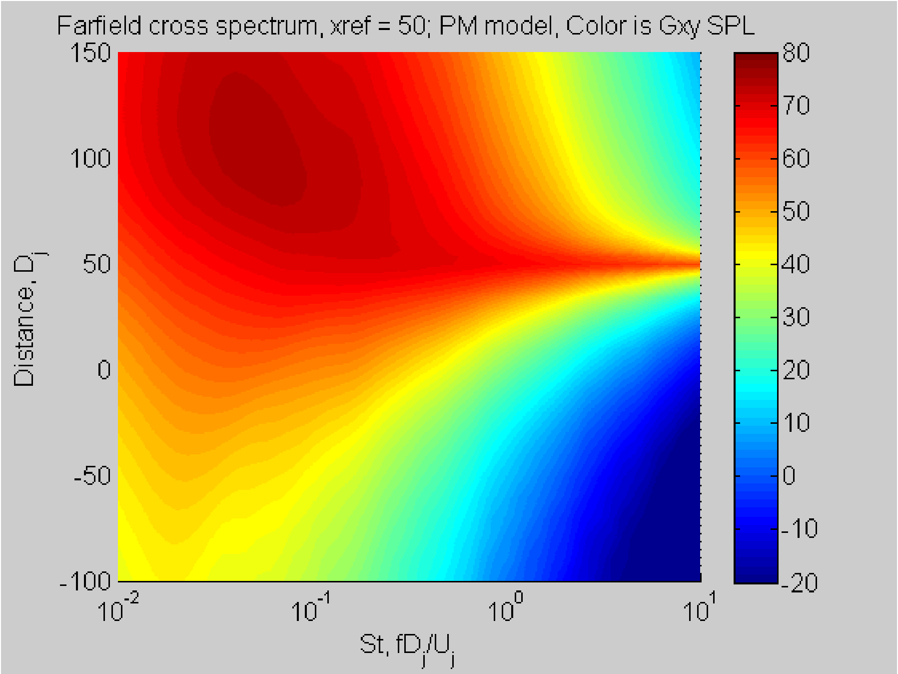
Near Field, y_2=2 *D*



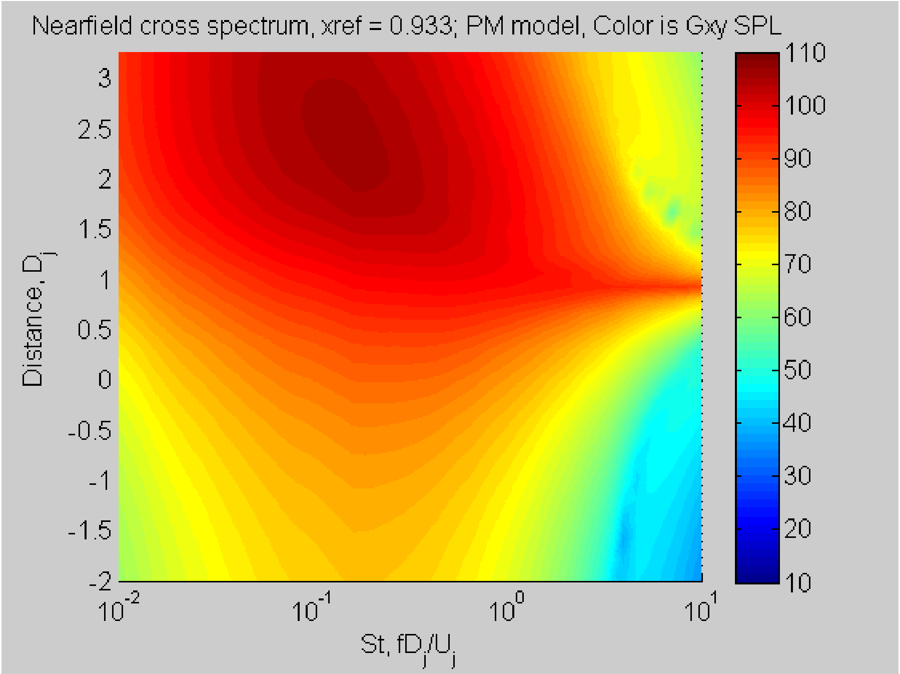
Directivity is relative to jet exit, so location of peak autopower is incorrect.

Cross Spectrum: Near vs. Far

Far Field, $y_2=100\ D$



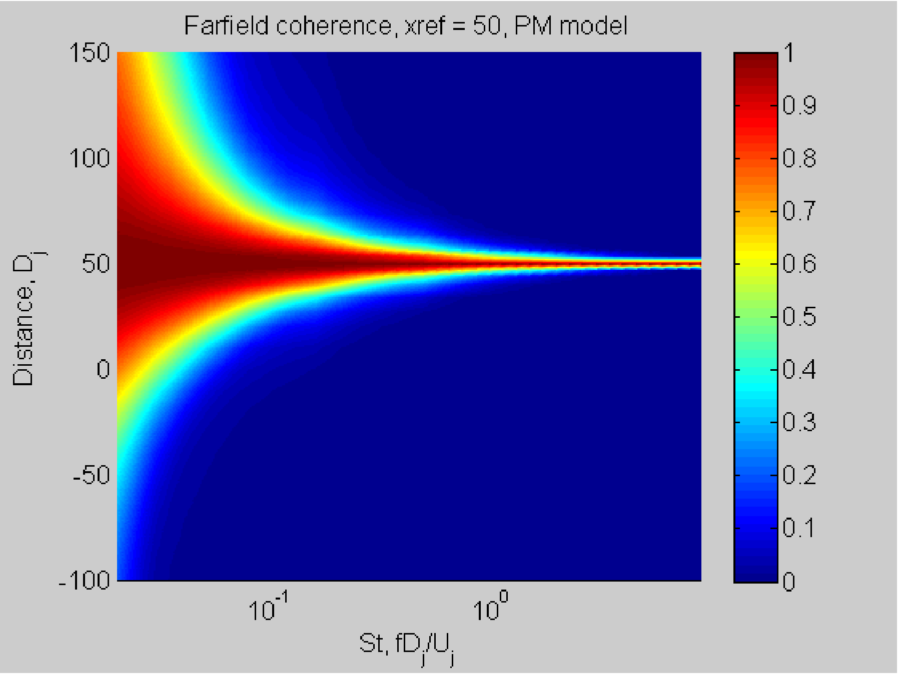
Near Field, $y_2=2\ D$



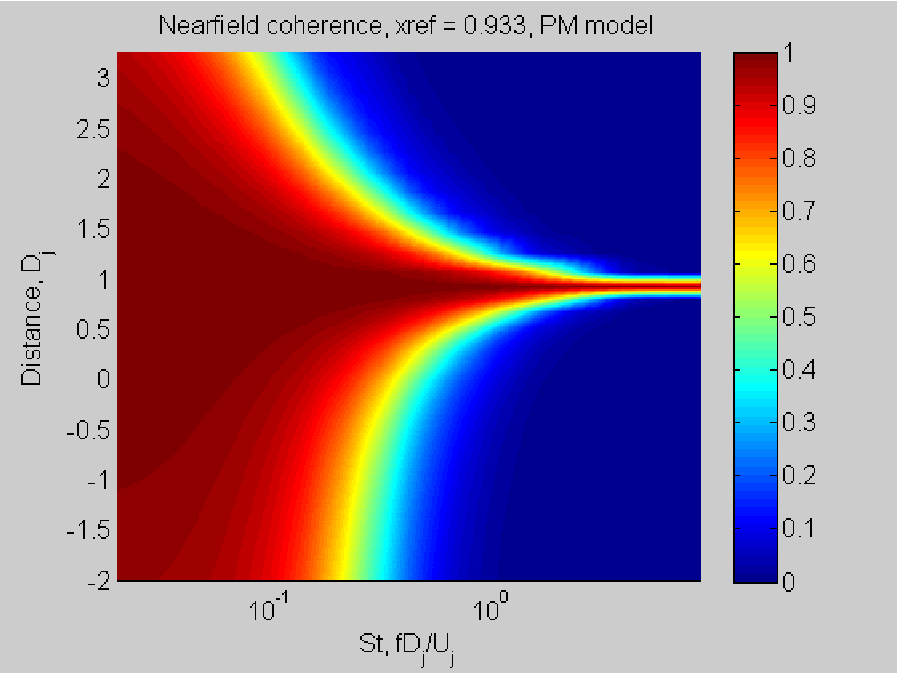
Peak power occurs at higher frequency, especially upstream.

Coherence: Near vs. Far

Far Field, y_2=100 *D*



Near Field, y_2=2 *D*

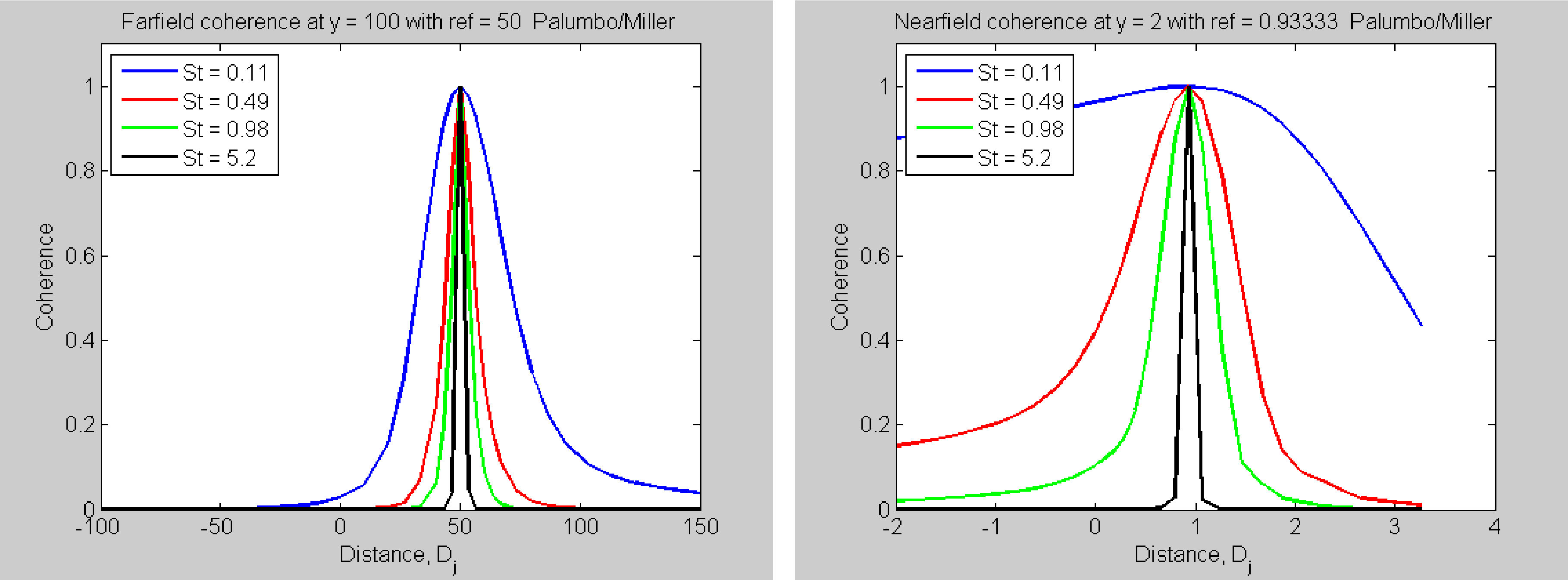


Coherence is much broader.

Coherence Cross Section: Near vs. Far

Far Field, y_2=100 *D*

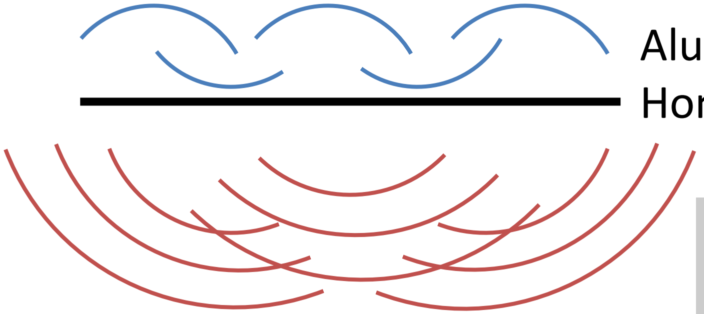
Near Field, y_2=2 *D*



The very wide coherence pattern in the near field is made obvious in these cross sections

Re-radiation of Boundary Layer Excited Plate

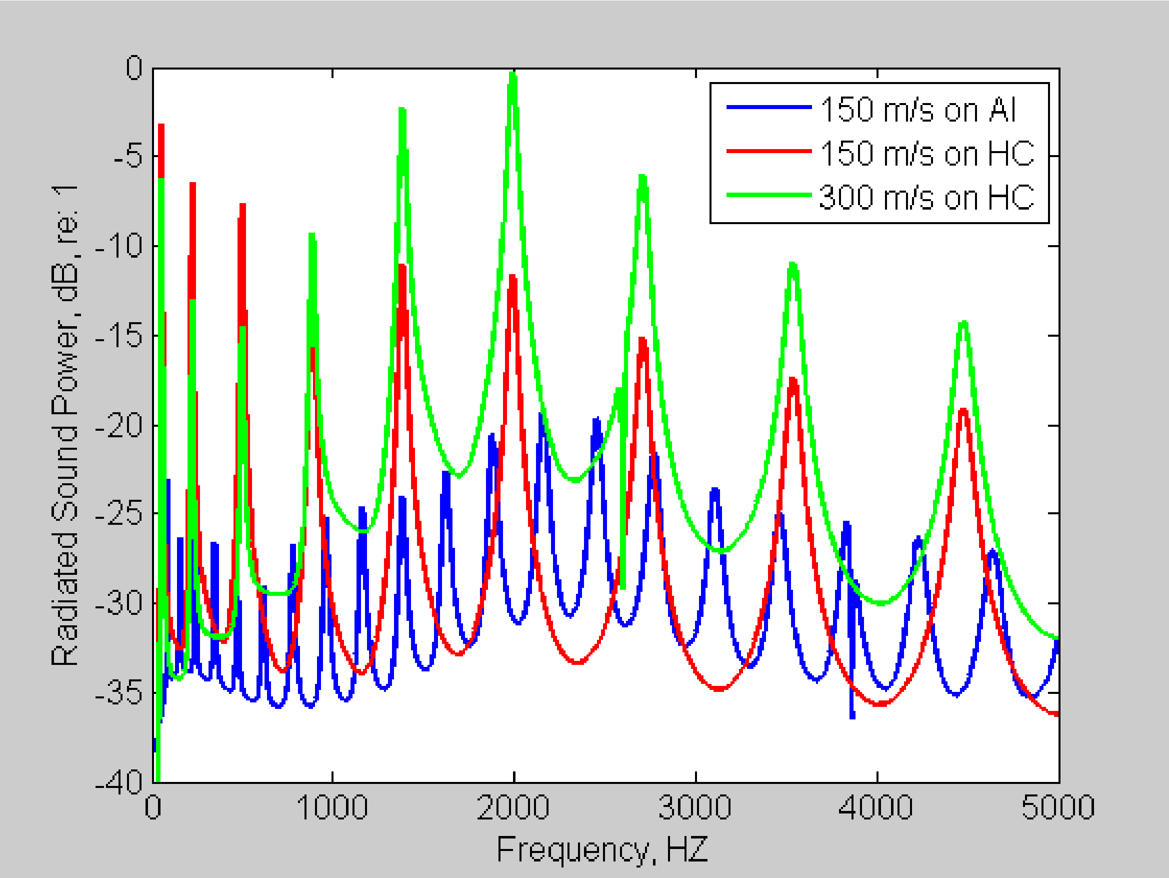
Boundary layer at 150 m/s and 300 m/s



Aluminum and Honeycomb Panels

Acoustic re-radiation

- Plate has both acoustic and hydrodynamic coincidence frequencies.
- When they occur in same frequency band, plate radiates very efficiently.



Conclusions

- Two approaches to formulating near-field predictions of the auto and cross spectra were pursued.
- The Miller/Ribner approach modernizes Ribner’s theory but has yet to be extended to the near field.
- The Palumbo/Miller approach can be extended to the near field, but is relying on far field directivity and convective amplification terms.
- Both approaches require experimental data to fully mature the models.