Do Recent Findings on Jet Noise Raise Questions about the Schultz Curve?

Micah Downing
Michael James
Blue Ridge Research and Consulting

Kent Gee
Brigham Young University

Sally Anne McInerny
University of Alabama

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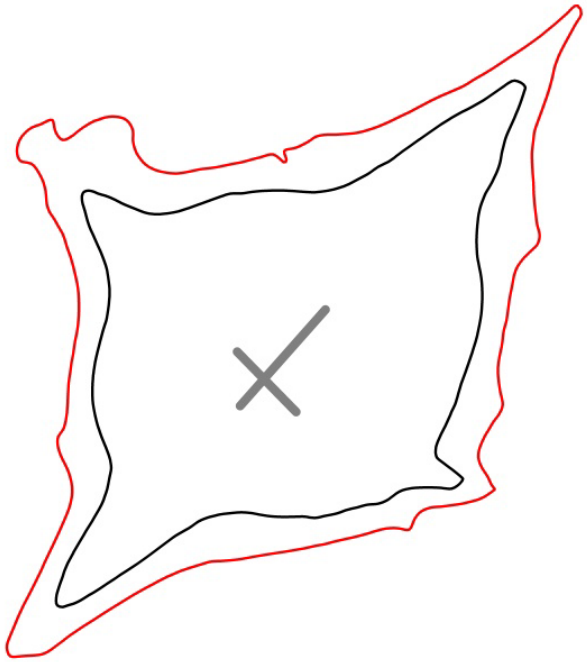
Overview

- Problem Statement
- Overview of New Findings
- Question Formed
- Question Asked

Problem Statement

- New generation fighter aircraft
  - Increased thrust
  - Significant noise levels
  - Complex nozzles
  - Dynamic directivity

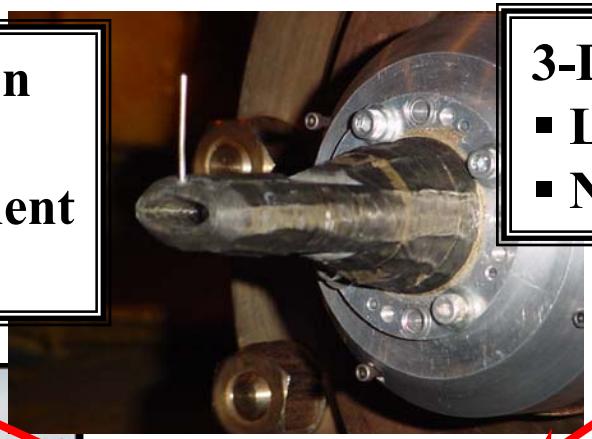


Also remember that

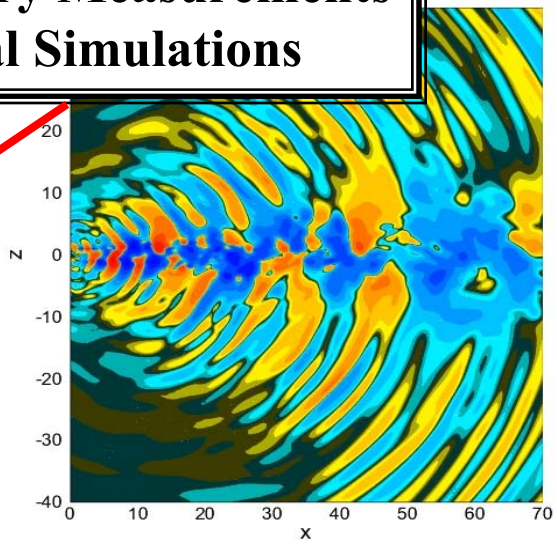
- Old generation commercial jets
  - Turbojet engines
  - Low by-pass
  - High thrust
  - 20+ dB louder than current generation

DoD Research Project

Non-linear Propagation
- Theory
- Laboratory Experiment
- Field Experiments



3-D Jet Noise
- Laboratory Measurements
- Numerical Simulations



3D Flight Tests
- Real Aircraft

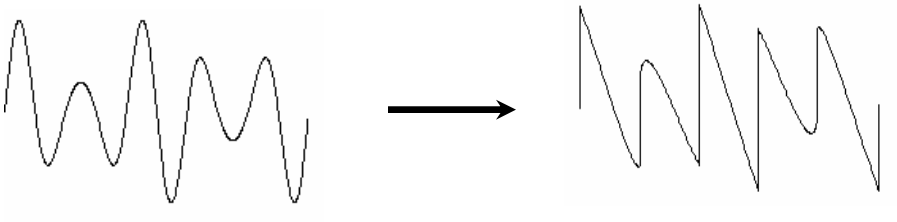
New and Improved Aircraft Noise Model:
- Dynamic Simulation
- Improved Noise Database

First, a Few Comments

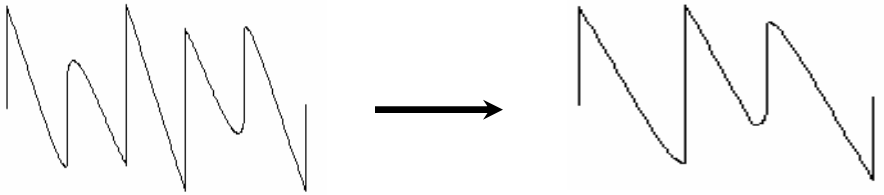
Nonlinearities in Jet Noise

Pestorius and Blackstock (1974), broadband spectrum:

- **Waveform steepening**
  - *Energy is transferred towards **high**-frequency range*

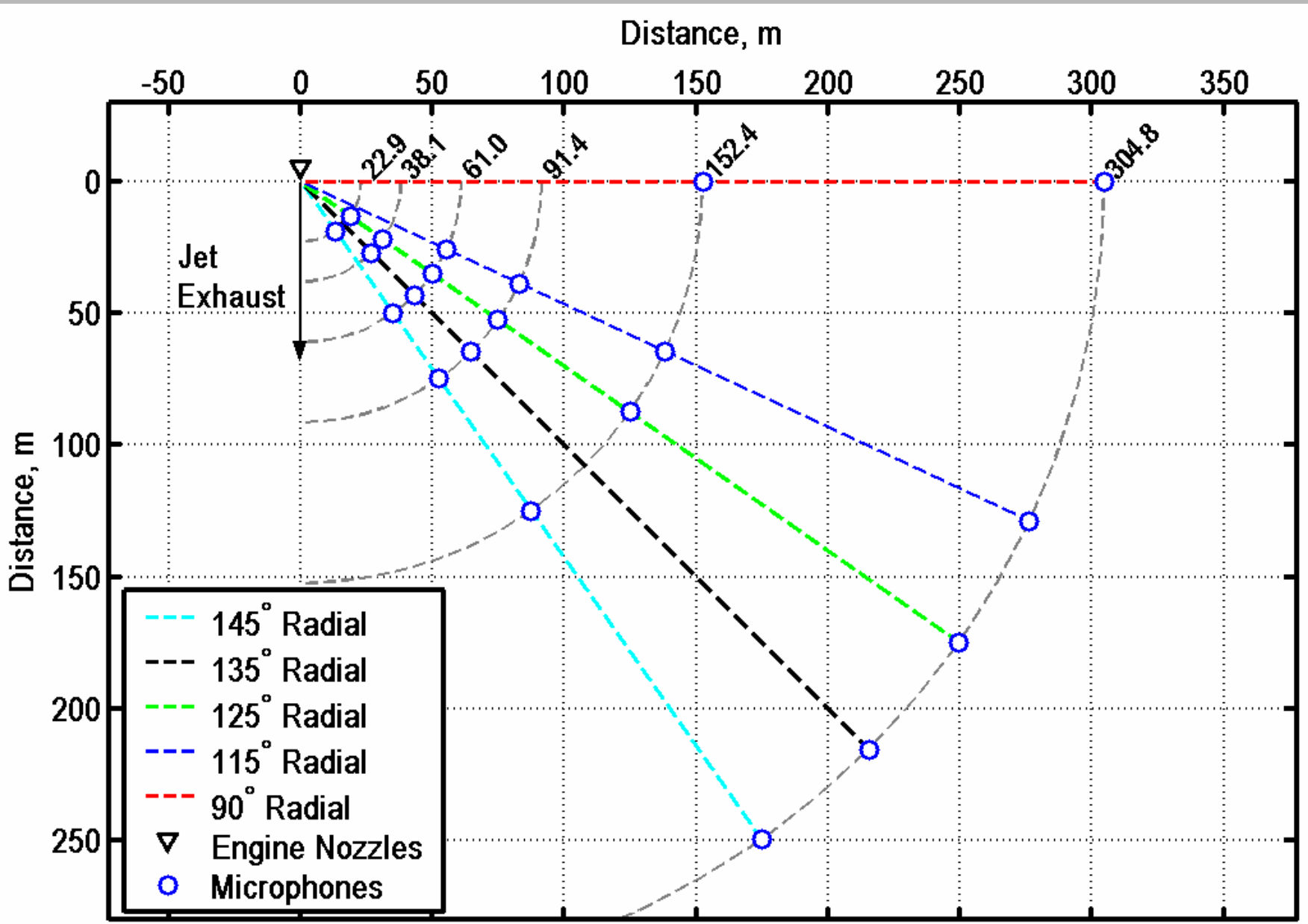


- **Shock coalescence**
  - *Energy is transferred towards **low**-frequency range*

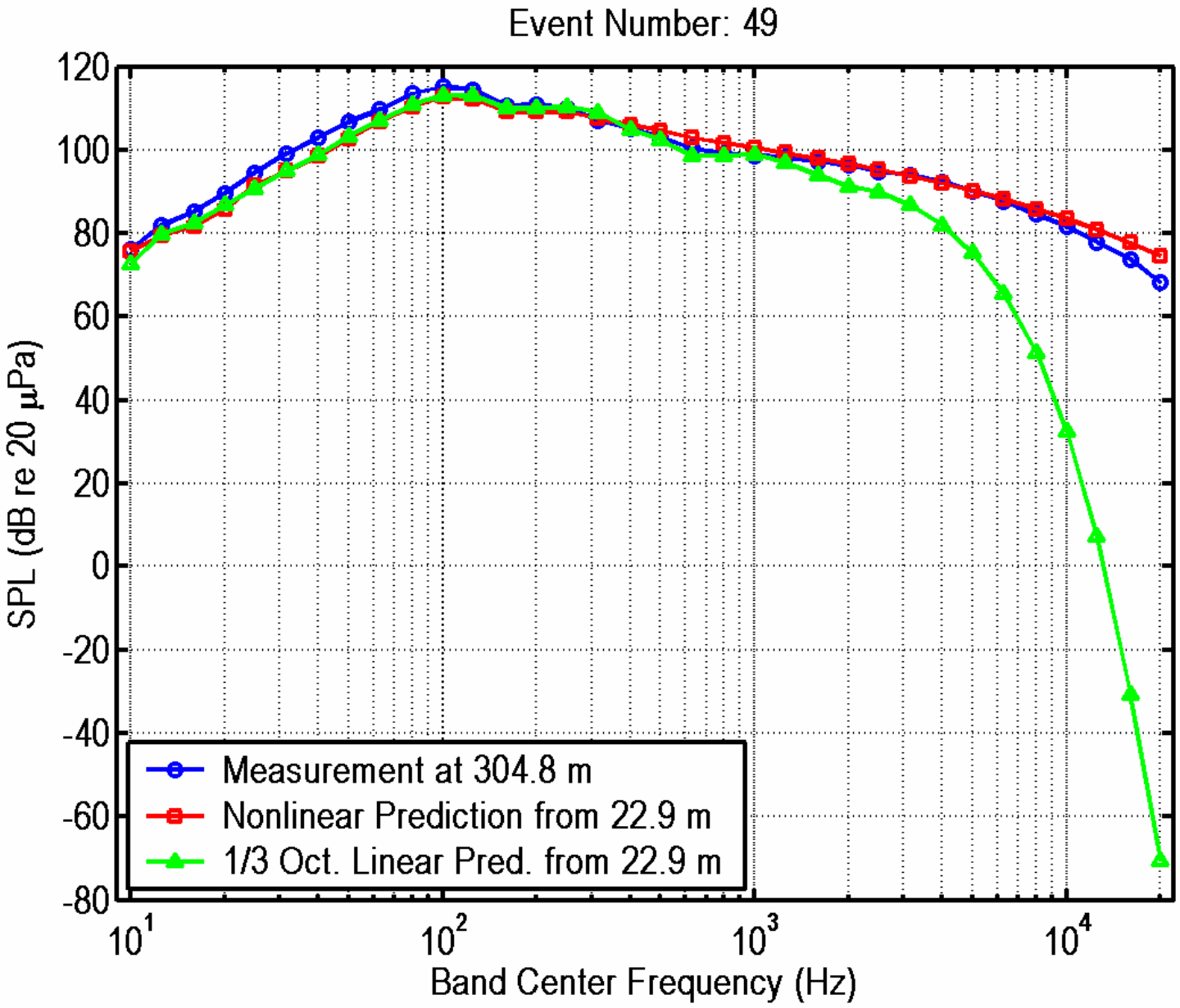


- *Use statistics to identify and quantify nonlinear propagation effects in the **pressure waveforms.***

Measured Field Data



125°, AB Nonlinear Prediction



Impact of Nonlinearity

- Question #1:

  Is there a *perceived* difference between linear and nonlinear propagation?

- Example: measured versus linear & nonlinear predicted waveforms

Measured

Linear Calc.

Nonlinear Calc.

Do you perceive a difference?

Linear vs. Nonlinear Calculations

- Calculate waveform from reference location
- Do you expect differences in metrics?

125° Level Calculations

Metric	Measured at 304.8 m (dB)	Nonlinear Prediction (dB)	Linear Prediction (dB)
OASPL-Flat	121.8	119.9	120.4
OASPL-A	111.0	111.4	110.2
OASPL-C	121.5	119.6	120.2
Mark VII PL	118.1	117.6	115.9

- Not what I expected based on my ear

Impact of Nonlinearity

- Question: How do we measure the perceived effect of “crackle”?
- Example:
  - Linear & nonlinear predicted waveforms
  - Nonlinear vs. Spectrally equivalent waveforms

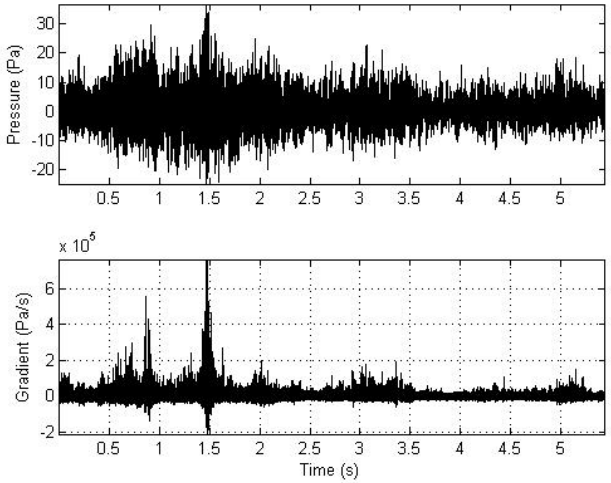
Input **Linear Calc.** **Nonlinear Calc.** **Gaussian**

- Spectral based measures do not seem to work!
- Need to account for shock structures – “crackle”

Potential Nonlinear Metrics

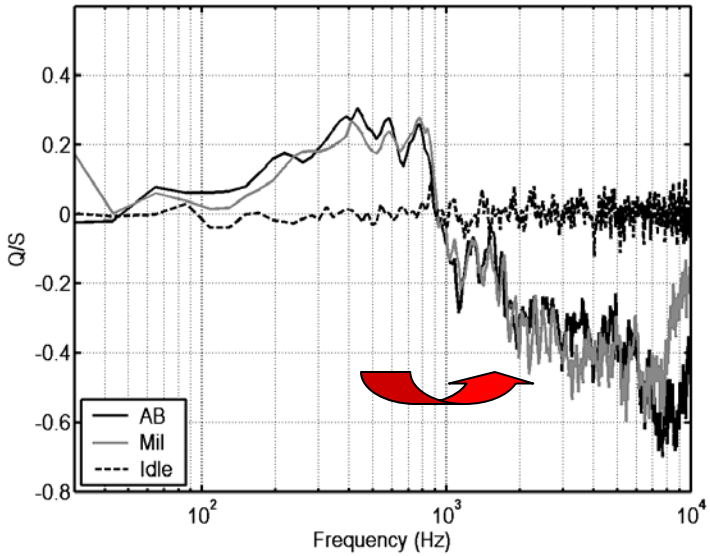
Physical Aspects

- *Basic: Lmax, Leq, A-wt, C-wt, etc.*
- **Statistical: Skewness & Kurtosis**
  - **Pressure**
  - **Pressure gradients**
- **Morfey-Howell Indicator**



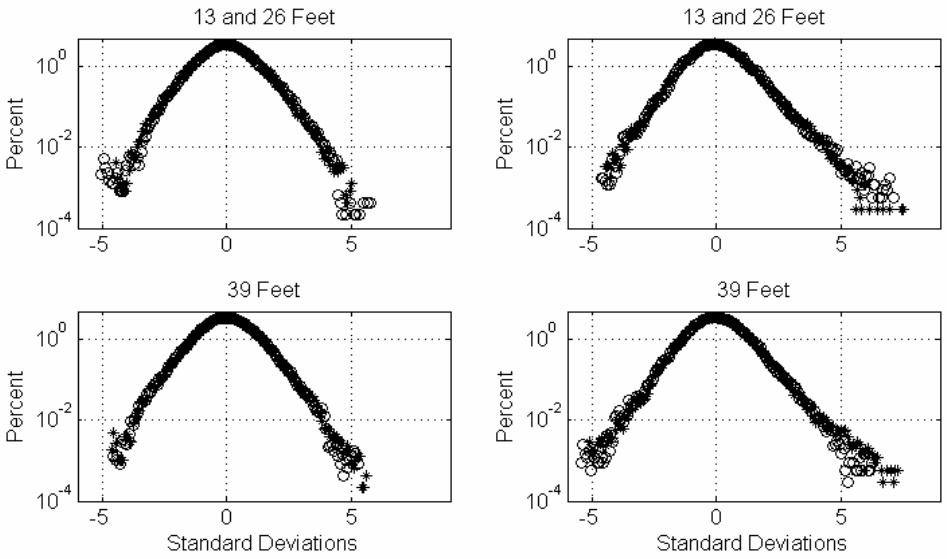
$$Q_{p^2 p}(f) = \mathrm{Im}\left[FT\left\{p^2(t)\right\} FT^*\left\{p(t)\right\}\right]$$

$$Q/S = \frac{Q_{p^2 p}}{p_{rms} S_{pp}}$$



From Gee *et al.*, *AIAA Journal,* May 2005

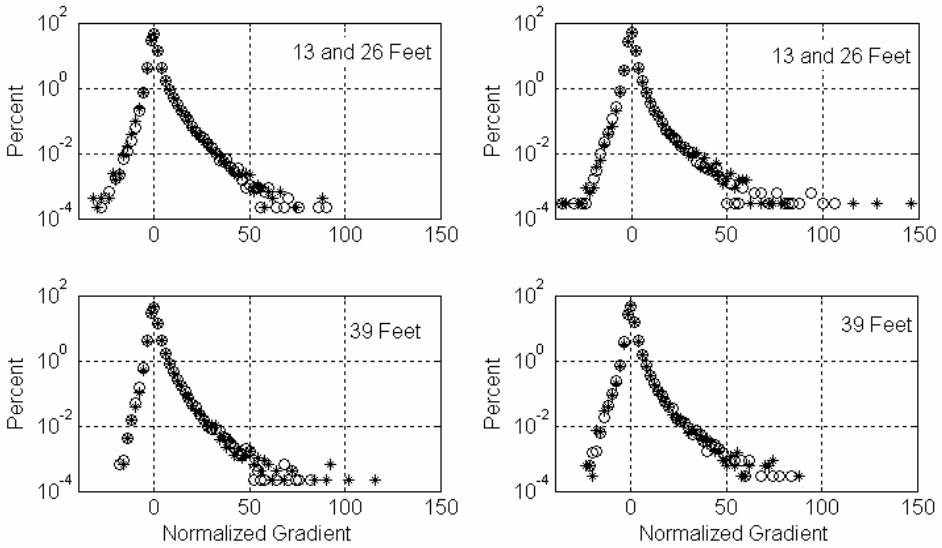
Statistical Parameters Military Jets



Histogram of Pressures

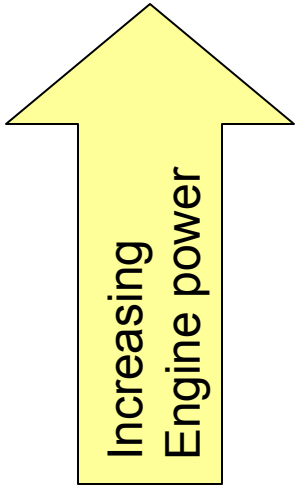
Histogram of Pressure Gradients

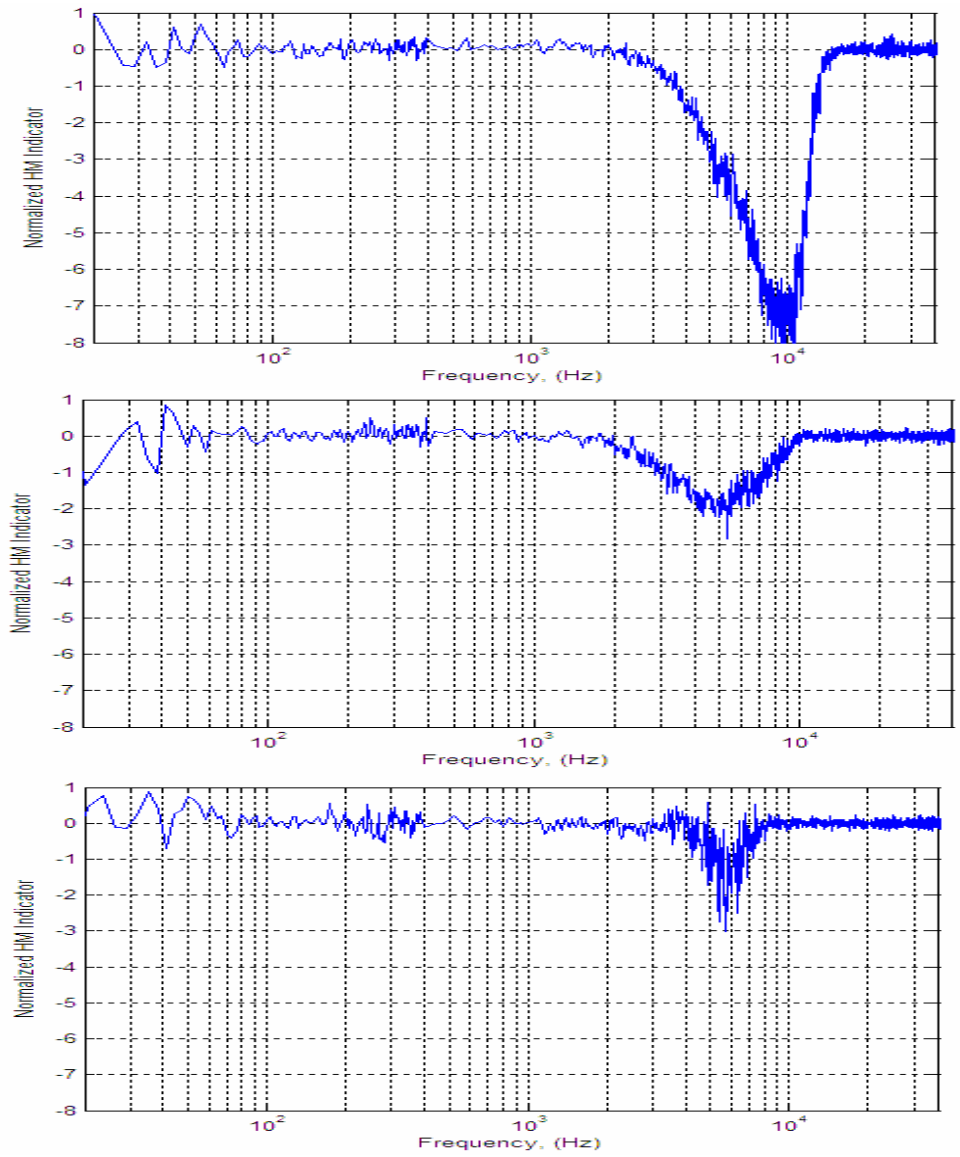
Highly skewed



Military Jet Noise: Q/S Plots

- Level, constant power flyovers
- Nonlinear effects noted



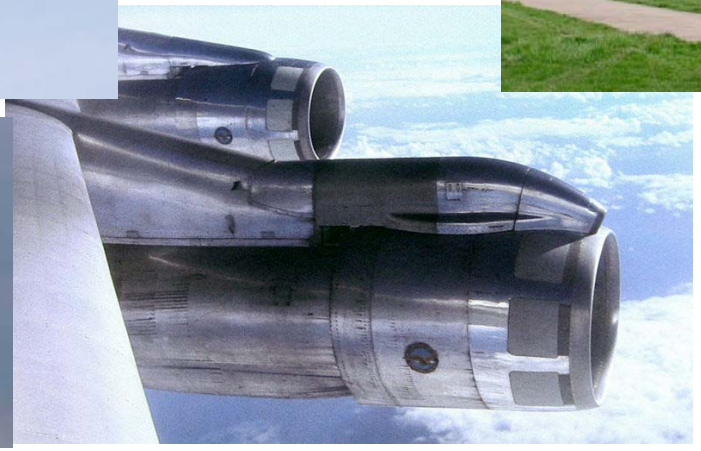


Are you still with me?

- Military jets
  - Low by-pass engines + high thrust = high velocity
  - Generate high amplitude acoustic waveforms which create shocks
  - Nonlinear propagation effects “crackle”
  - Subjectively “louder” waveforms for similar overall SPL levels
  - So now my question ….

So now my question:

What is the character of aircraft noise included in social surveys in the Schultz curve and following revisions?



Some Background on Aircraft Noise

- 1969 – FAA 14 CFR part 36
  - "Noise Standards: Aircraft Type Certifications"
- 1973 – Stage designation for newly produced aircraft
- 1977 – Stage 3 noise limits introduced
- 1985 – 4 engine Stage 1 aircraft banned
- 2000 – All Stage 3

Schultz Data 1978

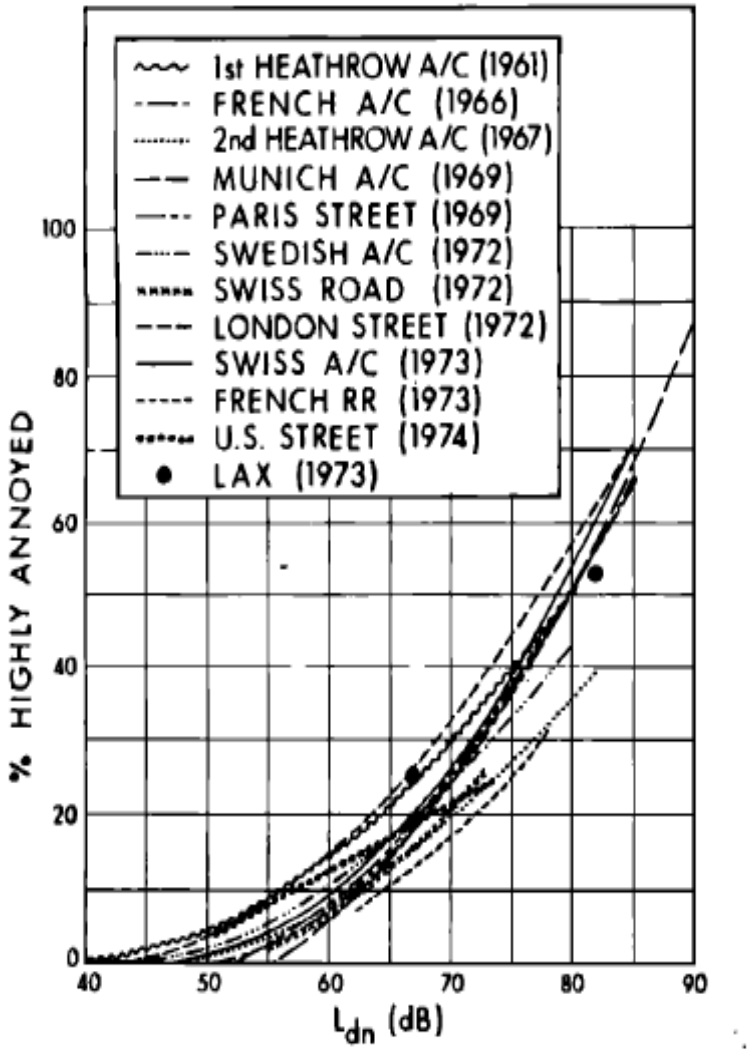


FIG. 2. Revised analysis of the clustering surveys using a rule for counting the percent highly annoyed that leaves out personal judgment in the individual surveys.

Miedema & Vos 1998

Reanalysis suggests differences between modes of transportation

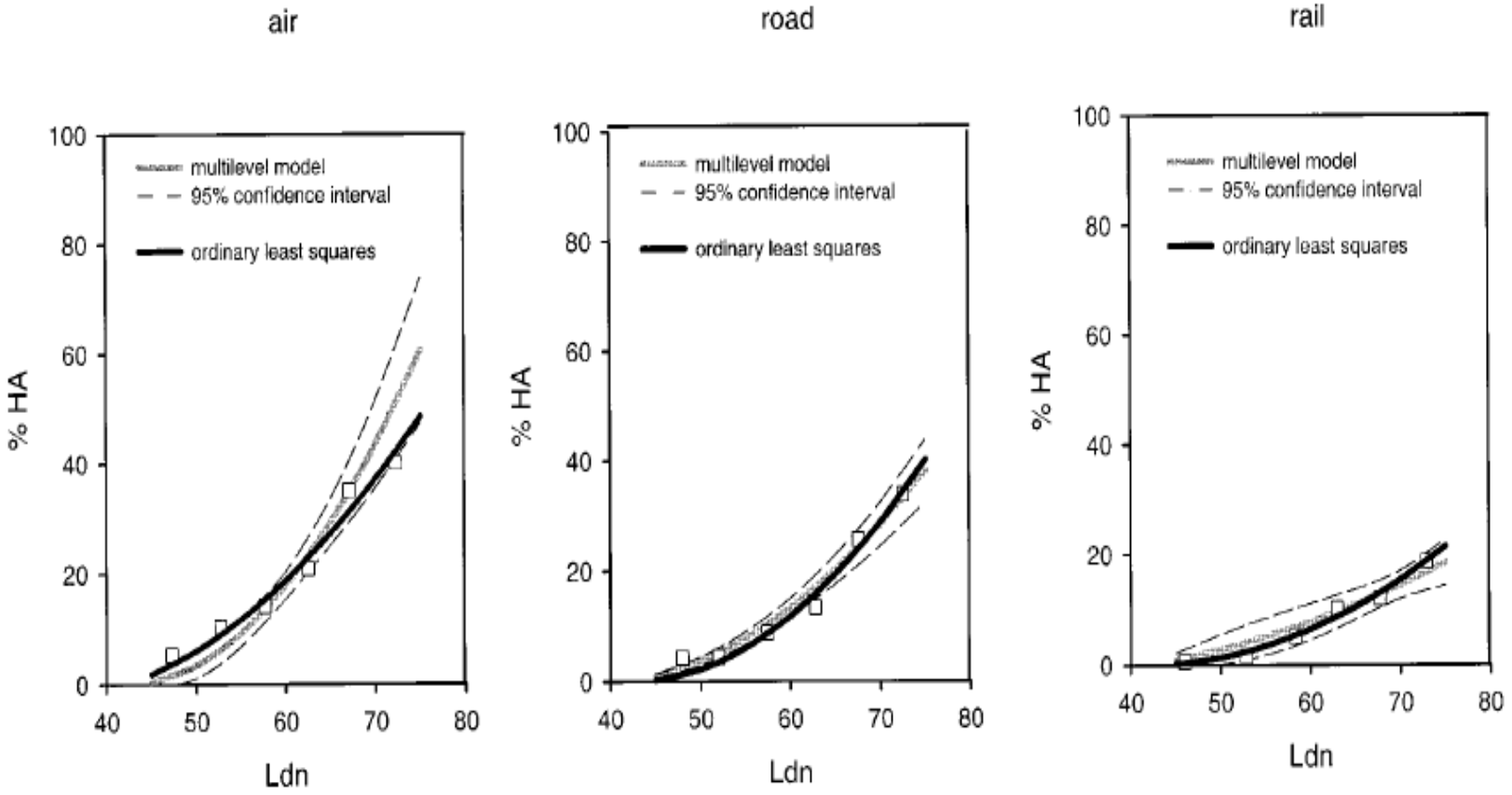


FIG. 3. Percentage highly annoyed persons (%HA) as a function of DNL. Two synthesis curves per mode of transportation, and the datapoints are shown. For the curves obtained with multilevel analysis the 95% confidence intervals are shown.

Aircraft Noise Surveys

AUL-210	Australian Five Airport Survey	(1980)
CAN-168	Canadian National Community Noise Survey	(1979)
FRA-016	French Four-Airport Noise Study	(1965)
FRA-239	French Combined Aircraft/Road Traffic Survey	(1984)
NET-240	Schiphol Combined Aircraft/Road Traffic Survey	(1984)
NOR-311	Oslo Airport Survey	(1989)
NOR-328	Bodo Military Aircraft Exercise Study	(1991–1992)
NOR-366	Vaernes Military Aircraft Exercise Study	(1990–1991)
SWE-035	Scandinavian Nine-Airport Noise Study	(1969-72,74,76)
SWI-053	Swiss Three-City Noise Survey	(1971)
UKD-024	Heathrow Aircraft Noise Survey	(1967)
UKD-242	Heathrow Combined Aircraft/Road Traffic Survey	(1982)
UKD-238	Glasgow Combined Aircraft/Road Traffic Survey	(1984)
USA-022	U.S.A. Four-Airport Survey (phase 1 of Tracor Survey)	(1967)
USA-032	U.S.A. Three-Airport Survey (phase II of Tracor Survey)	(1969)
USA-044	U.S.A. Small City Airports (small City Tracor Survey)	(1970)
USA-082	LAX Airport Noise Study	(1973)
USA-203	Burbank Aircraft Noise Change Study	(1979)
USA-204	John Wayne Airport Operation Study	(1981)
USA-338	U.S.A. 7-Air Force Base Study	(1981)

Ref: Schultz 1978 & Fidell et al. 1991 & Miedema and Vos, 1998

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Ref: Schultz 1978 & Fidell et al. 1991 & Miedema and Vos, 1998

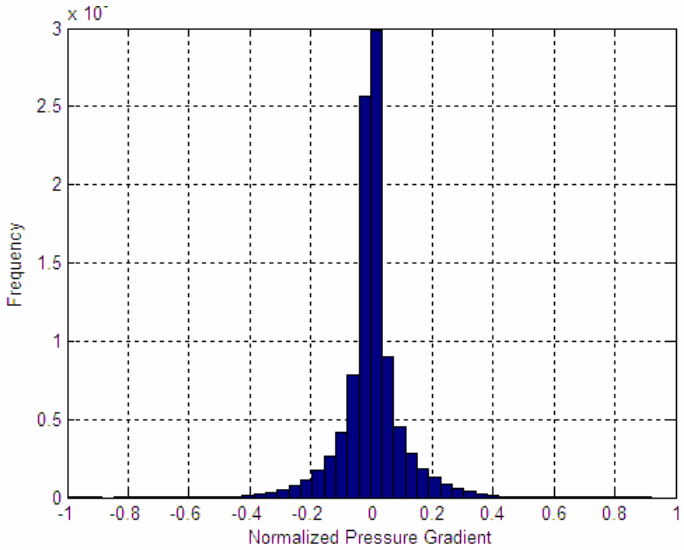
Analysis of Old Commercial Jet Noise

- Hard to get good data on old aircraft
  - Dynamic range of instrumentation
  - Medium of storage
  - (So, thanks David)
- Three examples:
  - 707 with newer engine
  - 727 departure
  - Concorde departure

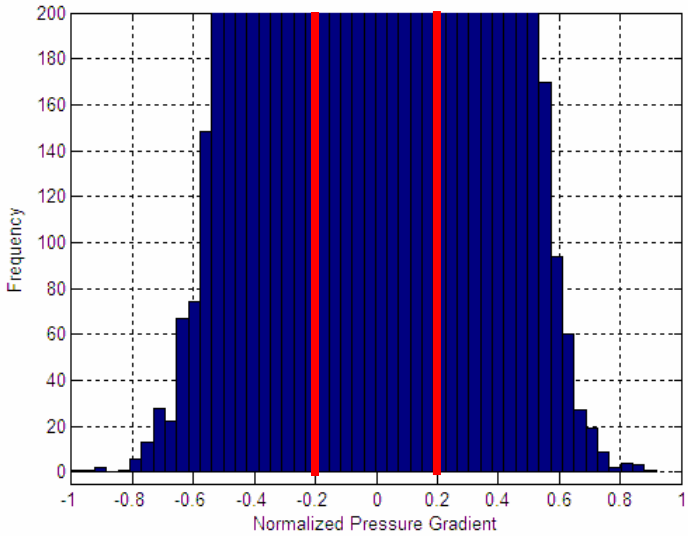
Analysis of Old Commercial Jet Noise

707 (with newer engine?)

Distribution of Normalized Pressure Gradient

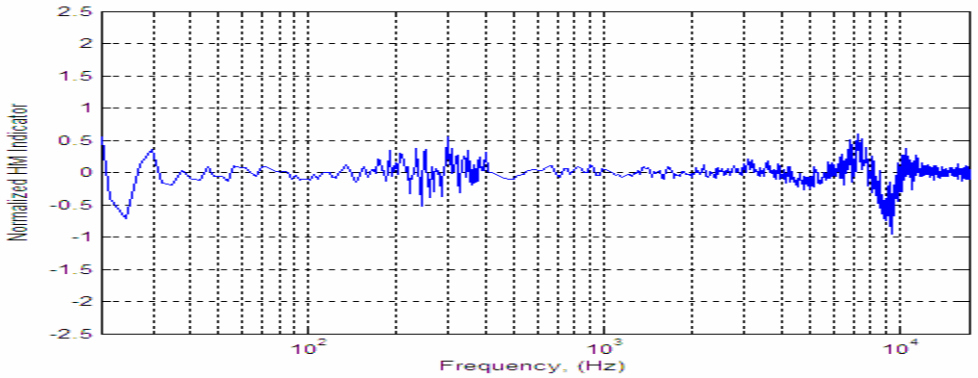


Zoom



Skewness 0.004

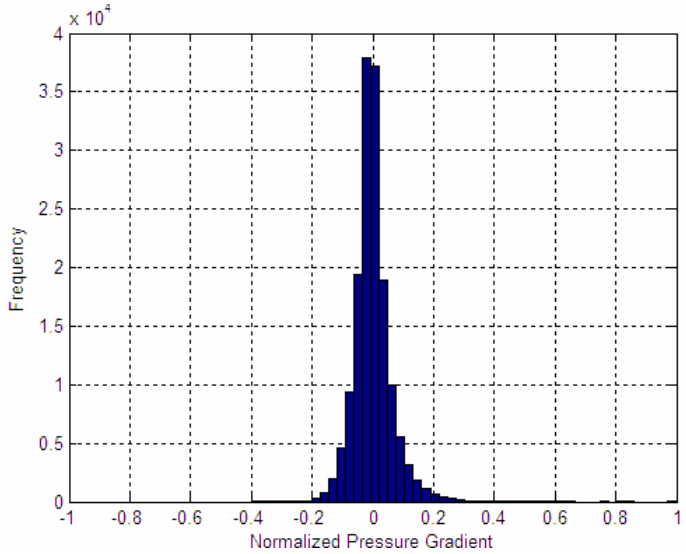
HMI



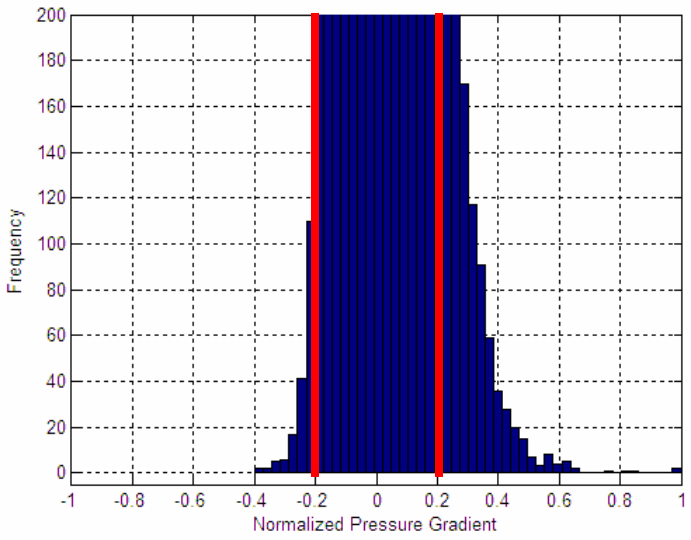
Analysis of Old Commercial Jet Noise

727

Distribution of Normalized Pressure Gradient

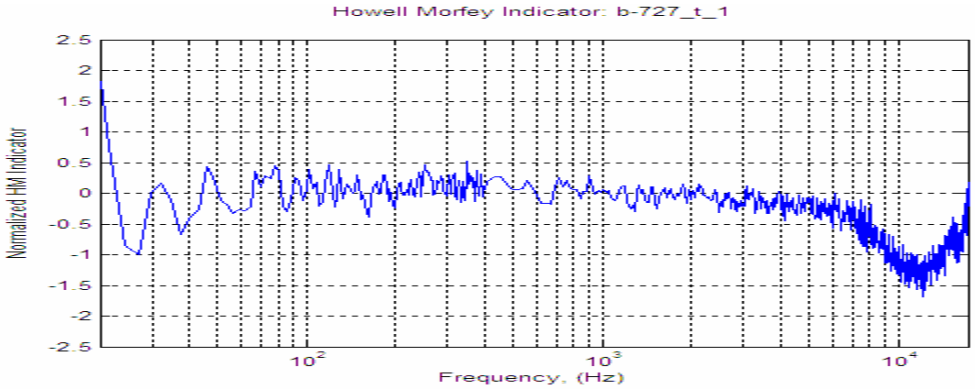


Zoom



Skewness 1.2

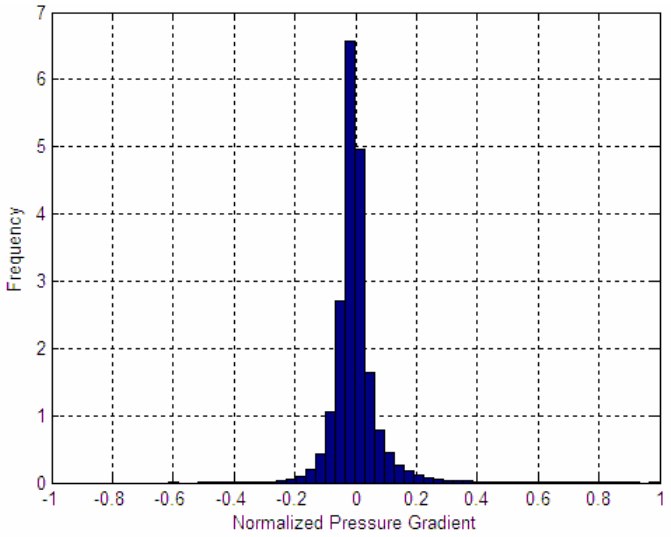
HMI



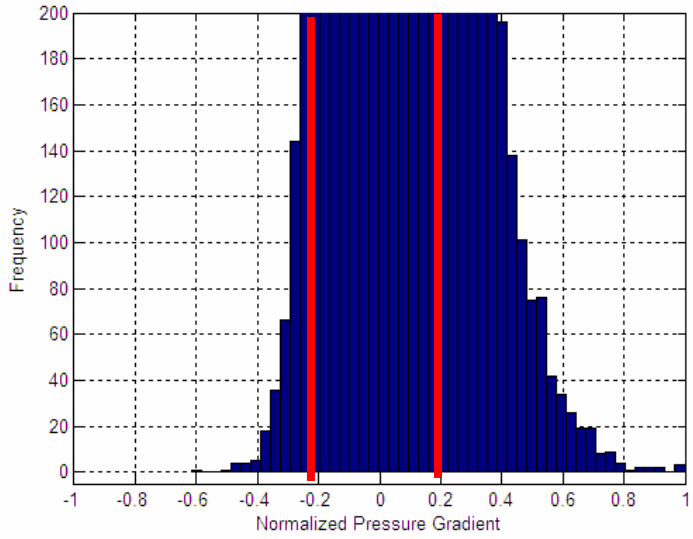
Analysis of Old Commercial Jet Noise

Concorde

Distribution of Normalized Pressure Gradient

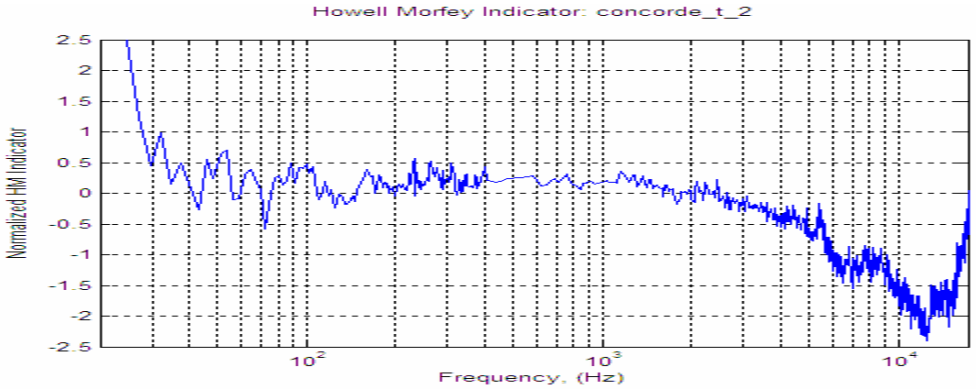


Zoom



Skewness 2.9

HMI



Wrap – Up & Question

- High amplitude jet noise
  - Nonlinear propagation effects
  - Shocks generate subjectively “louder” events
- Spectra-based metrics do not capture perceived loudness
- Old commercial aircraft noise seem to contain “crackle”
- Social surveys mainly involved old aircraft
- Does this explain difference noted by Miedema & Vos?
- **If so, can we adjust Schultz curve to better correlate with today’s commercial aircraft?**

Questions

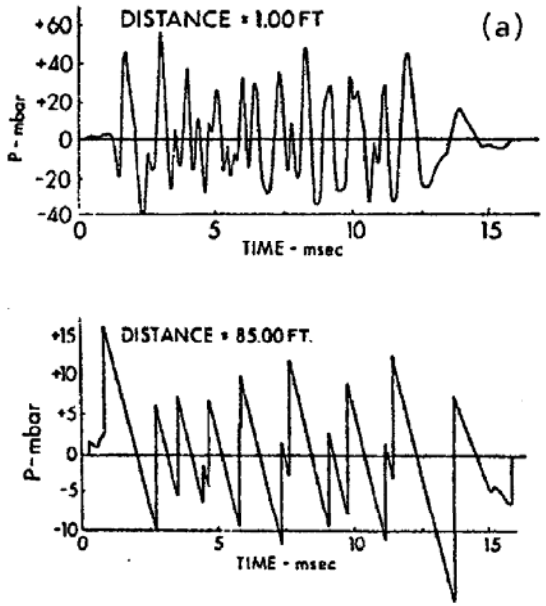
Thank you for listening

Back up

First, a Few Comments

Classic Blackstock data:

Steepening



Spectral Broadening

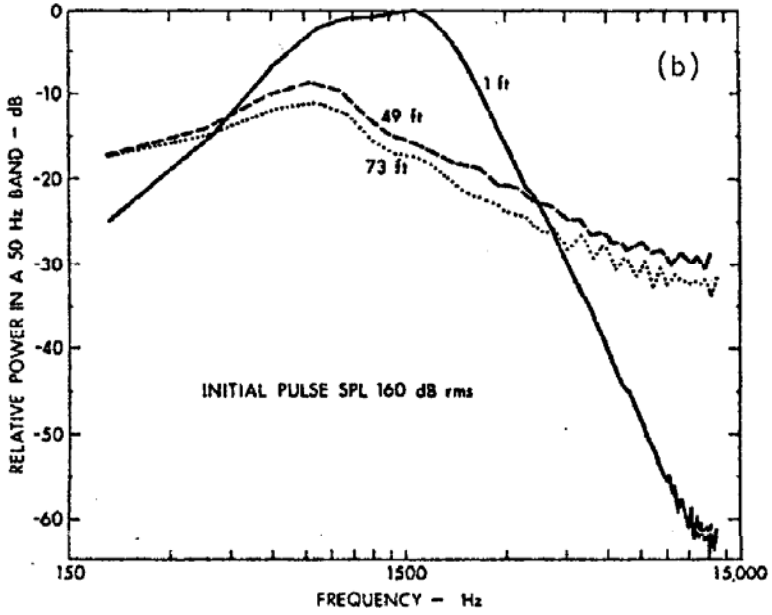
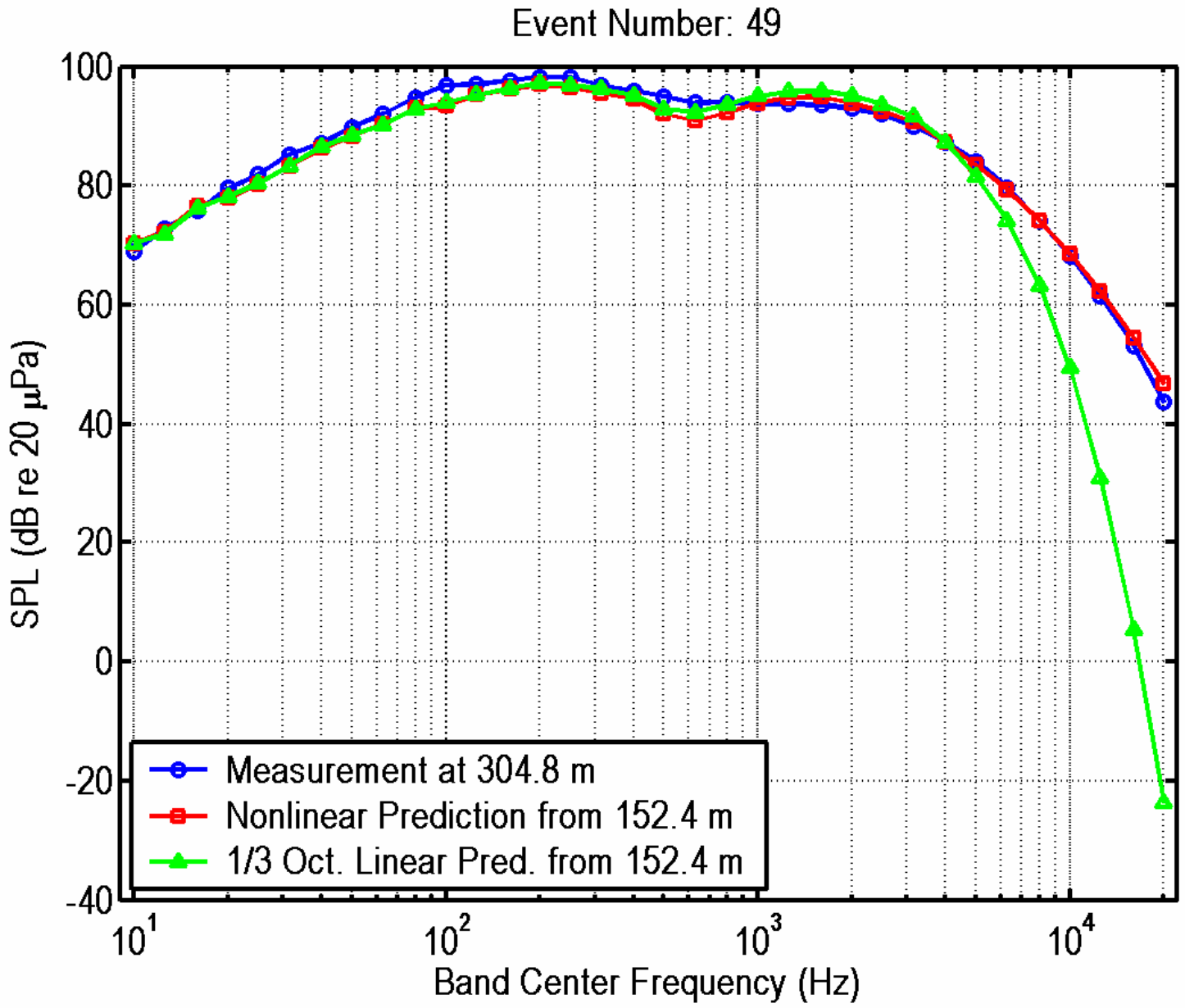


FIG. 4. (*a*) Comparison of measured noise waveforms near (at distance 1 ft = 0.3 m) and far away (85 ft = 29 m) from the source. (*b*) Related noise spectra measured at distances 1 ft (0.3 m), 49 ft (15 m), and 73 ft (27.3 m) (Pestorius and Blackstock, 1974).

[Hamilton and Blackstock, 1998]

90°, AB Nonlinear Prediction



Sample of Stage 3

- 757 Landing 
  - High by pass turbo fan
  - Crackle not present