Do Nonlinear Effects in Jet Noise Alter the Perception of Loudness?

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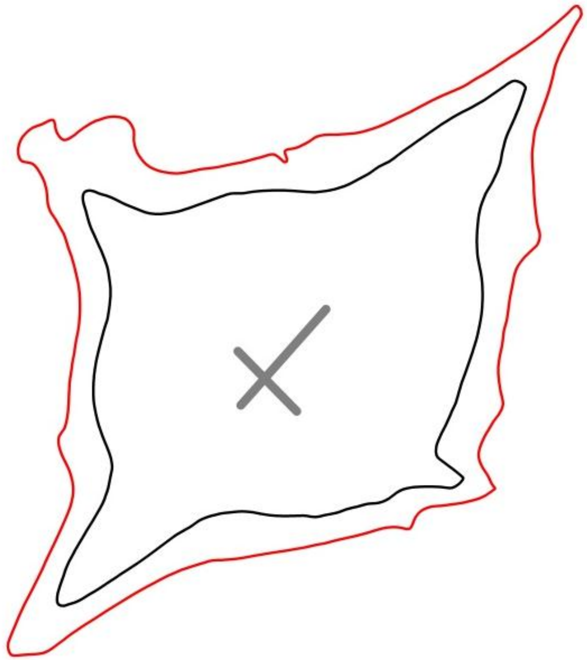
Overview

- Problem Statement
- Overview of New Findings
- Question Set-up
- 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

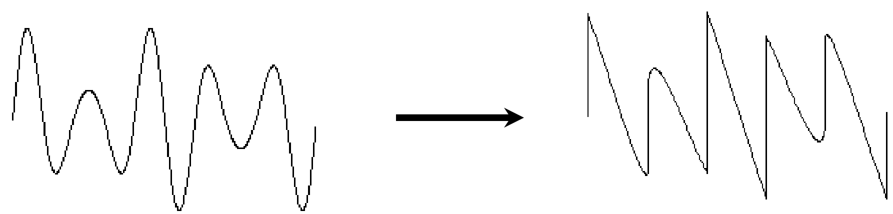
First, a Few Comments

Nonlinearities in Jet Noise

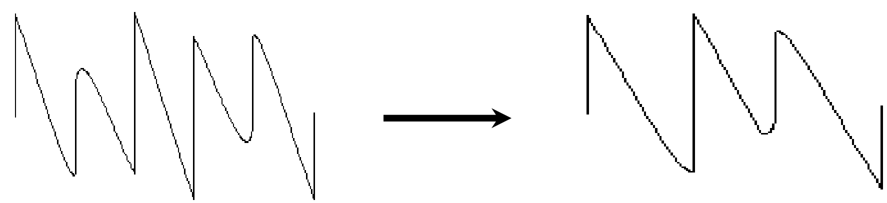
Pestorius and Blackstock (1974), broadband spectrum:

Energy is moved to both low AND high frequency:

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



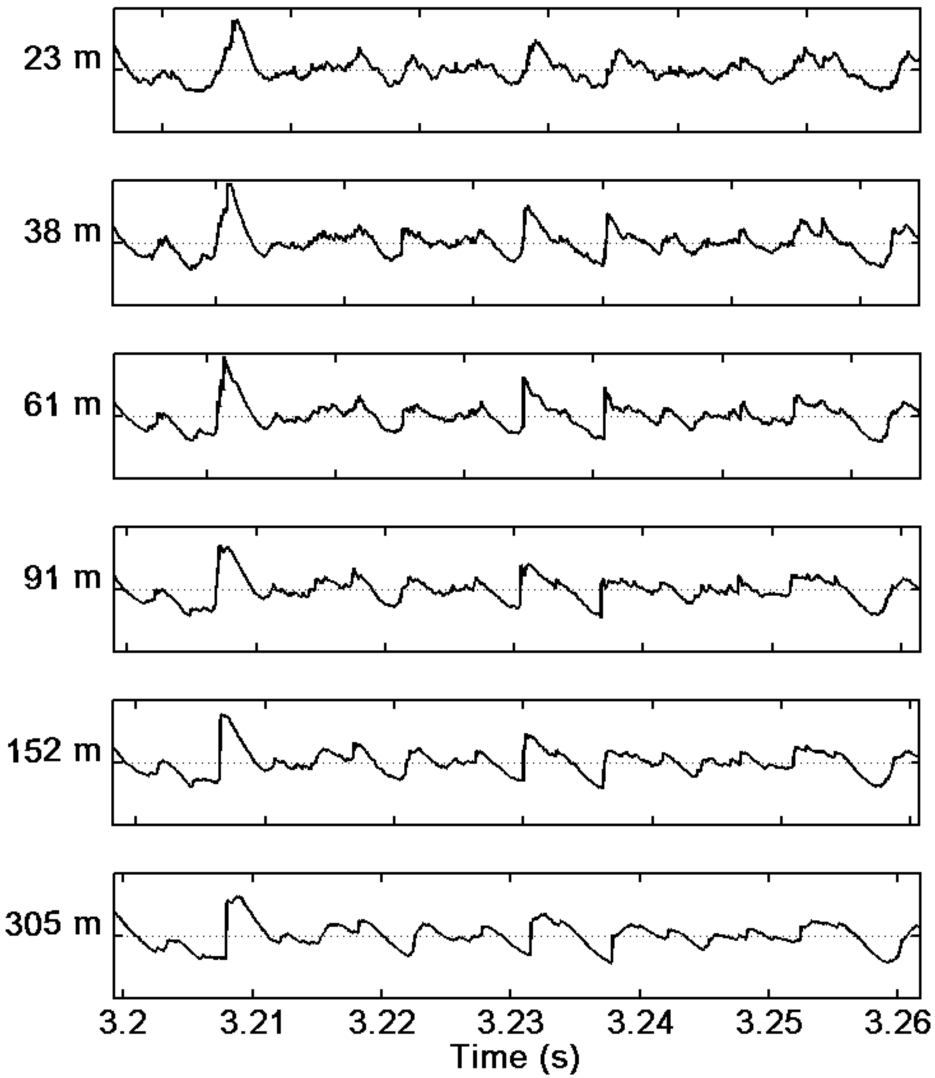
- **Shock coalescence**
  - *Energy is transferred towards* ***low***-*frequency range*



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

Nonlinearity and Jet Noise

- Static field test carried out in 2004 on F-22 Raptor
- Measured data and nonlinear prediction both show shock wave formation and spectral energy transfer
- The shock waves are very audible – “crackly.”



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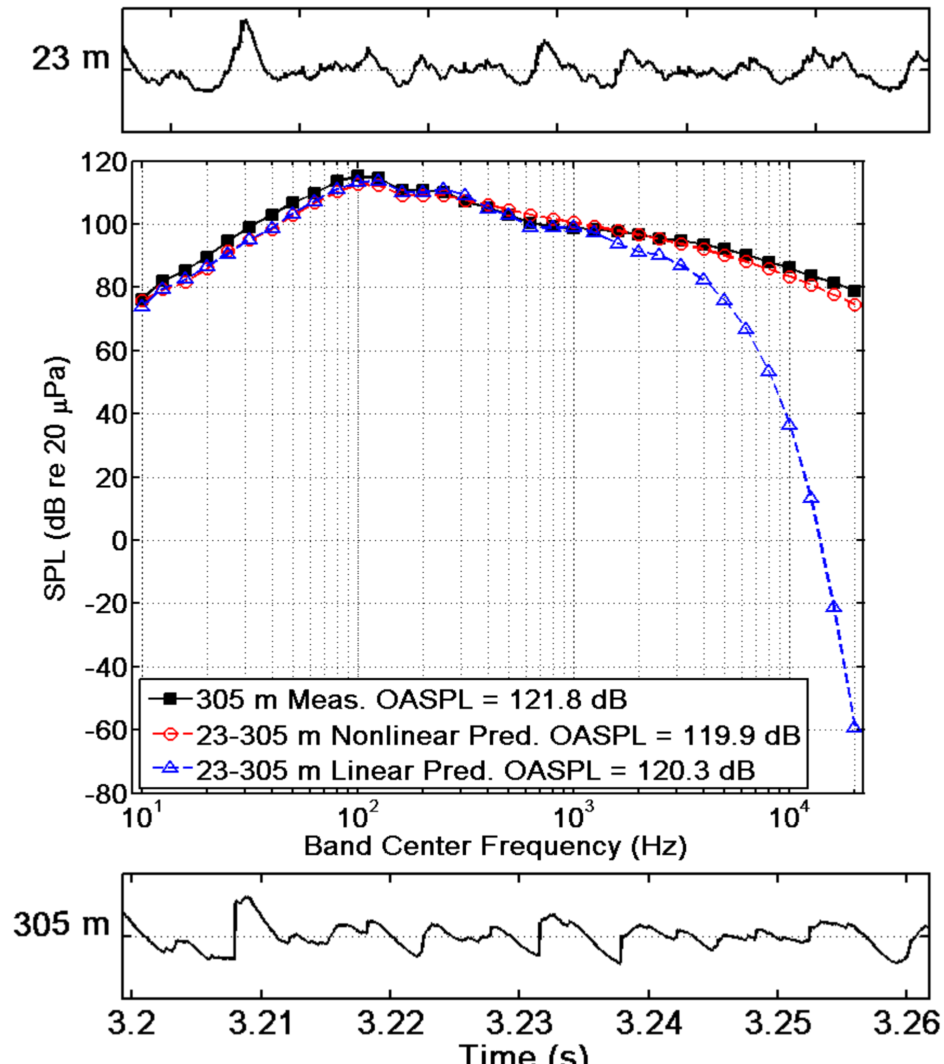

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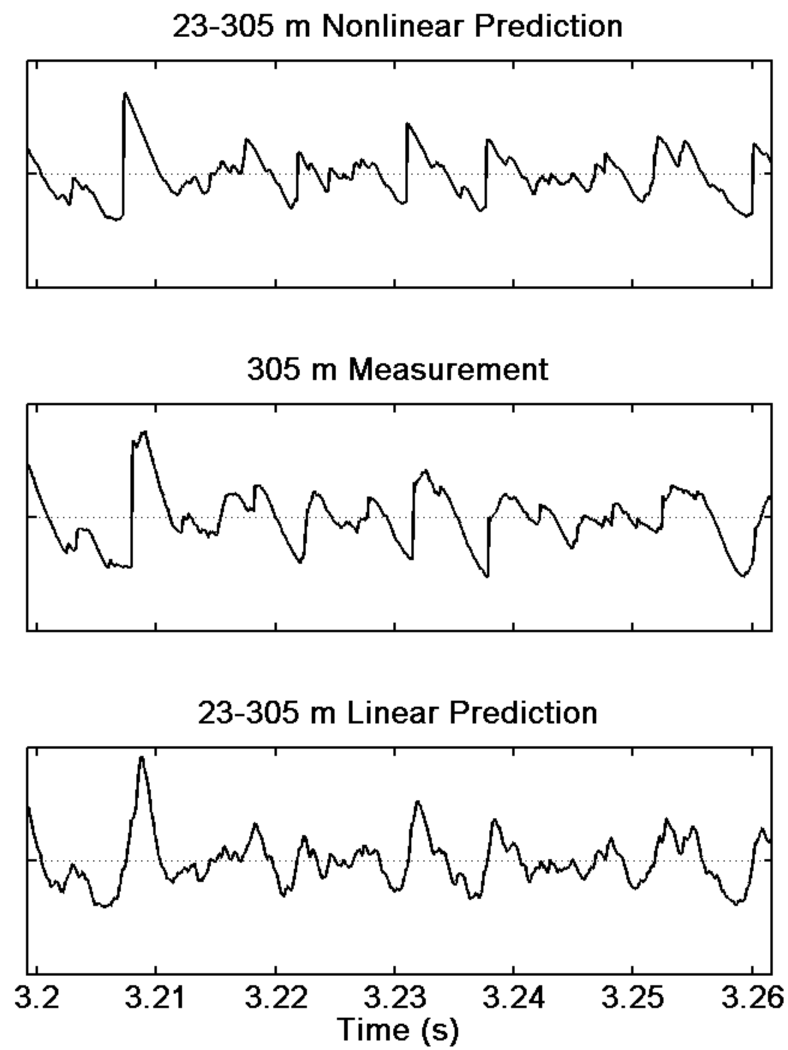

Calculating Nonlinearity Impact

Do you expect differences in metrics?

Metric	Measured at 305 m (dB)	Nonlinear Prediction (dB)	Linear Prediction (dB)
OASPL-Flat	121.8	119.9	120.3
OASPL-A	111.0	111.4	110.2
OASPL-C	121.5	119.6	120.2
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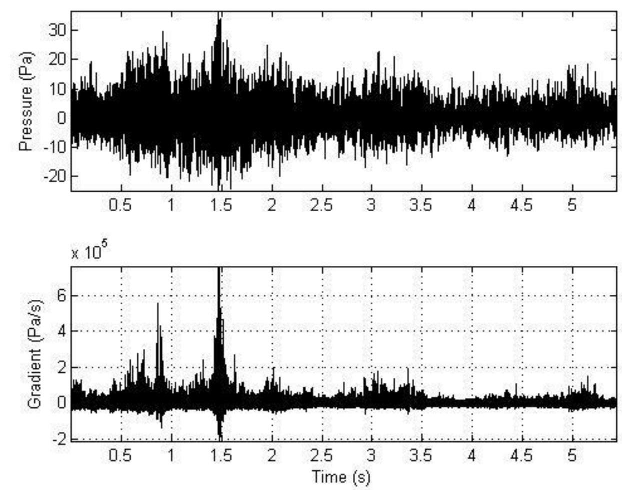
- Not what I expected based on my ear
- Recordings clearly show that the nonlinearity 'sounds' louder: Listen to waveforms embedded in: K. L. Gee, S. H. Swift, V. W. Sparrow, K. J. Plotkin, and J. M. Downing," "On the potential limitations of conventional sound metrics in quantifying perception of nonlinearly propagated noise," J. Acoust. Soc. Am. **121**, EL1-EL7 (2007).
- Additional explorations with time-varying loudness, successful with sonic booms, have proved unfruitful (See Swift and Gee, J. Acoust. Soc. Am., in press (2011).)

Potential Physical Nonlinear Metrics

How do we quantify these effects?

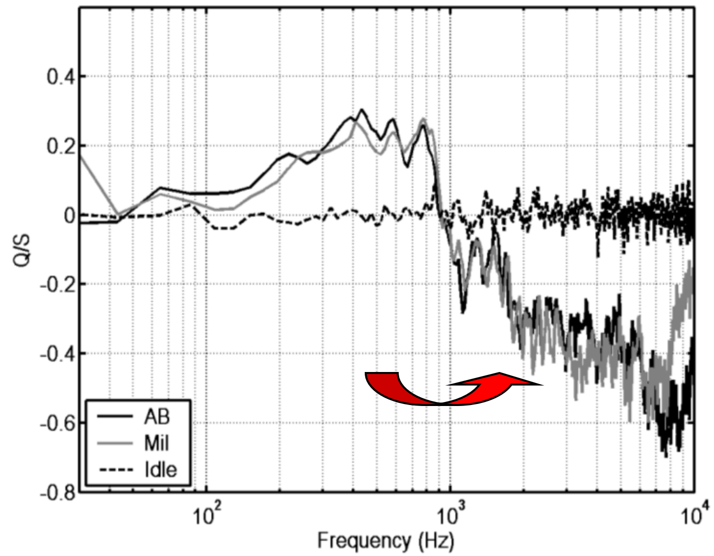
Physical Aspects

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



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

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



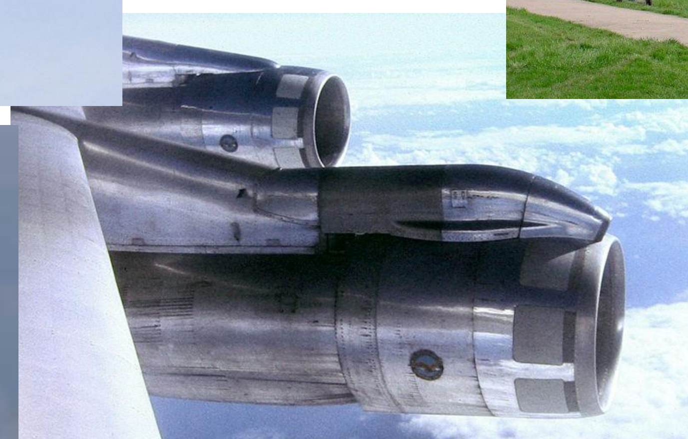
From Gee *et al.*, *AIAA Journal,* May 2005

Are you still with me?

- Military jets
  - Low by-pass engines + high thrust = high velocity and high acoustic amplitudes
  - High amplitude acoustic waveforms create shocks & nonlinearity
  - Nonlinear propagation creates “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 studies?



BRRC BLUE RIDGE RESEARCH AND CONSULTING

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

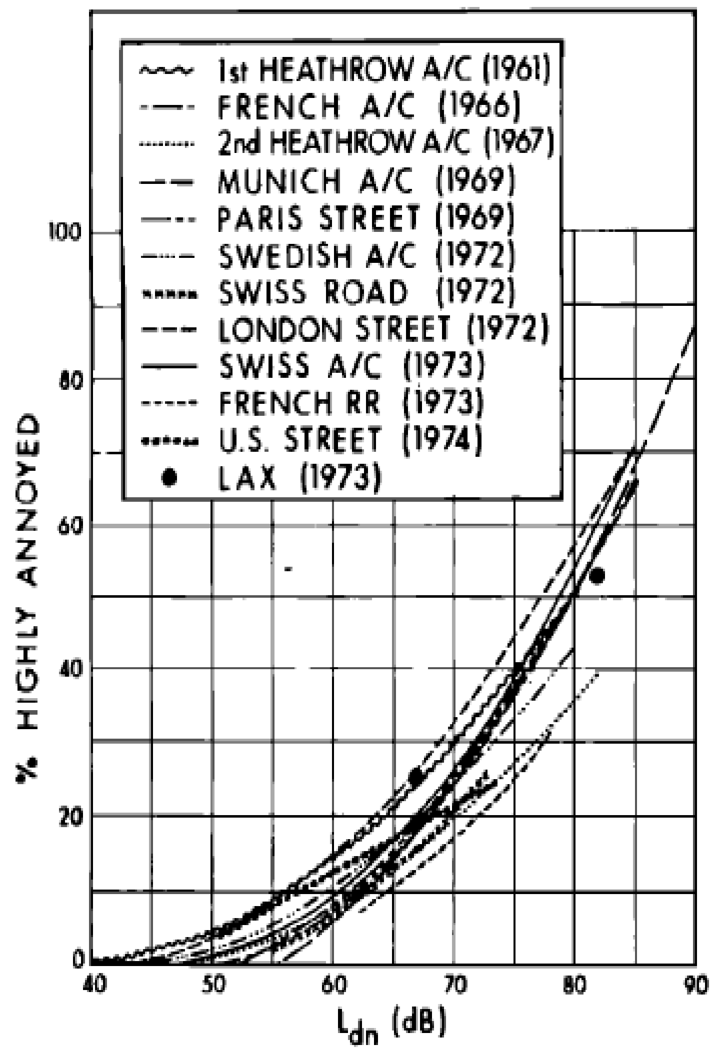


FIG. 2. Revised analysis of the clustering surveys using a rule for counting the percent highly annoyed that leaves out personal judgment in the individual surveys.

Miedema & Vos 1998

- Reanalysis suggests differences between modes of transportation

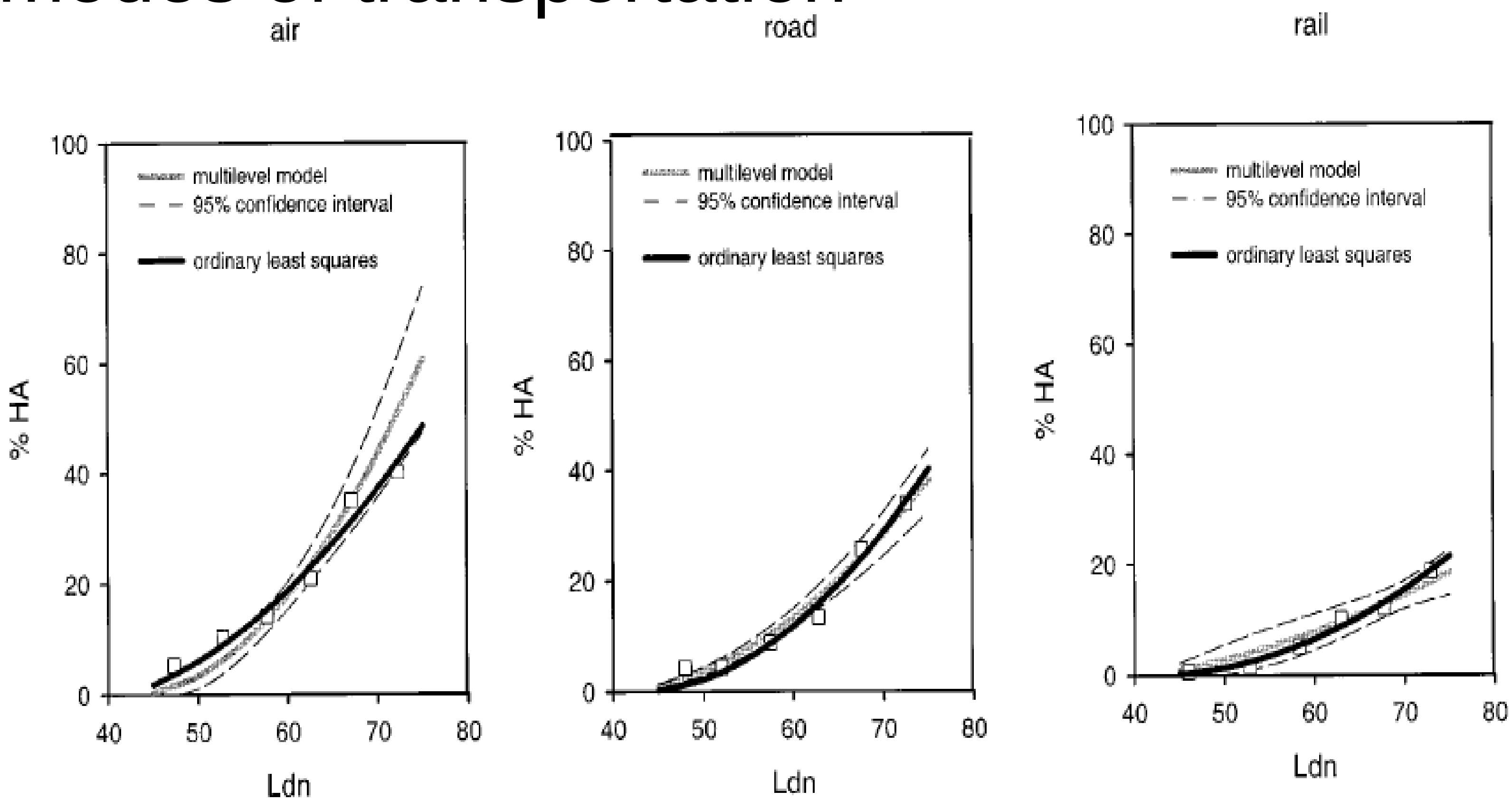


FIG. 3. Percentage highly annoyed persons (%HA) as a function of DNL. Two synthesis curves per mode of transportation, and the datapoints are shown. For the curves obtained with multilevel analysis the 95% confidence intervals are shown.

Aircraft Noise Surveys

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

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

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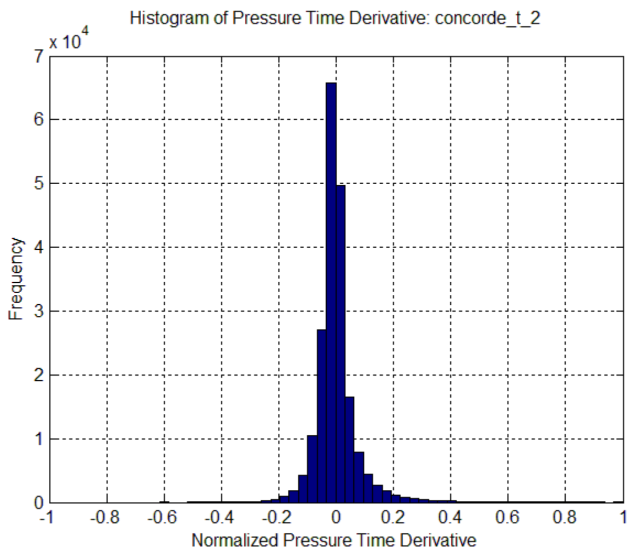
Analysis of Old Commercial Jet Noise

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

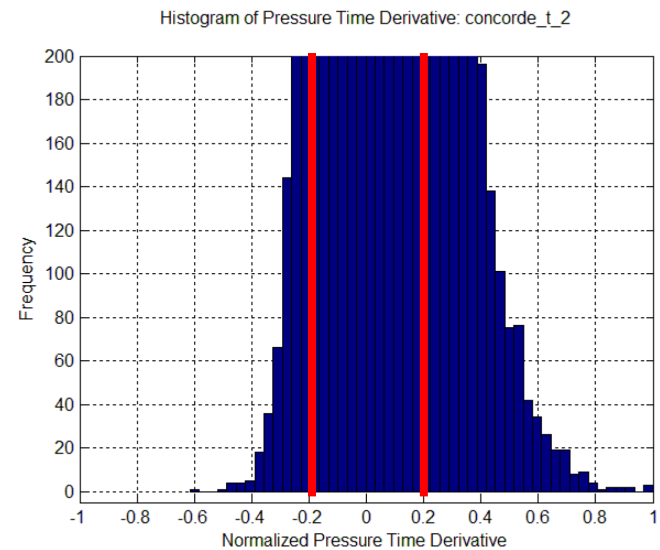
Analysis of Old Commercial Jet Noise

Concorde

Distribution of Normalized Pressure Time Derivative

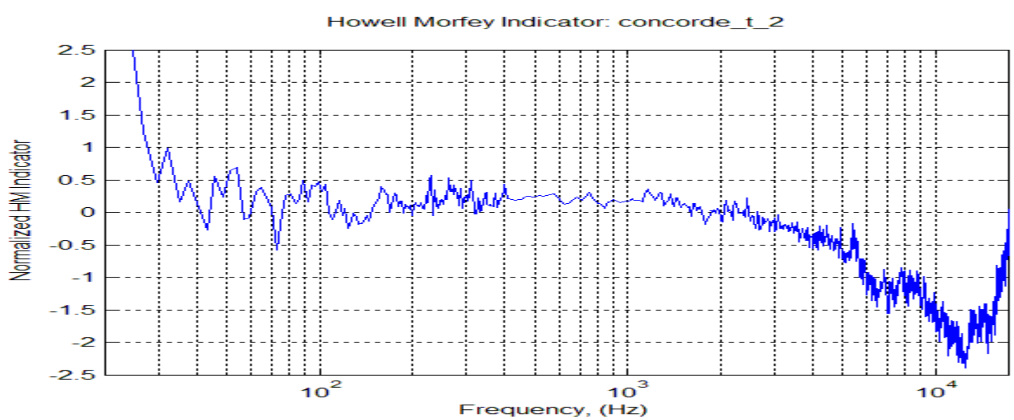


Zoom



Skewness 2.9

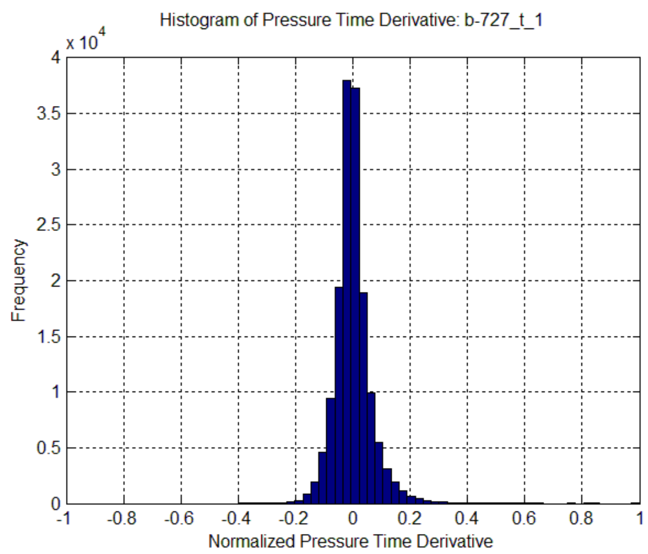
HMI



Analysis of Old Commercial Jet Noise

727

Distribution of Normalized Pressure Time Derivative



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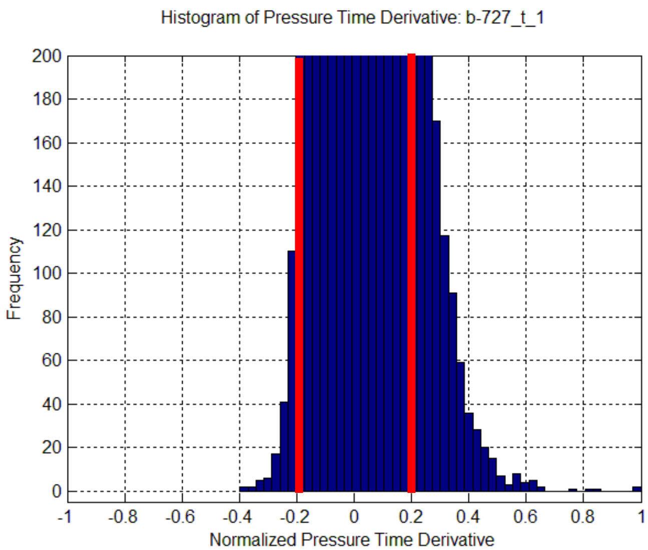
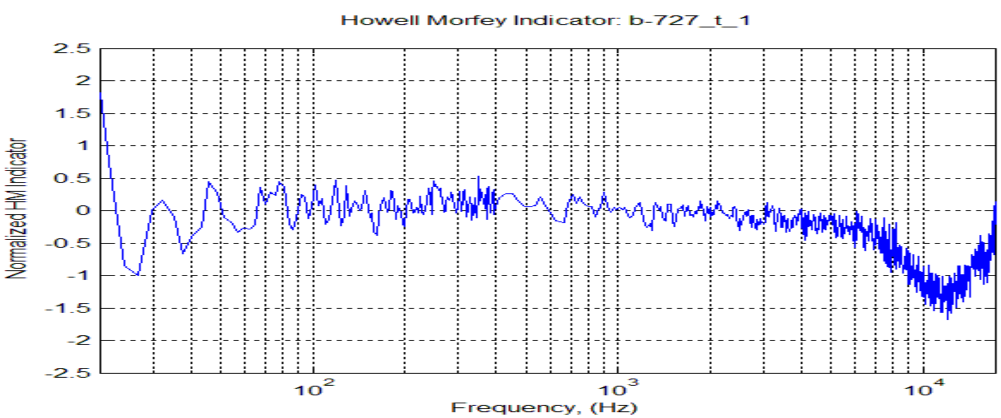


Skewness 1.2

HMI



Analysis of New Commercial Jet Noise

757

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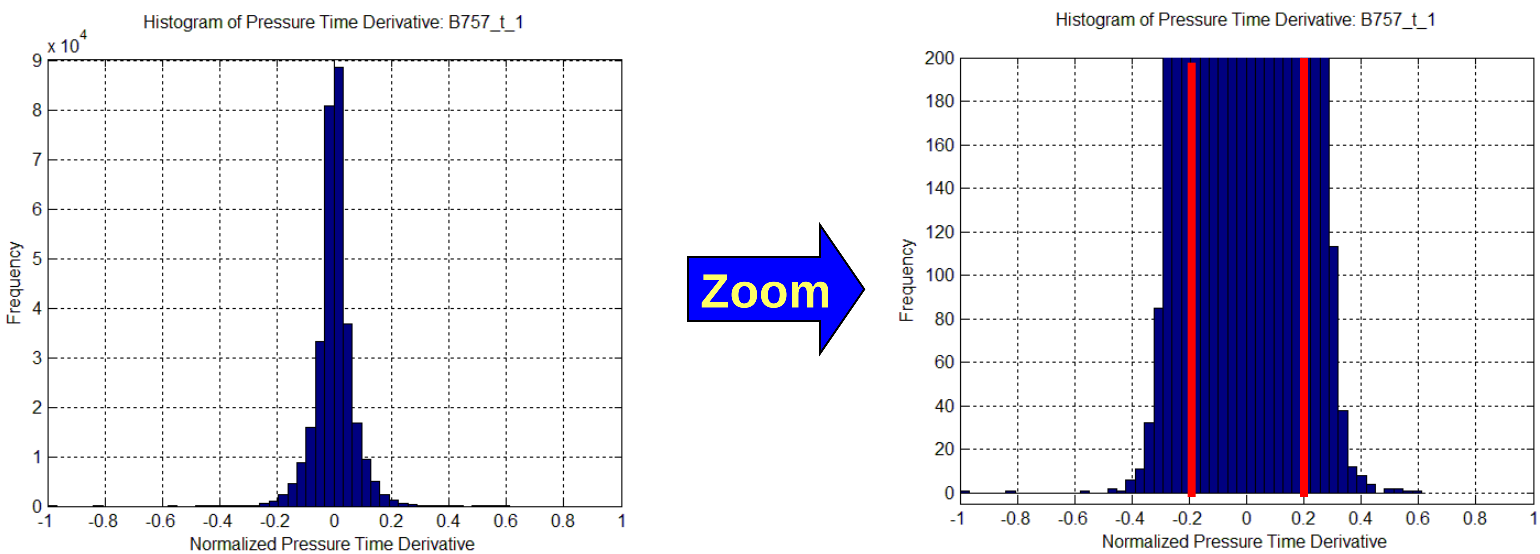
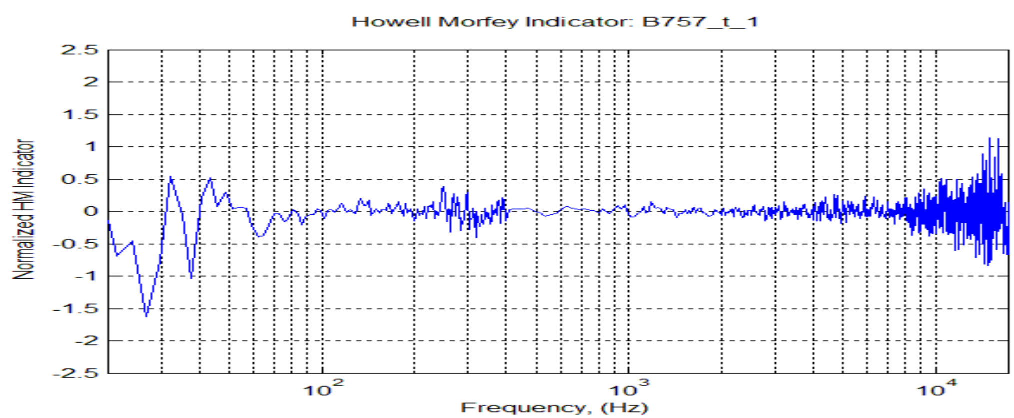


Skewness 0.0

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?

Wrap – Up & Question

- High amplitude jet noise
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  - 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, should we adjust Schultz curve to better correlate with today’s commercial aircraft that do not have “crackle”?**

Questions

Thank you for listening