

Time Delay Analysis of Turbofan Engine Direct and Indirect Combustion Noise Sources

(AIAA-2008-50 Spectral Separation of the
Turbofan Engine Coherent Combustion Noise Component)

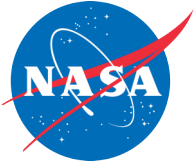
AARC Turbine Noise Workshop. Vancouver, BC, May 8-9,2008

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NASA John H. Glenn Research Center at Lewis Field, Cleveland, OH 44135

The core noise components of a dual spool turbofan engine were separated by the use of a coherence function. A source location technique based on adjusting the time delay between the combustor pressure sensor signal and the far-field microphone signal to maximize the coherence and remove as much variation of the phase angle with frequency as possible was used. The discovery was made that for the 130° microphone a 90.027 ms time shift worked best for the frequency band from 0 to 200 Hz while a 86.975 ms time shift worked best for the frequency band from 200 to 400 Hz. Hence, the 0 to 200 Hz band signal took more time than the 200 to 400 Hz band signal to travel the same distance. This suggests the 0 to 200 Hz coherent cross spectral density band is partly due to indirect combustion noise attributed to entropy fluctuations, which travel at the flow velocity, interacting with the turbine. The signal in the 200 to 400 Hz frequency band is attributed mostly to direct combustion noise. Results are presented herein for engine power settings of 48, 54, and 60 percent of the maximum power setting.

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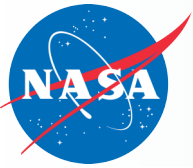
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INTRODUCTION

- Engine Combustion-Noise Sources

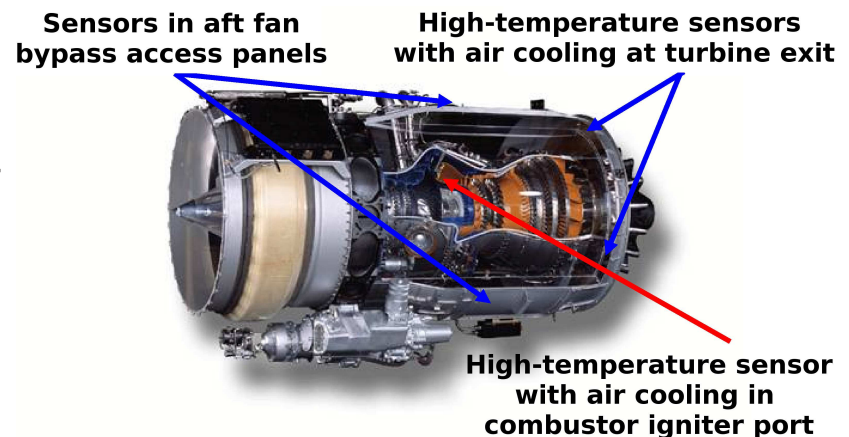
- ◇ direct: pressure fluctuations directly produced by unsteady combustion
- ◇ indirect: entropy fluctuations converted to noise by turbine stage

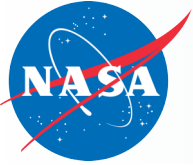
- Diagnostic Technique

- ◇ coherence analysis with adjustable time delay
- ◇ maximize coherence—minimize phase angle variation

- NASA/Honeywell EVNERT Data

- ◇ Honeywell Aerospace's San Tan outdoor engine test facility, 2005-2007
- ◇ Honeywell TECH977 research engine typical of 6,000-8,000 lbs thrust class
- ◇ far-field microphones & internal sensors





COHERENCE FUNCTION

- Coherence Function, $\gamma(f)$:

$$\gamma_{xy}^2(f) = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)} \quad 0 \leq \gamma_{xy}^2 \leq 1$$

$G_{xy}(f)$ = cross power spectral density

- Finite Data Sequences \Rightarrow Noise-Floor Concept

$$\gamma_{nn}^2 < \gamma_{xy}^2 \leq 1 \quad \gamma_{nn}^2 = 1 - (1 - P)^{1/(M-1)}$$
$$P = 0.95 \ \& \ M = 1120 \Rightarrow \gamma_{nn}^2 = 0.00267$$

P = P-percent confidence interval M = number of independent data segments

◇ traditionally: $\gamma_{nn}^2 = 0.1$

- Time-Shift (D) Far-Field Signal To Account For Propagation Delay

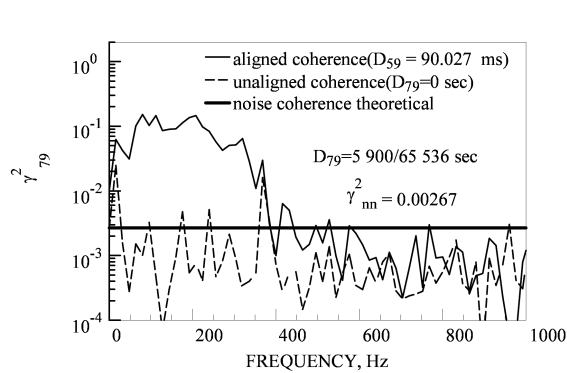
◇ unaligned ($D = 0$): only tones above noise floor

◇ aligned ($D > 0$): coherent broadband also above noise floor —

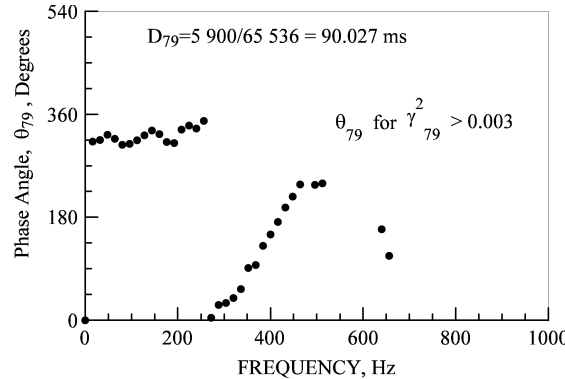
select D to minimize variation in $arg[G_{xy}(f; D)]$



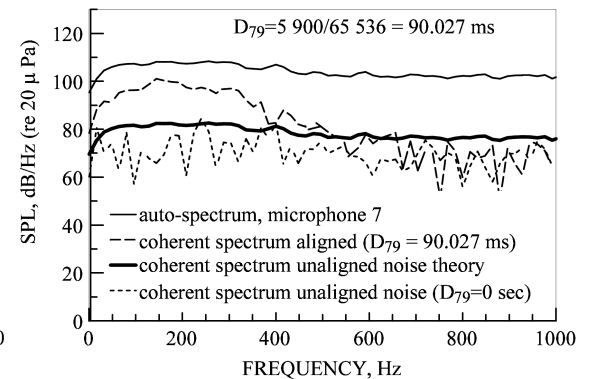
54 % POWER, 130 DEG. DIRECTION



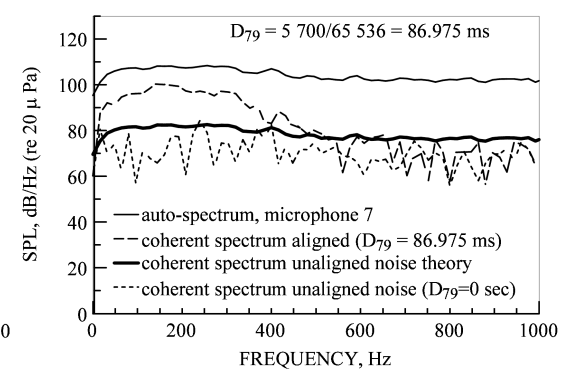
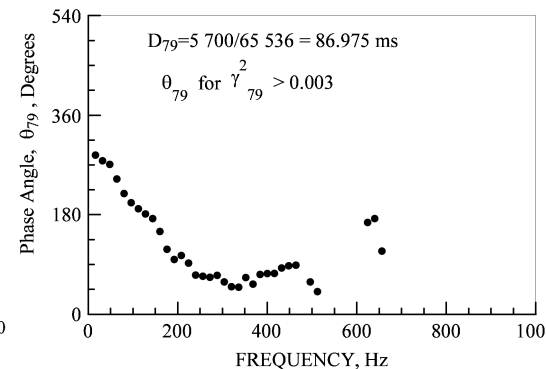
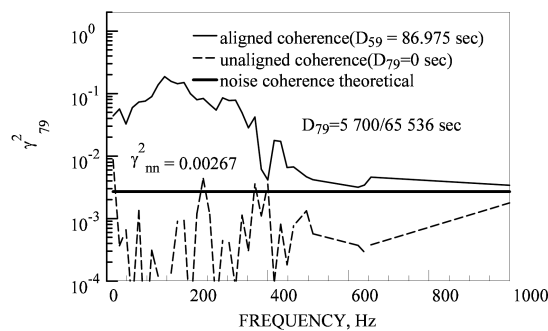
(a) Coherence between microphone at 130° and C1P1 combustor pressure sensor.



(b) Aligned cross-spectrum phase angle between microphone at 130° and C1P1 combustor pressure sensor.



(c) Coherent output power at microphone at 130° using C1P1 combustor pressure sensor.



- Coherent Signal In 0-200 Hz Band Took 3.05 ms Longer Time Than 200-400 Hz Band
- ◇ Same Δt for all power levels (48, 54, 60 %) and direction (110, 130, 160 deg.)



SUMMARY

- Variable Time-Delay Coherence Analysis of Honeywell/NASA EVNERT Static Engine-Test Data
 - ◇ internal pressure sensor & aft-quadrant far-field microphones
 - ◇ technique maximizes coherence and minimizes phase-angle variation
 - ◇ coherence noise floor is identified
- Aligned And Unaligned Coherence Techniques Used
 - ◇ method was successful
 - ◇ low levels of coherence validated as due to combustion noise
- Strong Indication of Indirect Combustion Noise
 - ◇ coherent noise in the 0-200 Hz frequency band had longer propagation time than the 200-400 Hz band
 - ◇ direct combustion noise propagates at the local speed of sound everywhere
 - ◇ indirect combustion noise propagates as entropy fluctuations with the local mean flow velocity until converted to acoustic waves in the turbine
 - ⇒ should take longer time to reach far-field microphone.

