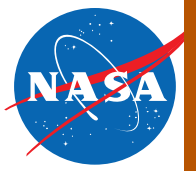
National Aeronautics and Space Administration



Tone and Broadband Noise Separation from Acoustic Data of a Scale-Model Counter-Rotating Open Rotor (AIAA-2014-2744)

Dave Sree - *Tuskegee University, Alabama, USA*

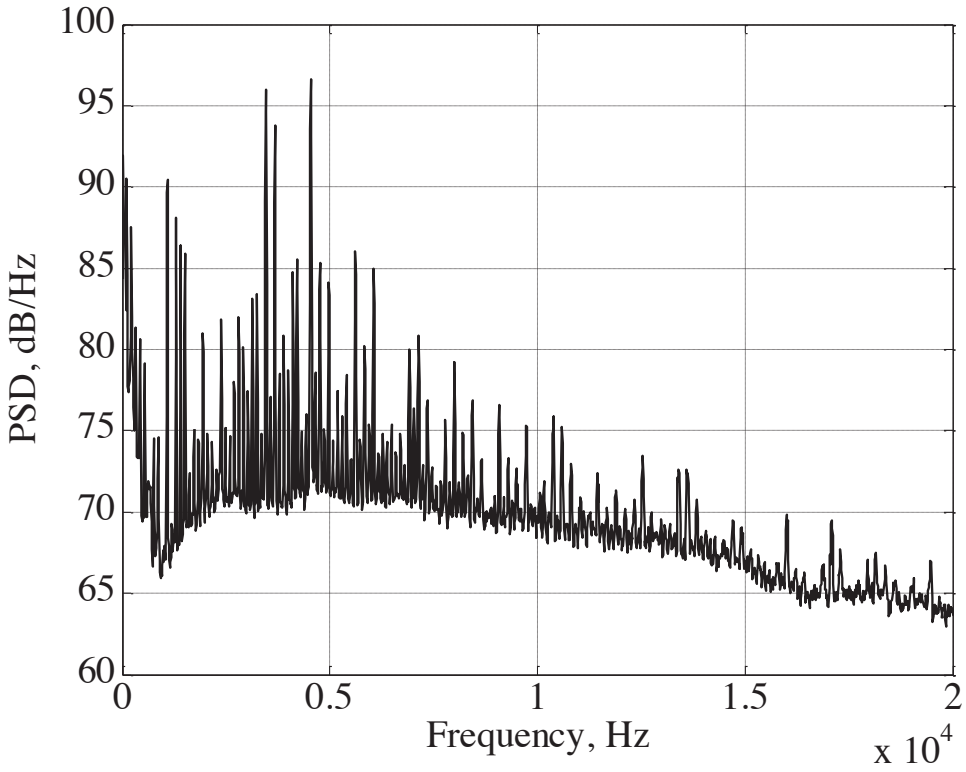
David B. Stephens - *NASA Glenn Research Center, Ohio, USA*

Funding for this research was provided by:
NASA Environmentally Responsible Aviation Project,
NASA Fixed Wing Project,
NASA Glenn Faculty Fellowship Program.

20th AIAA/CEAS Aeroacoustics Conference (AIAA Aviation 2014 Forum), Atlanta, GA

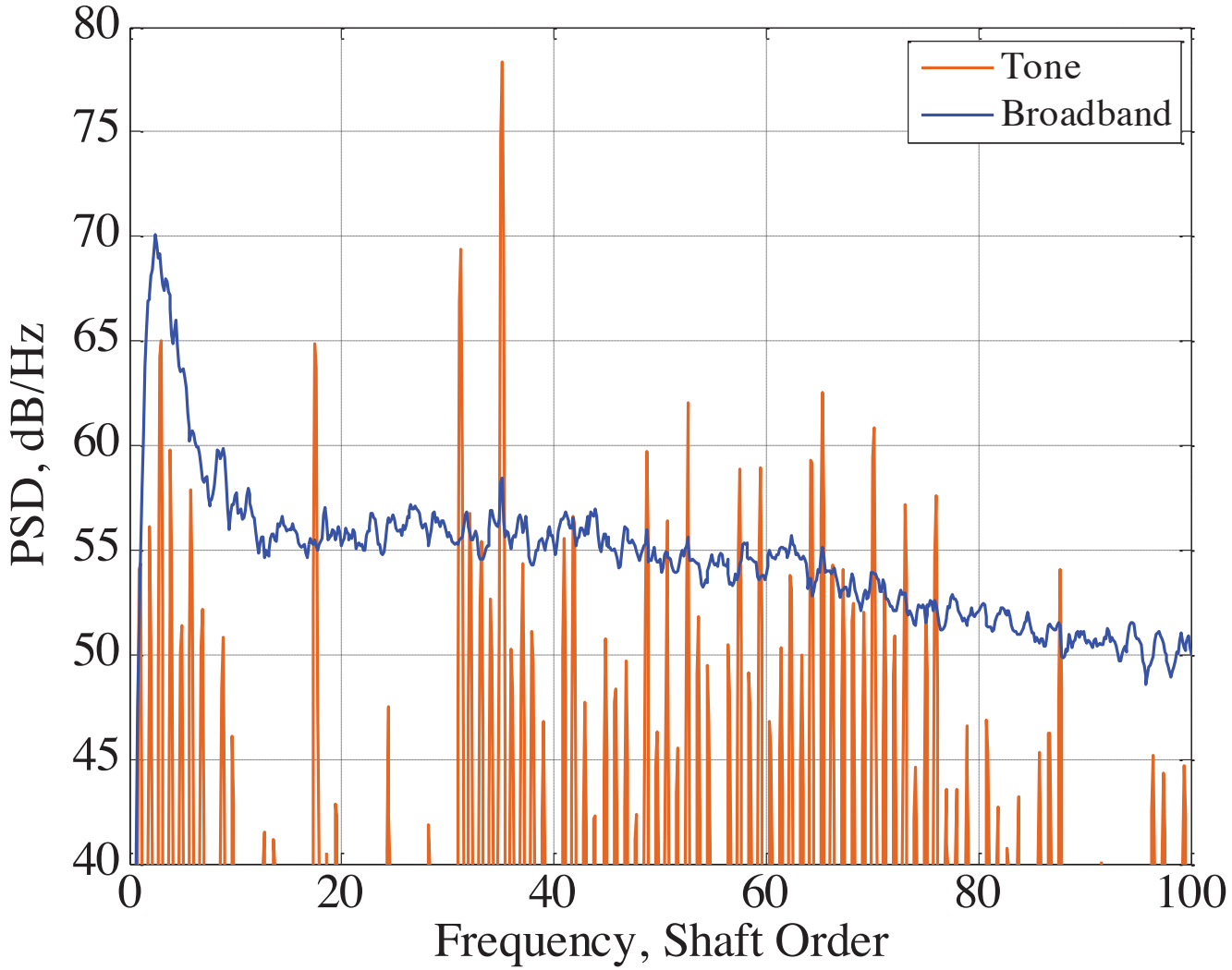
Open Rotor Acoustics

- ✧NASA/GE Open Rotor Test Campaign (2009-2012)
- ✧Open rotor spectra composed of tones and broadband – 12 x 10 blade counts produce many tones
- ✧Objective: <u>Develop a tool to separate tones and broadband</u>



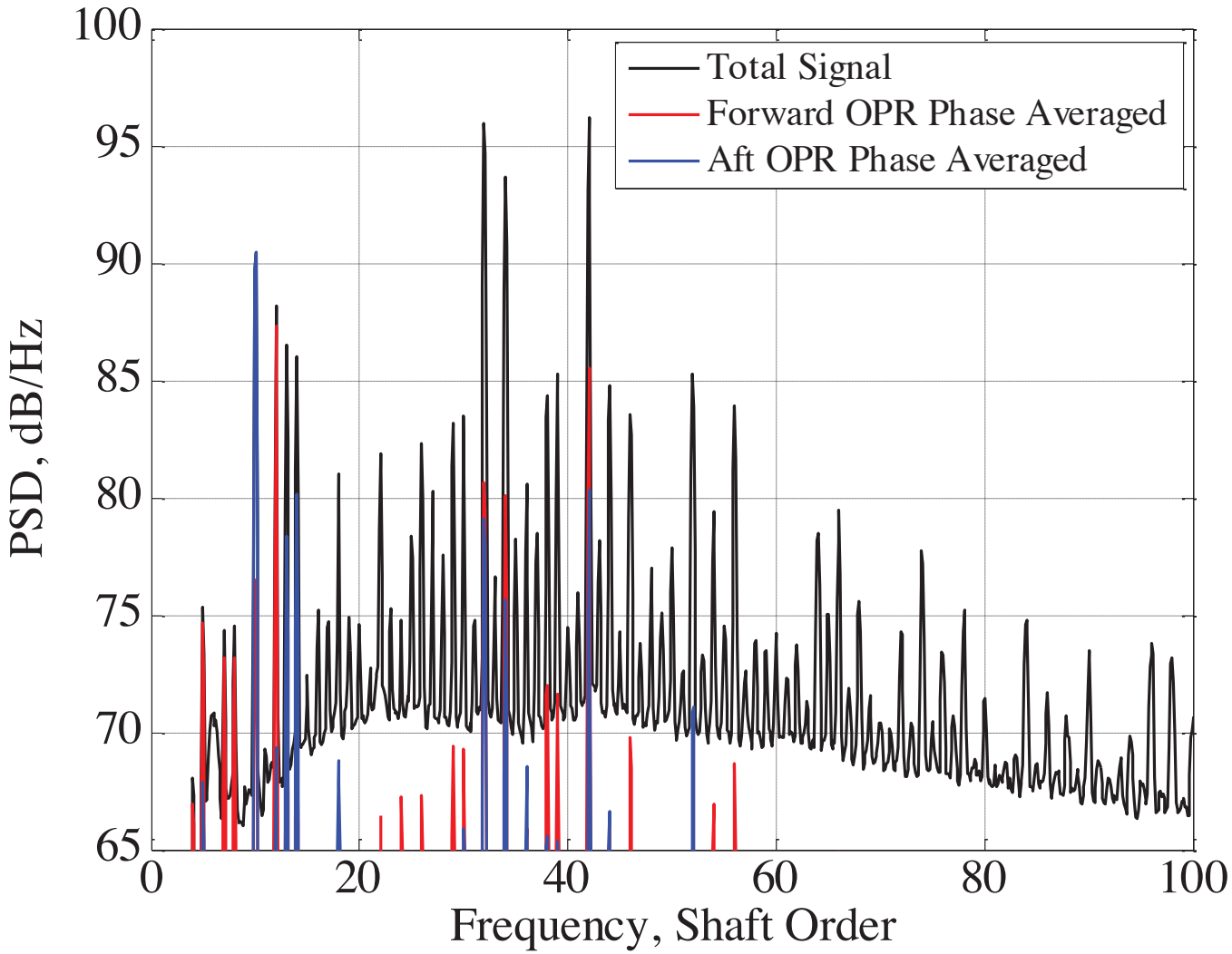
Synchronous Averaging for Fans

- **For single shaft data (like fan data), synchronous or phase-locked averaging provides an unambiguous way to separate tone and BB.**



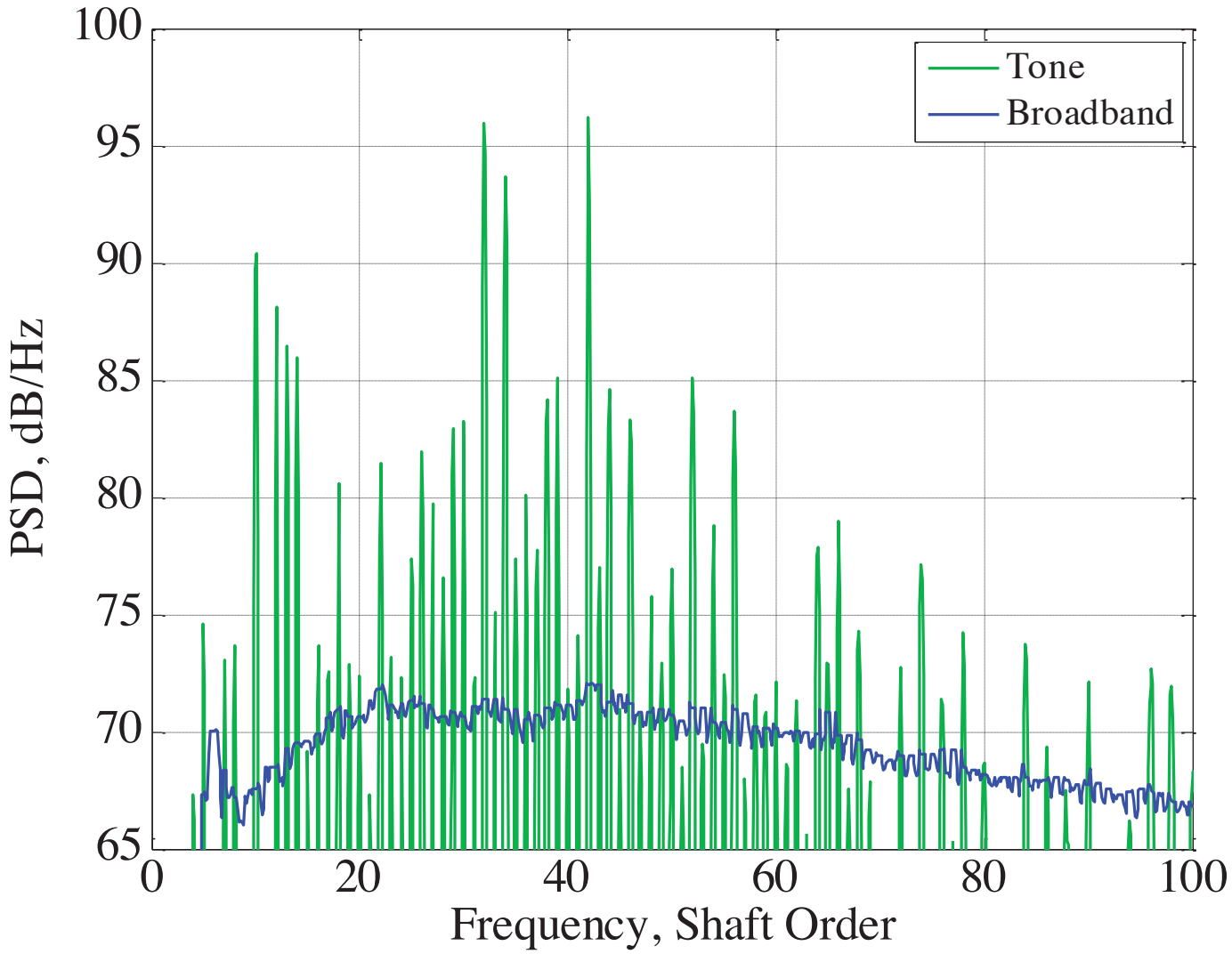
Synchronous Averaging for Open Rotor

- **For uncoupled two-shaft open rotor systems, phase between the rotors drifts and synchronous averaging only captures individual rotor tones, but not the interaction tones.**



Spectral Processing for Open Rotor Data

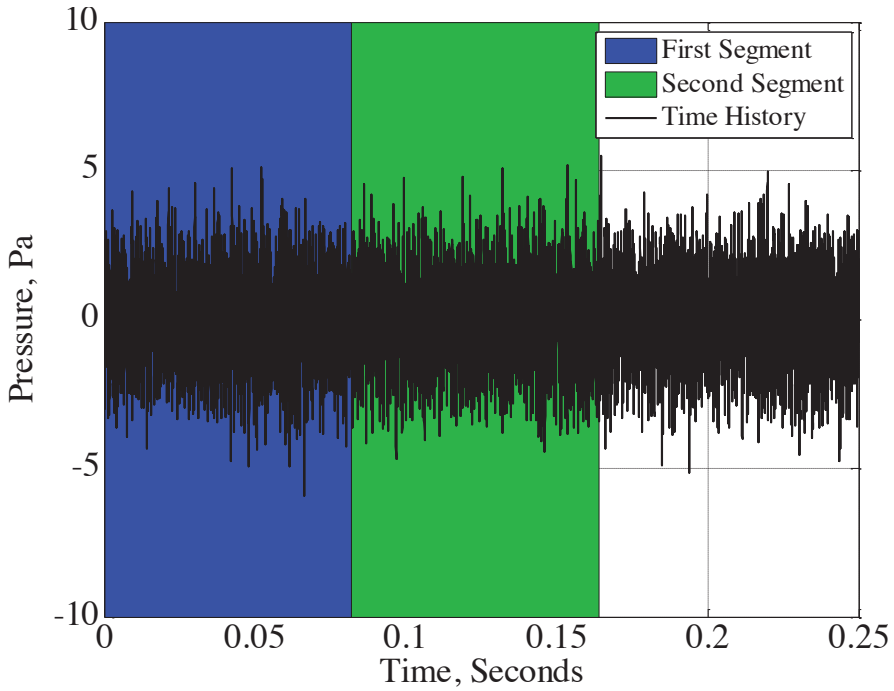
- "Clipping" the tones (say, via moving median approach) is one way of estimating the broadband, but how accurate is it?



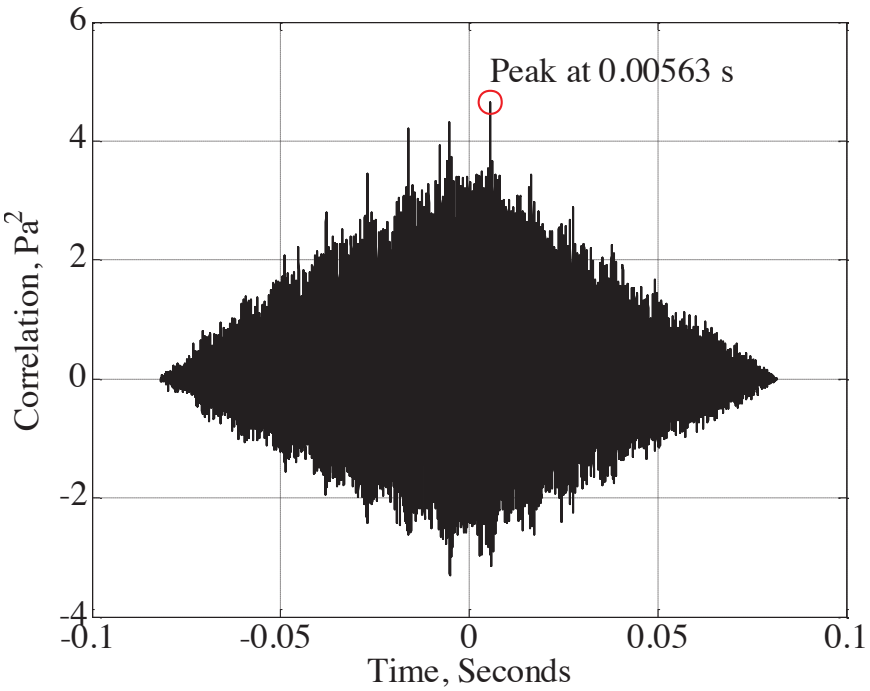
New Processing Method

✧**Capture correlated portion of signal before phase drifts too much**

Take two consecutive segments of the desired FFT length



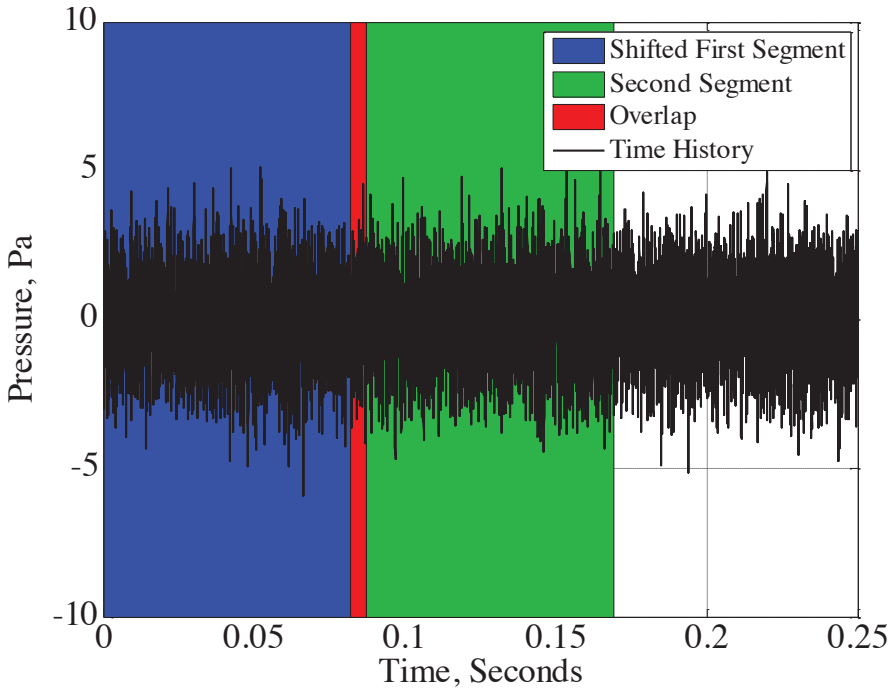
Calculate cross-correlation and find the time delay of the peak



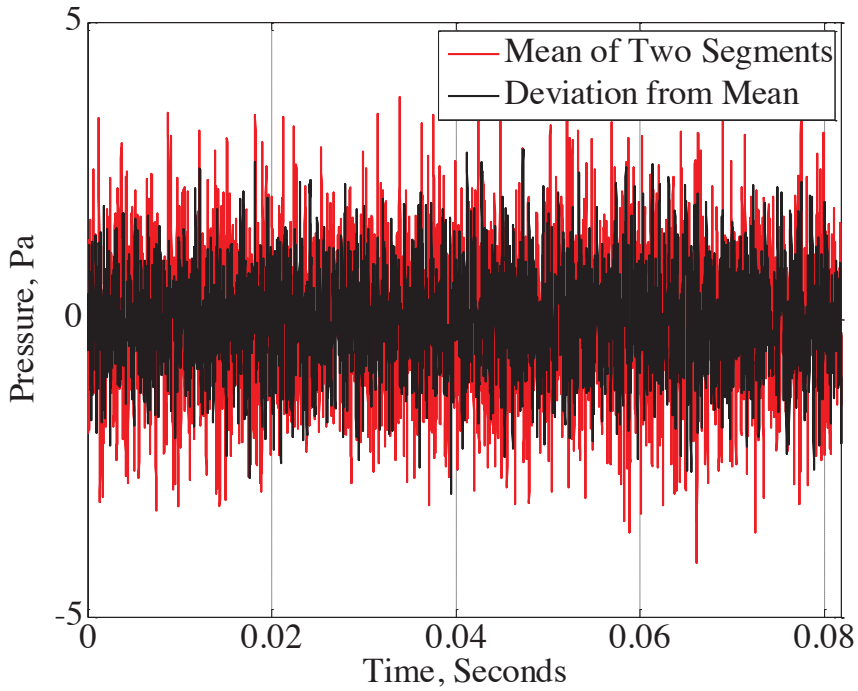
D. Sree, "A novel signal processing technique for separating tonal and broadband noise components from counter-rotating open-rotor acoustic data," *International Journal of Aeroacoustics*, 2013.

New Processing Method

Shift second segment by the time delay, maintaining segment length

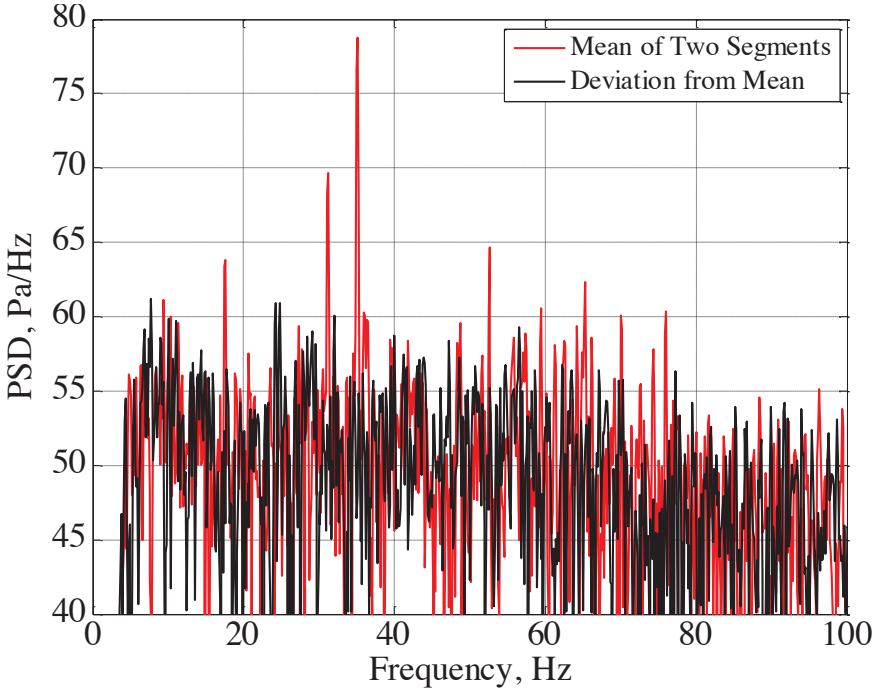


Calculate mean of the two segments and the deviation from the mean

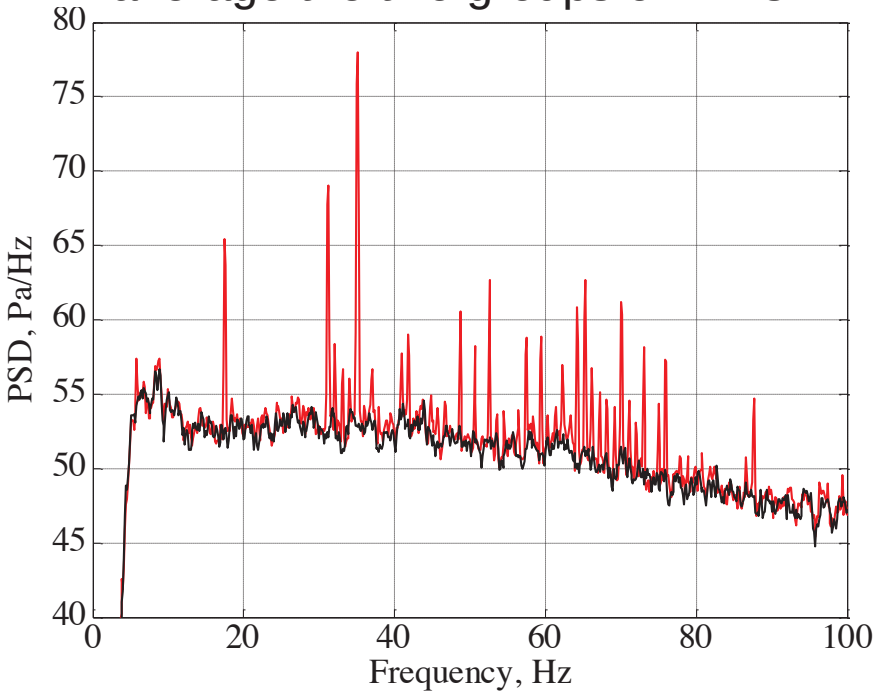


New Processing Method

Calculate the FFT of mean and deviation



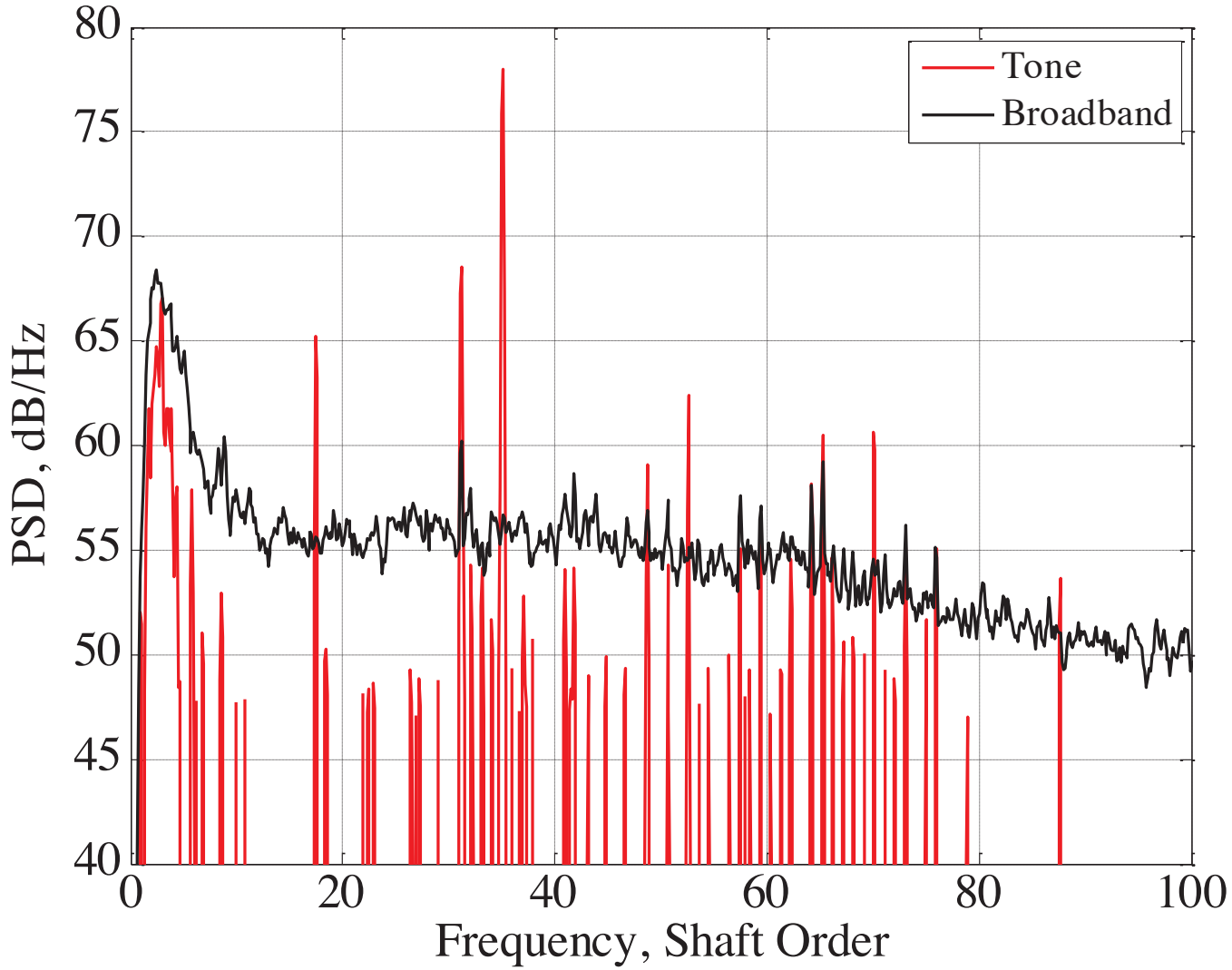
Repeat the process until end of the time record is reached, and then average the two groups of FFTs.



- **Tones end up in “segment mean”**
- **Broadband split; need to correct**
- **Usual spectral estimation like windowing, overlapping, etc. can be included**

New Method Applied to Fan Data

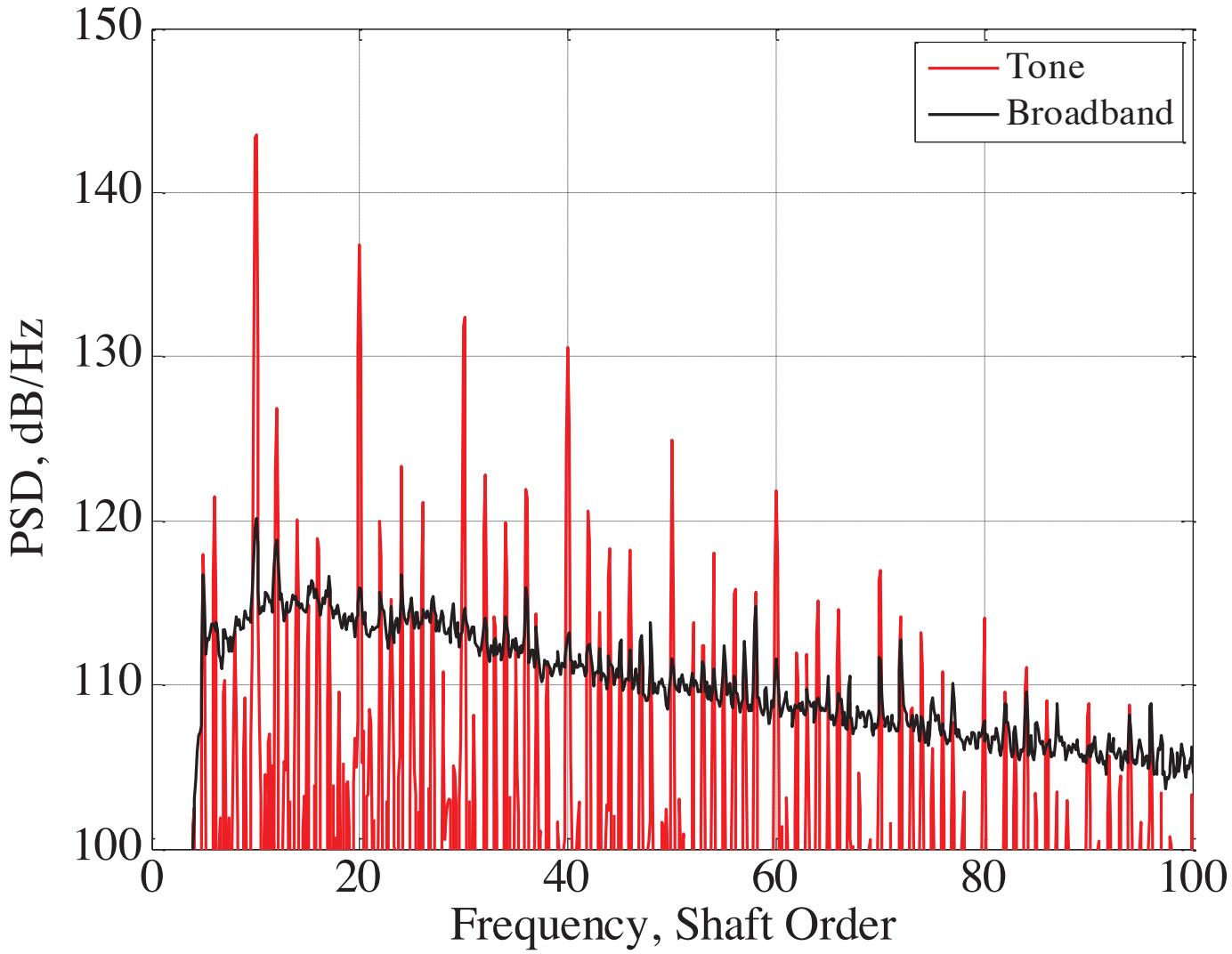
- ✧Results match synchronous averaging decomposition well
- ✧Some tone energy remaining in “broadband” at few frequencies



New Method Applied to Open Rotor Data

✧Operating condition: nominal cruise

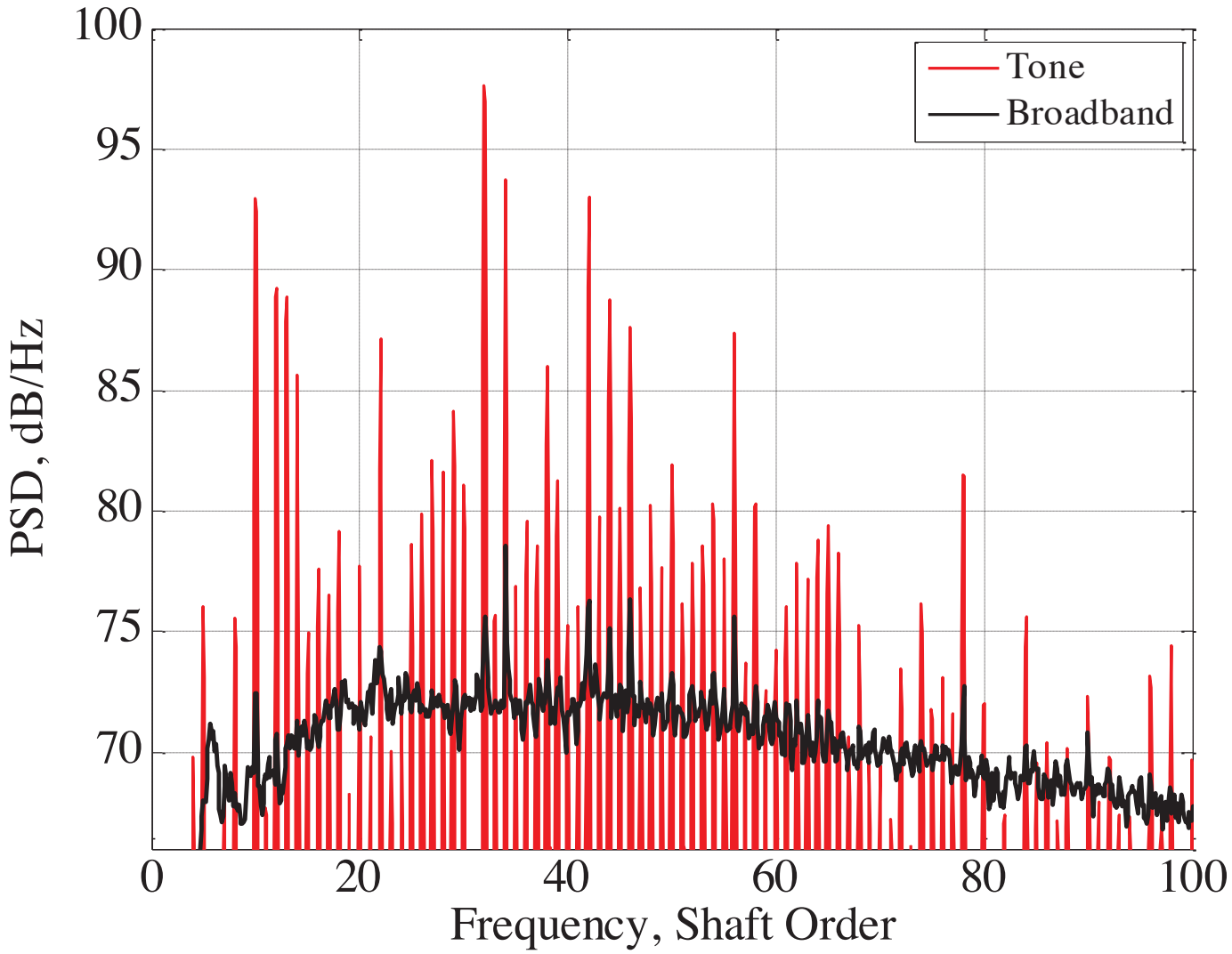
✧Results satisfactory



New Method Applied to Open Rotor Data

✧Operating condition: nominal take-off

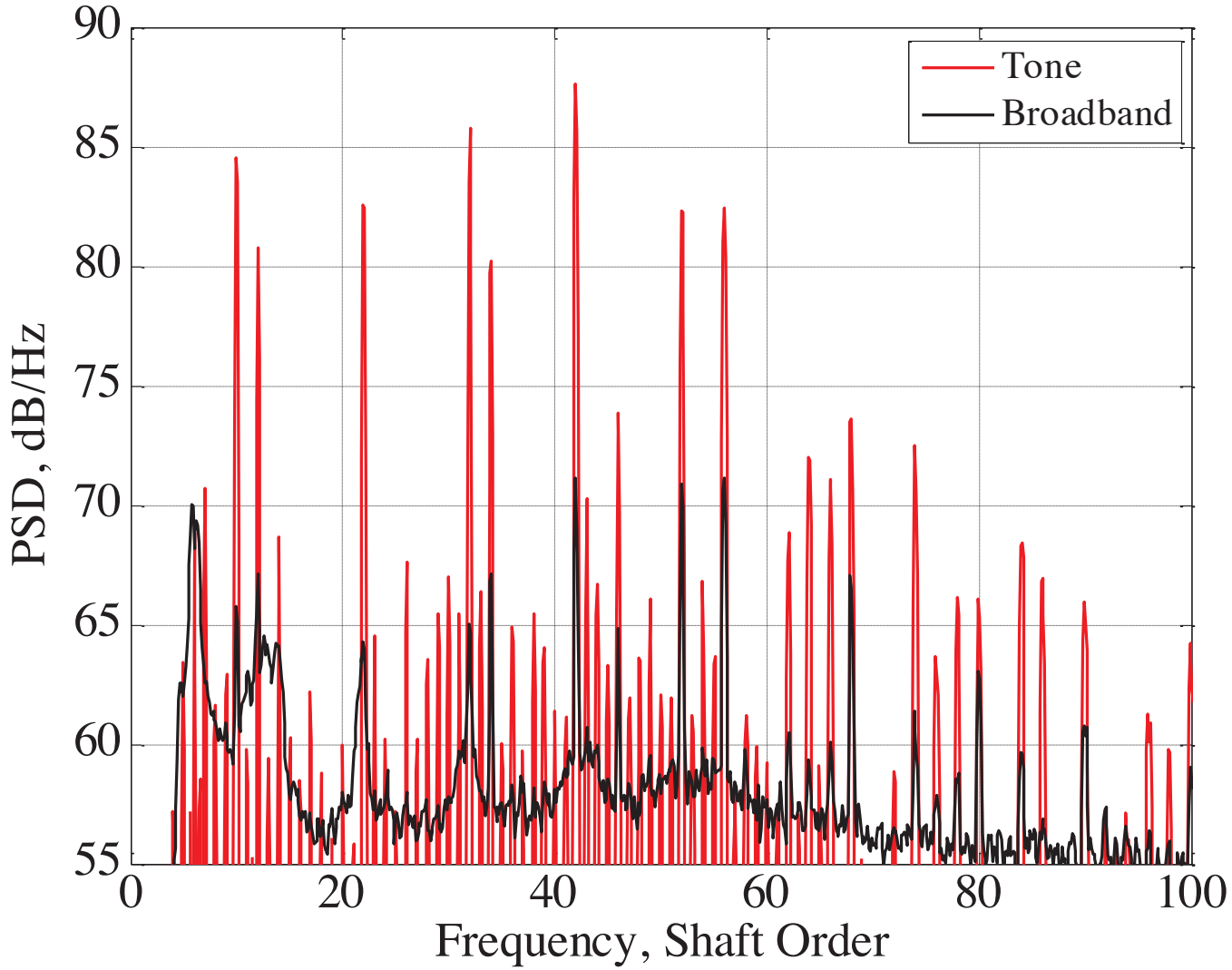
✧Results satisfactory; a few tones in the “broadband” spectrum



New Method Applied to Open Rotor Data

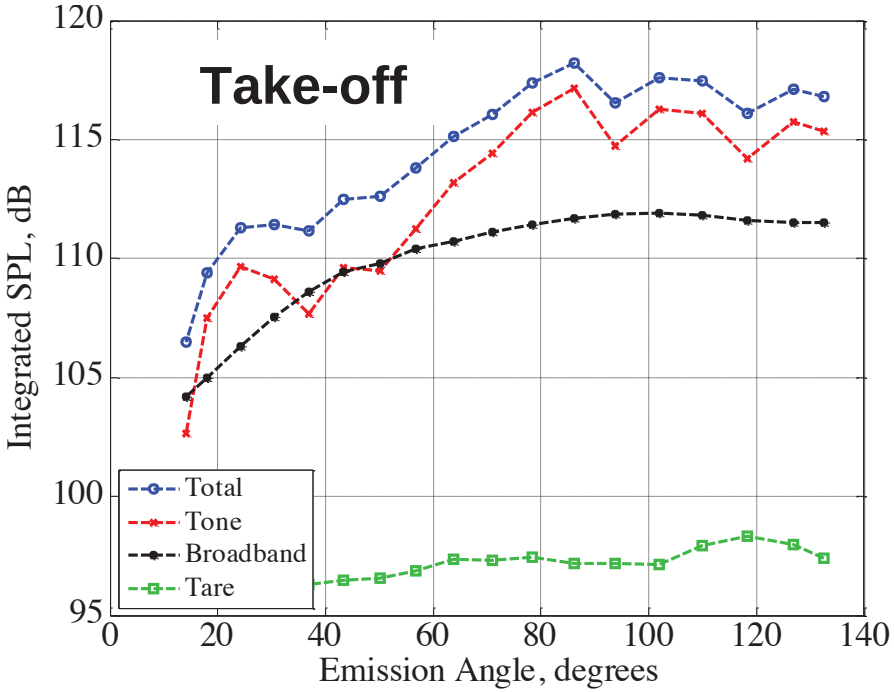
✧Operating condition: nominal approach

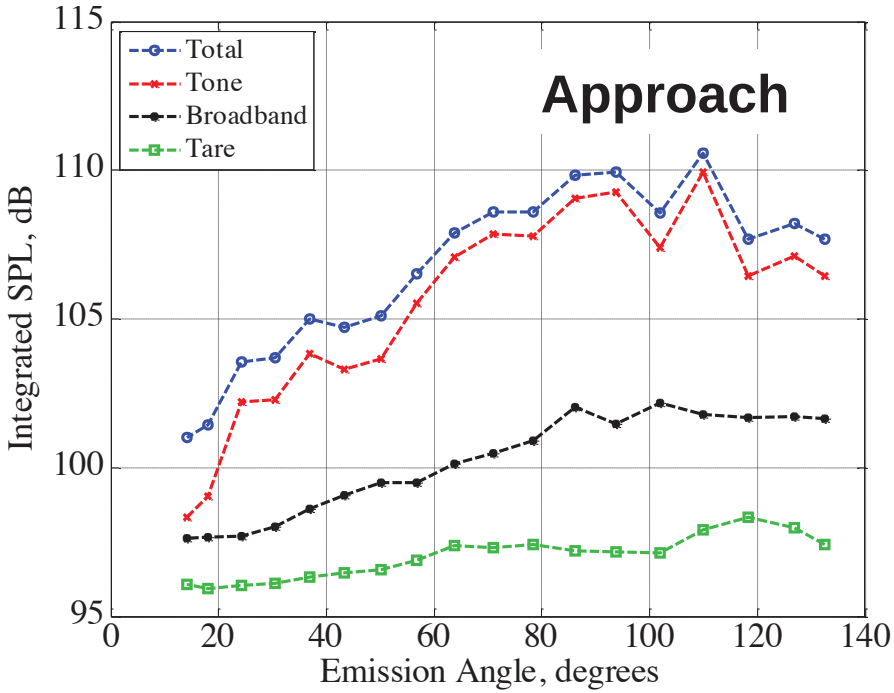
✧Results satisfactory; a few tones in the “broadband” spectrum

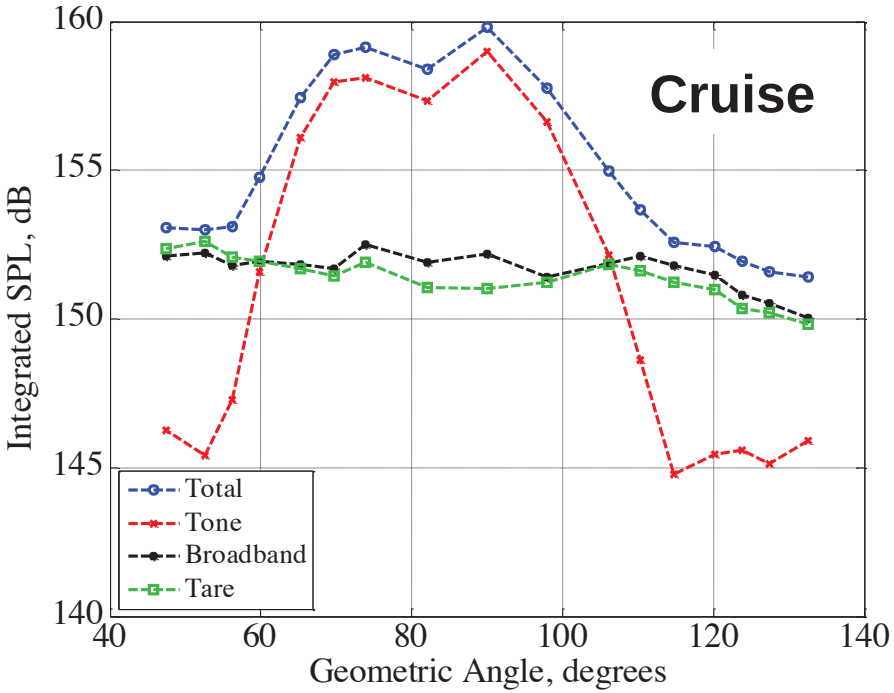


Sound Directivity

- ✧ **Broadband can be an equal contributor at some operating conditions**
- ✧ **Tones dominate at cruise**
- ✧ **Implications for noise reduction**

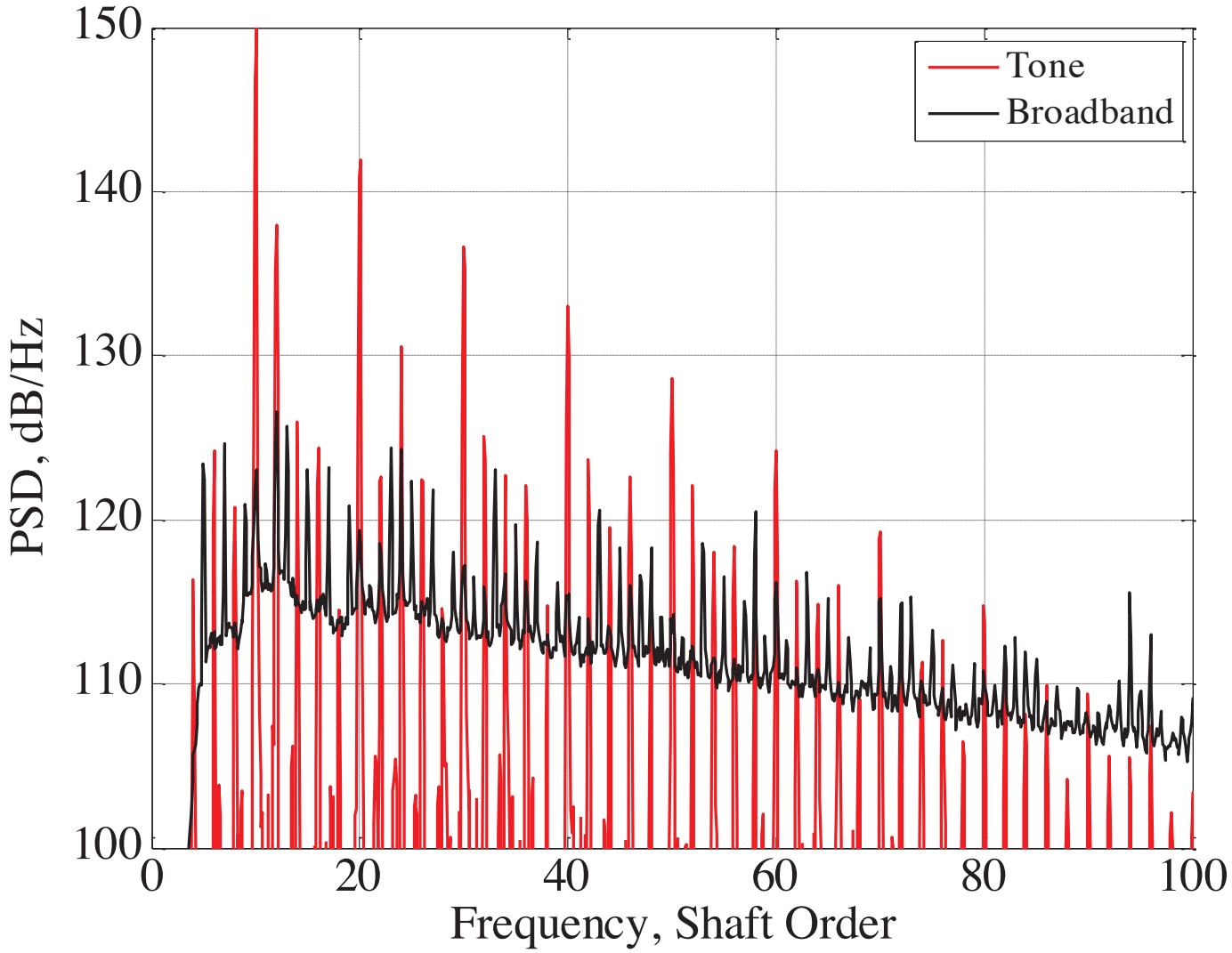






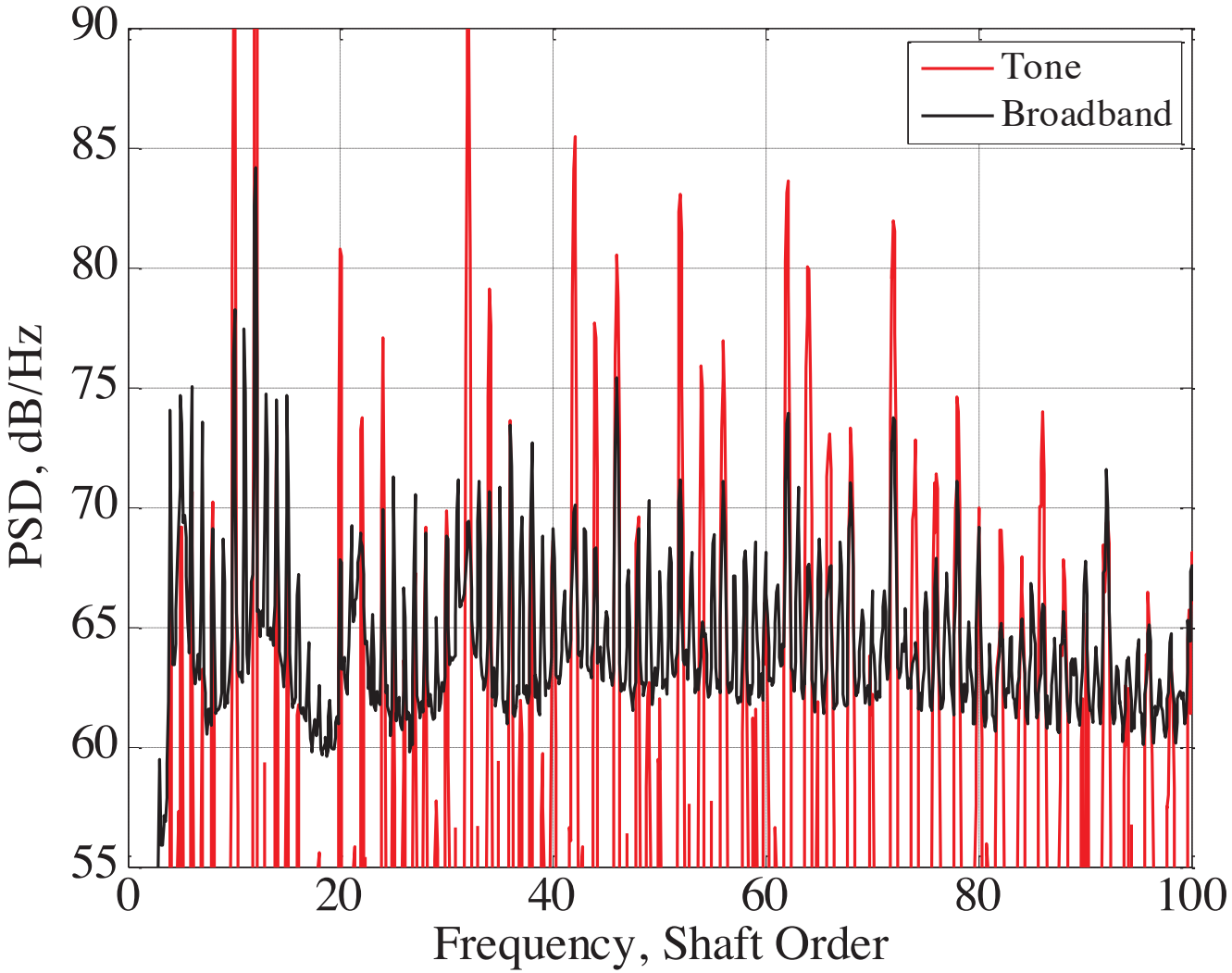
Investigation of limitations

- ✧ **Operating condition: cruise (higher thrust level)**
- ✧ **Results un-satisfactory, many tones end up in broadband**



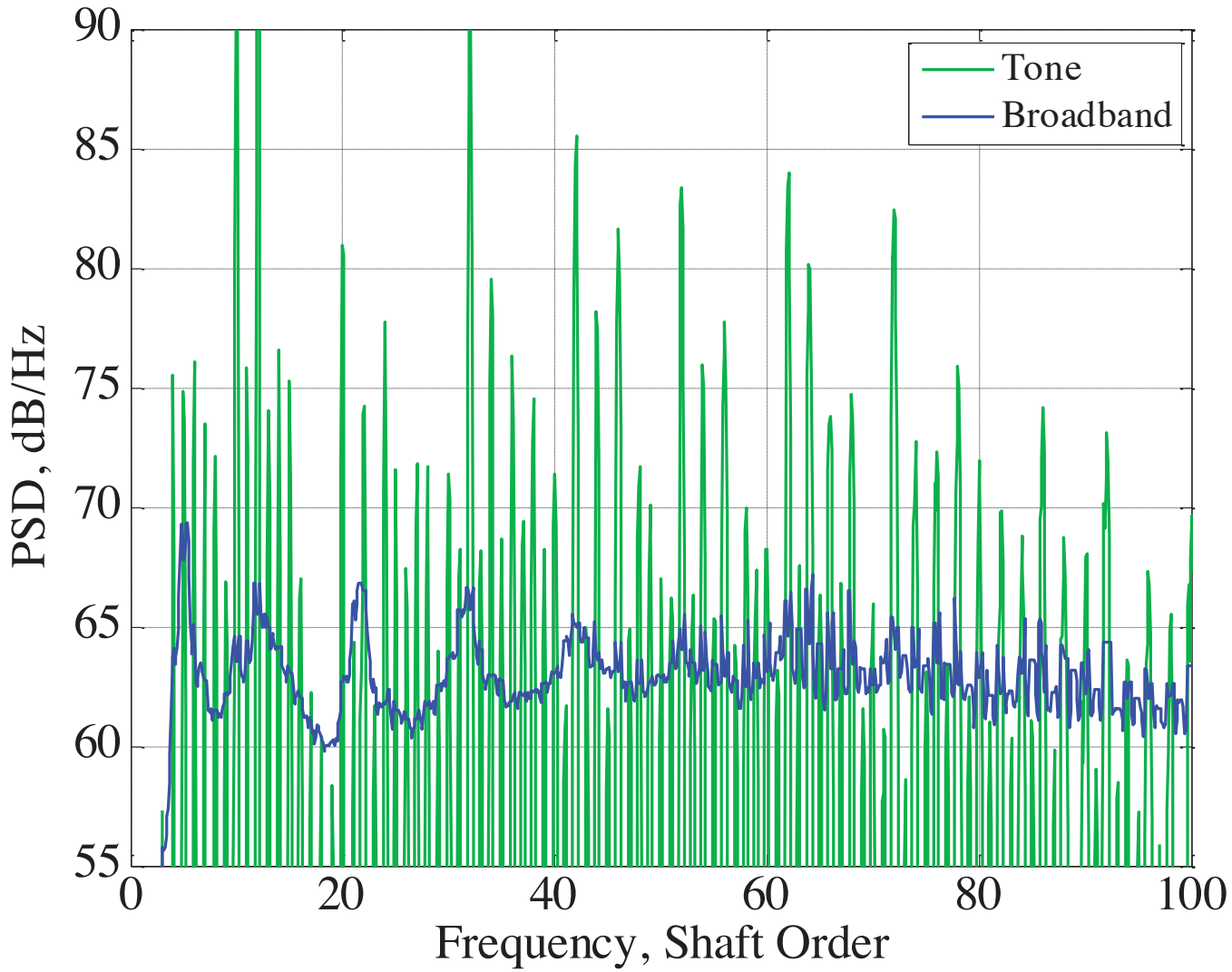
Investigation of limitations

- ✧ **Operating condition: approach (higher thrust level)**
- ✧ **Results unsatisfactory**



Investigation of limitations

- This data set also challenging for spectral methods



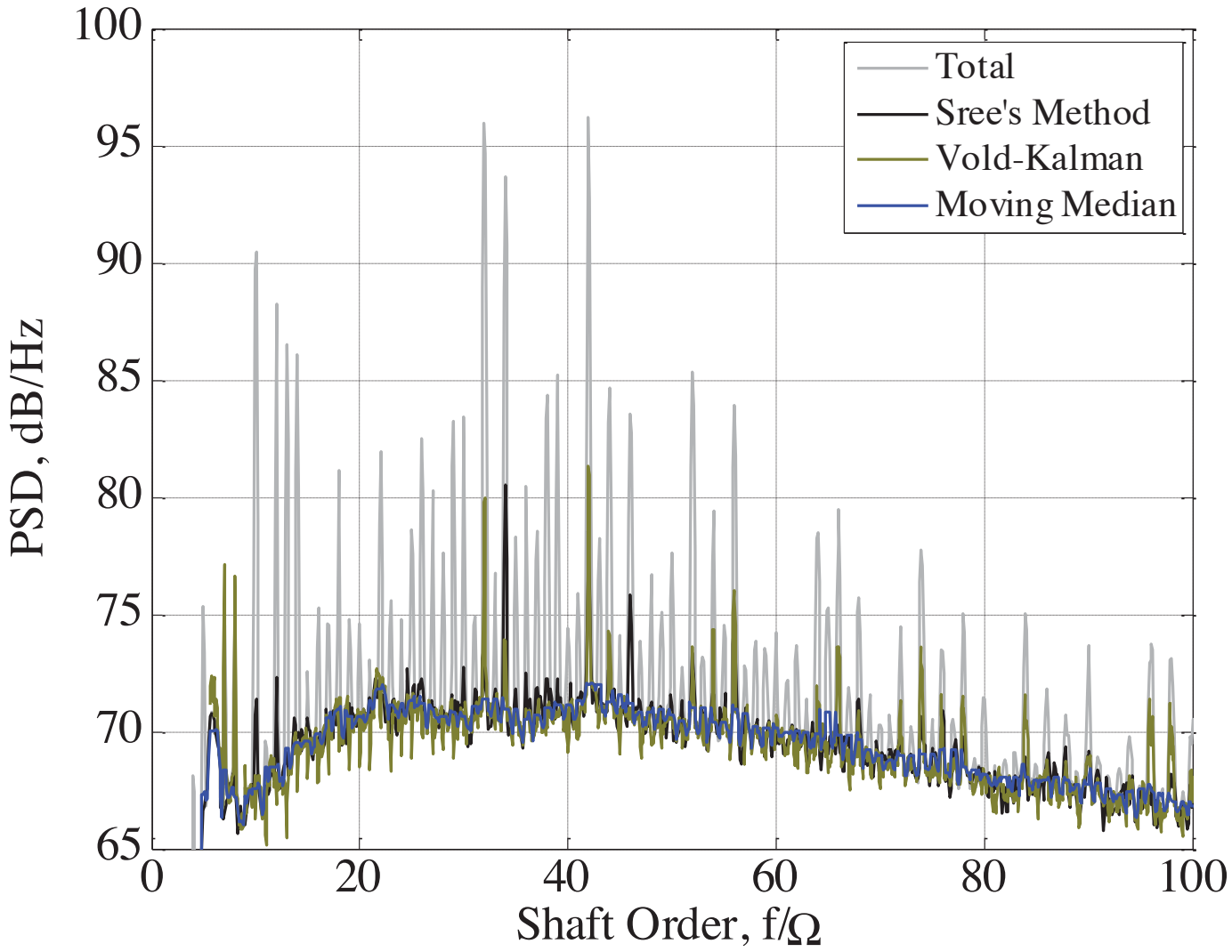
Summary of Methods

D. B. Stephens and H. Vold, "Order tracking signal processing for open rotor acoustics," *Journal of Sound and Vibration*, 2014.

	Spectral Methods	Phase Averaging	Vold-Kalman Order Tracking	Sree's Method
Application	Any	Single shaft	Multi-Shaft	Any
Input	Frequency Spectrum	Time Series	Time Series	Time Series
Output	Frequency Spectra	Time Series	Time Series	Frequency Spectra
Encoder Required	No	Yes	Yes	No
Processing Speed	Fastest	Medium	Slowest	Fast
Other Advantages	Robust	Well defined	Quantifies tone coherence with each shaft	Parameter free
Other Disadvantages	Ad-hoc, subjective	Fails for Open Rotors	May require filter bandwidth tuning	Only accounts for dominant frequency and harmonics

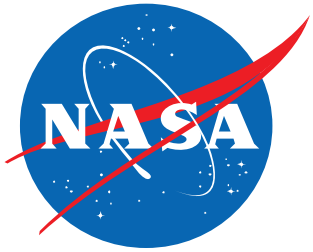
Comparison of Methods

- ✧ **Broadband levels largely similar**
- ✧ **Different tools fit different needs**



Conclusions

- A new signal processing method has been developed
- Separates tones and broadband
- Most open rotor measurements result in good separation, but not all
- Improvements still underway
- Applicability to other data sets being investigated
- Algorithm available as a short MATLAB script


NASA