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

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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: Develop a tool to separate tones and broadband
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

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

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

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