Electric Motor Noise Status

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NASA Acoustics Technical Working Group

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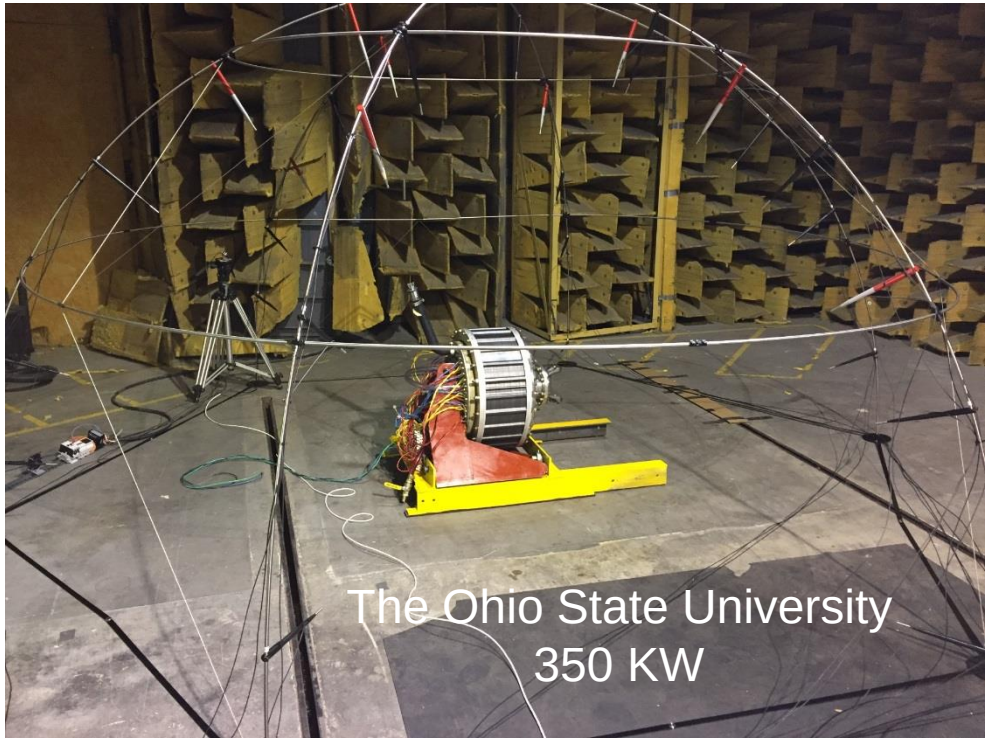
Objectives

- Determine impact of electric motor noise on overall acoustic radiation from aircraft
- Determine noise prediction approach for possible implementation in ANOPP

Types of Motors Investigated

DJI Phantom 2 920 KV
~150 W

UAS (Unmanned Aircraft System) Type

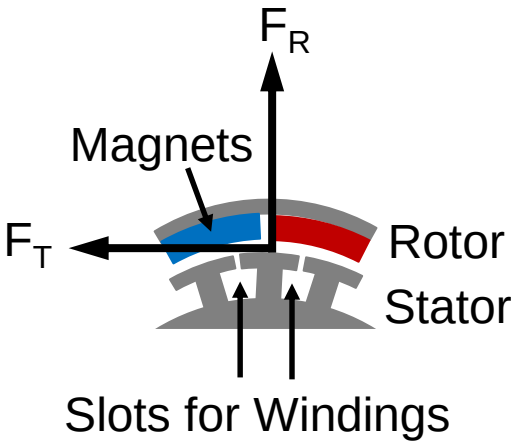


Future Aircraft Propulsion Applications

Results reported here are for unloaded motors

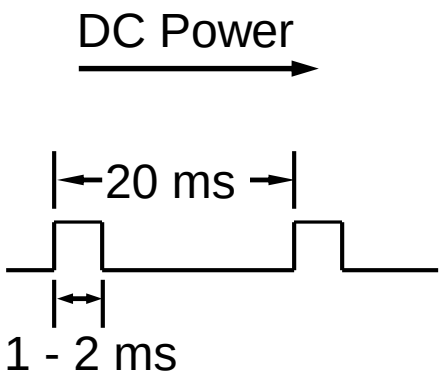
Electric Motor Noise

- Sound radiation in electric motors is predominantly related to electromagnetic forces in the airgap
- Time varying magnetic field produces radial and tangential forces
- Maxwell's equations describe the radial forces causing vibrations
- Vibrations drive the acoustic field
- The magnetic field is impacted by the non-uniform airgap and line current
- The magnetic field contains many harmonics
- Analytical, computational, and empirical methods exist for noise prediction



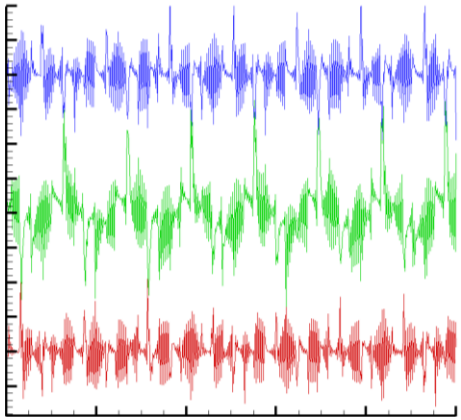
SMALL UAS MOTORS

Components of Small UAS Motor System



Pulse Position Modulation

Electronic Speed Controller (ESC)

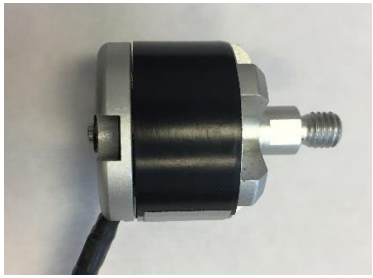


Current Probe Measurements

Blue Motor

3DR 2830-12 850KV
187 W

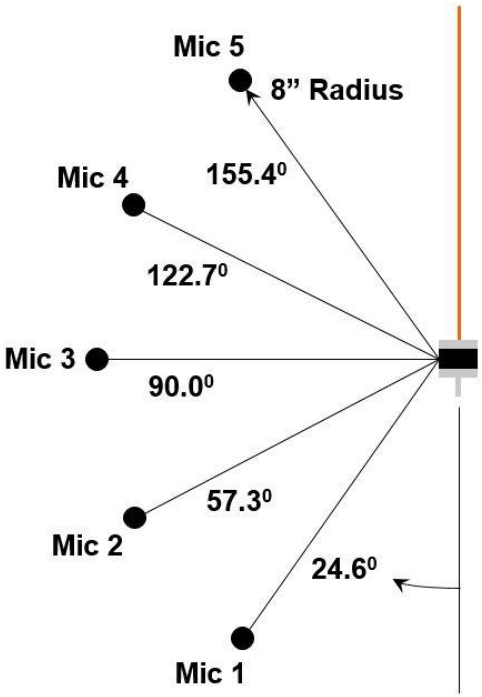
Silver Motor

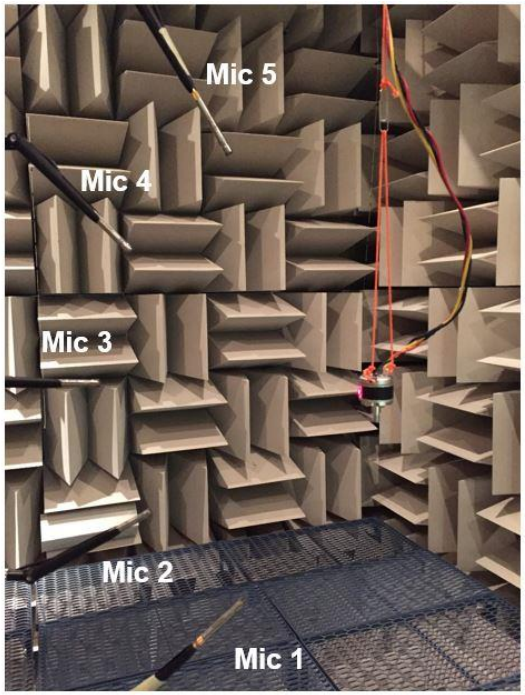


DJI Phantom 2 920KV
114 W

Outer Rotor
Three-Phase
Brushless DC Motor

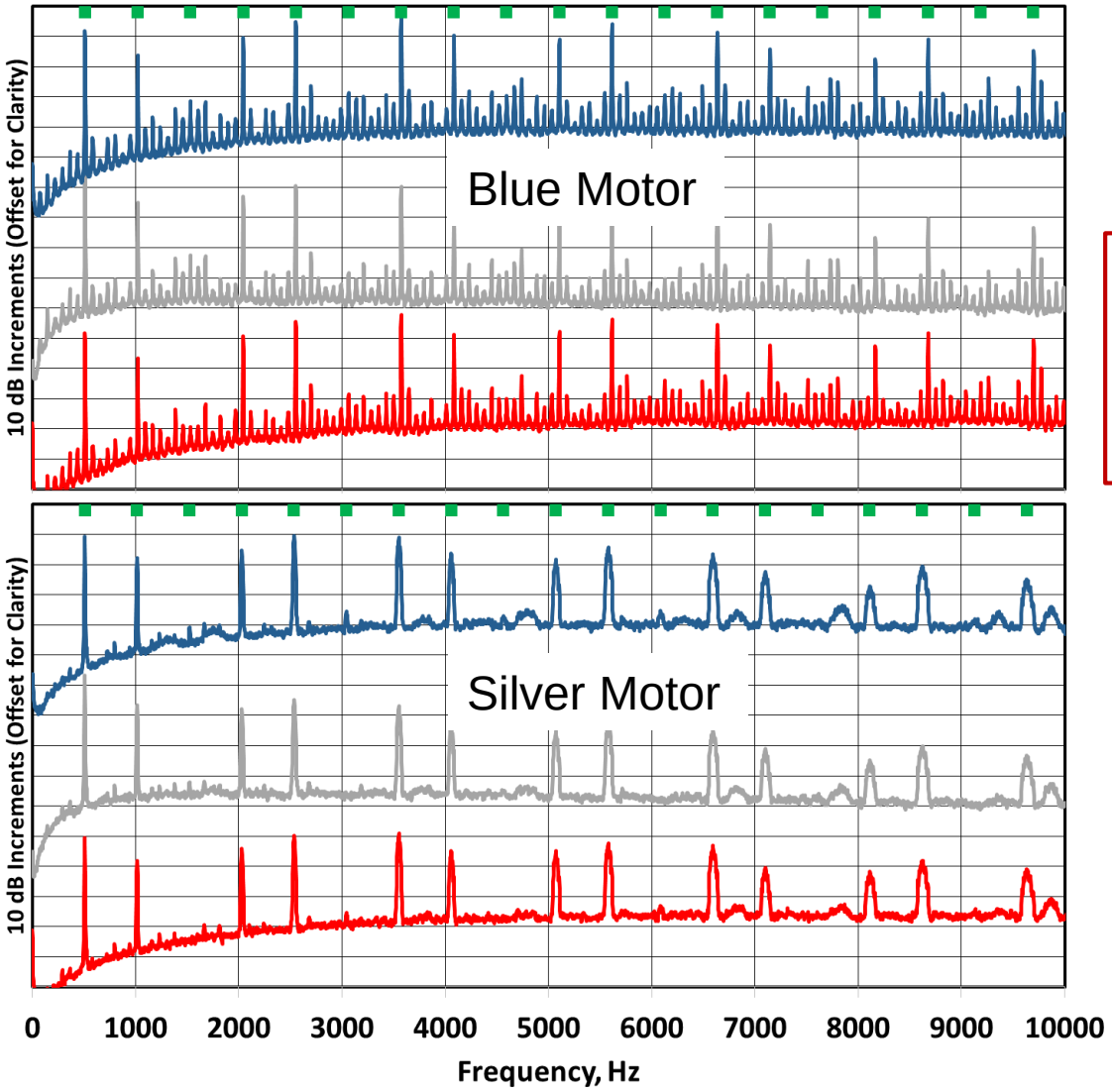
Motor Testing in the ATL





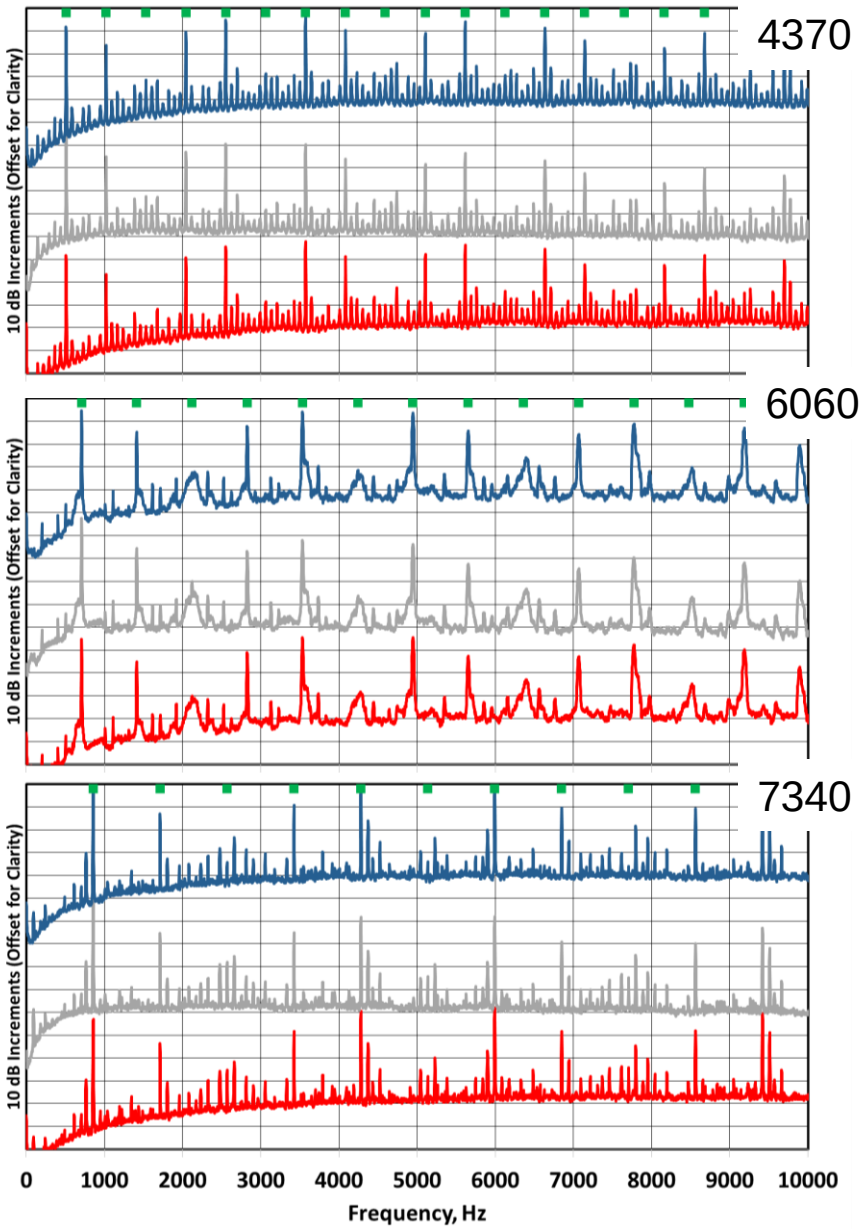
- Acoustic Test Laboratory (ATL)
  - 21 ft x 17 ft x 17 ft anechoic chamber
  - 100 Hz cut-off
- Tests were conducted with a “tethered” motor mount
- 5 microphones were located on an 8 in radius arc
- Simultaneous current probes measurements were made on the three-phase input to the motor
- Motor speed measured with laser tachometer

Current Probe Measurements at the Same Speed



For the same speed, the spectral content of the current probe signals can be different for different motors

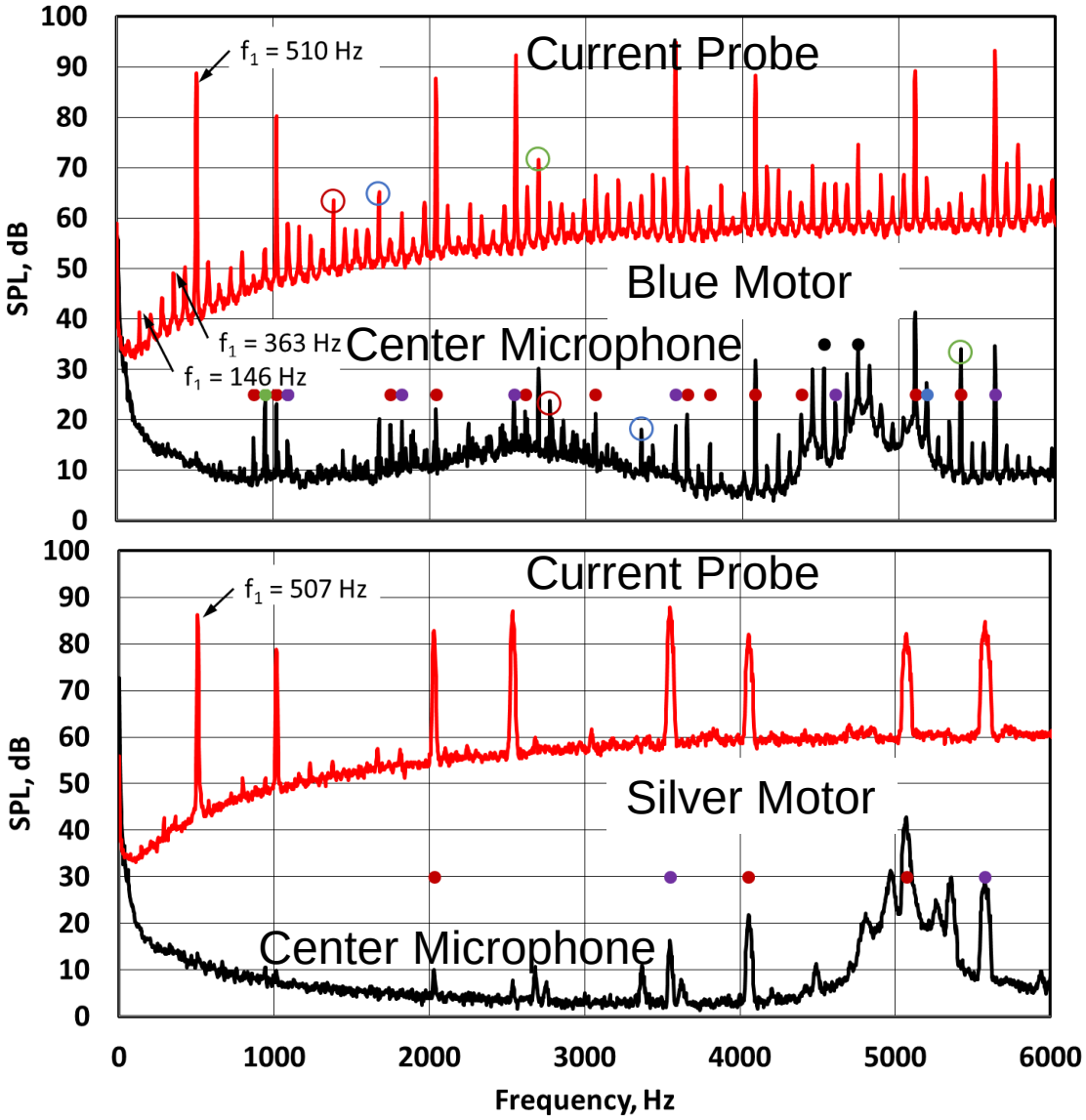
Current Probe Measurements at Different Speeds



Blue Motor

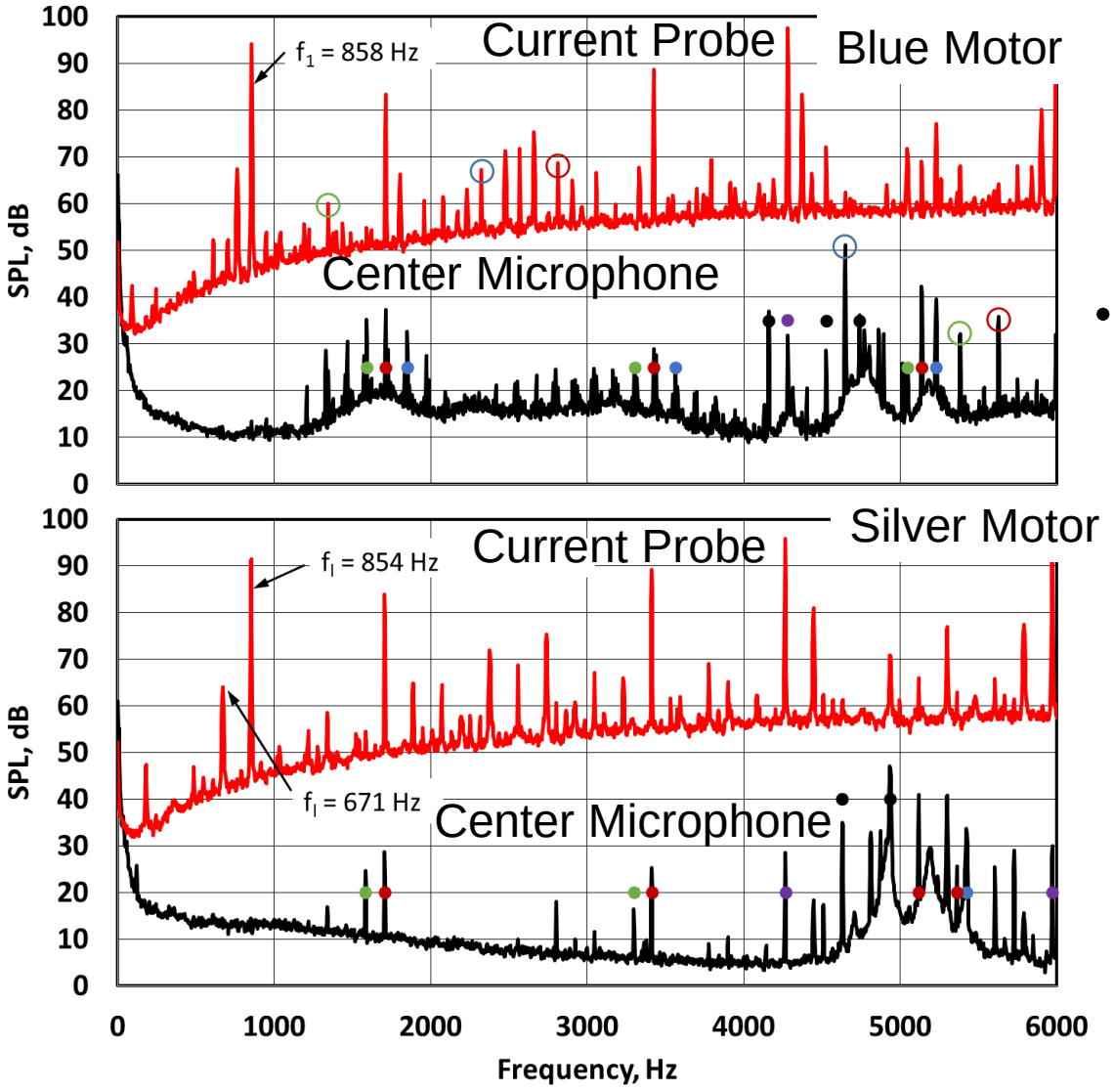
For the same motor, the spectral content of the current probe signals depends on the motor speed

Acoustic Radiation at 4370 RPM



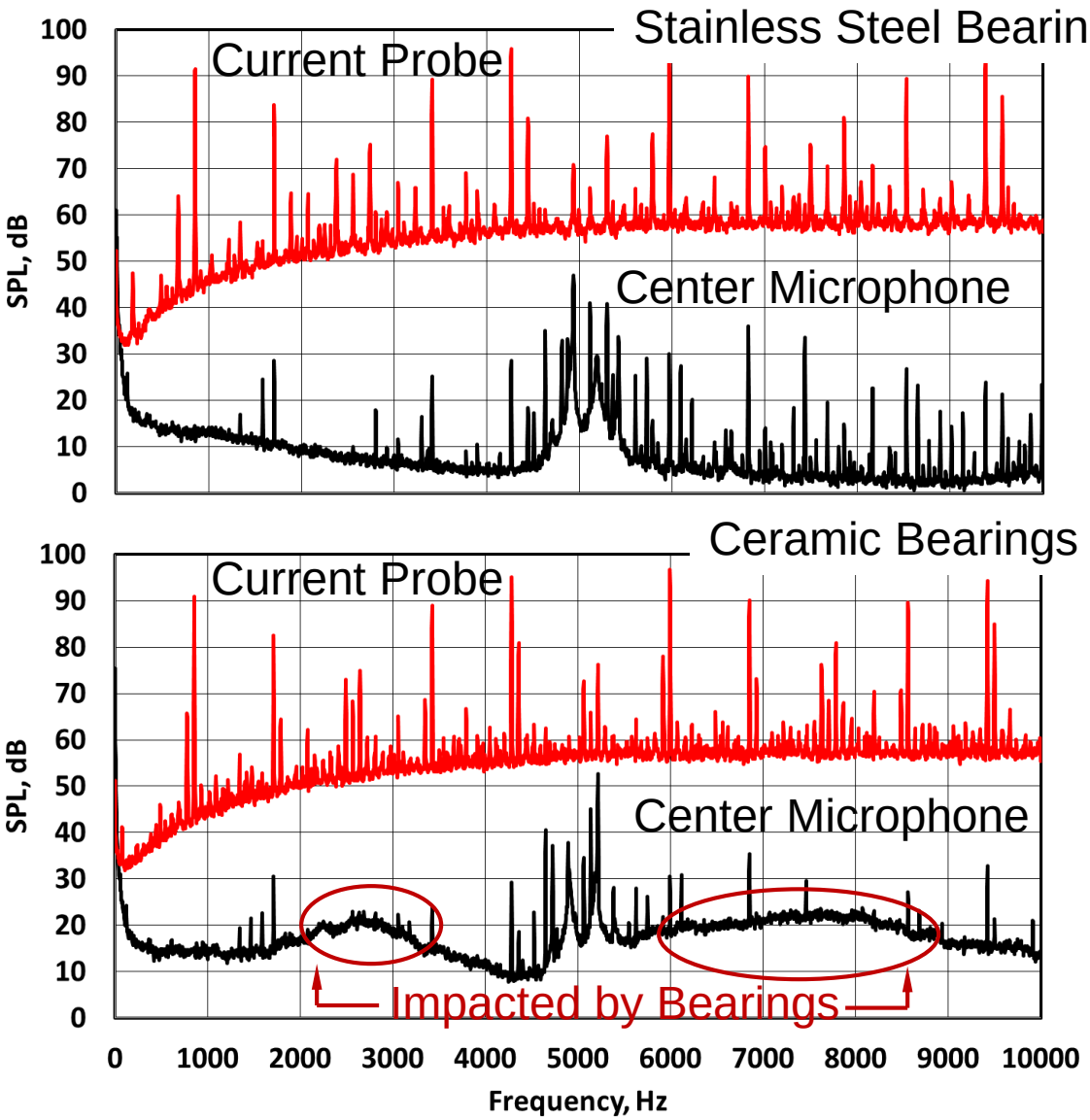
- Large number of tones in acoustic spectra
- Amplitudes of acoustic harmonics can be as large as the fundamentals
- Number of tones in acoustic spectra increases with increasing number of non-harmonically related current frequencies
- Peak amplitudes are similar for two motors and occur at similar frequencies

Acoustic Radiation at 7310 RPM



- Large number of tones in current and acoustic spectra for both motors

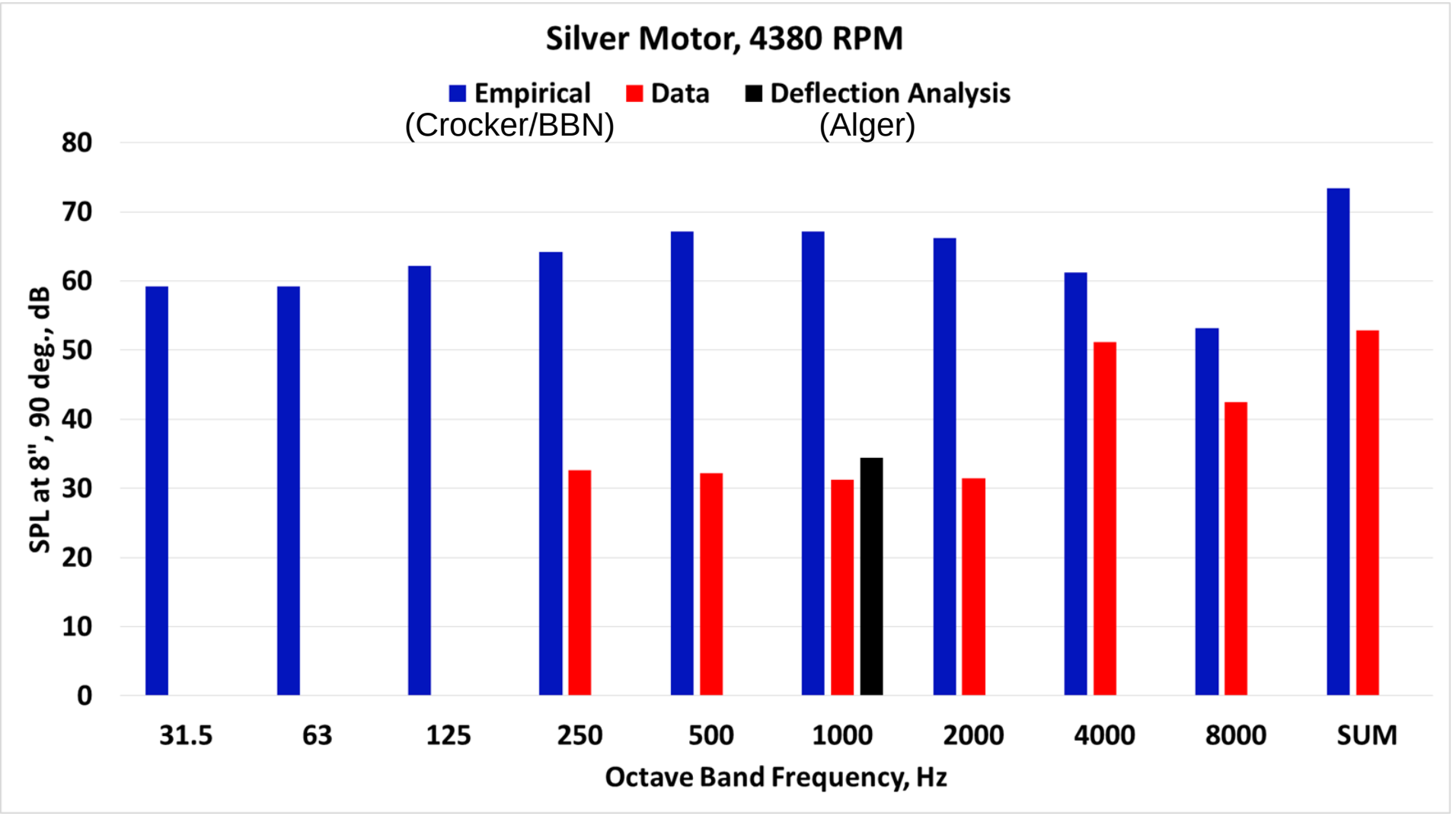
Impact of Bearings on Acoustic Radiation



Silver Motor

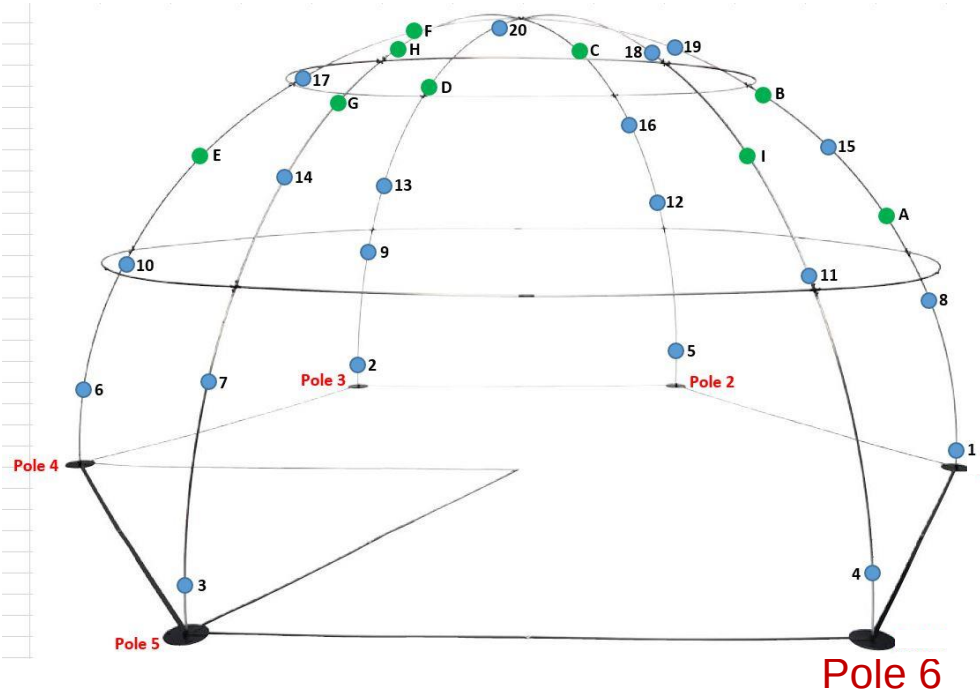
- Ceramic bearings required smaller duty cycle for the same motor speed
- Two broadband humps associated with bearing noise
- Broadband noise levels from bearing noise masks some tones

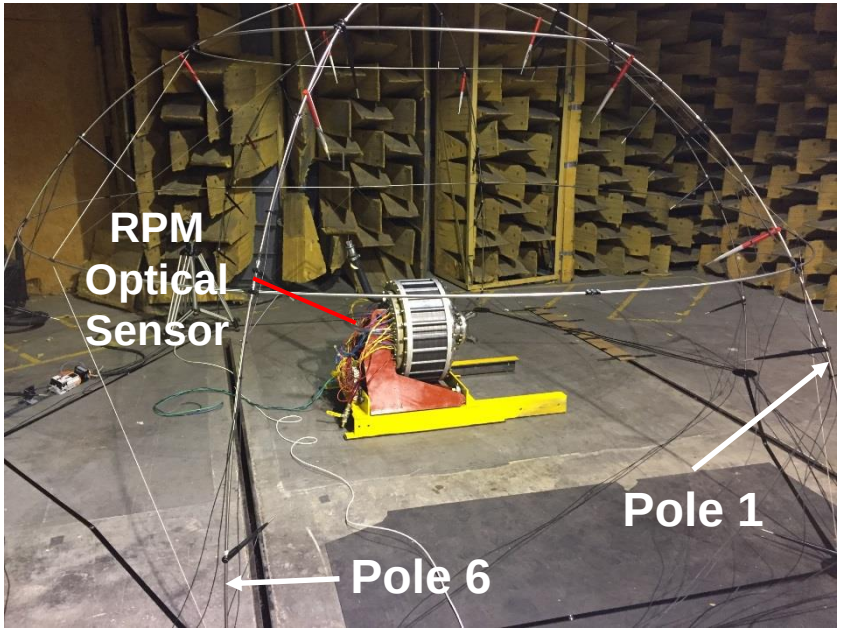
Motor Noise Predictions



OSU MOTOR

OSU Setup in Hemi-Anechoic Chamber

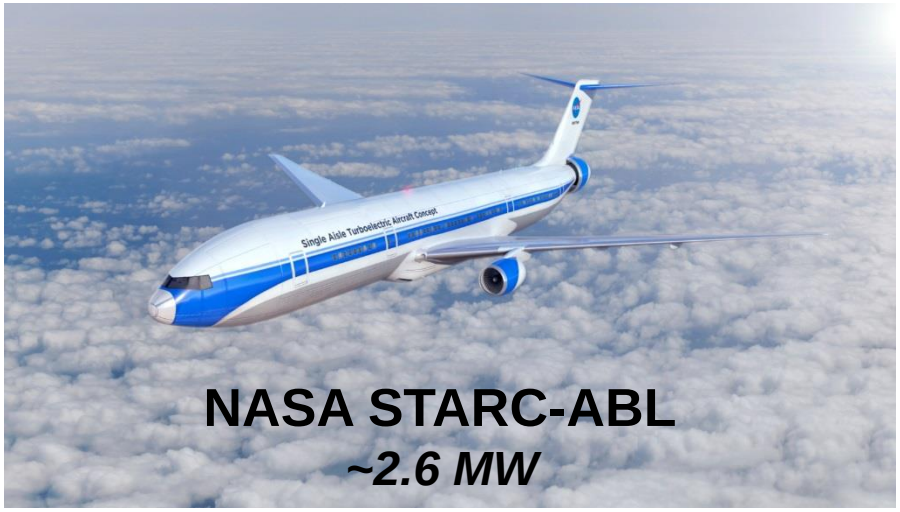




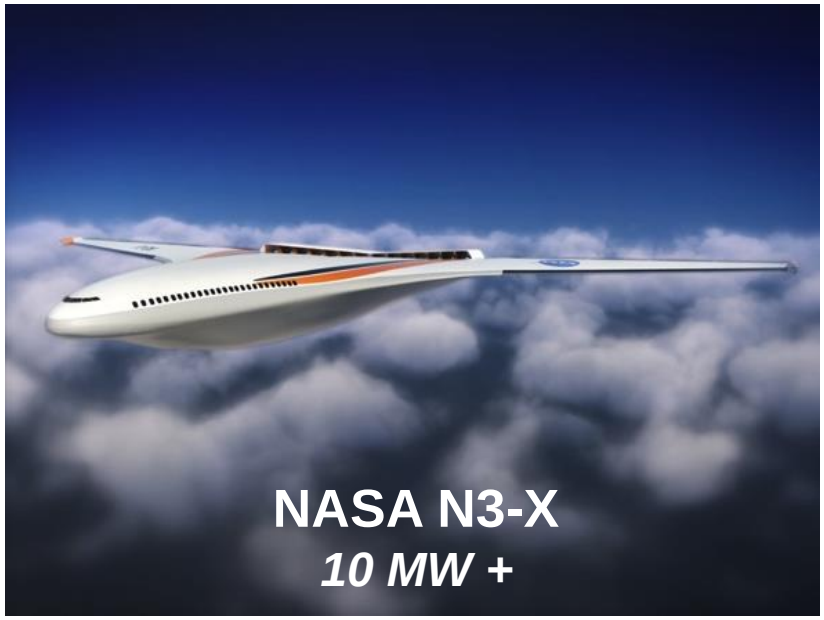
- Inductance motor
- No inverter
- Coolant leak limited locations where acoustic measurements could be made

Electric Propulsion Concepts

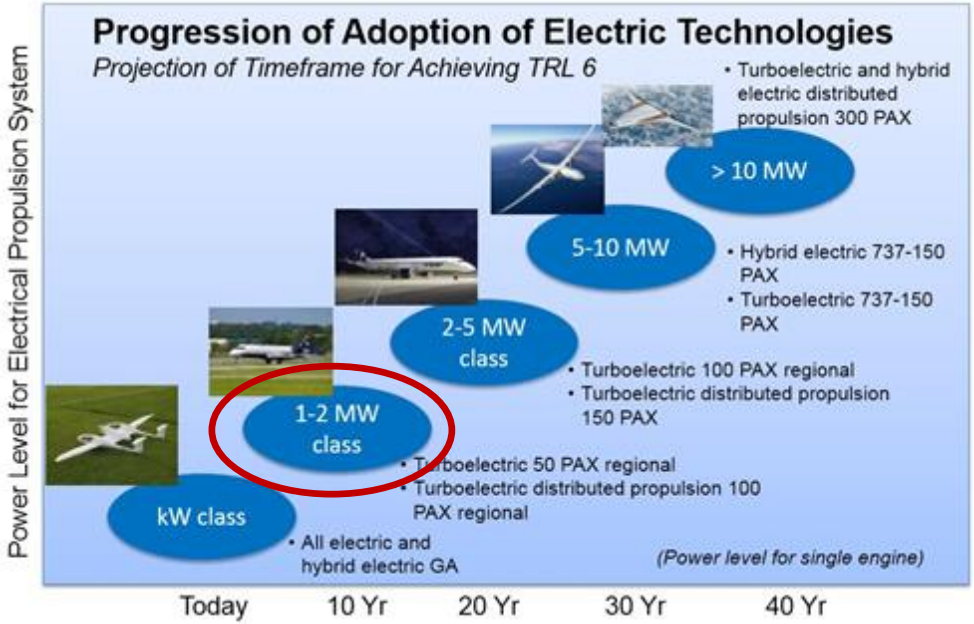
Boeing SUGAR-Volt
5 – 10 MW



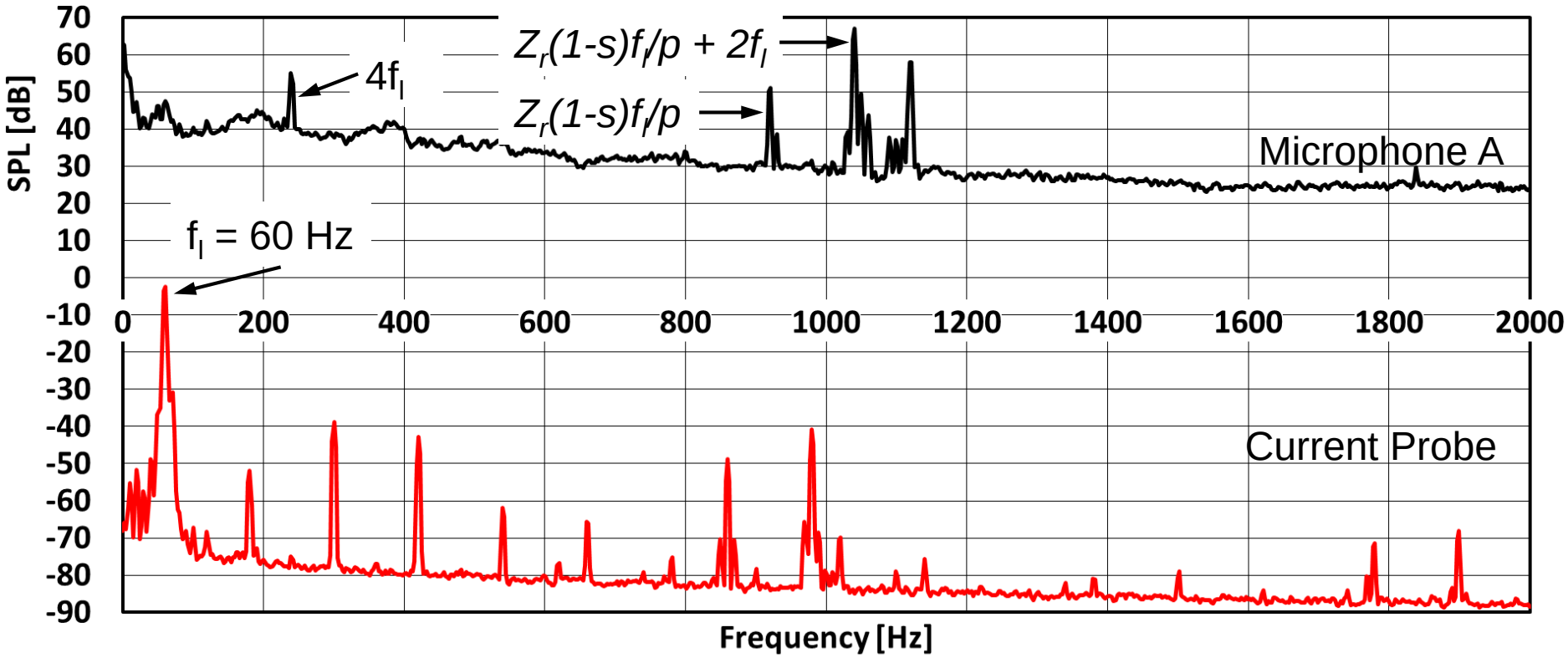
NASA STARC-ABL
~2.6 MW



NASA N3-X
10 MW +

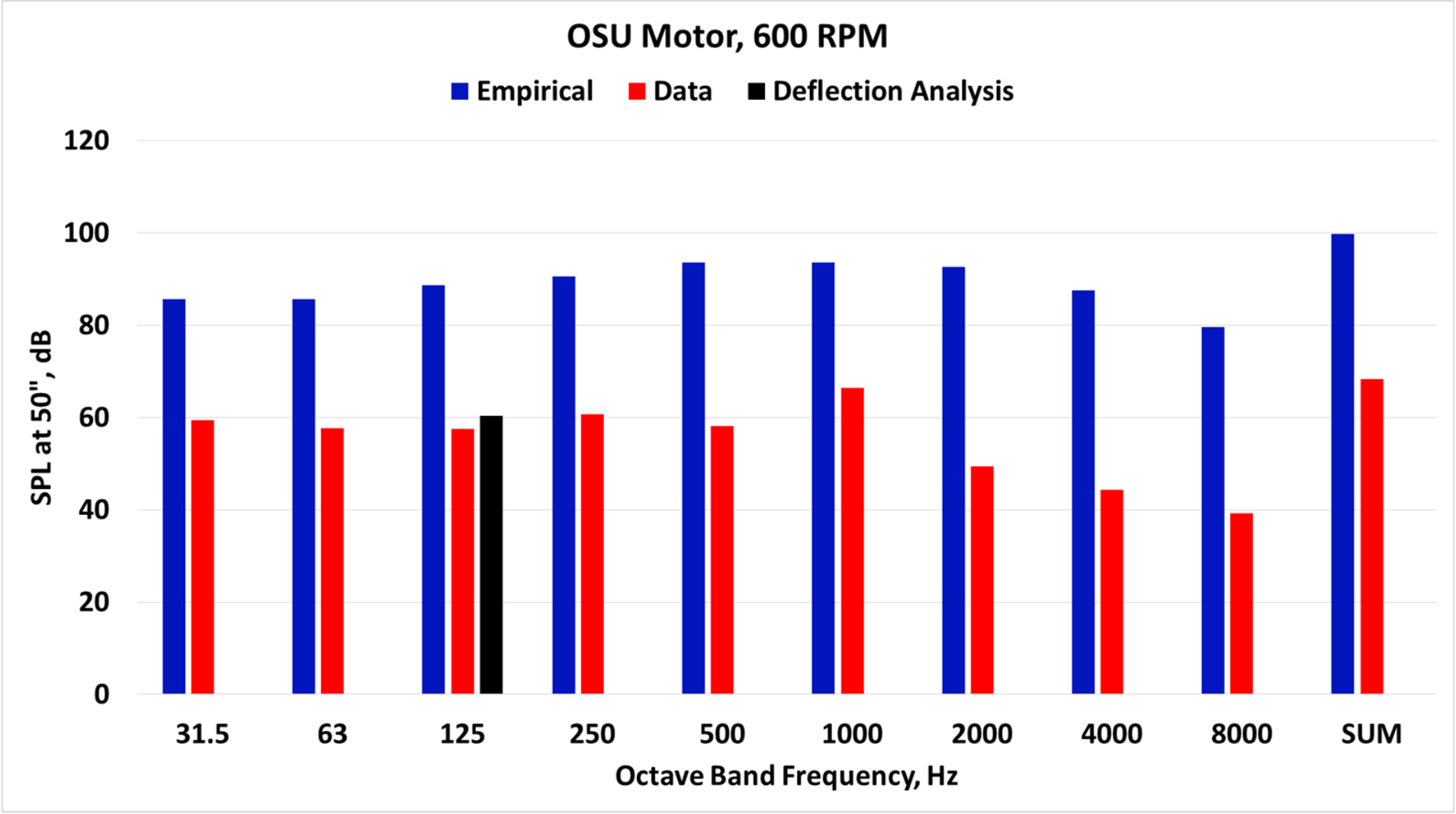


Current and Acoustic Signatures



Z_r = # rotor slots
f_l = line frequency
p = # pole pairs
s = slip

Motor Noise Predictions



Conclusions

- For small UAS motors
  - Spectral content of current probe signal depends on the motor and motor speed
  - Current probe spectra containing non-harmonic fundamental frequencies are associated with acoustic spectra containing a significant number of spectral peaks
  - Amplitudes of harmonics in acoustic spectra can be as large as the fundamentals
- For the larger inductance motor
  - The acoustic signals have relatively few spectral peaks (with no inverter) compared to smaller UAS motors
  - The acoustic signal contains spectral peaks associated with the electromagnetic field and possibly associated with the structure

Future Plans

- For small UAS motors
  - Repeat measurements for a second electronic speed controller
    - Determine if controller data shown here is representative of controllers used for small UAS motors
- For the larger inductance motor
  - Acquire acoustic data for the second generation OSU motor with inverter
  - Investigate different acoustic prediction schemes
- Acquire acoustic data for intermediate size (67 kW) electric motor (NASA's X-57 Maxwell Aircraft)

BACKUP SLIDE

Motor Noise – Empirical Predictions

For a conventional totally enclosed fan-cooled (TEFC) motors with powers under 750 kW, the A-weighted sound power level is estimated as:

$$PWL = 27 + 10\log(kW) + 15\log(rpm) + 10\log(conformal\ surface\ area)$$

Second term: rated value of electric power
Third term: shaft speed in rpm
Fourth term: surface area in square-meters for computing sound power.

- **The correlation includes a table to predict the un-weighted octave band sound power levels.**
- **High uncertainty: newer motors can be 5 to 10 dB quieter, cooling fans can increase the noise by 5 to 8 dB.**

References

Crocker, M.J., "Handbook of Noise and Vibration Control," John Wiley & Sons, Inc., Chapter 82, pp. 1001-1009, 2007.

***Noise and Vibration Control for Mechanical Equipment*, Manual TM5-805-4/AFM 88-37/NAVFAC DM-3.10, manual prepared by Bolt, Beranek, and Newman for Joint Department of the Army, Air Force, and Navy, Washington, DC, 1980, Chapter 7.**