Electric Motor Noise Status

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NASA Acoustics Technical Working Group

Dr. Brenda S. Henderson
Dennis L. Huff
NASA Glenn Research Center
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

UAS (Unmanned Aircraft System) Type

DJI Phantom 2 920 KV
~150 W

The Ohio State University
350 KW

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

- **DC Power**
- **20 ms**
- **1 - 2 ms**
- **Pulse Position Modulation**

**Electronic Speed Controller (ESC)**

**Current Probe Measurements**

- **3DR 2830-12 850KV**
  - **187 W**
- **Silver Motor**
- **DJI Phantom 2 920KV**
  - **114 W**
- **Blue Motor**

**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
For the same speed, the spectral content of the current probe signals can be different for different motors.
Current Probe Measurements at Different Speeds

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

- 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

Silver Motor, 4380 RPM

- **Empirical** (Crocker/BBN)
- **Data**
- **Deflection Analysis** (Alger)

SPL at 8\(^\circ\), 90 deg., dB

Octave Band Frequency, Hz

- 31.5
- 63
- 125
- 250
- 500
- 1000
- 2000
- 4000
- 8000
- SUM
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 +

Progression of Adoption of Electric Technologies
Projection of Timeframe for Achieving TRL 6

- Turboelectric and hybrid electric distributed propulsion 300 PAX
- > 10 MW
- 5-10 MW
- Hybrid electric 737-150 PAX
- Turboelectric 737-150 PAX
- 2-5 MW class
- Turboelectric 100 PAX regional
- Turboelectric distributed propulsion 150 PAX
- 1-2 MW class
- Turboelectric 50 PAX regional
- Turboelectric distributed propulsion 100 PAX regional
- kW class
- All electric and hybrid electric GA

Power Level for Electrical Propulsion System

Today, 10 Yr, 20 Yr, 30 Yr, 40 Yr

(Power level for single engine)
Current and Acoustic Signatures

\[ Z_r (1-s) f_i / p + 2f_i \]

\[ Z_r (1-s) f_i / p \]

- \( Z_r \) = \# rotor slots
- \( f_i \) = line frequency
- \( p \) = \# pole pairs
- \( s \) = slip
Motor Noise Predictions

OSU Motor, 600 RPM

- **Empirical**
- **Data**
- **Deflection Analysis**

![Graph showing SPL at 50\(^\circ\) dB for different octave band frequencies (31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, SUM) for the OSU Motor at 600 RPM.](image-url)
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:

\[ PWL = 27 + 10\log(kW) + 15\log(rpm) + 10\log(\text{conformal surface area}) \]

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