Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Presented by:

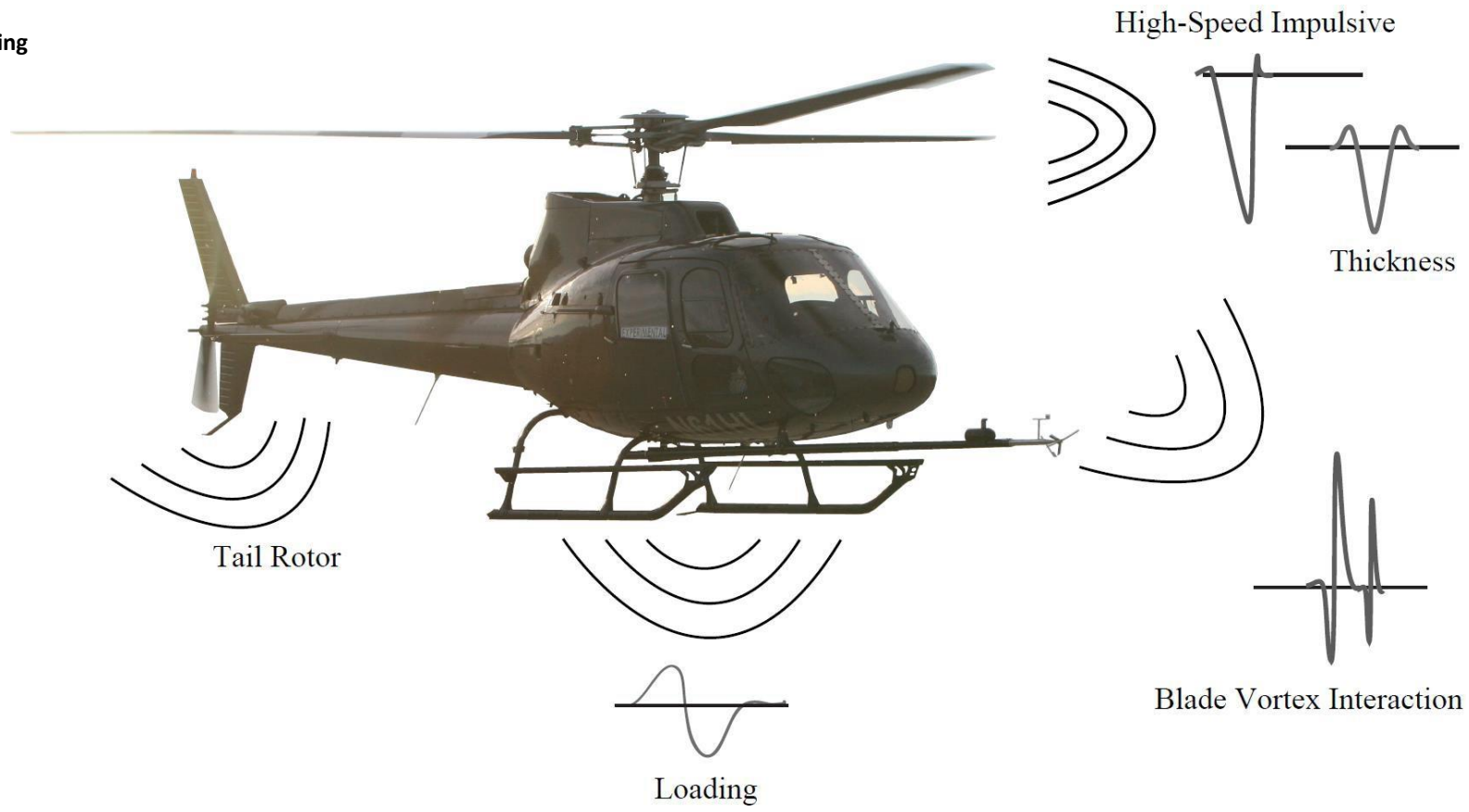
James Stephenson
U.S. Army Aviation and Missile Research, Development, and Engineering Center

Eric Greenwood
NASA Langley
Aeroacoustics Branch

Motivation

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



Motivation

Aerodynamics Affecting BVI Noise

- Inflow
- Blade Loading
- Advance Ratio

Flight Test Uncertainties

- Inconsistent Vehicle Flight Path
- Inconsistent Vehicle Velocity
- Atmospheric Effects (Wind, Temperature, Etc.)
- Blade-Blade Variations
- Variable Weight (Fuel burn)

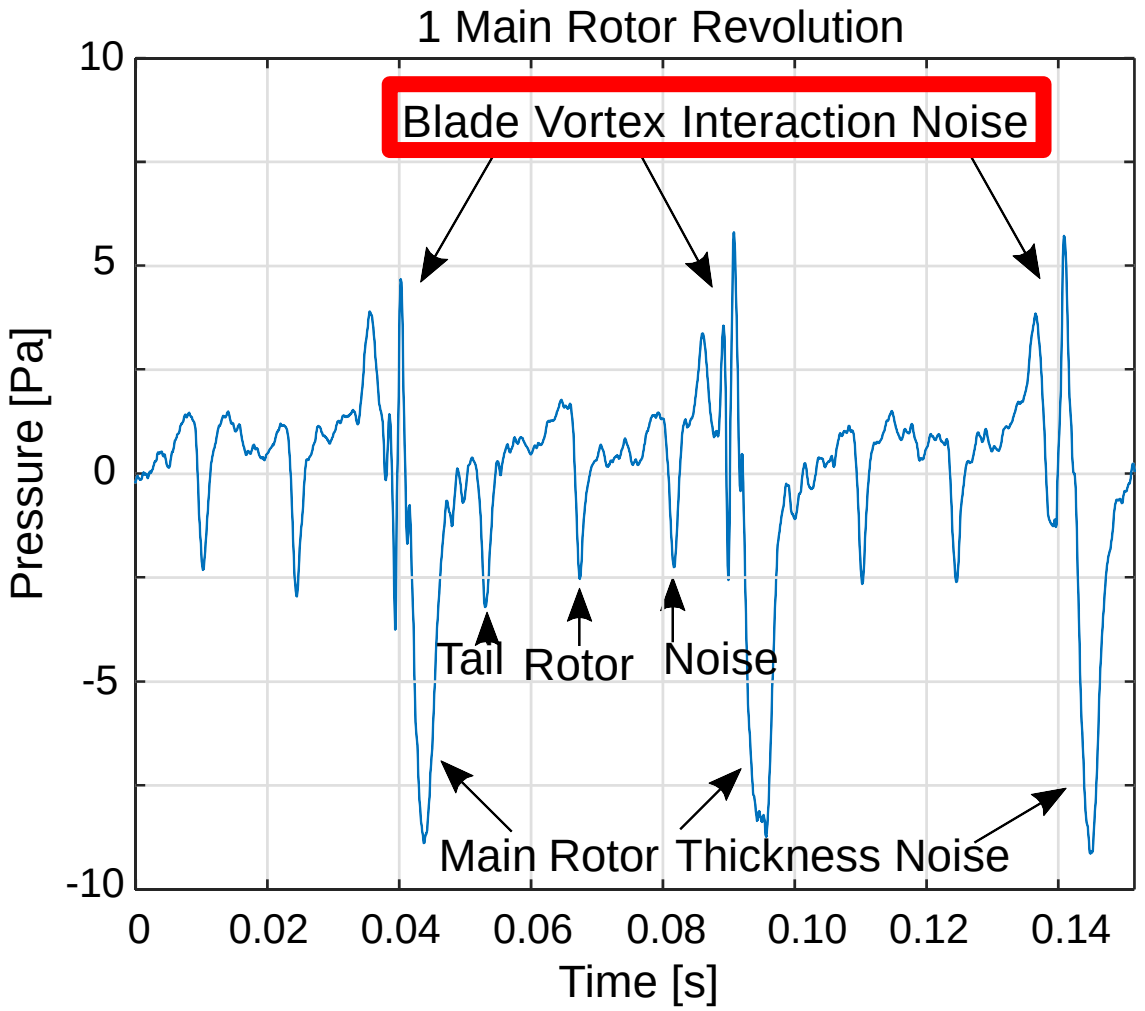
Schmitz, F. H., Boxwell, D. A., Lewy, S., and Dahan, C., "In-Flight Far-Field Measurement of Helicopter Impulsive Noise," *American Helicopter Society 32nd Annual Forum*, 1976.

Lowson,M. V., "Focusing on Helicopter BVI Noise," *Journal of Sound and Vibration*, Vol. 190, (3), 1996, pp. 477–494.

Motivation

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



Wavelet Transform

$$\tilde{p}(l,t) = \frac{1}{\sqrt{l}} \int_{-\infty}^{\infty} p(t')\ \psi_w^*\left(\frac{t'-t}{l}\right) dt'$$

Morlet Wavelet

$$\hat{\psi}_M(l\ \omega, \omega_\psi) = \sqrt{2\pi l\ \frac{f_s}{N}}\ \pi^{-1/4}\ H(\omega)\ e^{-(l\omega-\omega_\psi)^2/2}$$

Wavelet Energy

$$E(f,t) = \frac{1}{C_\psi}\ \frac{|\tilde{p}(f,t)|^2}{l^2}$$

Inverse Wavelet Transform

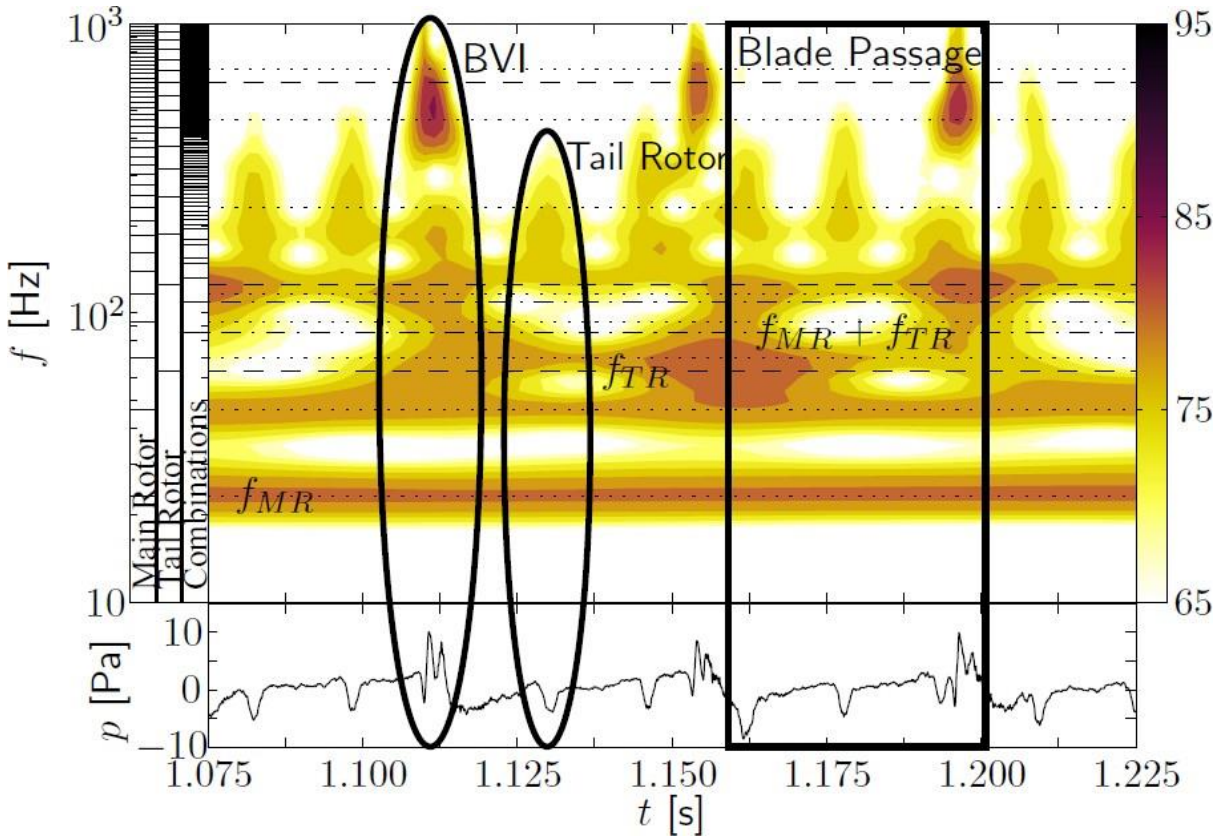
$$p(t') = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \int_{l} \frac{1}{\sqrt{l'}}\ \tilde{p}(l',t)\ \psi_w\left(\frac{t'-t}{l'}\right) \frac{dl'\ dt}{l'^2}$$

Torrence, C. and Compo, G. P., "A Practical Guide to Wavelet Analysis," *Bulletin of the American Meteorological Society*, Vol. 79, (1), 1998, pp. 61–78.
Farge, M., "Wavelet Transforms and their Applications to Turbulence," *Annual Review of Fluid Mechanics*, Vol. 24, 1998, pp. 395–457.

Analysis Technique

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

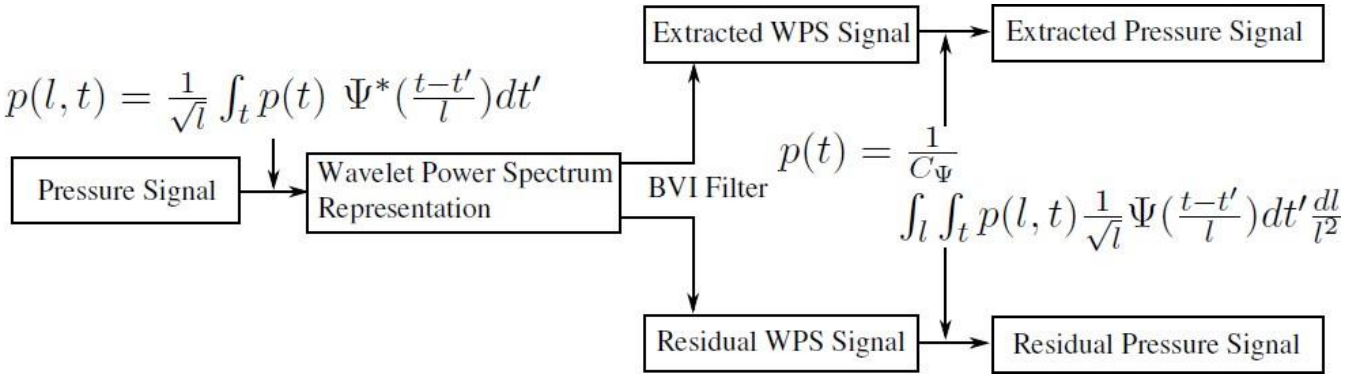
Stephenson & Greenwood



Martin, R. M. and Hardin, J. C., "Spectral Characteristics of Rotor Blade/Vortex Interaction Noise," *Journal of Aircraft*, Vol. 25, (1), 1988, pp. 62–68.
Stephenson, J. H., *Extraction of Blade Vortex Interactions from Helicopter Transient Maneuvering Noise*, Ph.D. thesis, University of Texas at Austin, 2014.

BVI Filter

$$\tilde{p}(f_j, t_i) = \begin{cases} \tilde{p}(f_j, t_i) & \text{if } f_j > f_{cut} \text{ and} \\ & E(f_j, t_i) > E(f_{MR}, t_i) - A_{cut} \\ 0 & \text{otherwise} \end{cases}$$



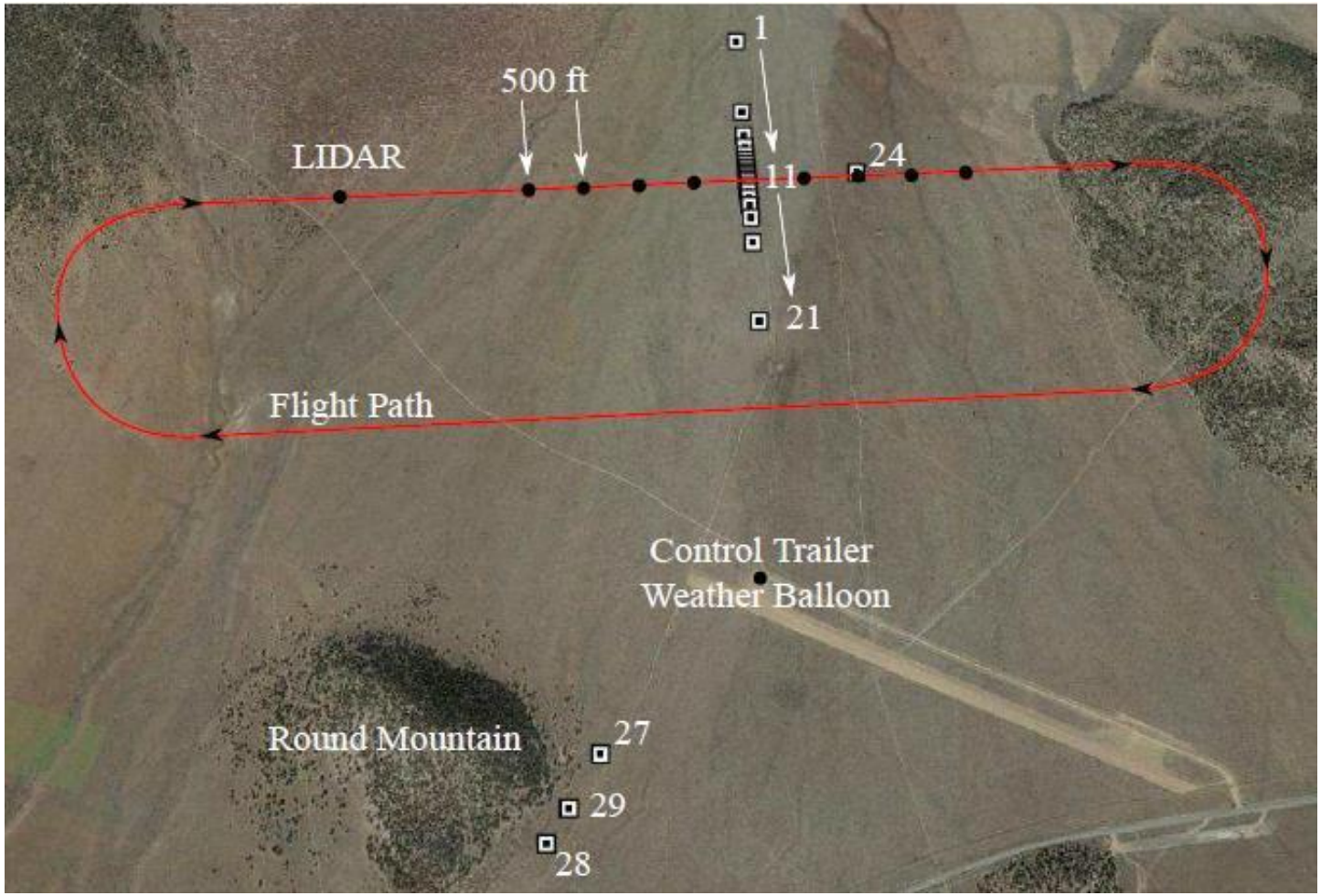
Davis, W., Pezeshki, C., and Mosher, M., "Extracting and Characterizing Blade–Vortex Interaction Noise with Wavelets," *Journal of the American Helicopter Society*, Vol. 42, (3), 1997, pp. 264–271.

Stephenson, J. H., Tinney, C. E., Greenwood, E., and Watts, M. E., "Extracting Blade Vortex Interactions using Continuous Wavelet Transforms," *Journal of Sound and Vibration*, Vol. 333, (21), 2014, pp. 5324–5339.

Experiment Description

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



Experiment Description

- (28) Wireless Acoustic Microphone Systems
  - ½" B&K 4189 – 25 kHz sampling
  - 15" Diameter ground board
  - GPS Receiver

- Weather Systems
  - Tethered Weather Balloon
    - Weather Sonde (200')
    - (up to 4) Temperature, Humidity, Pressure Sensors (~50')
  - ZephIR 300 LIDAR System
    - Wind velocity at 12 altitudes up to 1000'
  - (5) Ground Weather Stations
    - Located near Mics 1,11,21,24,27

Vehicle Characteristics

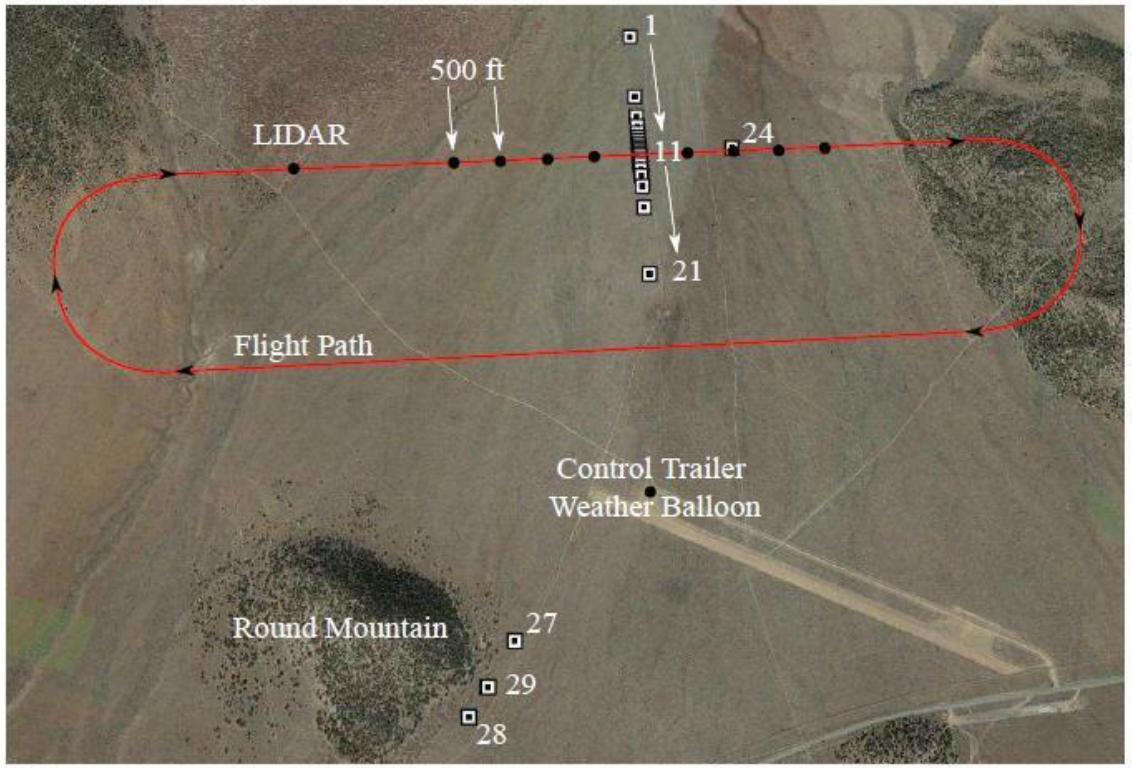
	MR	TR	
Number of Blades	3	2	
Radius (R)	10.69	1.86	[m]
Blade Pass Frequency (f)	19.5	104	[Hz]

- Aircraft Navigation and Tracking System (ANTS) (20 Hz sampling)
  - GPS Receiver
  - Inertial Navigation Data
- Air-Data Boom (5 Hz)
  - Outside Air Temperature
  - Static and Dynamic Pressures
  - Wind Velocities

Flight Conditions

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



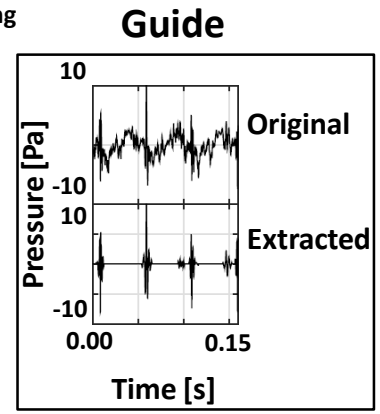
6° Descent Condition

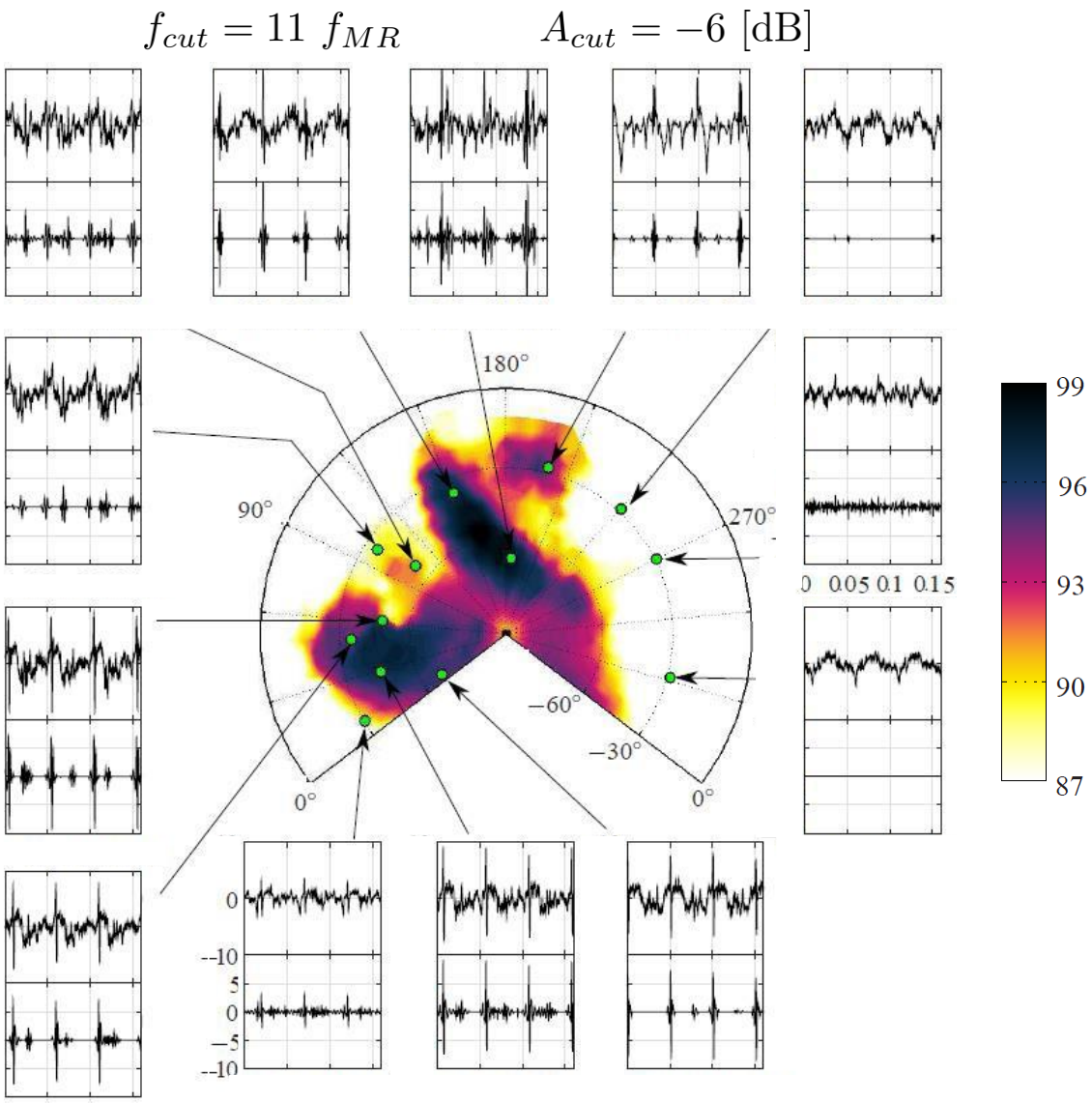
	KIAS	KTAS	Nom. Takeoff Wgt 4400	3915 [lb]
80 KIAS	80	87 (Typ)	11	13
80 KTAS	73 (Typ)	80	12	13

Results

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

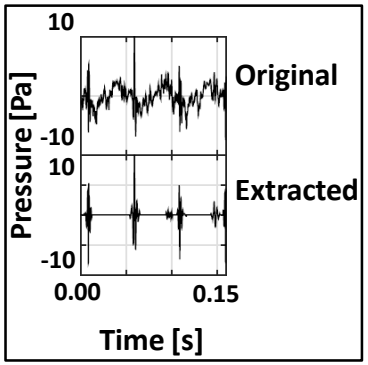




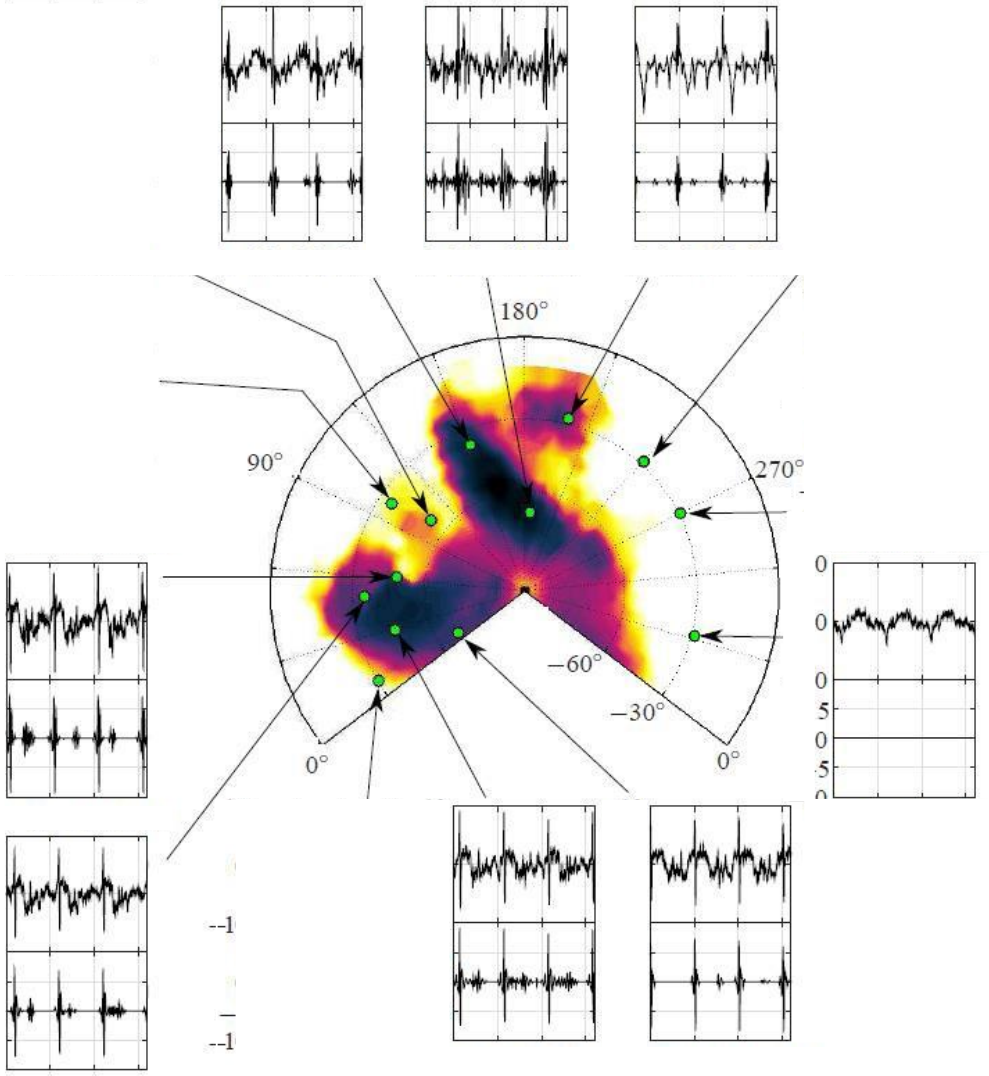
Results

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



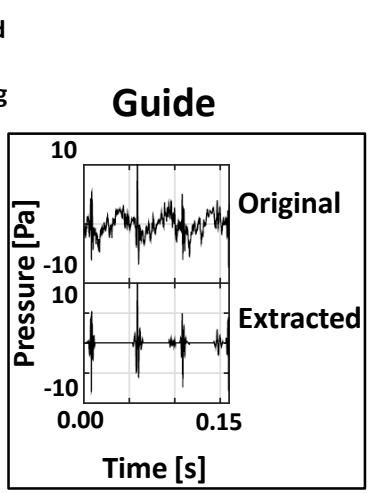
$f_{cut} = 11\ f_{MR}$ $A_{cut} = -6$ [dB]



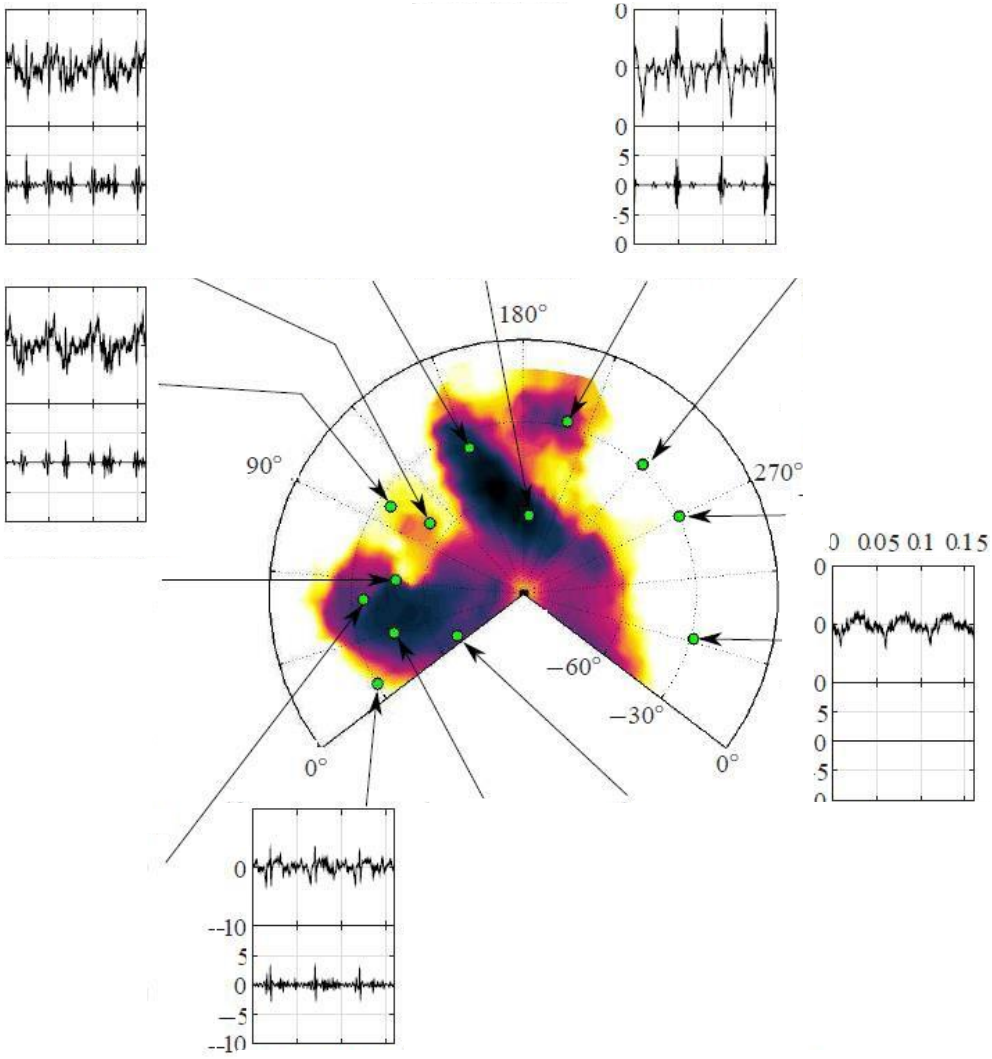
Results

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



$f_{cut} = 11\ f_{MR}$ $A_{cut} = -6$ [dB]

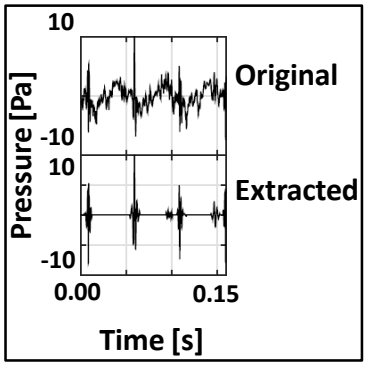


Results

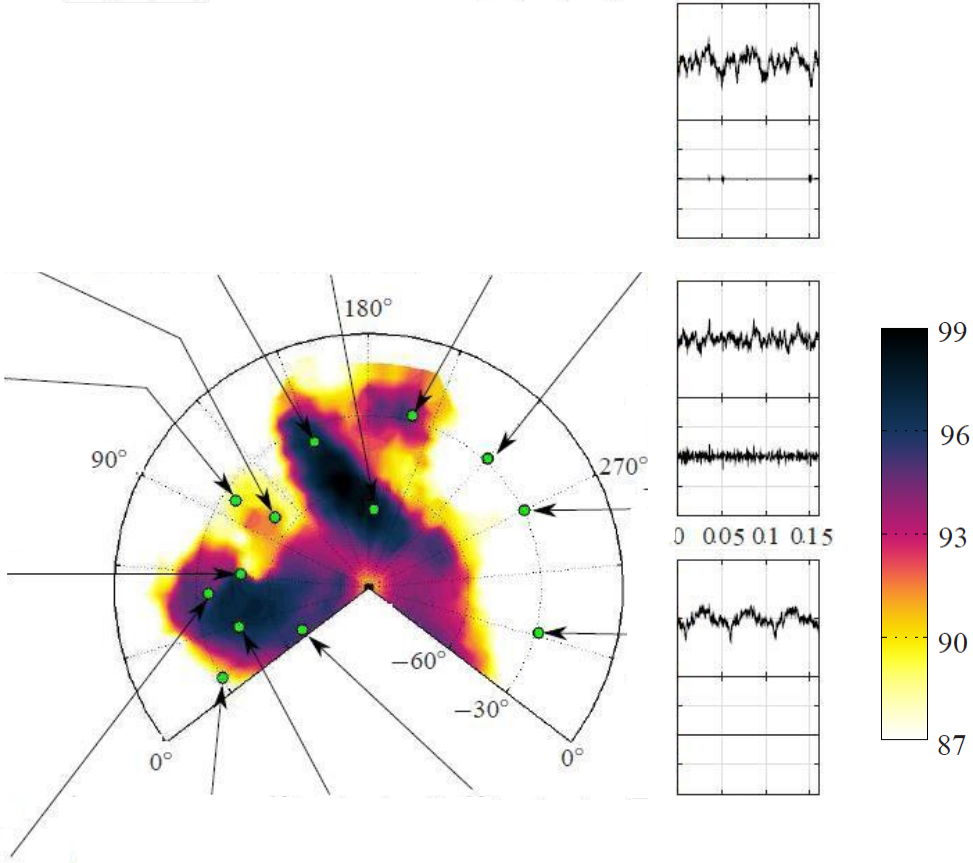
Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

Guide



$f_{cut} = 11\ f_{MR}$ $A_{cut} = -6$ [dB]

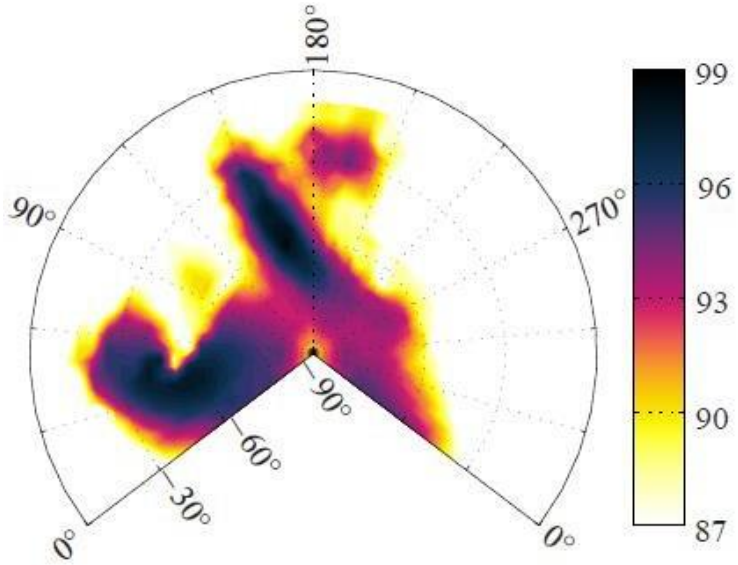


BVI Extraction VS BVISPL

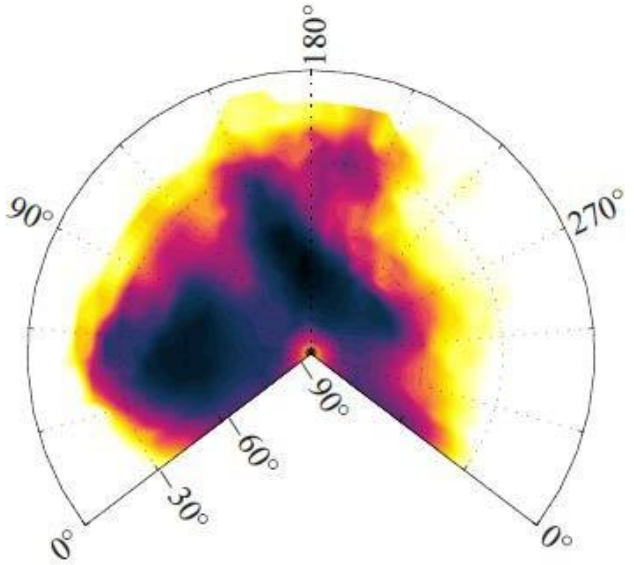
Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

BVI Extraction [dB]



BVISPL [dB]



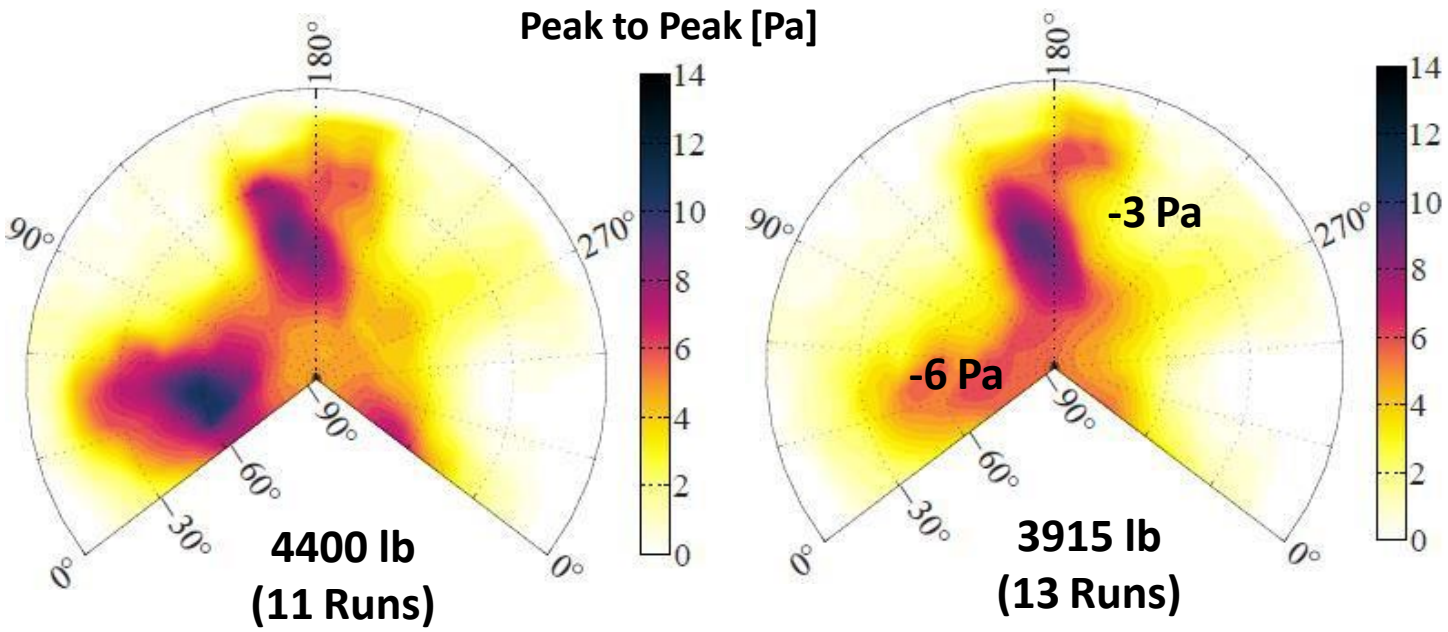
$$f_{cut} = 11\ f_{MR}$$

Average BVI

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

80 KIAS



$$\Delta W_{nom} = 11\% \rightarrow -1.5\ Pa \approx 1.0\ dB$$

$$\Delta W_{max} = 17\% \rightarrow -2.4\ Pa \approx 1.3\ dB$$

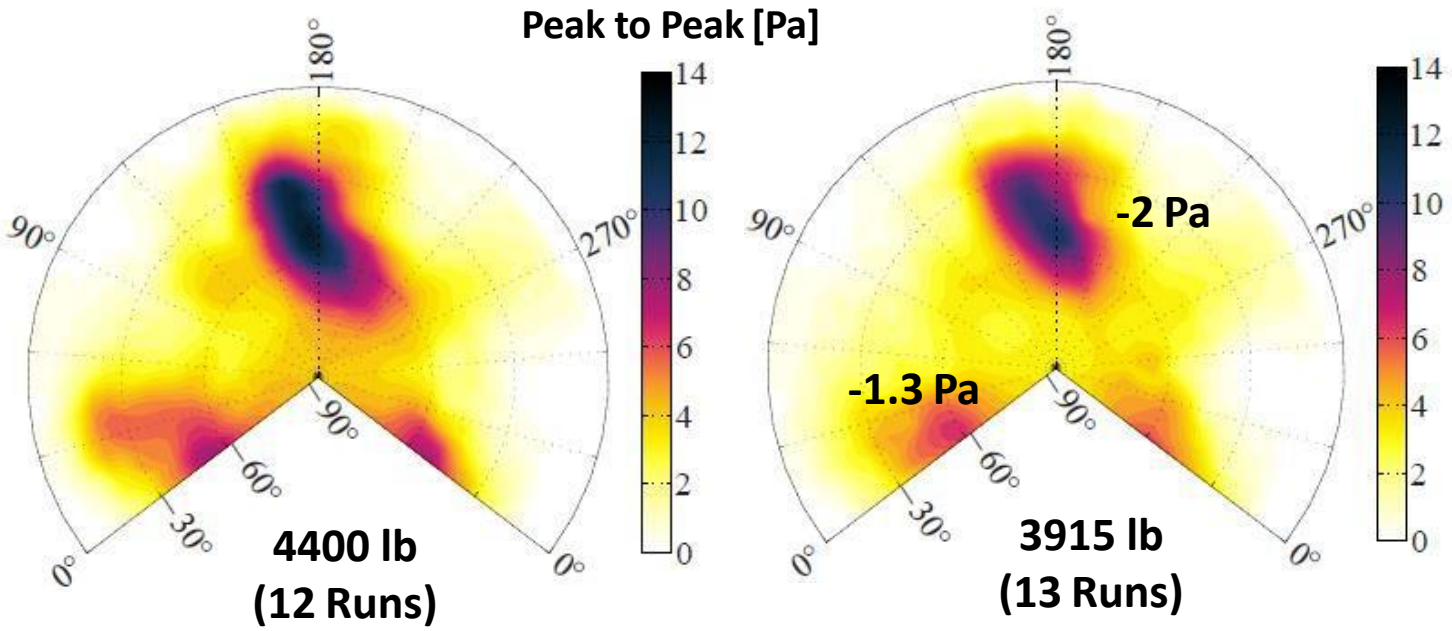
$$\alpha_{TPP} = -\frac{D}{W} - \gamma ?$$

Average BVI

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

80 KTAS (~73 KIAS)



$$\Delta W_{nom} = 11\% \rightarrow -1.5\ Pa \approx 1.0\ dB$$

$$\Delta W_{max} = 17\% \rightarrow -2.4\ Pa \approx 1.3\ dB$$

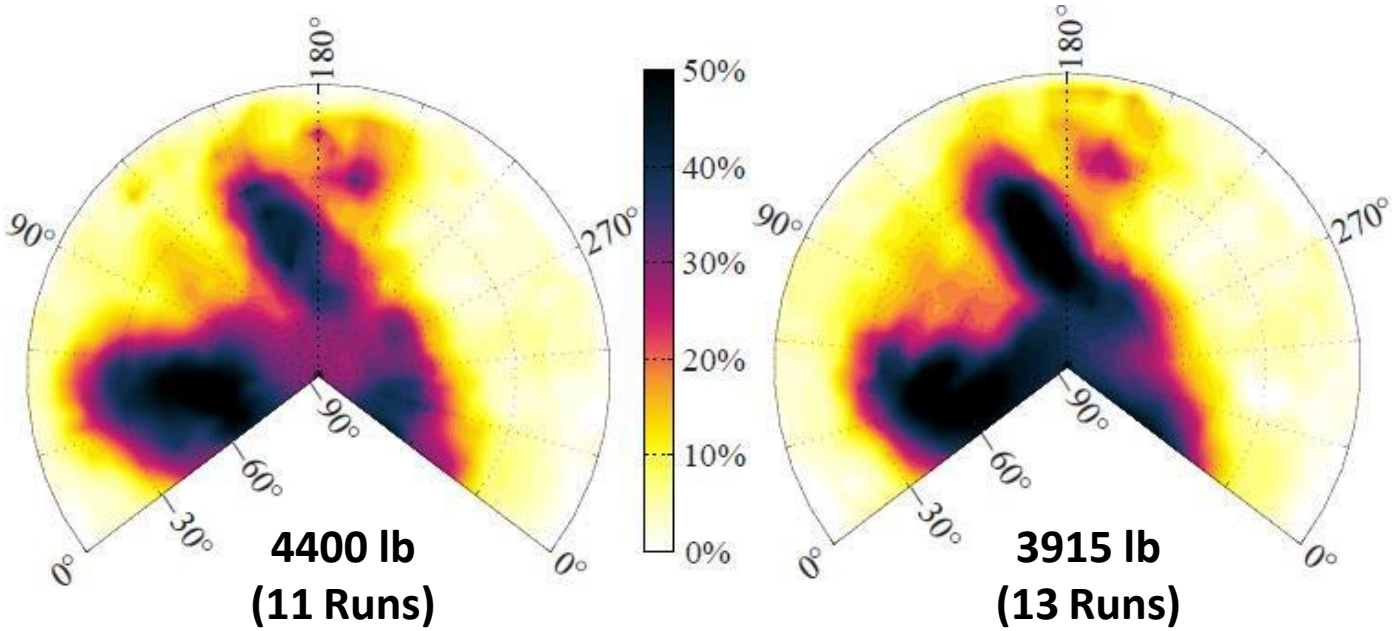
$$\alpha_{TPP} = -\frac{D}{W} - \gamma ?$$

BVI Standard Deviation

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

80 KIAS



4400 lb (11 Runs)

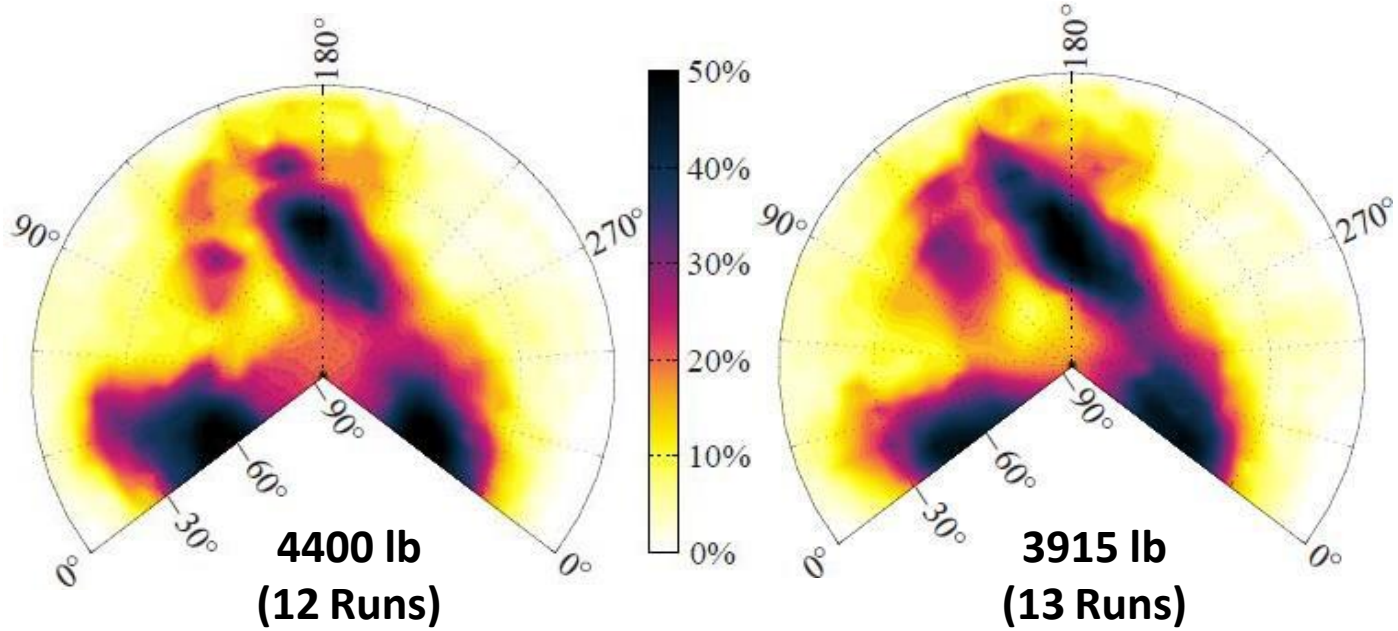
3915 lb (13 Runs)

BVI Standard Deviation

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

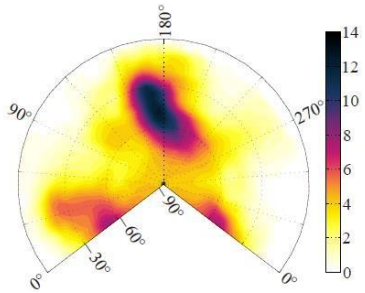
Stephenson & Greenwood

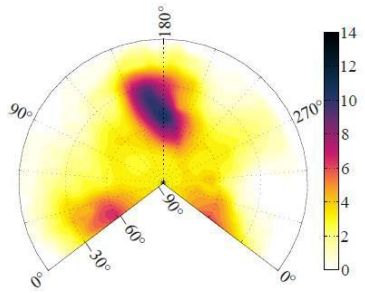
80 KTAS (~73 KIAS)



4400 lb (12 Runs)

3915 lb (13 Runs)





Conclusions

- BVI noise can be strongly affected by weight
  - Vortex Strength + Tip-Path Plane?

- BVI noise highly variable
  - Up to 50% of normalized standard deviation
  - Can be used to identify secondary BVI events

Questions?

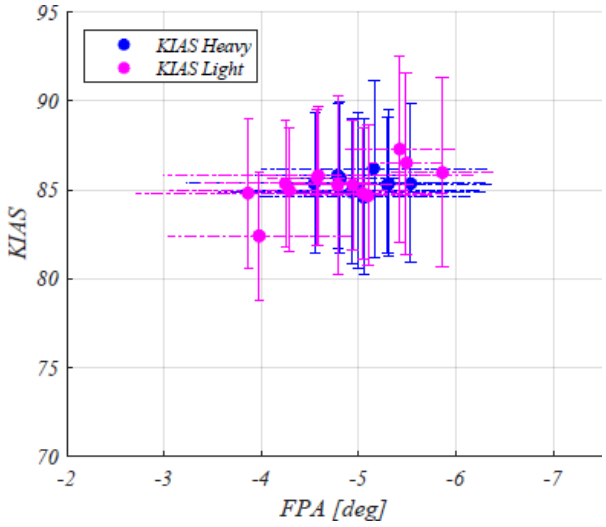
Acknowledgements

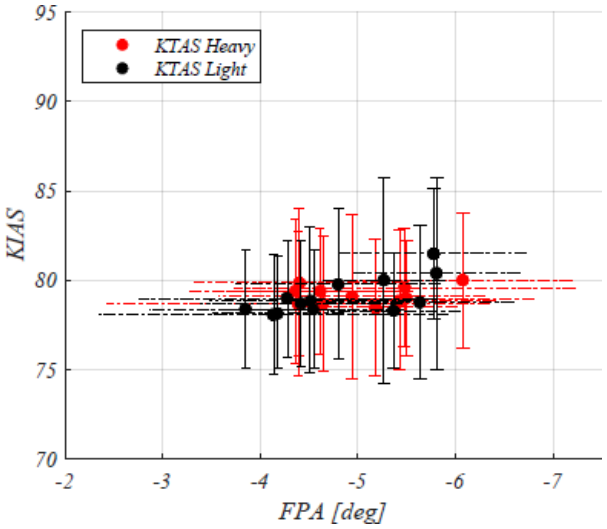
- Mike Watts
- David Conner
- Keith Scudder
- Andrew McCrae
- Nikolas Zawodny
- Aris Helicopters

Flight Path and Speed Consistancy

Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood



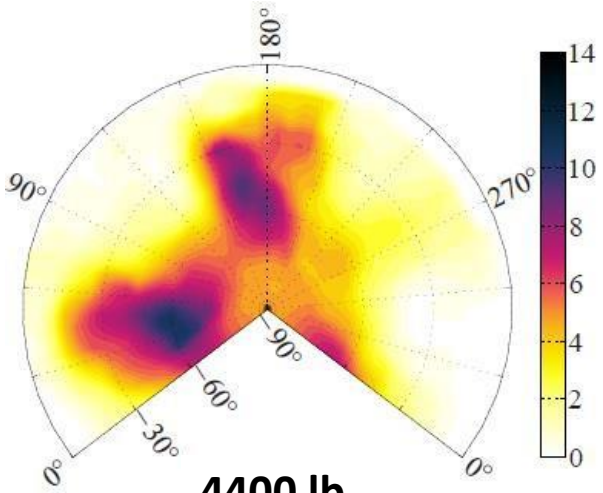


Average BVI

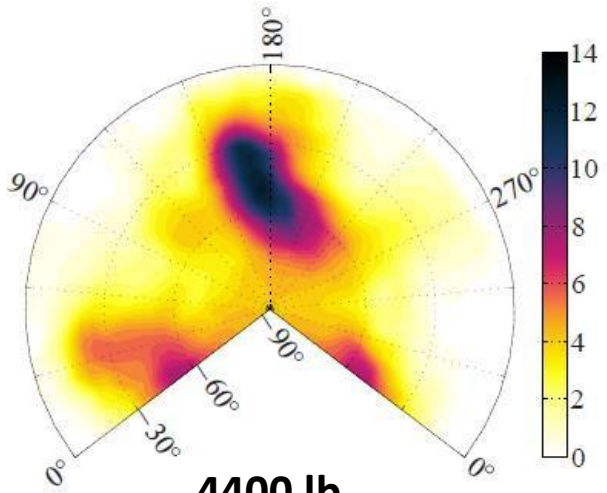
Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

80 KIAS

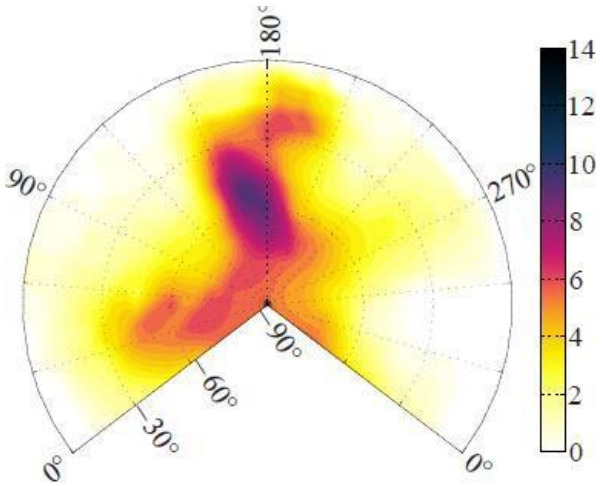


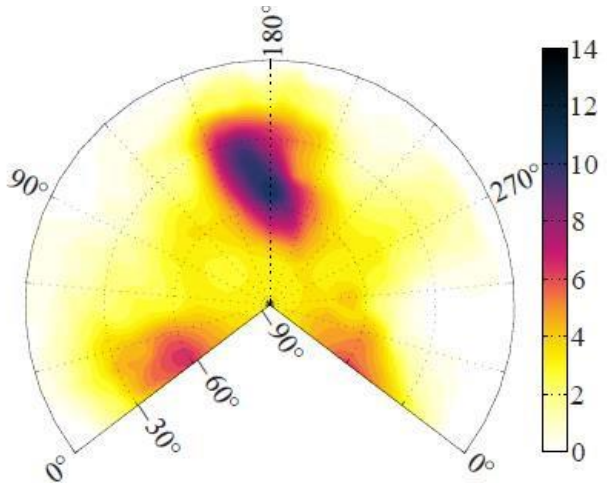
80 KTAS



4400 lb

4400 lb





3915 lb

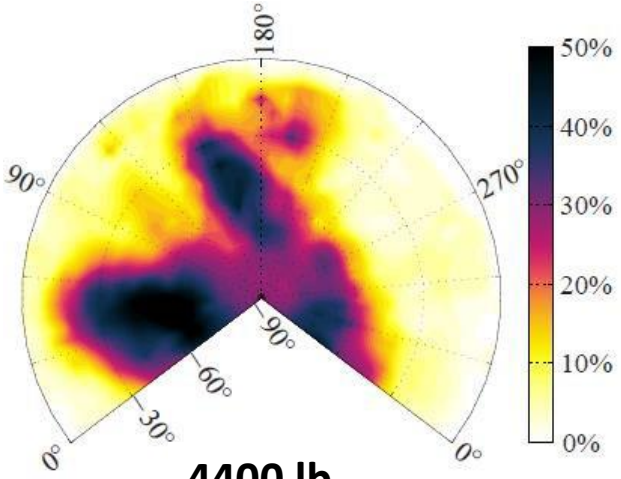
3915 lb

BVI Standard Deviation

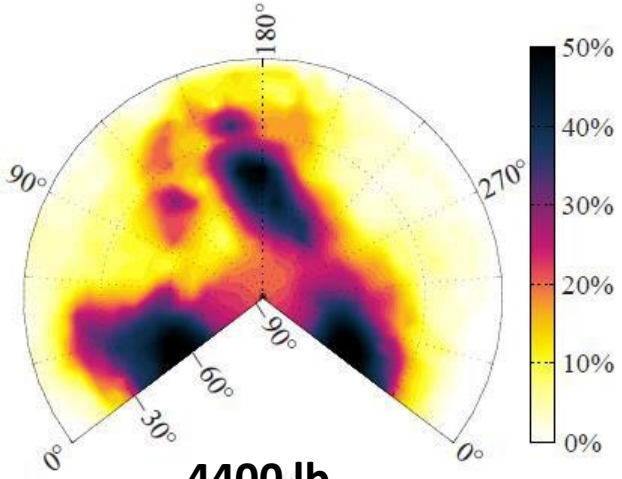
Effects of Vehicle Weight and True Versus Indicated Airspeed on BVI Noise During Steady Descending Flight

Stephenson & Greenwood

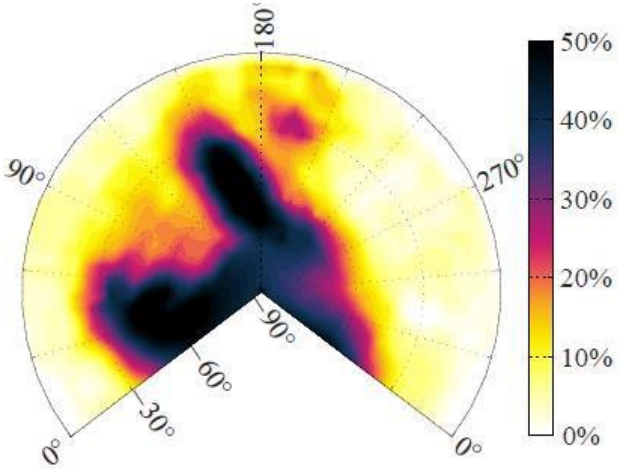
80 KIAS



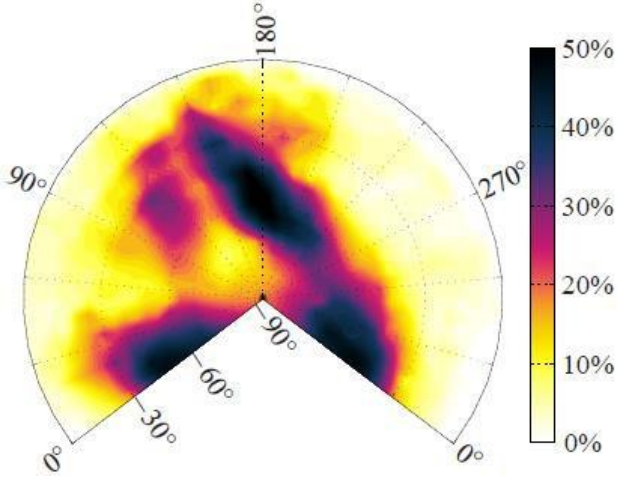
80 KTAS



4400 lb



4400 lb



3915 lb

3915 lb