Snowmobile Noise Measurement

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Who cares about snowmobile noise

- North America – US and Canada collaborate on standards and levels
  - SAE Snowmobile Committee– Anyone interested in helping can apply
  - Snowmobile Safety Certification Committee (SSCC) only manufacturers
  - Transport Canada – Regulating group (like EPA)
- Yellowstone National Park
- Sweden – Leads the EU effort
- EU – All legislation in EU member countries starts in the EU parliament, if they refuse jurisdiction than member countries can regulate on their own.
  - In process of writing full set of snowmobile regulations – noise, exhaust emissions, safety (machinery directive)

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Snowmobiles in Yellowstone Park

- Reason for start of Clean Snowmobile Competition
- Rules change yearly
  - Combination of snow coaches and snowmobiles
  - A group of 10 snowmobiles is equivalent to 1 snowcoach
  - Snowmobiles typically quieter than snowcoaches
  - Nearly all snowmobiles must be part of guided tour
  - Only snowmobiles allowed in must meet Best Available Technology (BAT)
    - For 2015 only the Ski Doo 600 and 900 Ace are listed on the website
  - Constant monitoring since 2003 in various places in the park
  - Monitoring data is used as input to models to predict where/when snowmobiles can be heard in the park at all times

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SAE Snowmobile Noise Standards

- J192 – Maximum Exterior Sound Level for Snowmobiles
  - 1970 original implementation
  - Level hasn't changed but manufacturers have become much more compliant and speed and power of sleds has increased tremendously
- J1161 - Operational Sound Level Measurement Procedure for Snowmobiles
- J2567/J2641 - Measurement of Exhaust Sound Levels of Stationary Snowmobiles

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J192

- Maximum allowable level is 78 dBA + 2dBA
- 15 mph to full throttle acceleration noise test
- Performed in summer or winter
  - Correction for summer testing
- Required instrumentation
  - Type A SLM, slow weighting, maximum A weight
  - Engine speed sensor
  - Sensor capable of recording when full throttle is achieved
  - Sensor to indicate vehicle position at start, full throttle, and end of course
  - Sensor to determine vehicle velocity
  - Weather information – Thermometer, Barometer, Sling Psychrometer (Dew point), Windvane, Anemometer
- Microphone 15m (50ft) from center of snowmobile path at a height of 1.2m (4ft)

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J192 – Test Surface

- Snow Surface
  - Maximum of 3 inches of loose snow sufficiently compacted to support the snowmobile without significant penetration
  - Hardness of the snow shall be verified prior to testing
    - Snowmobile traverses the test lane as slow as clutch engagement allows and verify at least 25mm of track penetration
  - Depth of packed snow measured with ¼ inch cylindrical probe pushed into snow with 20 lbs. of force, minimum depth of 3 inches required
- Grass Surface
  - Maximum of 3 inches of grass free of visible droplets of water
  - Evaluate using sound source
  - Apply correction if needed

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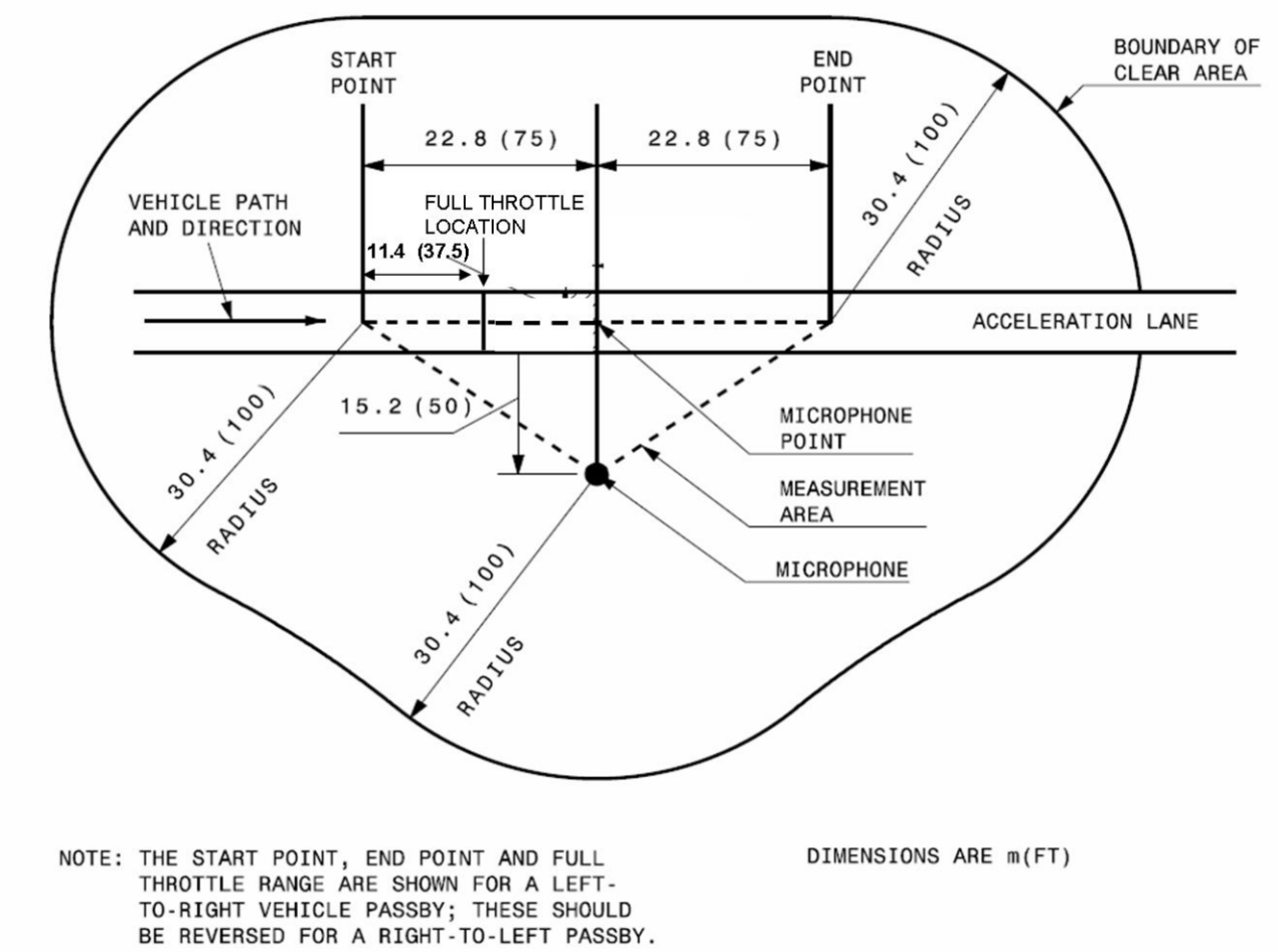
J192 Test Course



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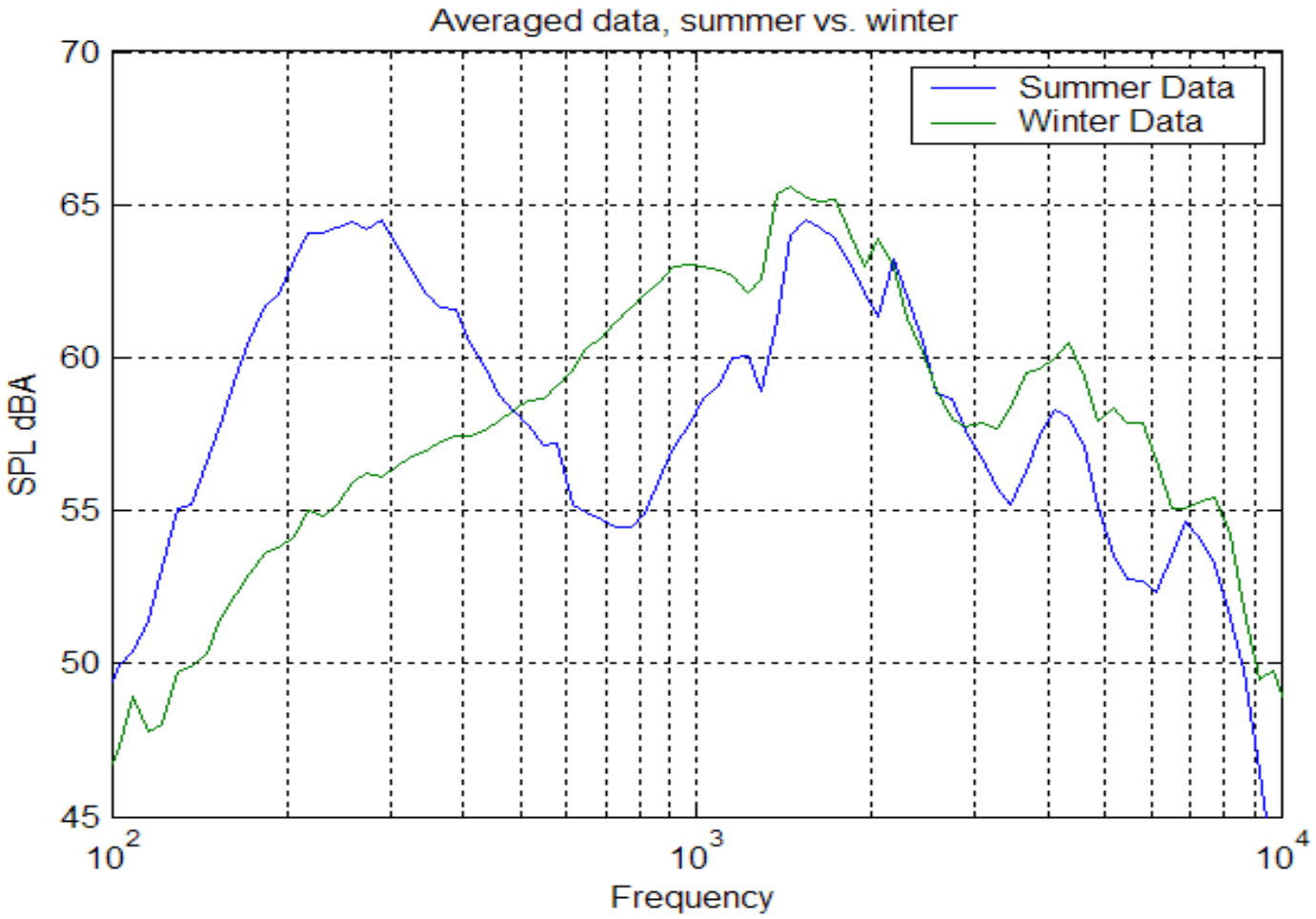
Summer vs. Winter



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J1161 – Steady State Test

- Steady state passby test
- In many areas average speed of a snowmobile is less than 20 mph
- Test Speed of 15 mph
- Minimum 3 runs within 2 dB for each side
- Type 1 SLM, Slow Response, A weighted
- Weather recorded
- Speed verified by GPS or other accurate device
- Same surface as J192 with Grass surface correction

- Maximum allowable level is 73 dBA

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J2567 – Stationary Test Procedure

- The snowmobile shall be parked at the test site with an operator seated in the normal operating position, and the forward traveling path of the snowmobile clear of obstructions.
- The brake shall be set throughout the test.
- The engine shall be started and run until reaching normal operating temperature range, as specified by the manufacturer.
- The operator shall slowly open the throttle until a steady 4000 rpm ± 250 rpm engine speed is achieved, while holding the snowmobile stationary by applying the brakes.

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J2567 Stationary Test

- The microphone shall be located at a distance of 4.00 m / 157.5 in from the longitudinal plane of symmetry and 1.22 m / 48.0 in above the ground plane in line with the exhaust outlet. If there is more than one exhaust outlet it shall be located with reference to the centermost point of the multiple outlets.

- Level must not exceed 88 dBA

- Level was derived by testing many vintage and newer models with and without aftermarket exhaust to find a level which did not reject ANY stock snowmobiles.

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There is more than one way to measure snowmobile noise

Single Microphone

Pass-by (SAE J192)

Total Sound Energy

Sound Power

Source Localization

Sound Intensity

Beamforming

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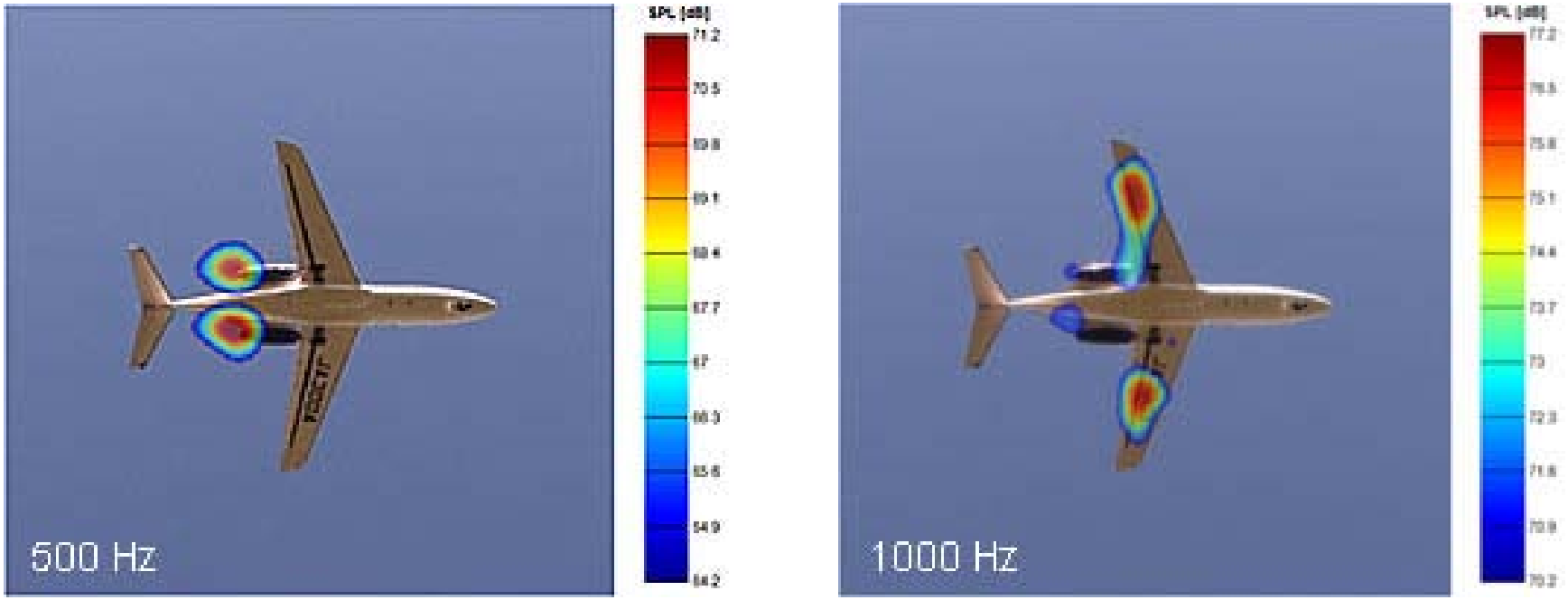
Source localization methods allow you to identify exactly where the sound originates on a complex system



Source: http://www.aero.jaxa.jp/eng/publication/magazine/apgnews/2012_no24/apn2012no24_04.html

Identifying the noise source allows engineers to tailor noise treatments to specific areas or sub-systems

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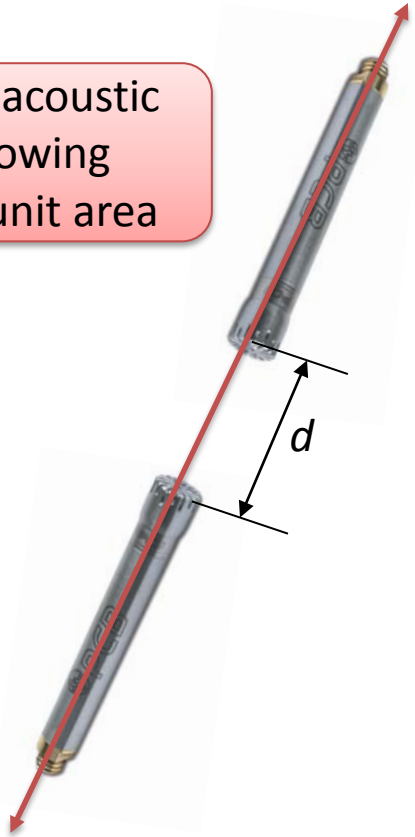
Sound intensity measures magnitude and direction of acoustic waves

Amount of acoustic power flowing through a unit area



Sense Direction
(Dipole Pattern)

Angular frequency (rad/s)

cross spectrum

$$I(\omega) = -\frac{1}{\rho_0 \omega d} \mathrm{Im}\left[G_{12}(\omega)\right]$$

Air density

$$L_I = 10 \log_{10}\left(\frac{I}{I_{ref}}\right) \quad \mathrm{dB}$$

$$I_{ref} = 1 \ \mathrm{pW/m^2}$$

*Fahy, Frank, “Sound Intensity Second Edition”, 1995
*ISO 9614

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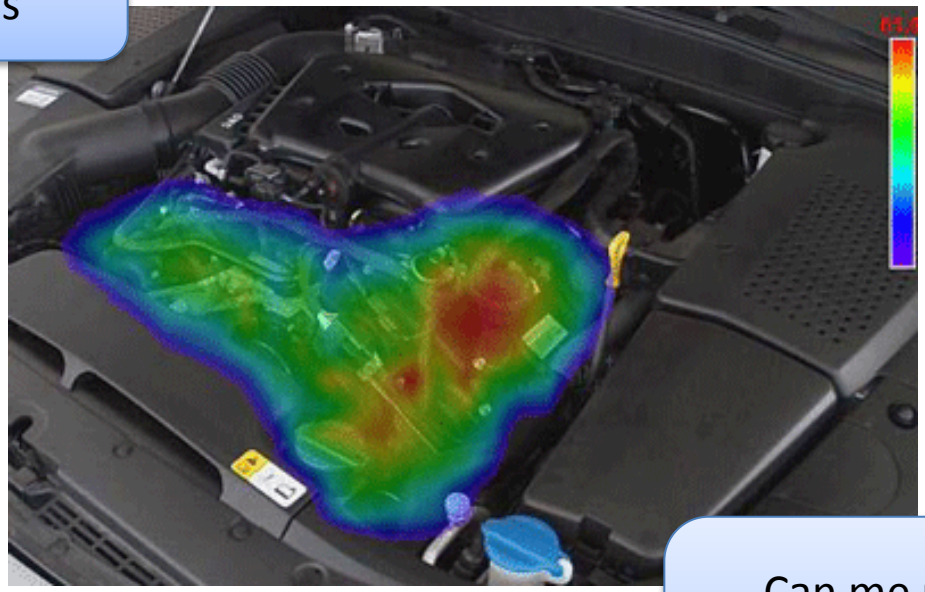
Example: Sound intensity measurement of an engine in an automobile

Good for stationary noise sources



Can me mounted to a moving vehicle for intensity measurements over many operating conditions

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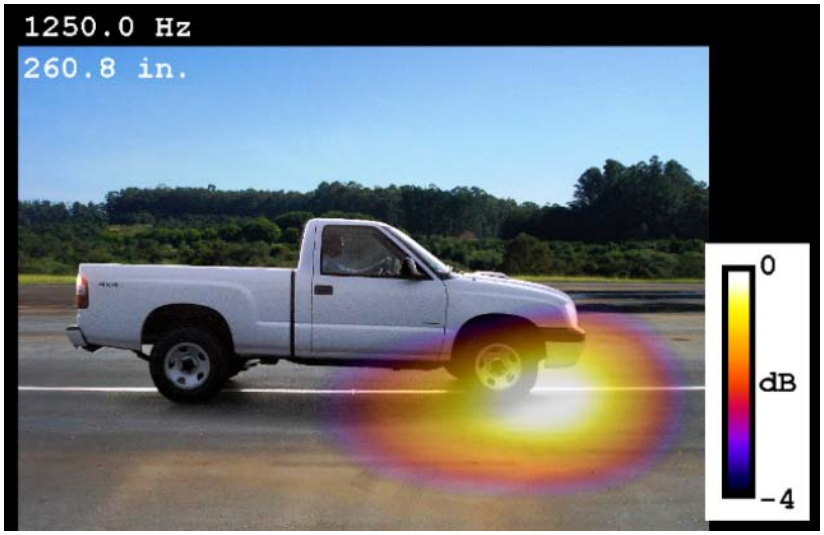
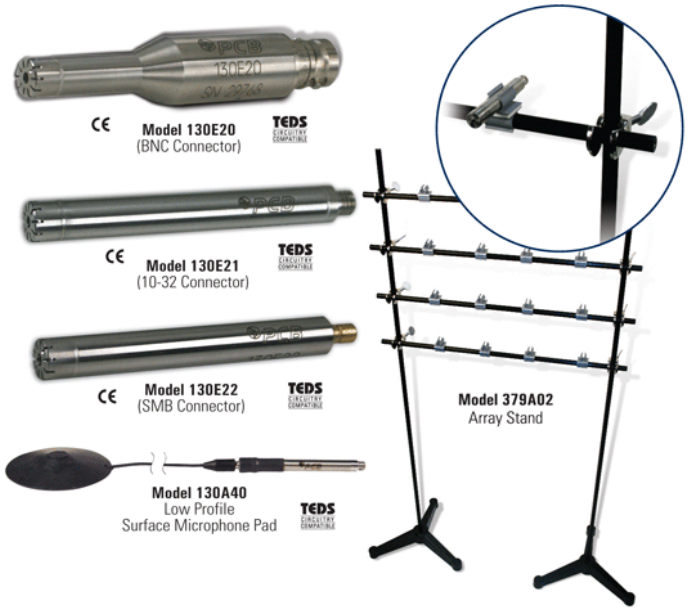
Beamforming uses a large array of microphones to “paint” a sound picture over a source





Easily used in combination with a video camera during pass-by events

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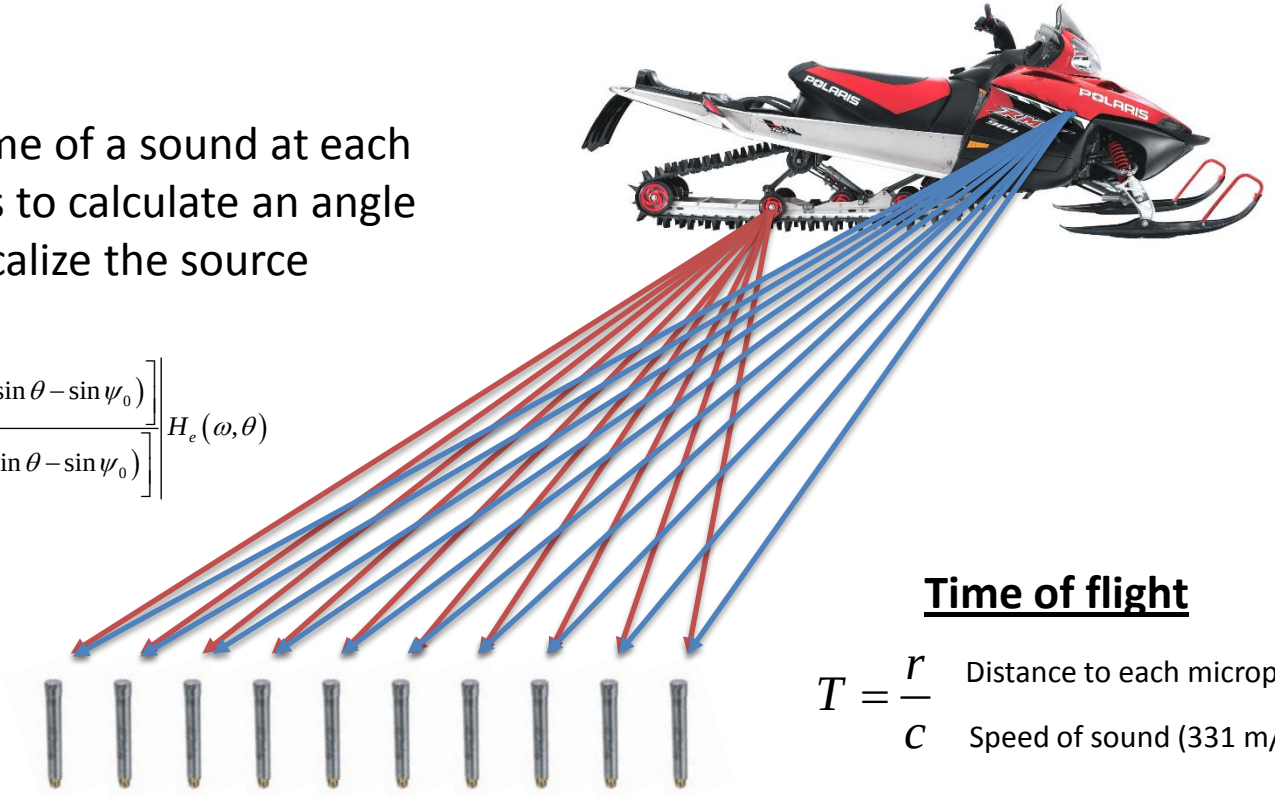
Beamforming works because sound from a source takes different amounts of time to travel to each microphone

The relative arrival time of a sound at each microphone allows us to calculate an angle of that sound, and localize the source

$$P_{Array}(\omega,\theta) = N\frac{A(\omega)}{r}\left|\frac{1}{N}\frac{\sin\left[\frac{N}{2}kd\left(\sin\theta-\sin\psi_0\right)\right]}{\sin\left[\frac{1}{2}kd\left(\sin\theta-\sin\psi_0\right)\right]}\right|H_e(\omega,\theta)$$

Time Delay Between Microphones: $\tau = \frac{d}{c}\sin\psi_0$



Time of flight

$$T = \frac{r}{c}$$

r Distance to each microphone

c Speed of sound (331 m/s @ 0° C)

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Sound power provides a metric for measuring sound energy that is independent of path characteristics, such as distance and ground conditions.

Surface Averaged Sound Pressure Level

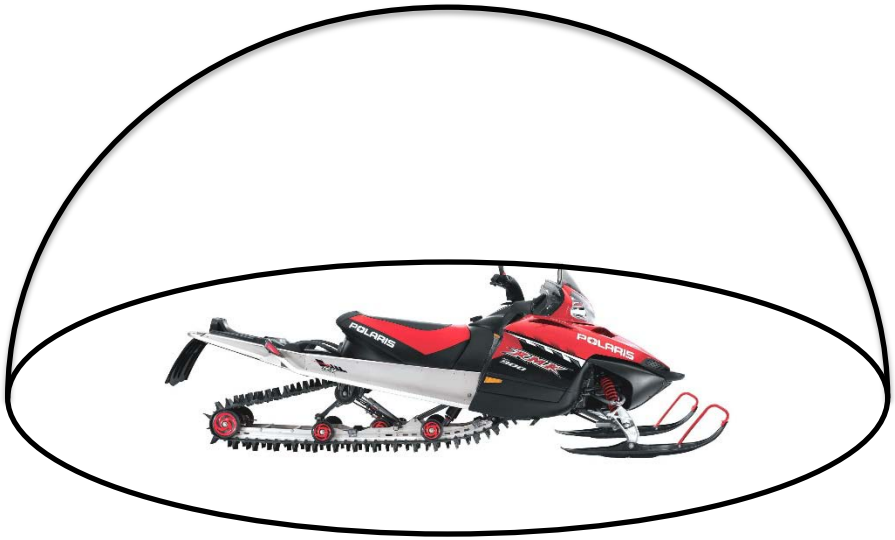
Surface Area

Sound Power Level

$$L_W = \overline{L_P} + 10\log_{10}\left(\frac{A}{A_0}\right)$$

$$A_0 = 1\,m^2$$

Useful in providing A-B comparison data of noise treatments



Usually use 10-20 microphones locations over an enclosing volume (hemisphere or box)

Source is stationary in this test

References:

ISO 3744/ANSI S12.54 Free Field
ISO 3745/ANSI S12.55 Anechoic
ISO 3746/ANSI S12.56 Survey Method

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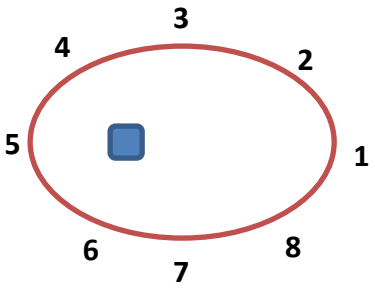
When spatially averaging sound pressure levels, make sure you average the mean-square values!



$$SPL = L_P = 10\log\left(\frac{p_{rms}^2}{p_{ref}^2}\right)$$

Location	SPL (dBA)	p_rms^2/p_ref^2	
1	78	63095734.45	
2	73	19952623.15	
3	70	10000000	
4	65	3162277.66	
5	60	1000000	
6	65	3162277.66	
7	68	6309573.445	
8	71	12589254.12	$\overline{L_P}$
mean	68.8	14908967.56	71.7 dBA

3 dB error in this example if you average incorrectly.

Remember that 3 dB is a doubling of sound intensity!

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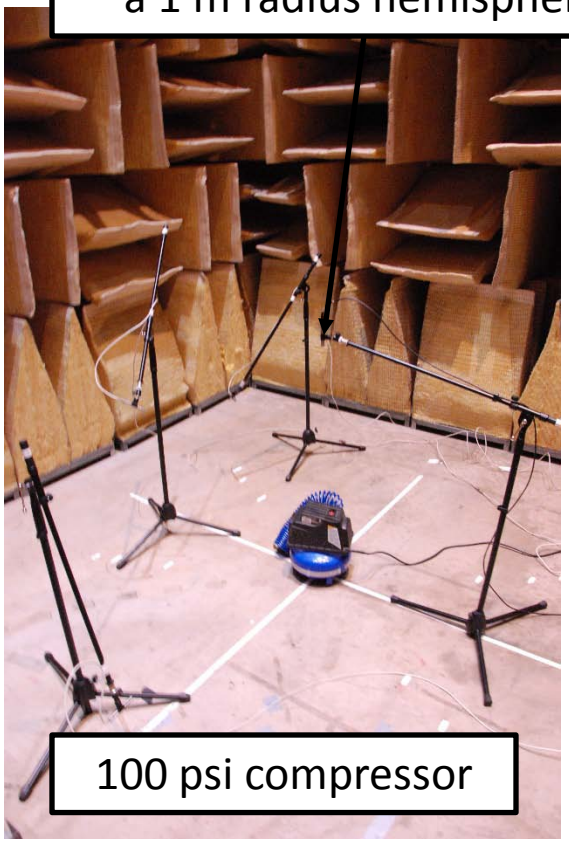
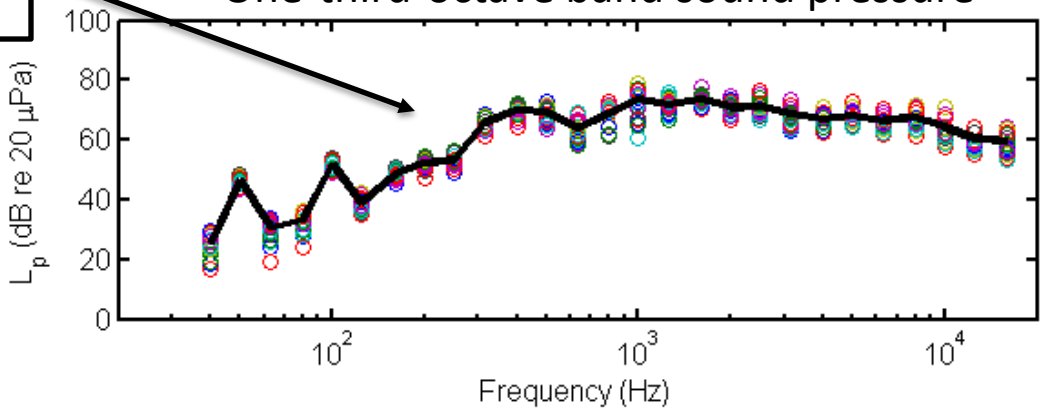
Example of ANSI S12.54/ISO 3744 sound power

20 Microphone locations over a 1 m radius hemisphere

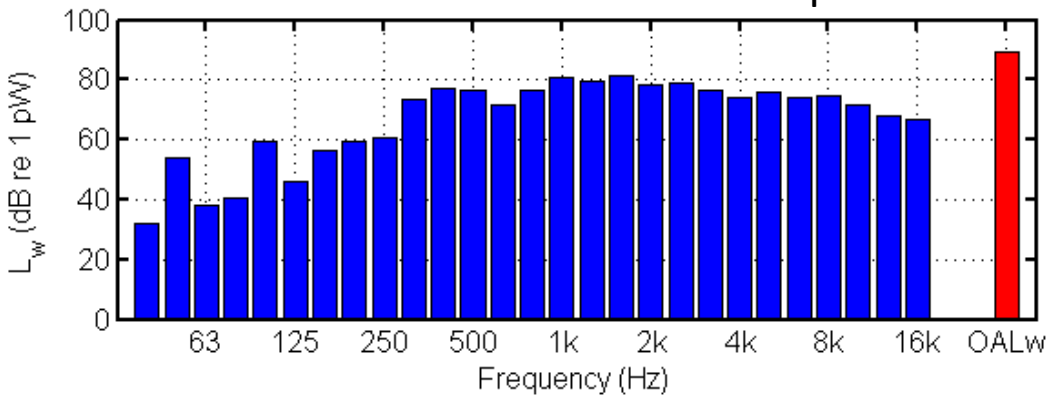


100 psi compressor

One-third-octave band sound pressure



One-third-octave band sound power



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In conclusion:

- Snowmobile noise is important to many groups
- Understand the SAE noise standards
  - SAE J192
  - SAE J1161
  - SAE J2567
- Explore other ways to characterize the noise from your sled using more advanced measurements
  - Sound power → source noise with no path effects
  - Sound source localization → pinpoint important sound sources
- Advanced measurement techniques will improve your noise control treatment package

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