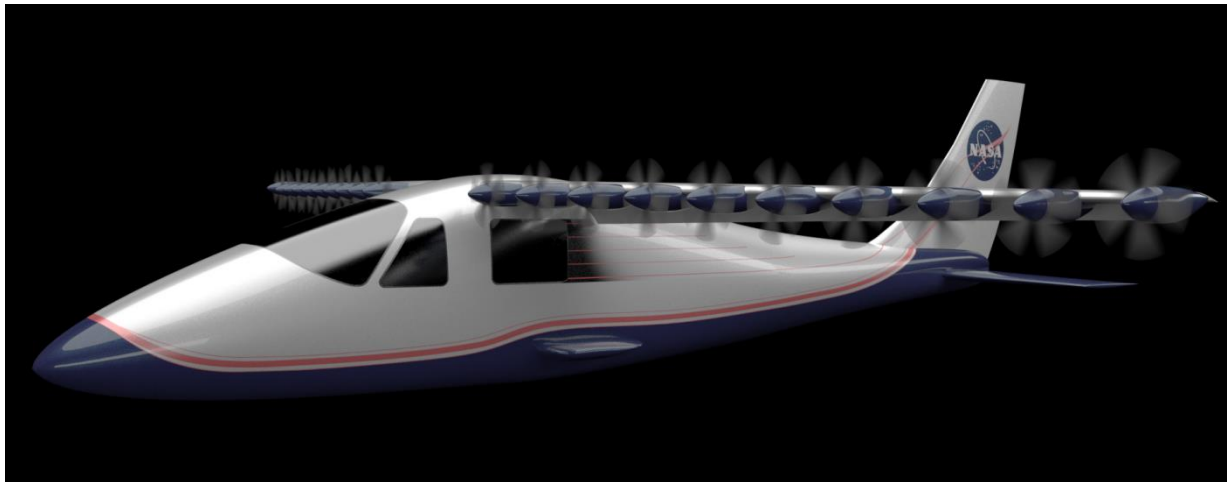


Perception-Influenced Acoustic Design of DEP Systems

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NASA Langley Research Center



LaRC Cross-Directorate Forum 4
Distributed Electric Propulsion: Opportunities and Challenges

2 October 2014

Outline

- Perception-influenced Acoustic design
 - DEP application
- Acoustic Assessment with Perception
 - Auralization of DEP designs and configurations
- Opportunities & Challenges for Noise
 - Regulatory, Technical, Economic, Societal

Perception-Influenced Design

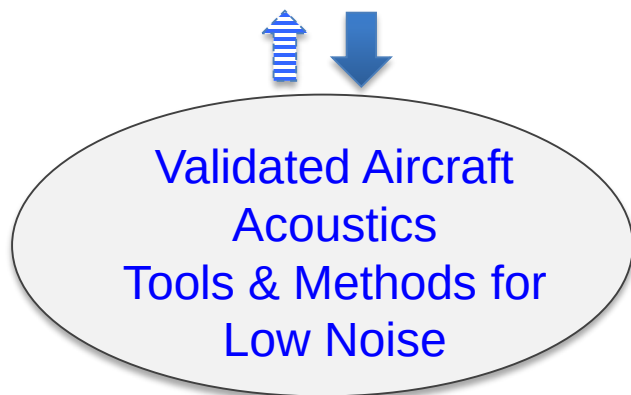
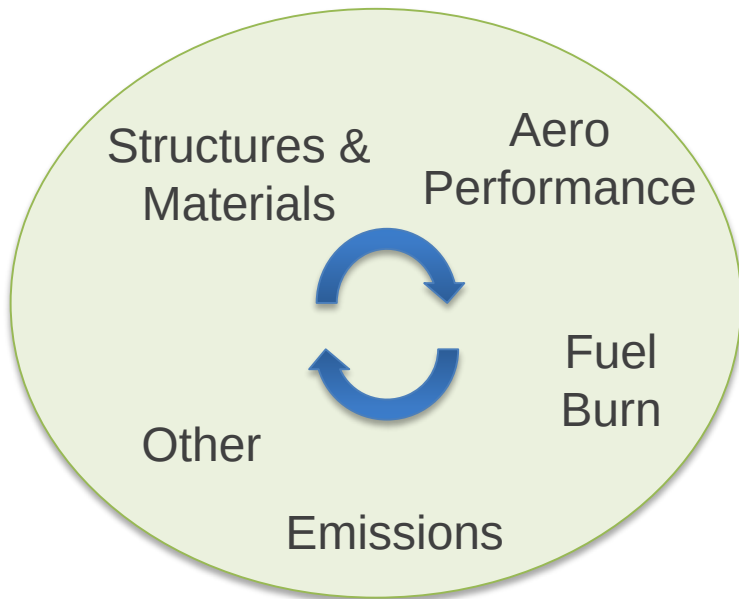


- NASA and industry acoustic research currently prioritized by source noise rankings based on specific metrics
 - Current noise metrics (e.g. certification metrics) are assumed to fully capture noise annoyance/impact on “community”
- Revolutionary/transformational air vehicles
 - Have unique configurations (from very small to large)
 - Have unique propulsion systems (e.g. electric motors, multi-rotor)
 - Have new missions
 - How and where they operate are different from other aircraft
 - Alternative certification procedures may be required
 - Provide guidance in determining certification metrics, i.e. sonic boom
- Alternative low noise design strategies are critical to support development of new configurations flying in broad range of operational environments

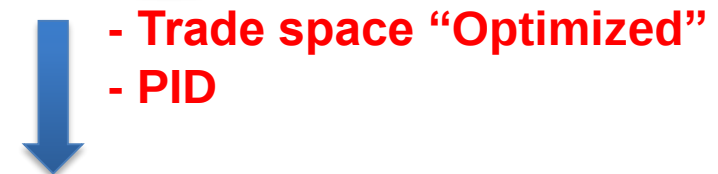
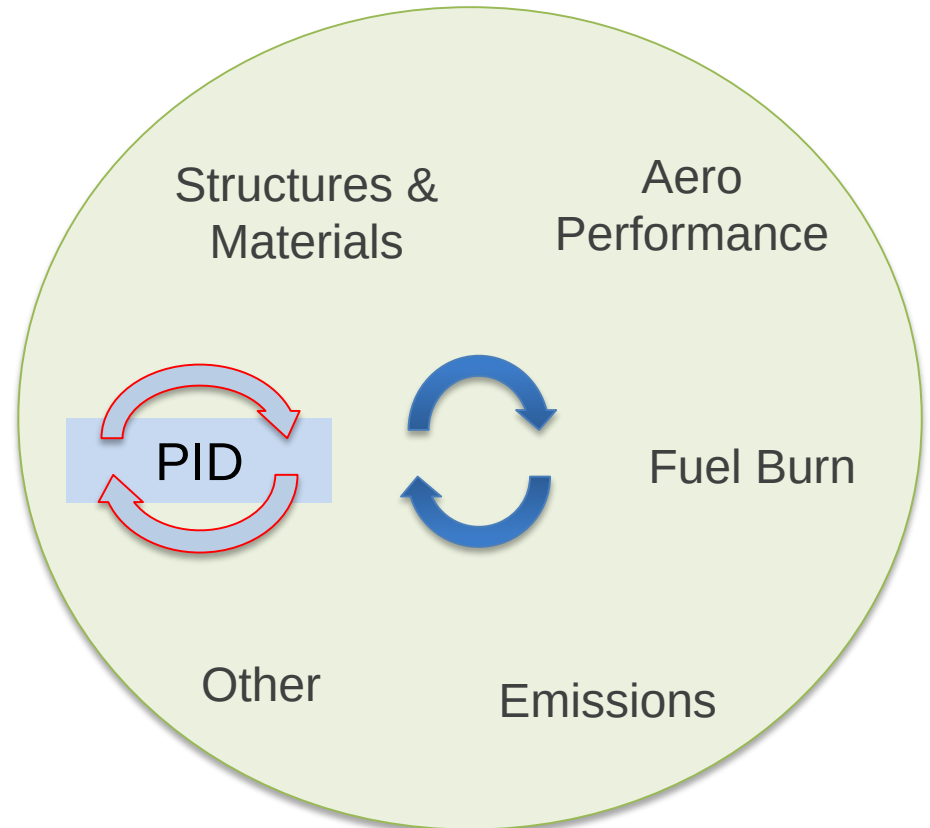
Perception-Influenced Design



Present



Perception-Influenced Design (PID)

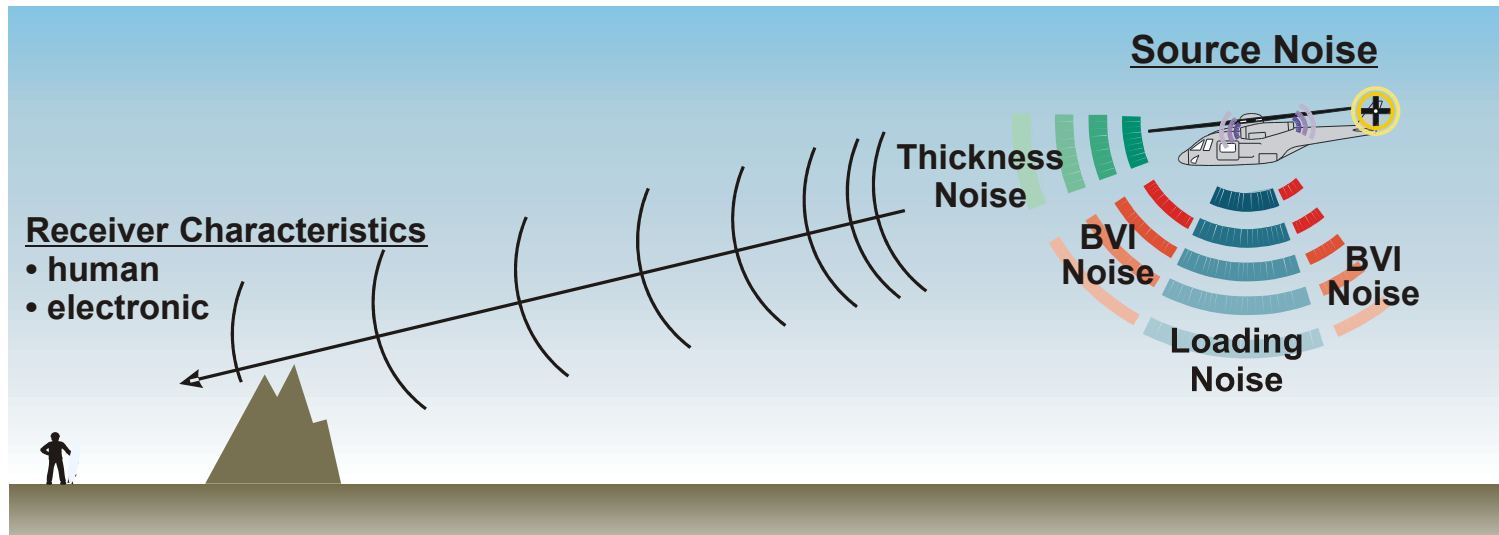
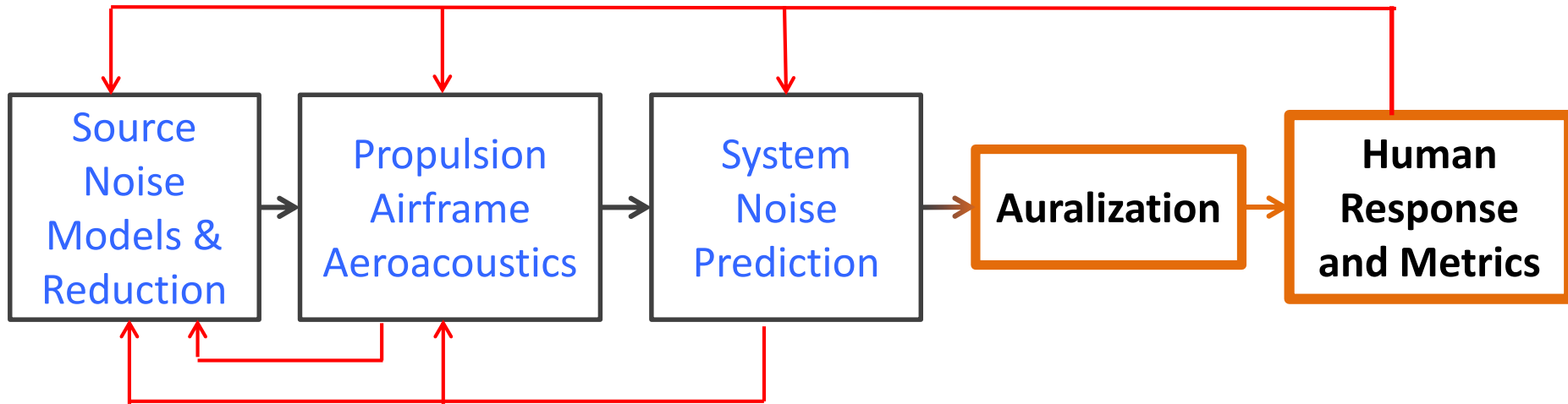


Design that achieves acoustic goals within multidisciplinary space

Perception-Influenced Acoustic Design

Validated Aircraft Aeroacoustics
Tools & Methods for
Low Noise

Human Perception



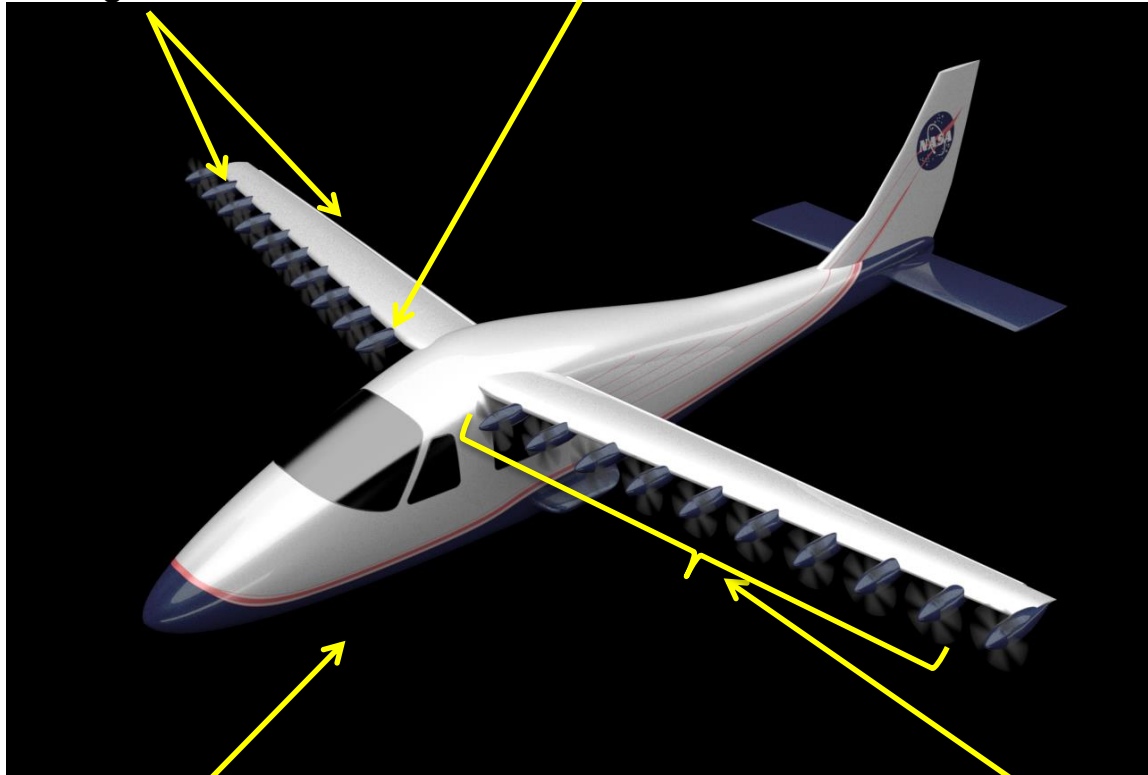
DEP: Component and System Noise

High lift systems (LEP & T.E.)

- Motor nacelles
- Minimize turbulent edge flows

Engine/airframe integration

- Prop-prop interaction
- Prop-wing interaction



Landing gear placement

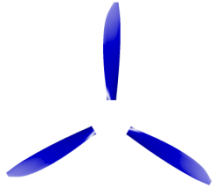
- Gear design details, weight
- Flow into gear

Propulsion/LEP System

- Propeller noise
- Electric motor noise
- Low annoyance/detection configurations

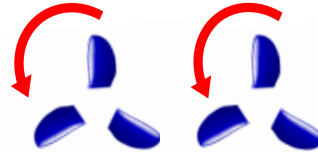
Noise Reduction Opportunities for Multi-Prop Configurations

1. Reduced tip speed



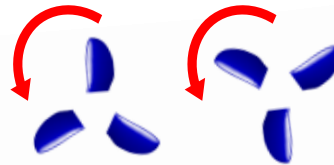
# Props	# Blades	RPM	BPF (Hz)	Tip Speed (m/s)	Unit Thrust (lbs)	Scale	Diameter (m)
1	3	2500	125	262	480	100%	1.98
2	3	2500	125	249	240	95%	1.88
4	3	2500	125	236	120	90%	1.78
8	3	2500	125	223	60	85%	1.68
18	3	6500	325	170	26	25%	0.49

2. Spread Spectrum



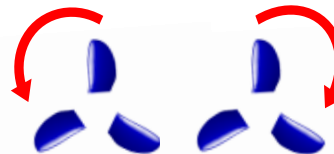
Props at different RPM
(incoherent)

3. Spread Phase



Both props at same RPM
(coherent)

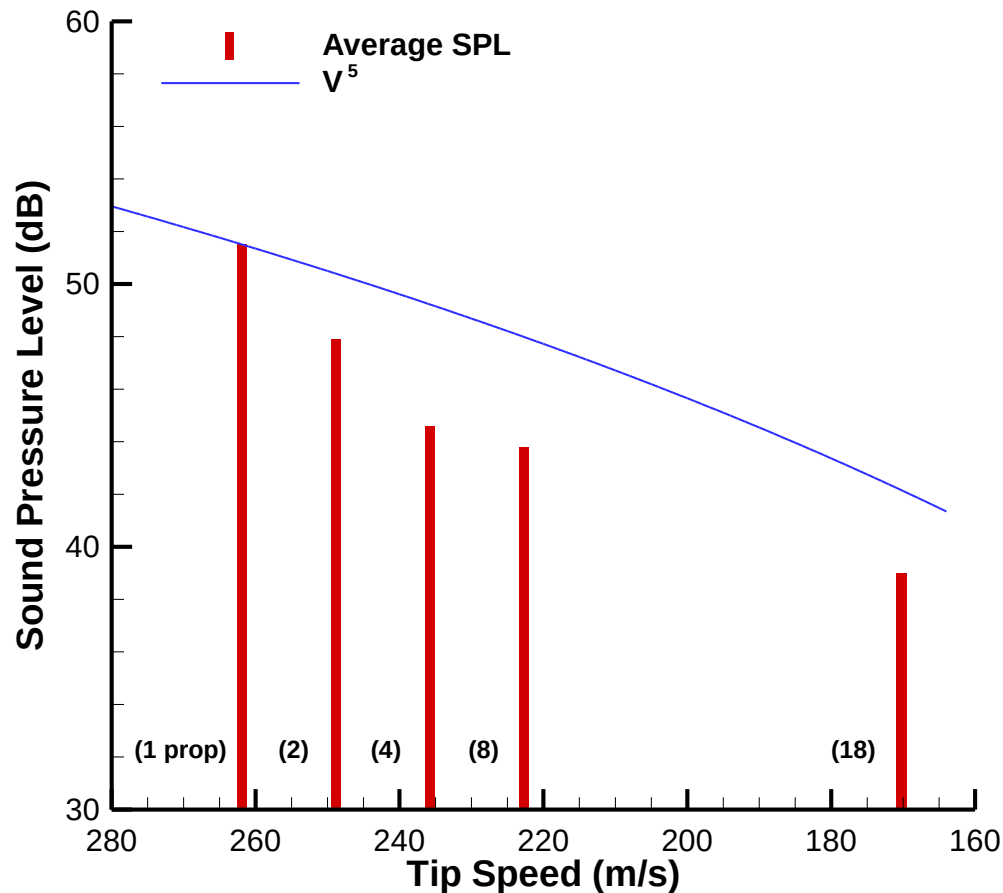
4. Counter-Rotating



Coherent or incoherent

Challenge: Implementation maintaining performance or control

Effects of Reduced Tip Speed



Tip Speed		Constant	Noise Reduction (dB) (TS 262 m/s to 170 m/s)
QL Avg	Circumferential	N props at constant thrust	12.5
V^5 (*)	Helical	Single prop @ constant input power	9.4

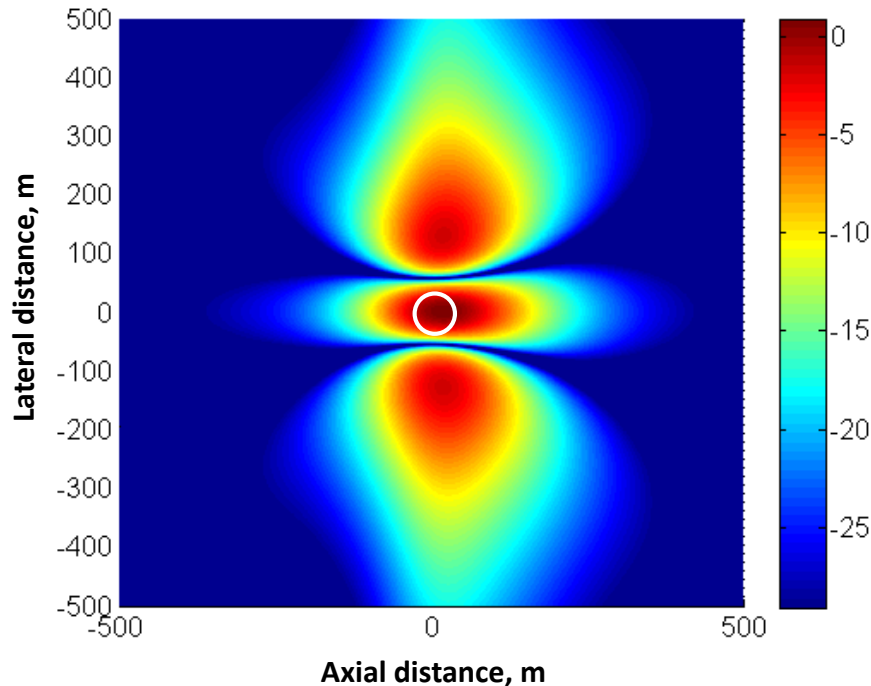
*SAE AIR 1407, May 1977

Time Averaged Radiation Patterns

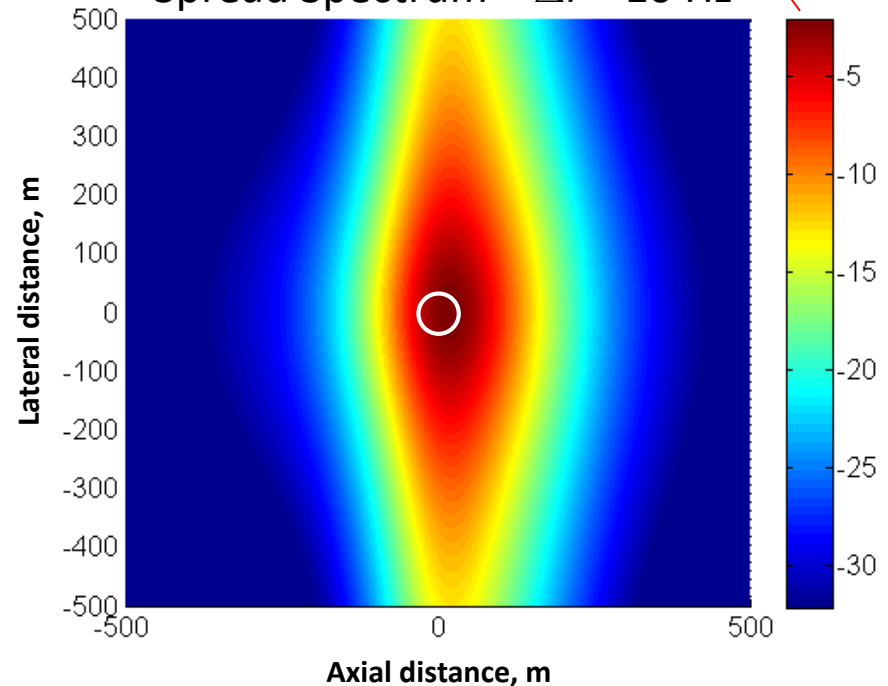
2 Sources

Peak power
down 3dB

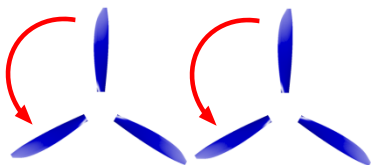
Coherent



Spread Spectrum – $\Delta f = 10$ Hz

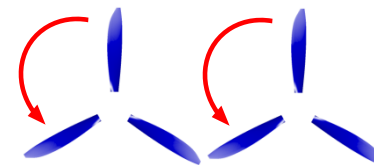


Both at 125 Hz and in phase



Same average
radiated power

120 Hz 130 Hz



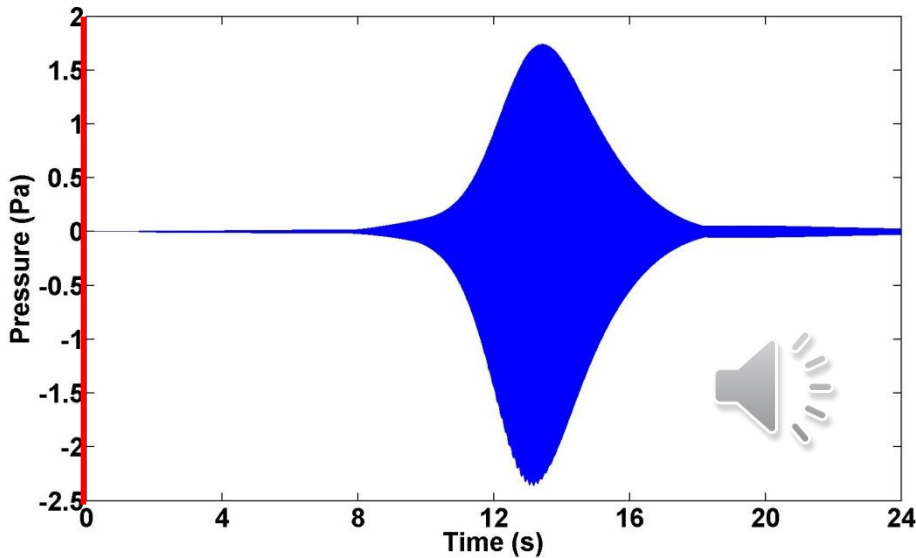
Stationary source, pure tone, altitude=150 m

General Aviation Prop

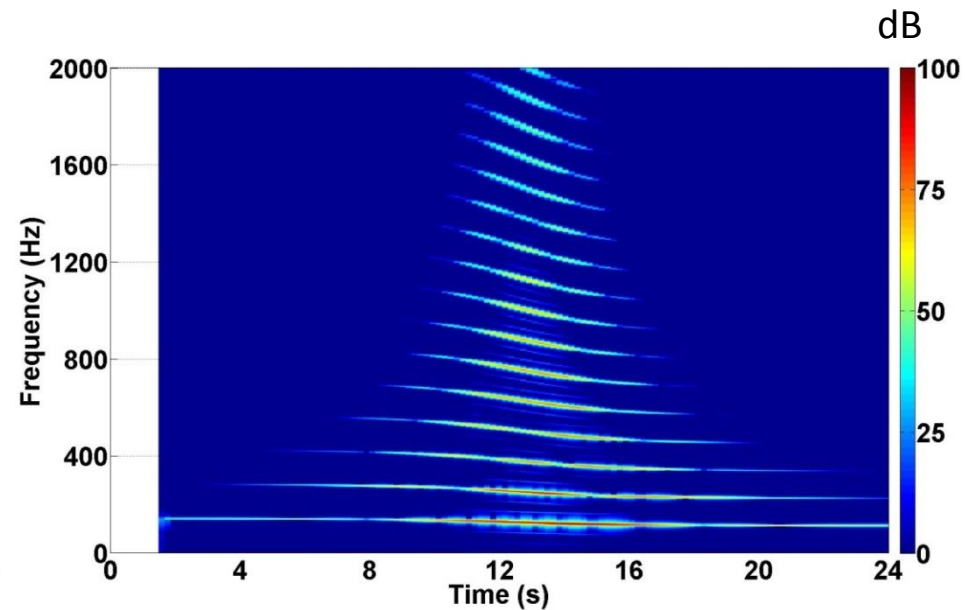
Average Source Power = 101.8 dB

Peak Level at Centerline Receiver = 101.4 dB

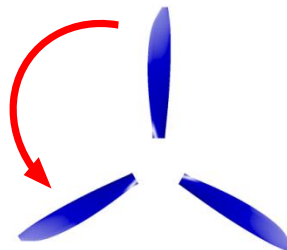
Time History



Spectrogram



135 Hz



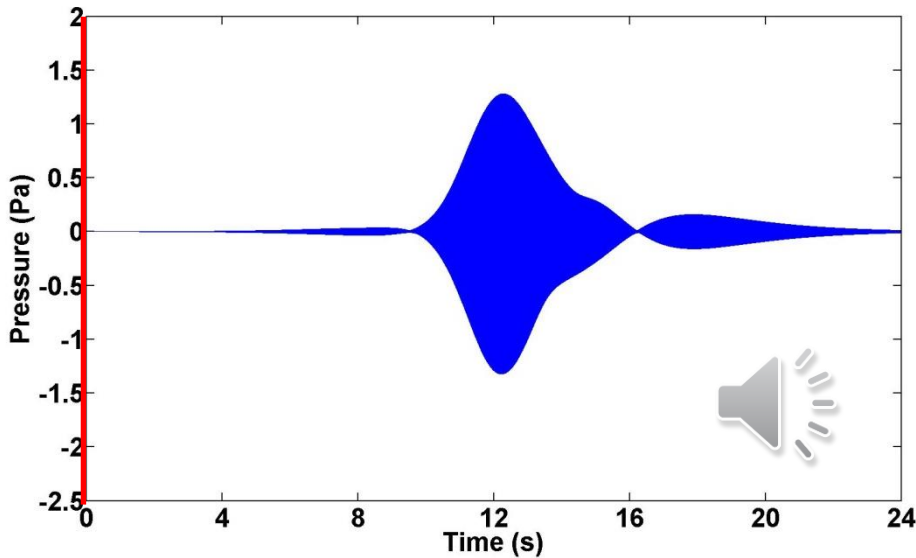
Maximum pressure on centerline

18 LE Props – Coherent DEP

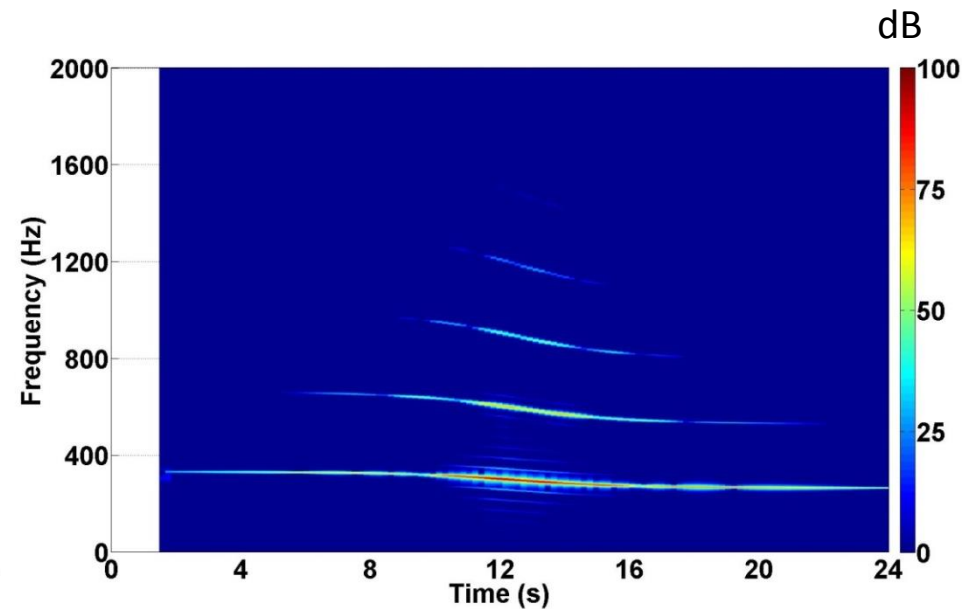
Average Source Power = 89.0 dB (-12.8 dB re: GA Prop)

Peak Level at Centerline Receiver = 96.4 dB (-5 dB re: GA Prop)

Time History



Spectrogram



All 293.3 Hz and in phase



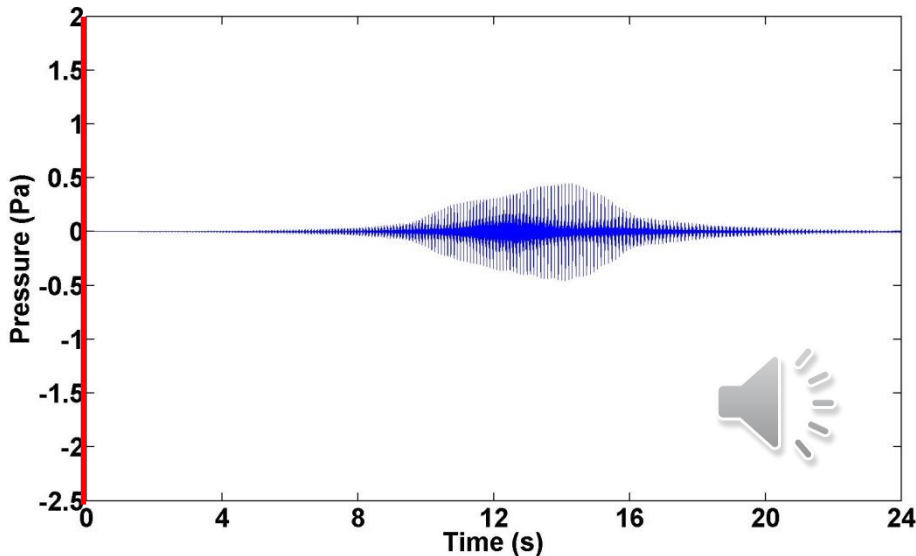
Maximum pressure on centerline

18 LE Props – Spread Spectrum DEP

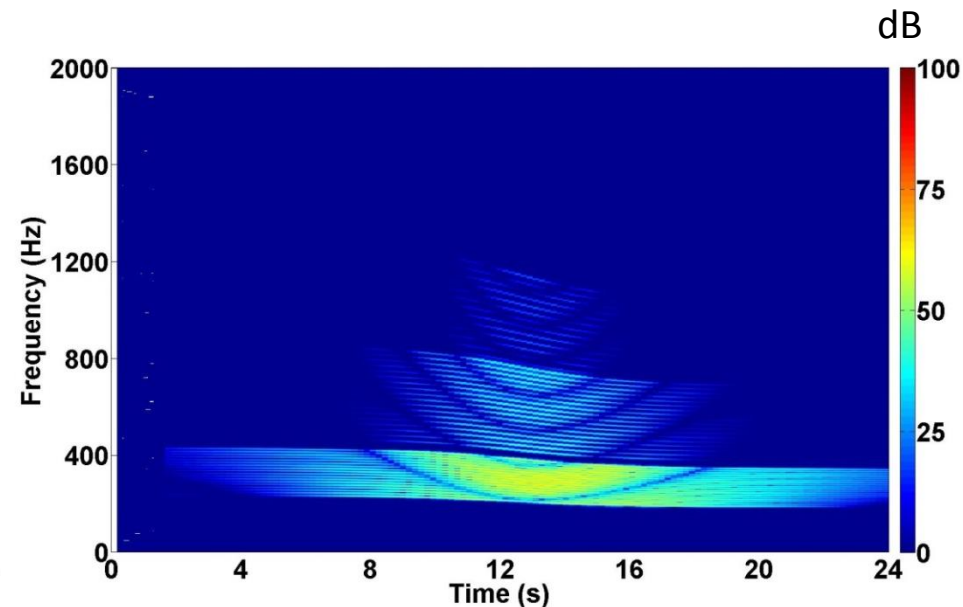
Average Source Power = 89.0 dB (-12.8 dB re: GA Prop)

Peak Level at Centerline Receiver = 90.1 dB (-11.3 dB re: GA Prop)

Time History



Spectrogram



$\Delta f = 10 \text{ Hz}$



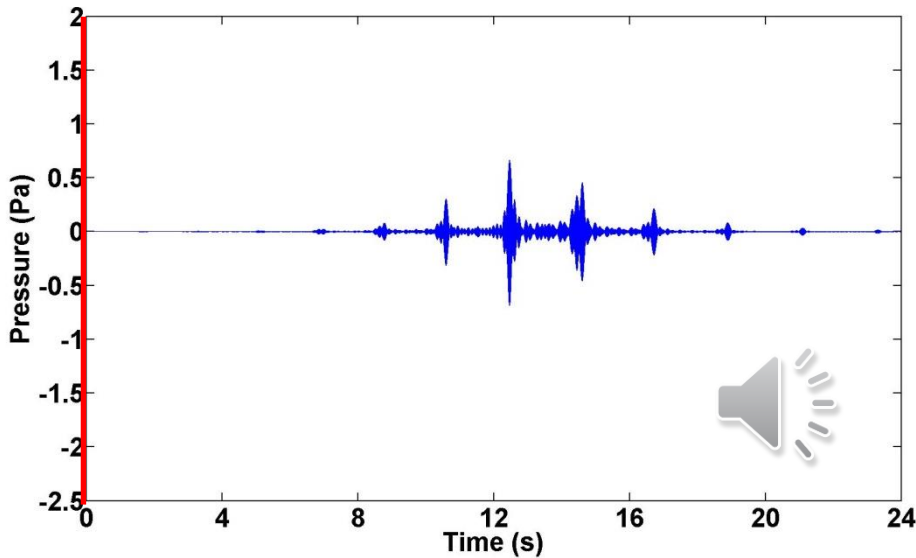
Maximum pressure not on centerline

18 LE Props – Spread Spectrum DEP

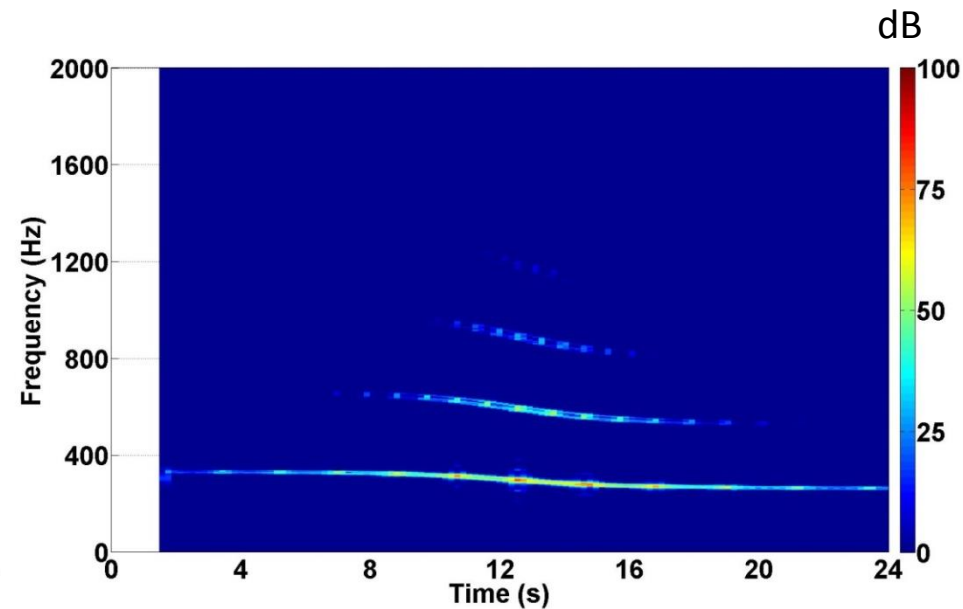
Average Source Power = 89.0 dB (-12.8 dB re: GA Prop)

Peak Level at Centerline Receiver = 90.7 dB (-10.7 dB re: GA Prop)

Time History



Spectrogram



$\Delta f = 0.5 \text{ Hz}$



Maximum pressure not on centerline

Exterior Effects Room (EER)



Capabilities:

- 31 channel 3-D audio (Vectsonic) system
 - 27 K&H O300 satellite speakers
 - 4 K&H O900 subwoofers
- 16 Hz – 20 kHz compensated frequency range
- Human-rated facility
- Active/passive stereo projection system
- Seating capacity: 39



Perception-Influenced Acoustic Design of DEP Systems

Remarks

- **Noise can be shaped through design, configuration and operation**
 - Example: 15db noise reduction due to lower tip speed.
- **Noise is an interdependent function of technical, societal, regulatory, economic issues and challenges**
 - What can we do to make it less annoying? What characteristics of noise are unacceptable?
 - Can noise be tailored for community acceptance?
 - Do certification noise metrics adequately capturing noise impact on the community?
 - Can we fully capture the noise signature/character with prediction?
Auralization?
 - Incomplete
 - Not well integrated
 - Tool development and validation
- **Can PID processes enable balanced vehicle designs: maintain performance while reducing noise?**