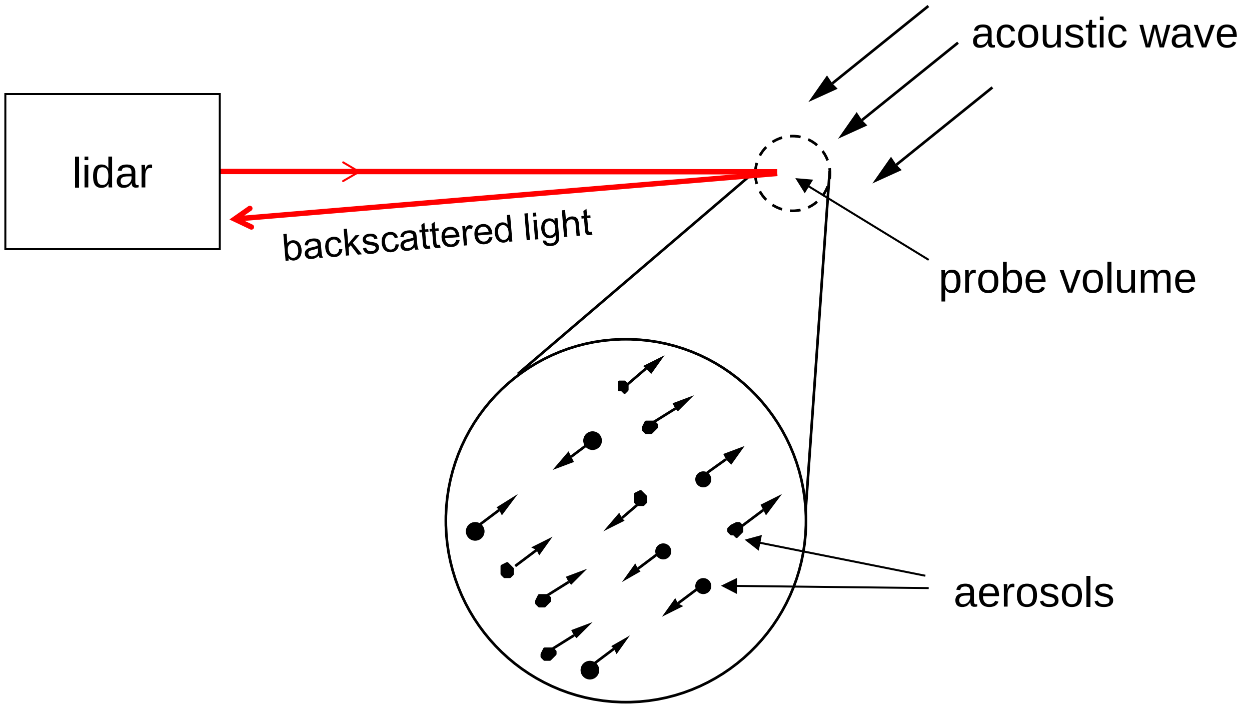
Remote Acoustic Detection Using a Coherent Laser Radar

Gabriel Lombardi, Jerry Butman, and David Rodham
Phase Coherence, Inc.
2908 Oregon Ct., I-10
Torrance, CA 90503

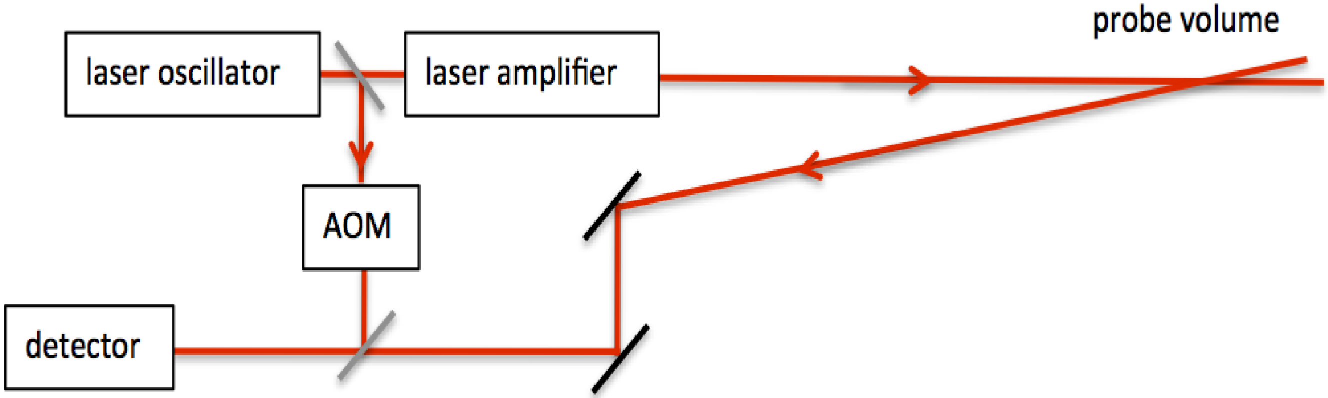
18th Coherent Laser Radar Conference
June 27-July 1, 2016
University of Colorado
Boulder, Colorado

Remote Virtual Microphone



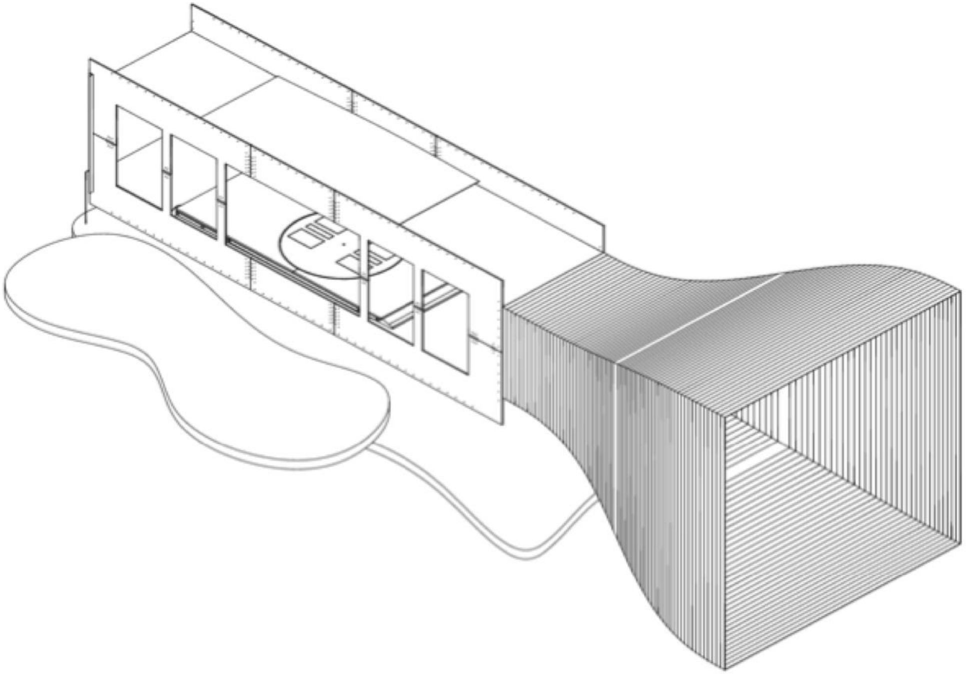
- Acoustic wave imparts motion to ambient aerosols.
- Fluid-dynamic turbulence also causes aerosol motion.
- Acoustic motion is distinguished from turbulence by acceleration.

Optical Schematic



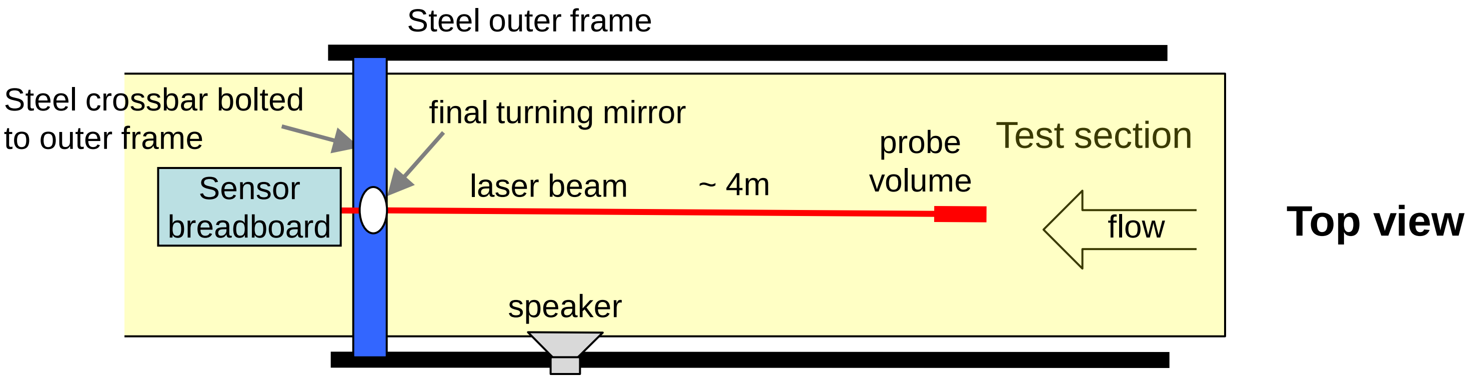
- Bistatic arrangement for range resolution
- 1.55 µm laser wavelength
- 25 W power
- Heterodyne detection with 200 MHz IF
- 1.5 GHz bandwidth InGaAs detector
- 25 cm probe volume length

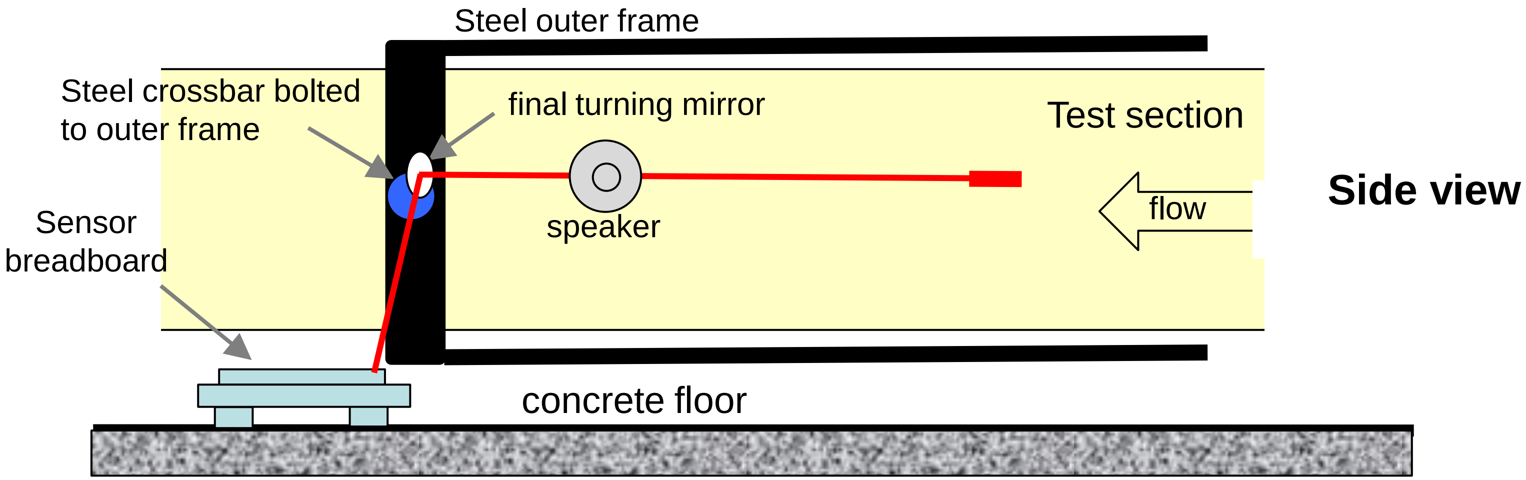
Lucas Wind Tunnel (Caltech)



- Closed-return tunnel.
- 1.3 m x 1.8 m x 7.5 m test section
- Speeds up to 60 m/s.

Wind Tunnel Test Setup, 1





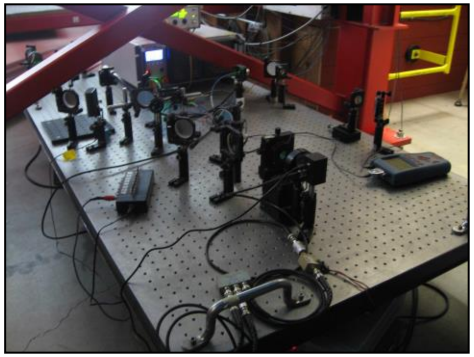
- Virtual microphone is in undisturbed flow.
- Highly reverberant environment.

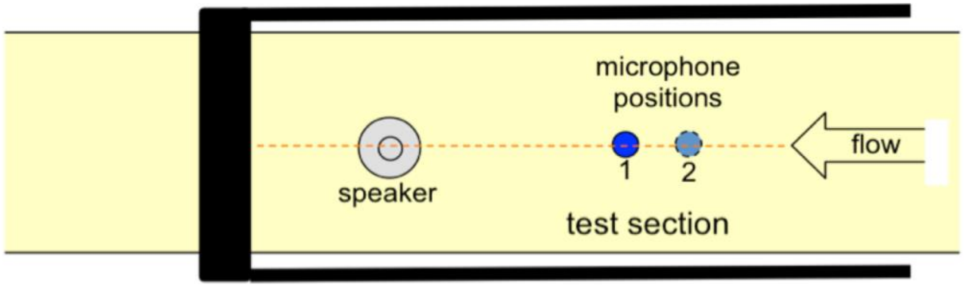
Wind Tunnel Test Setup, 2

Speaker mounted
on tunnel sidewall

Microphone and laser beam path in the wind tunnel

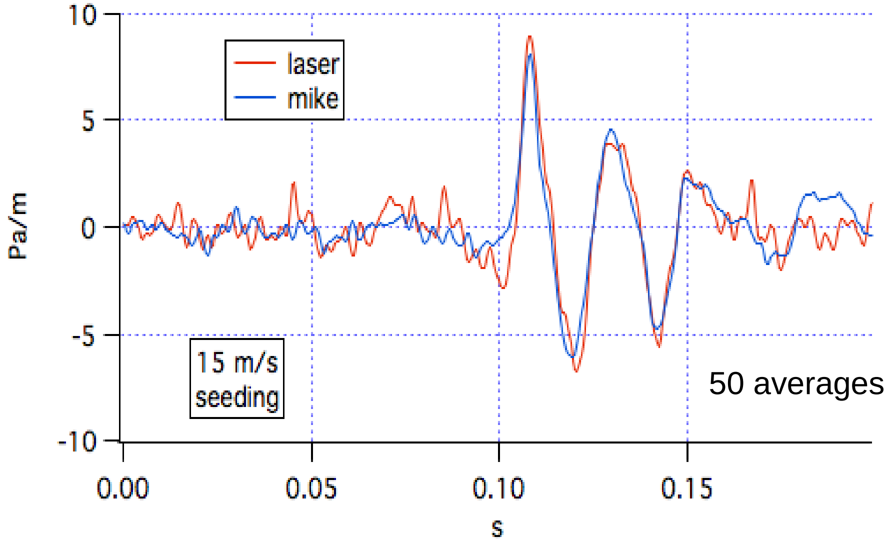
Sensor breadboard
underneath tunnel

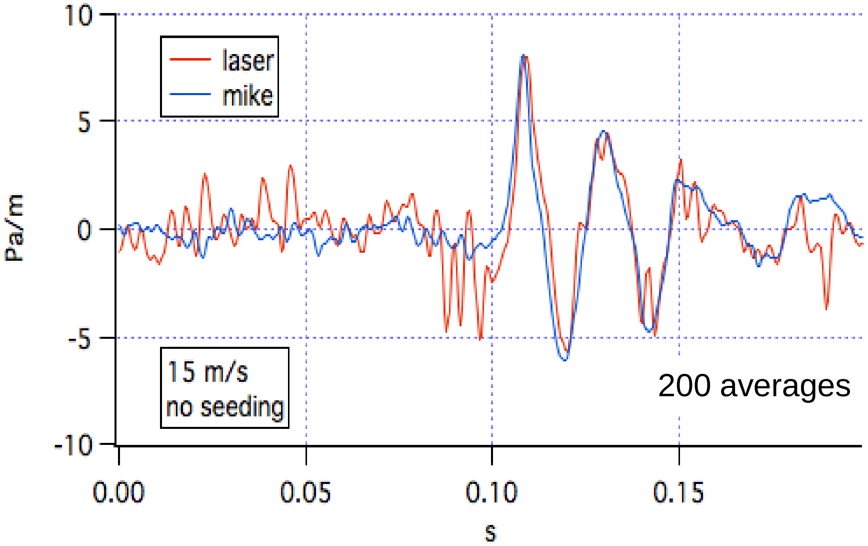




- Laser sensor measures acoustic <u>acceleration</u> in direction along laser beam.
- Acoustic truth is determined by measurement of pressure <u>gradient</u> in same direction.

Pressure Gradient Waveforms





$$\frac{\partial p}{\partial x} \approx \frac{p_2 - p_1}{x_2 - x_1}$$

$$-\frac{\partial p}{\partial x} = \rho \frac{\partial u_x}{\partial t}$$

- Lidar measurement of pressure gradient matches microphone measurement.

Pressure Time Series From Pressure Gradient

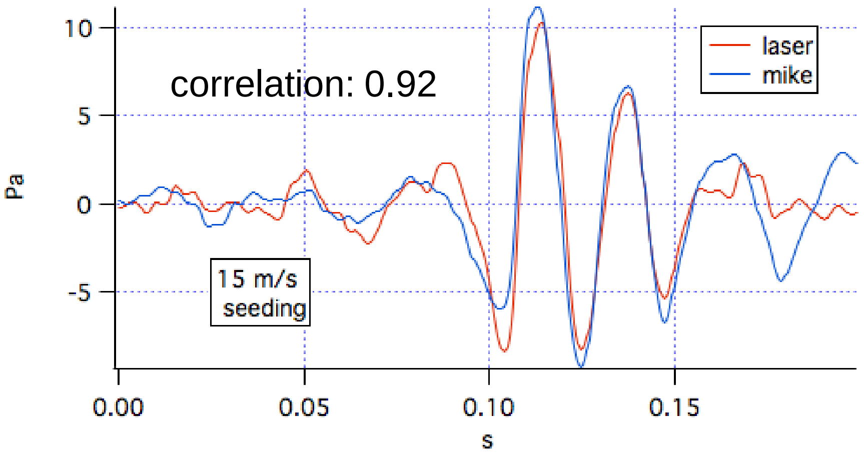
Newton's Law: $$-\frac{\partial p}{\partial x} = \rho \frac{\partial u_x}{\partial t}$$

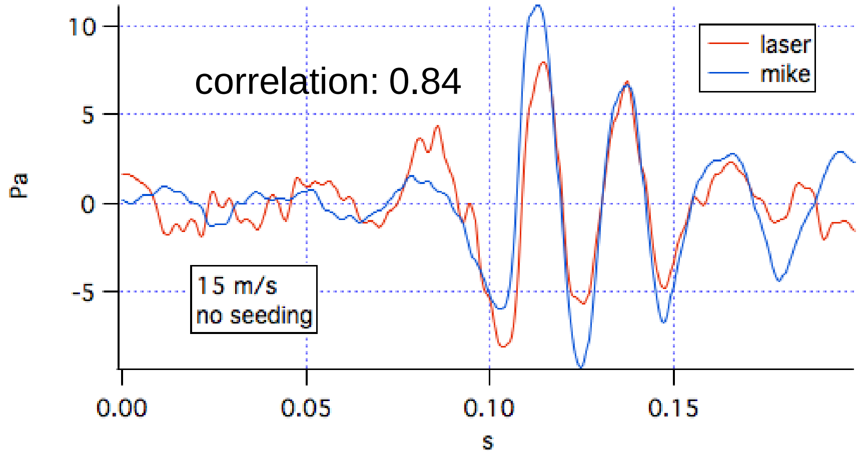
Pressure far field: $$p = \rho c u_x$$

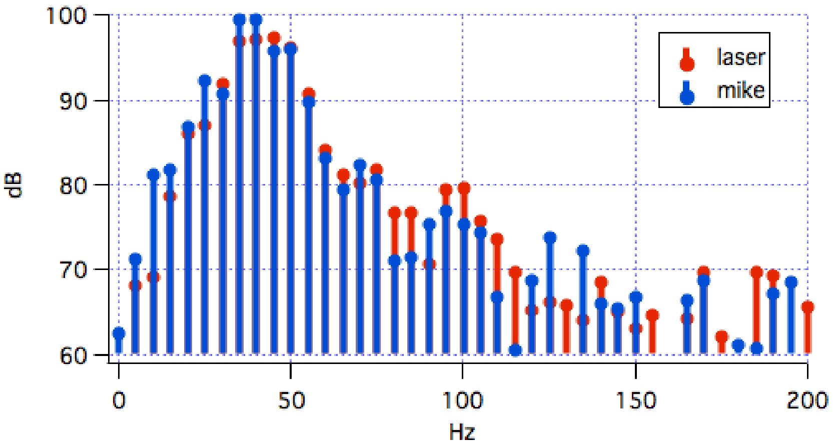
Pressure time series: $$p(t) = -c \int \frac{\partial p(t',x)}{\partial x} dt'$$

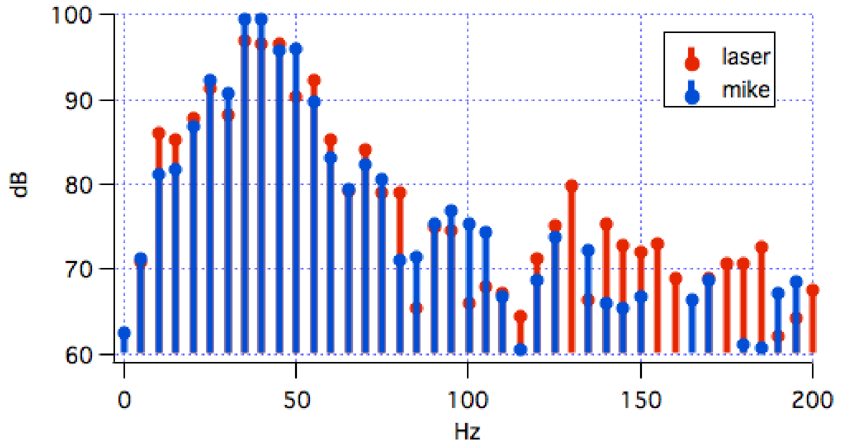
- Acceleration is the observable.
- Calculate the pressure gradient from acceleration.
- Integrate to compute pressure.

Pressure Waveforms

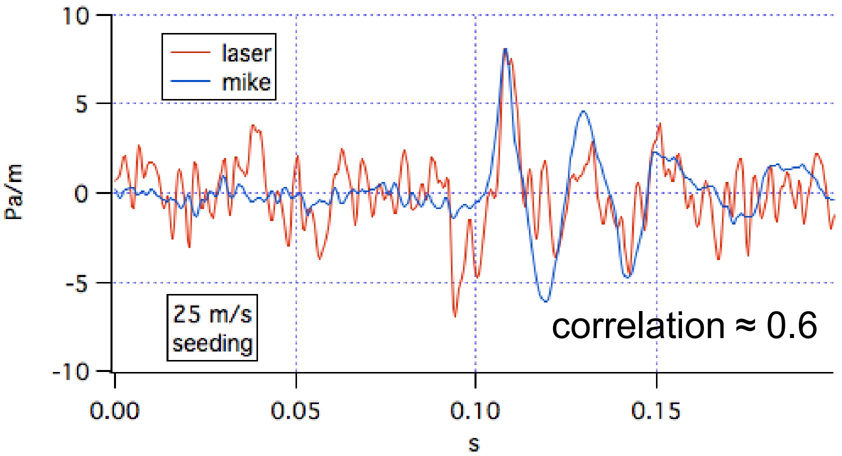


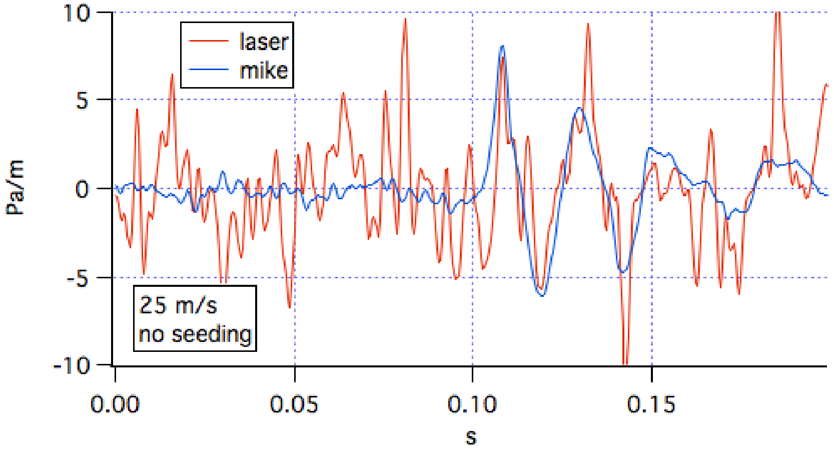


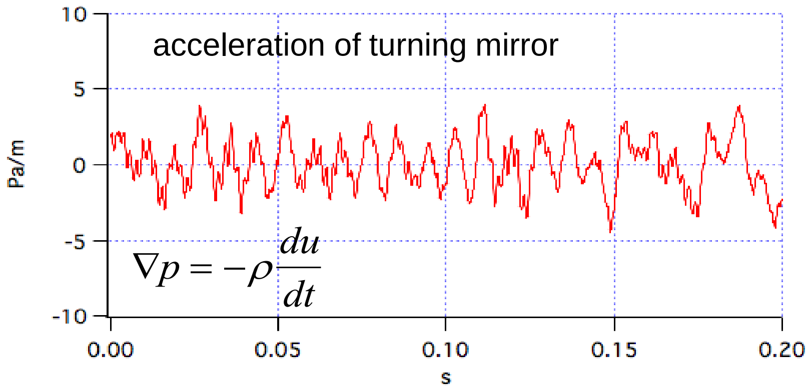


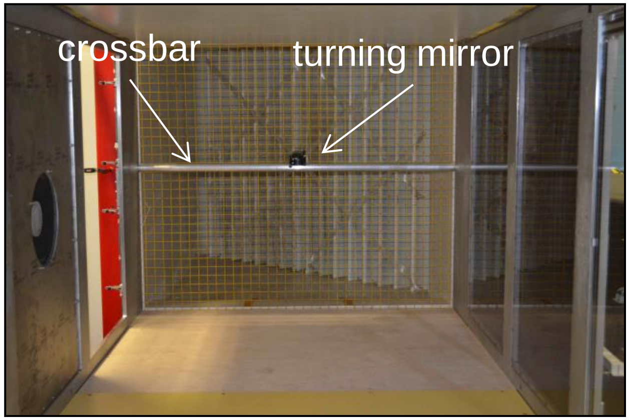


Higher Tunnel Speeds



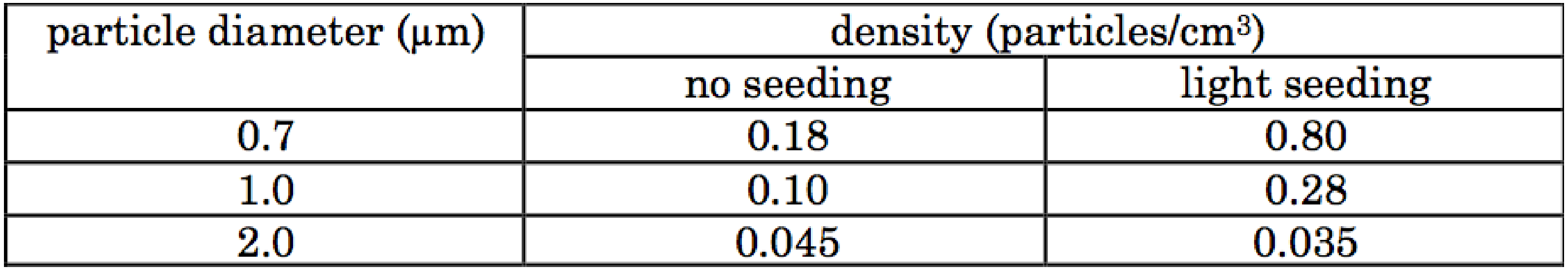






- Both seeded and unseeded signals were degraded at higher wind speed.
- Degradation due to vibration of the final turning mirror.

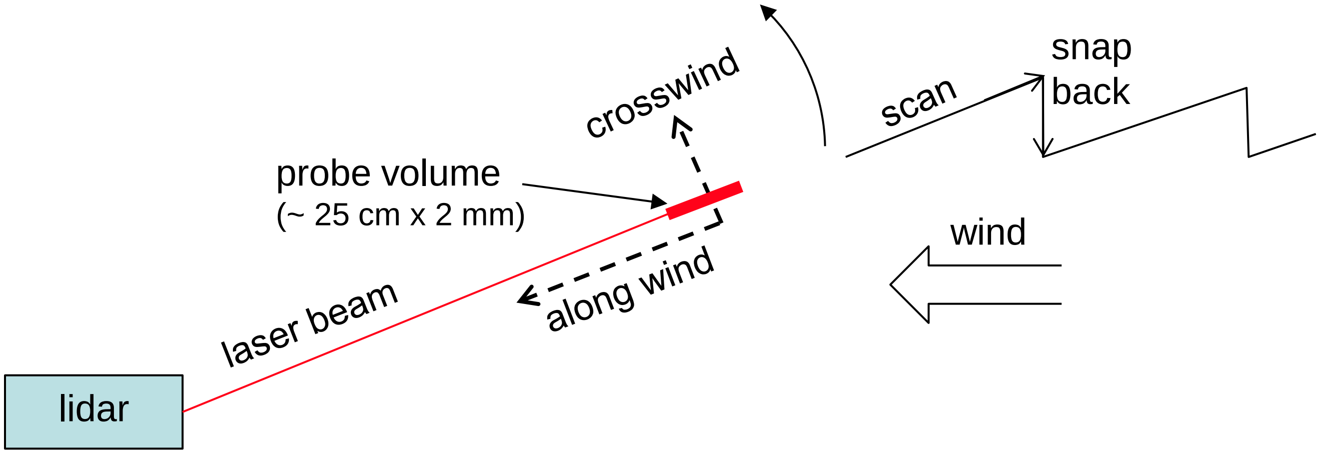
Particle Seeding Densities



particle diameter (μm)	density (particles/cm^3)	
	no seeding	light seeding
0.7	0.18	0.80
1.0	0.10	0.28
2.0	0.045	0.035

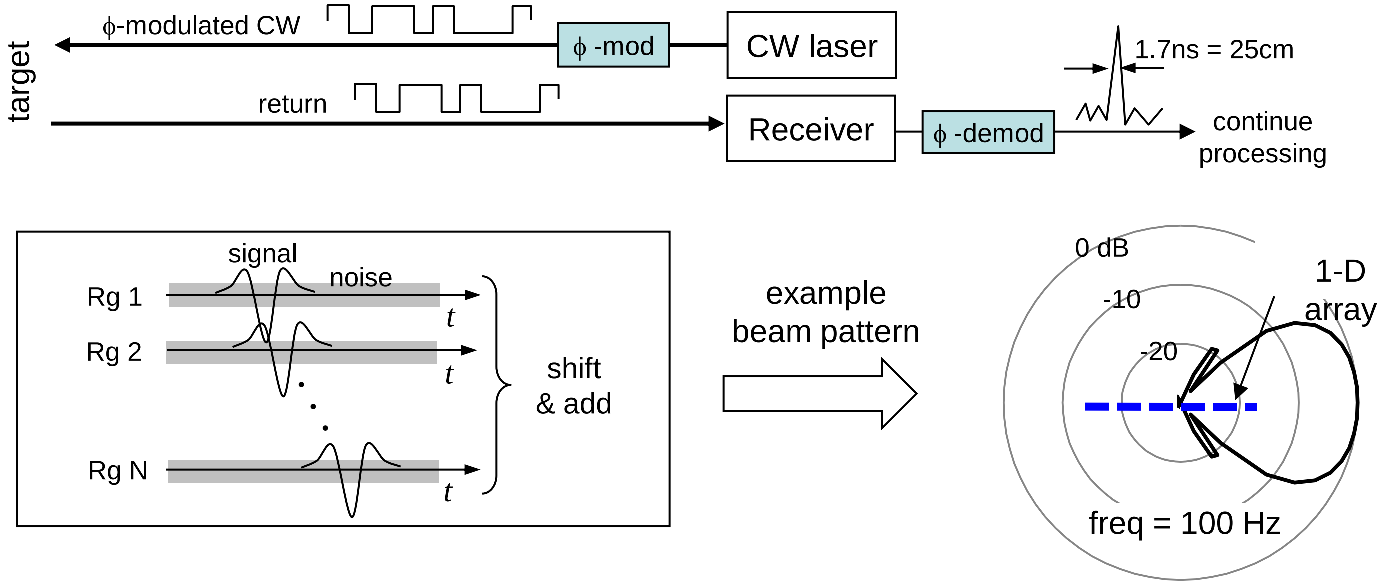
- Light seeding is comparable to clean outside air.
- Open return tunnels would not require seeding.

Crosswind Compensation



- Particles must remain in probe volume for ~1 ms.
- Crosswind scanning is required for beam at an arbitrary angle.

Linear Array for Acoustic Beamforming

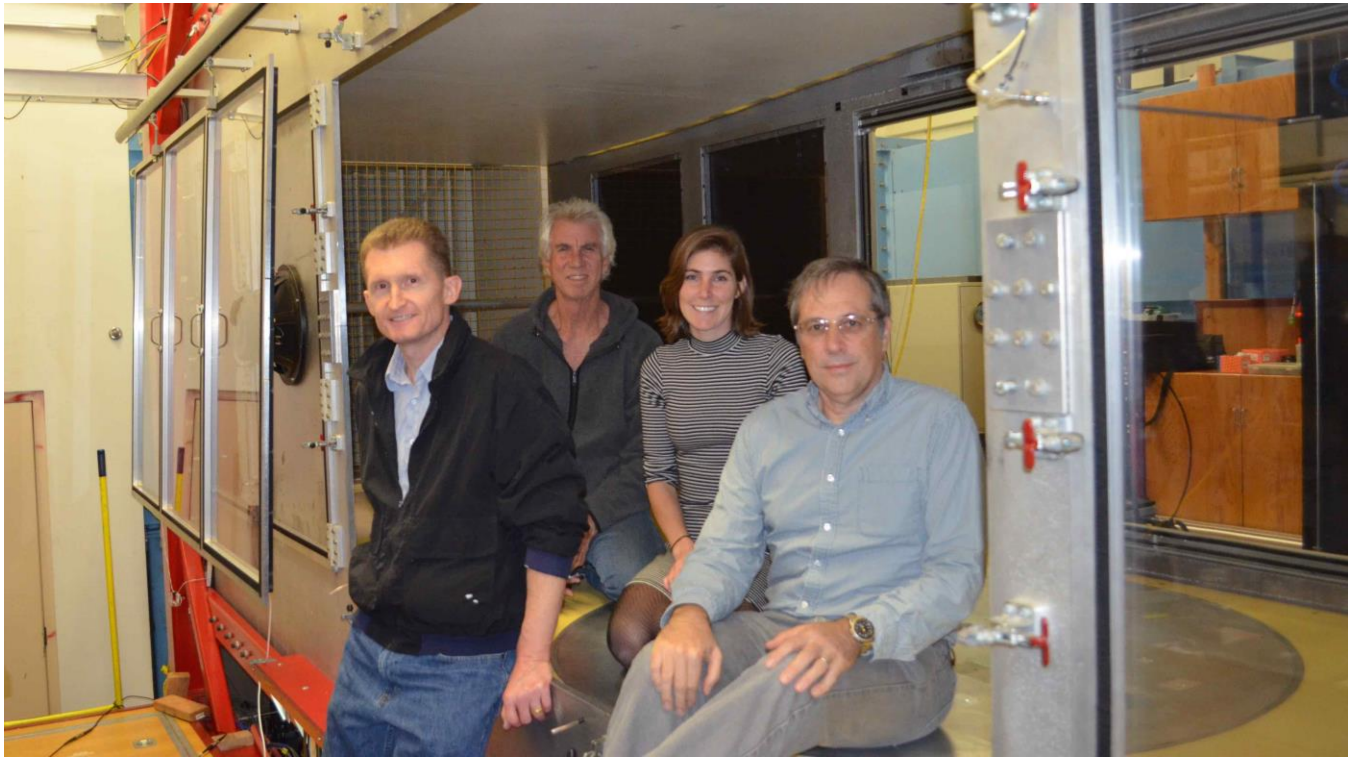


- Incorporate radar modulation techniques to provide multiple range gates.
  - 600 MHz modulation rate provides 25 cm range gates
- Discriminates against acoustic reflections and tunnel noise.

Summary

- Virtual remote microphone was demonstrated.
- Advantages over conventional microphones:
  - immune to wind noise
  - does not disturb flow (non-intrusive)
  - readily deployed and moved
  - beamforming/directionality

Acknowledgements



For expert mechanical design: David Windisch
For helpful discussions: Ben Sim and Fred Schmitz
Support at Caltech's Lucas Wind Tunnel: Stephanie Rider

This work was supported by the Army Small Business Innovation Research program.