

How low can you go?

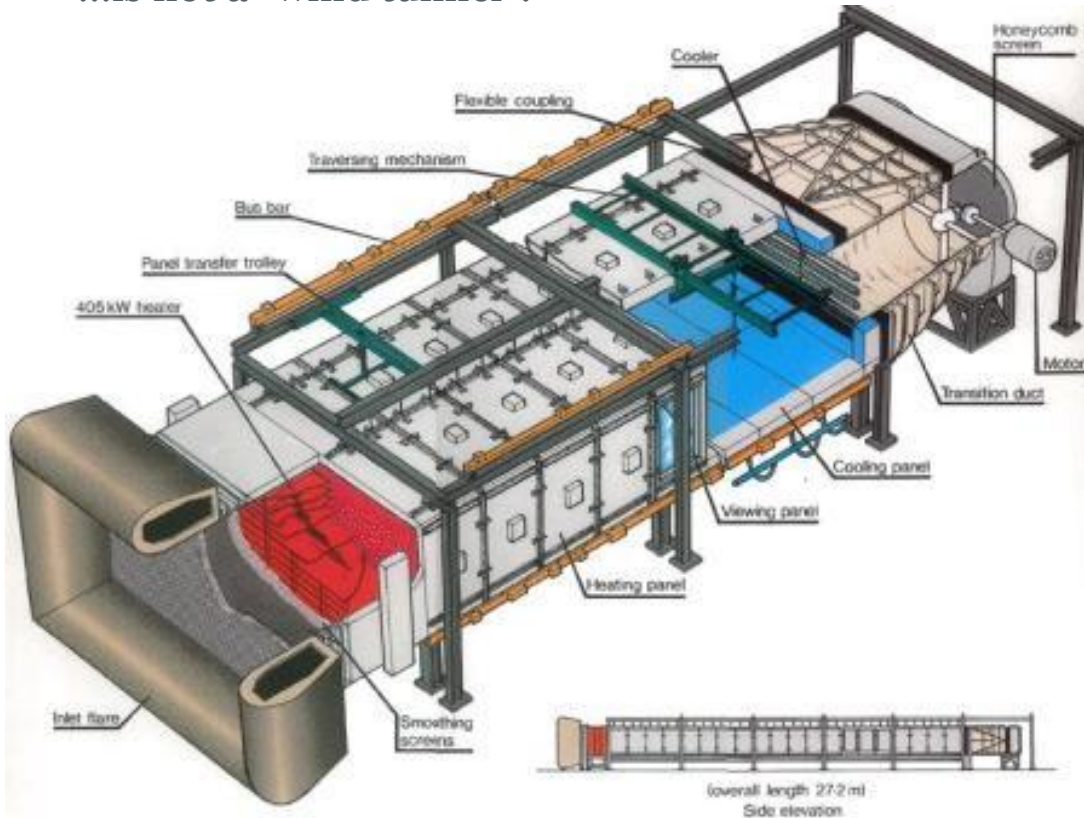
The EnFlo Environmental Wind Tunnel and its measurement challenges

David M. Birch

Head of Centre for Aerodynamics & Environmental Flow

The EnFlo facility

...is not a “wind tunnel”.



Simulating the atmospheric boundary layer.

- Test section approx. 3m x 2m
- Very high Re needed
- 1m thick rough-wall turbulent boundary layer matching atmospheric statistics
- ... with temperature gradient inlet boundary conditions
- ... and surface heat flux
- ... in an open return

~ 1 MW power draw

at free-stream speeds of ~2 m/s.

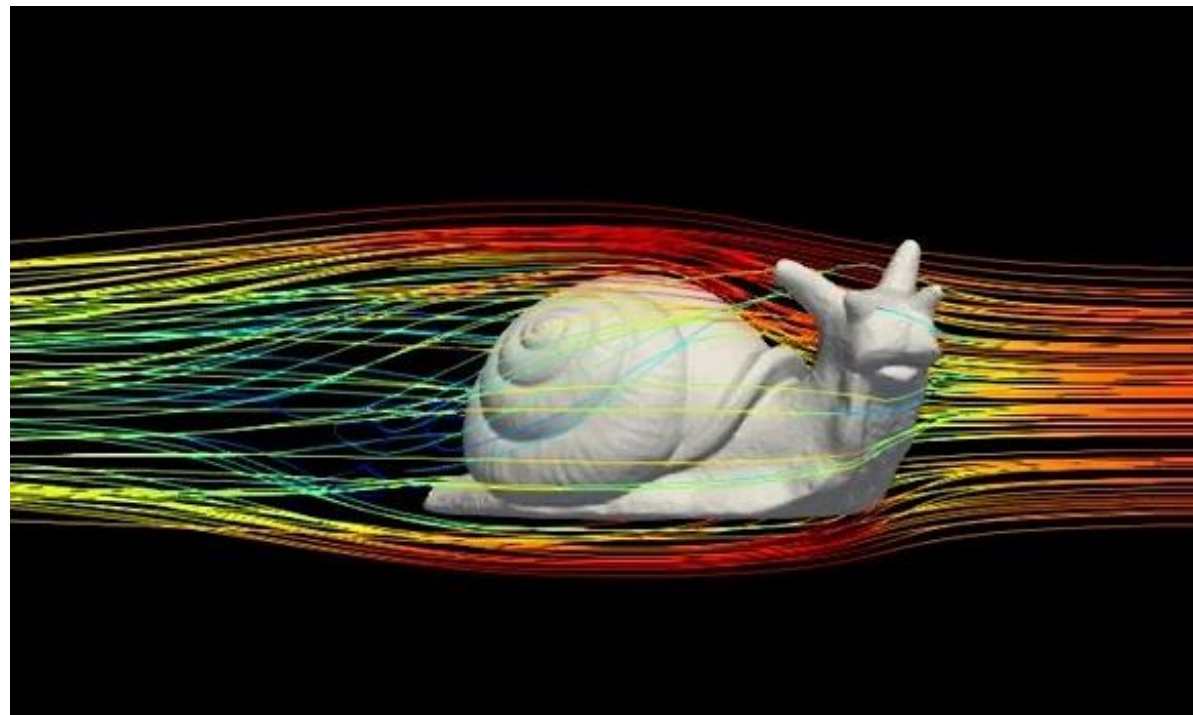


ENFLO
NATIONAL
FACILITY



Slower \neq easier.

Things get complicated.



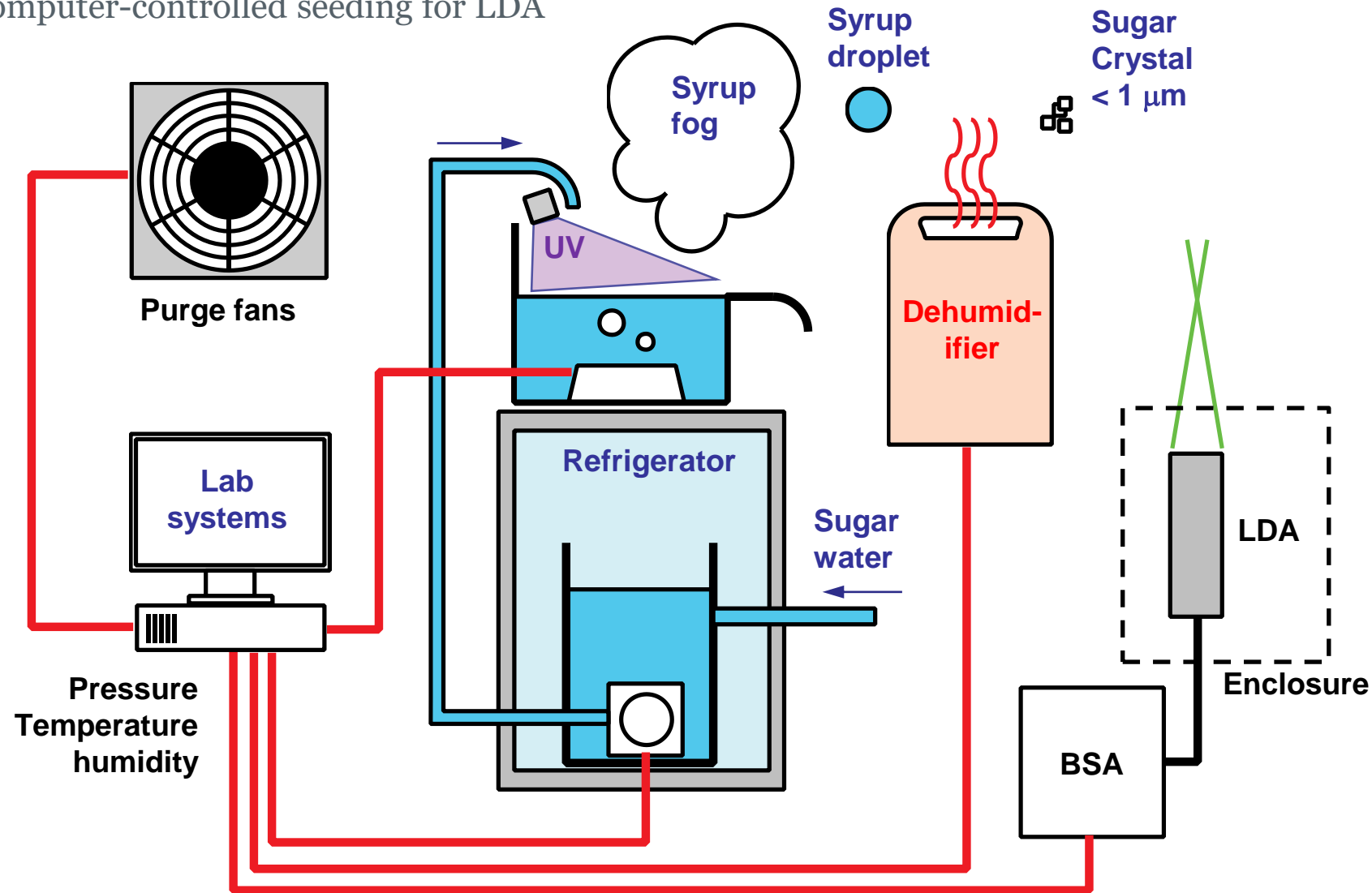
Consequences of running an ultra-low-speed environmental wind tunnel:

- Statistical convergence can take an entire day
- Bandwidth of interest 0 – 200 Hz
- Minimum length scales \sim 5 mm
- Maximum dynamic pressure $<$ 1 Pa
- Measuring at 15°C to 70°C in same experiment
- Need to measure scalar concentration in time

**Despite what you might have heard,
measurement doesn't get easier at low speeds.**

Automating laser diagnostics

Computer-controlled seeding for LDA



Sugar crystal seeding

- Controllable density and size
- Remotely controlled and fully automated
- Safe and tasty
- Laser optics get caramel-coated...

Measuring pressures less than 1 Pa

= pressure head of 100 mm air

Start with most sensitive sensors on the market



160 Pa FS

Measurement
range

Full-scale range

Repeatability

Total error band (TEB)

Acceleration

Temperature

Noise

11094

IEEE SENSORS JOURNAL, VOL. 21, NO. 9, MAY 1, 2021

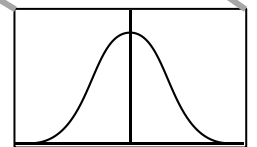


Dynamic Compensation of Ultra-Low-Range
Pressure Sensors

Paul Nathan, Rebecca Manning, and David M. Birch^{1b}

$$P(T) = P(T_0) + kT$$

Temperature control



Measuring pressures less than 1 Pa

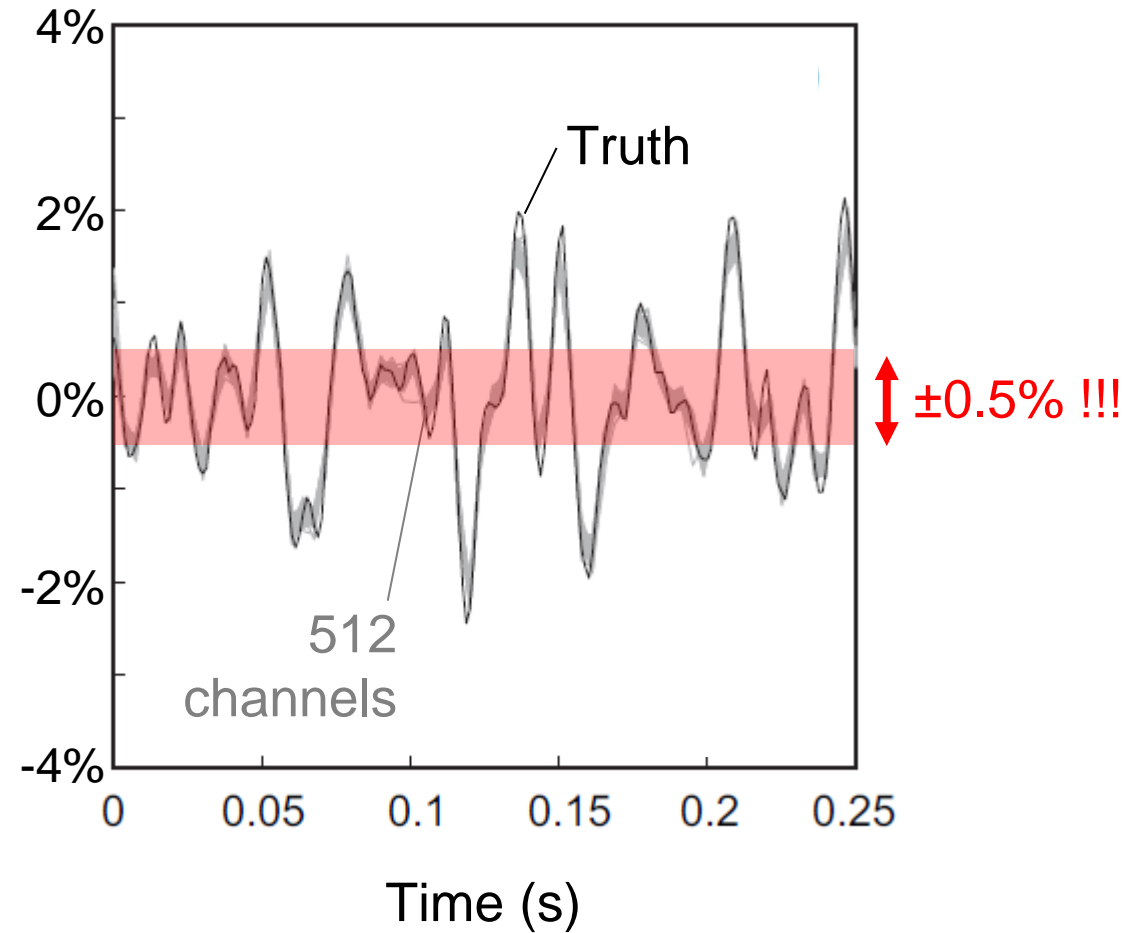
= pressure head of 100 mm air

Start with most sensitive
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160 Pa FS

% Full scale
pressure



Measuring pressures less than 1 Pa

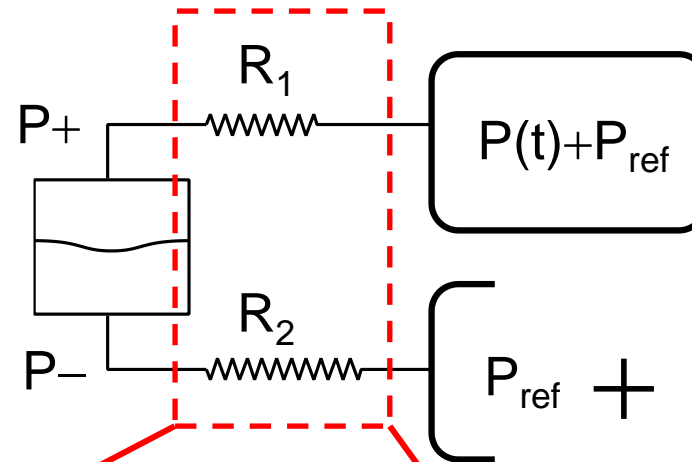
= pressure head of 100 mm air

Start with most sensitive sensors on the market



160 Pa FS

...But these are differential pressure sensors!



Dynamic calibration of ultra-low-range pressure measurement systems

Joy Schmeer, Paul Hayden, and David M. Birch

(In review)

Measuring pressures less than 1 Pa

= pressure head of 100 mm air

Start with most sensitive
sensors on the market



160 Pa FS

...But these are differential
pressure sensors!



...And calibrate 1024 lines simultaneously.

Gas concentration measurements at ultralow speeds

A very expensive undertaking.



Measuring trace amounts of hydrocarbons in air at 400 Hz.

- Instruments are large and can cause blockage
- ~£40k per channel
- Requires heavy umbilical (vacuum line, fuel gas lines, signal cables)

Can we at least get close using solid-state CMOS devices?

- Low cost
- Compact construction

But very low bandwidth.



Gas concentration measurements at ultralow speeds

A very expensive undertaking.



Measuring trace amounts of hydrocarbons in air at 400 Hz.

- Instruments are large and can cause blockage
- ~£40k per channel
- Requires heavy umbilical (vacuum line, fuel gas lines, signal cables)

Also needs ultralow range, temperature-independent gas velocity measurement

-Already done:
<10 mm/s, 0°C – 70°C.



Questions?

