Intake unstart testing in the University of Manchester HSST

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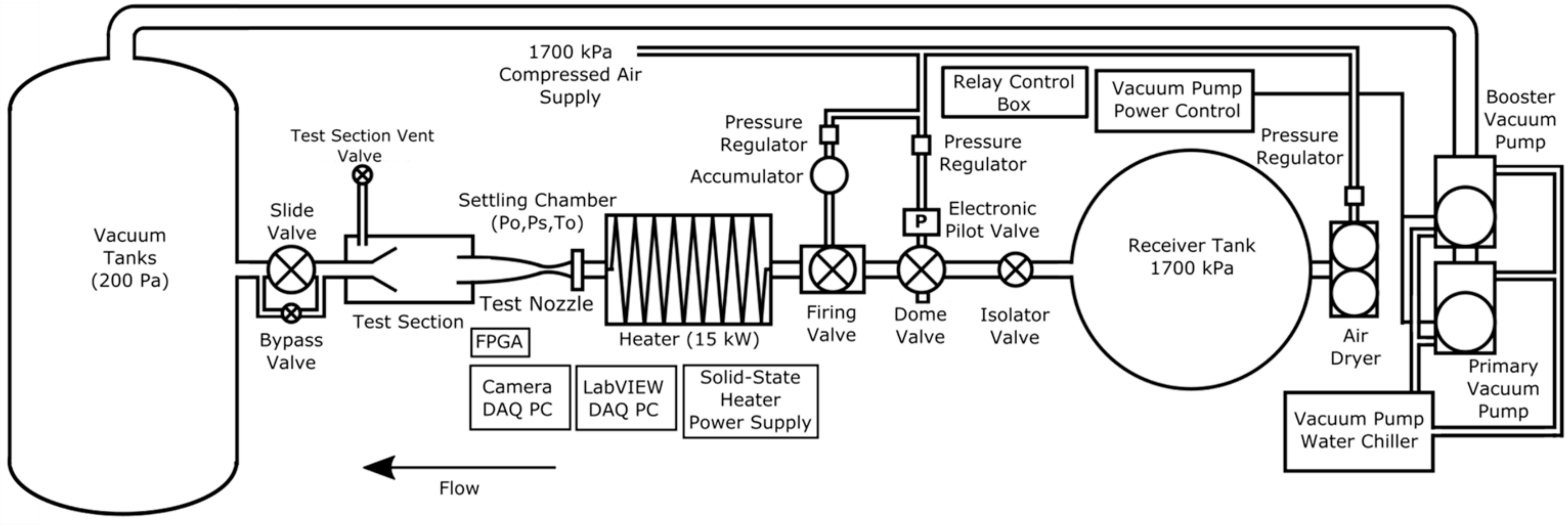
HSST



1700 kPa
Compressed Air
Supply
Relay Control
Box
Vacuum Pump
Power Control
Booster
Vacuum
Pump
Pressure
Regulator
Pressure
Regulator
Pressure
Regulator
Accumulator
Test Section Vent
Valve
Settling Chamber
(Po,Ps,To)
Electronic
Pilot Valve
Receiver Tank
1700 kPa
Vacuum
Tanks
(200 Pa)
Slide
Valve
Test Nozzle
Test Section
Bypass
Valve
FPGA
Heater (15 kW)
Firing
Valve
Dome
Valve
Isolator
Valve
Air
Dryer
Primary
Vacuum
Pump
Camera
DAQ PC
LabVIEW
DAQ PC
Solid-State
Heater
Power Supply
Vacuum Pump
Water Chiller
Flow

Testing Capabilities

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- Schlieren (including BOS)
- PIV
  - 3D3C steady
  - 2D2C steady and unsteady
- PSP (steady and unsteady)
- Surface shape
- Thermography

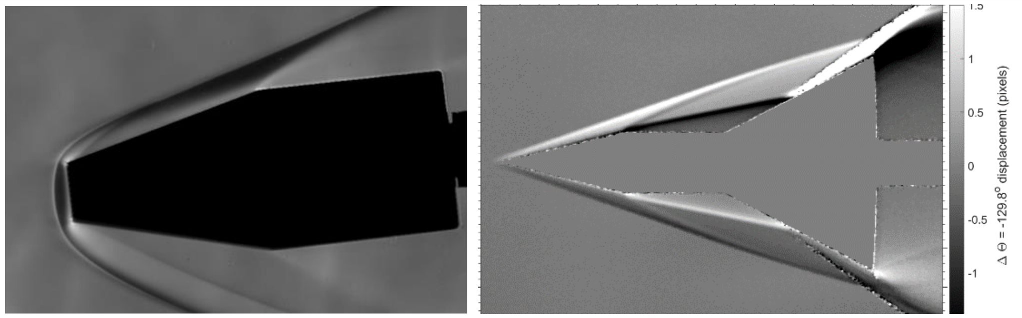


Image Credit: Dr Tom Fisher

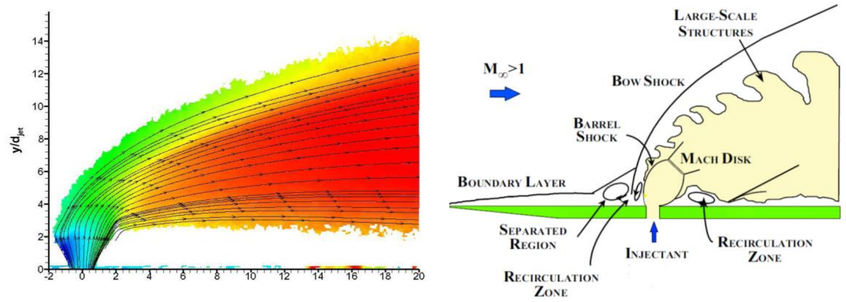
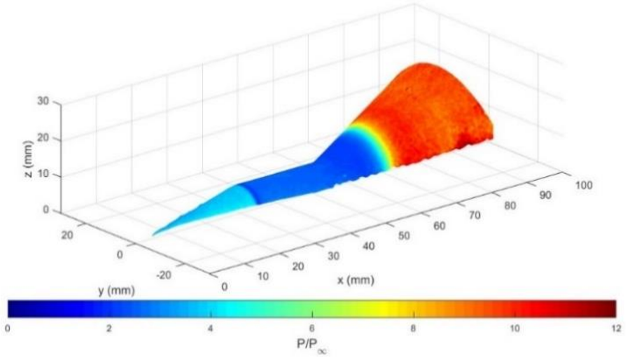
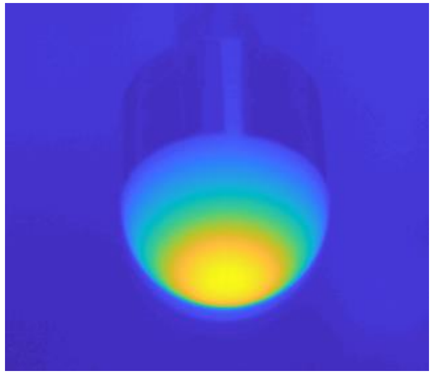


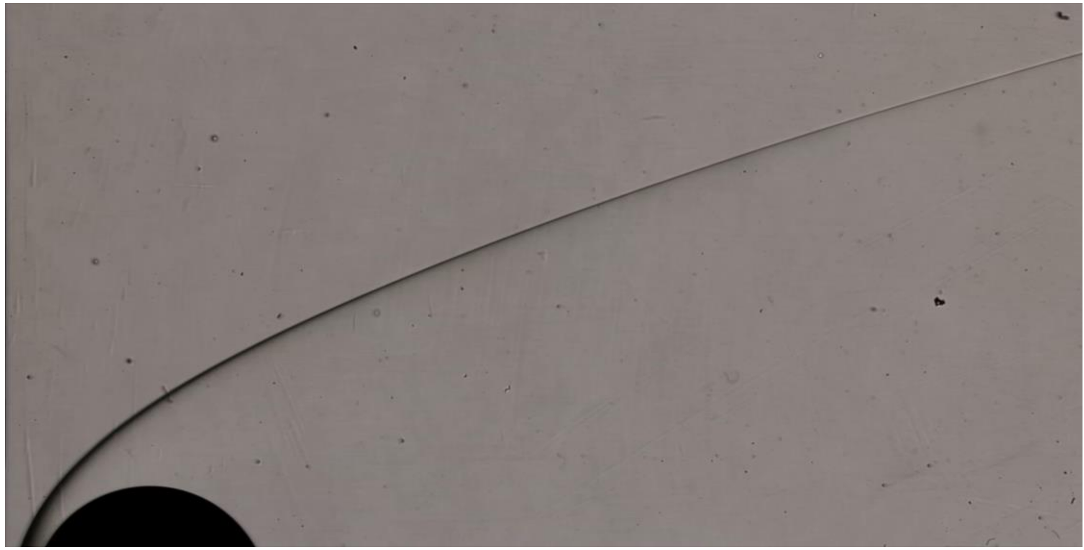
Image Credit: Dr Erinc Erdem

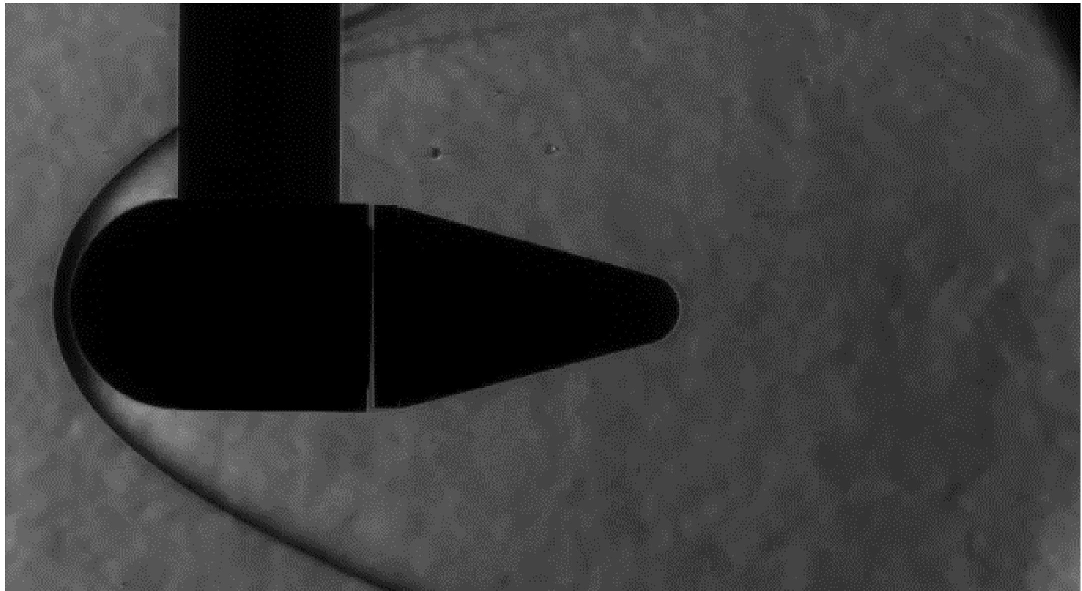




Testing Capabilities

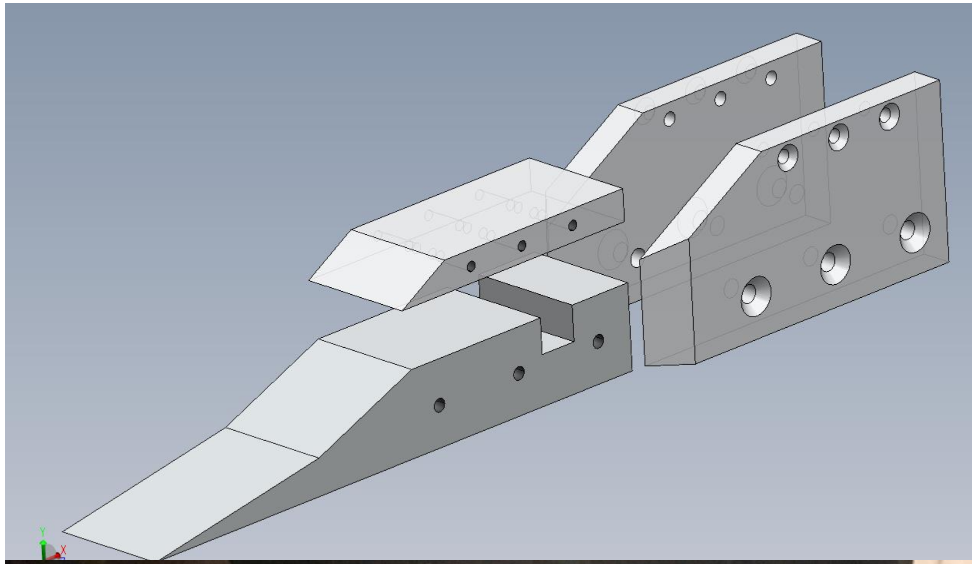
- Floor/sting mounted models
- Force measurement
- Drop testing
- Release/separation testing
- Intake testing

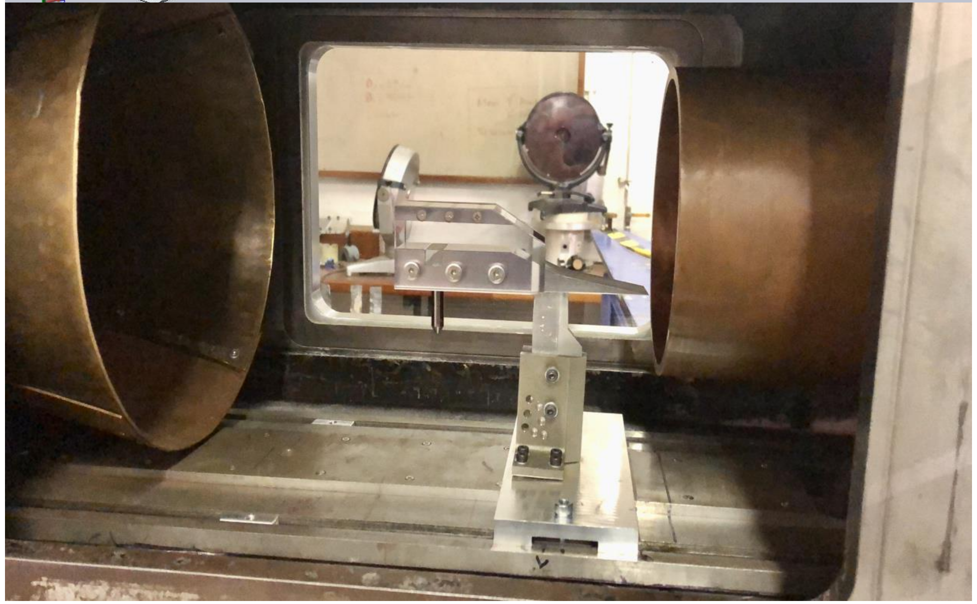




Intake Model

- A double ramp intake with a cowl
  - Ramp angle of 10 and 22 degrees
  - Shock impingement is inside the intake
  - Moveable barrier to adjust blockage



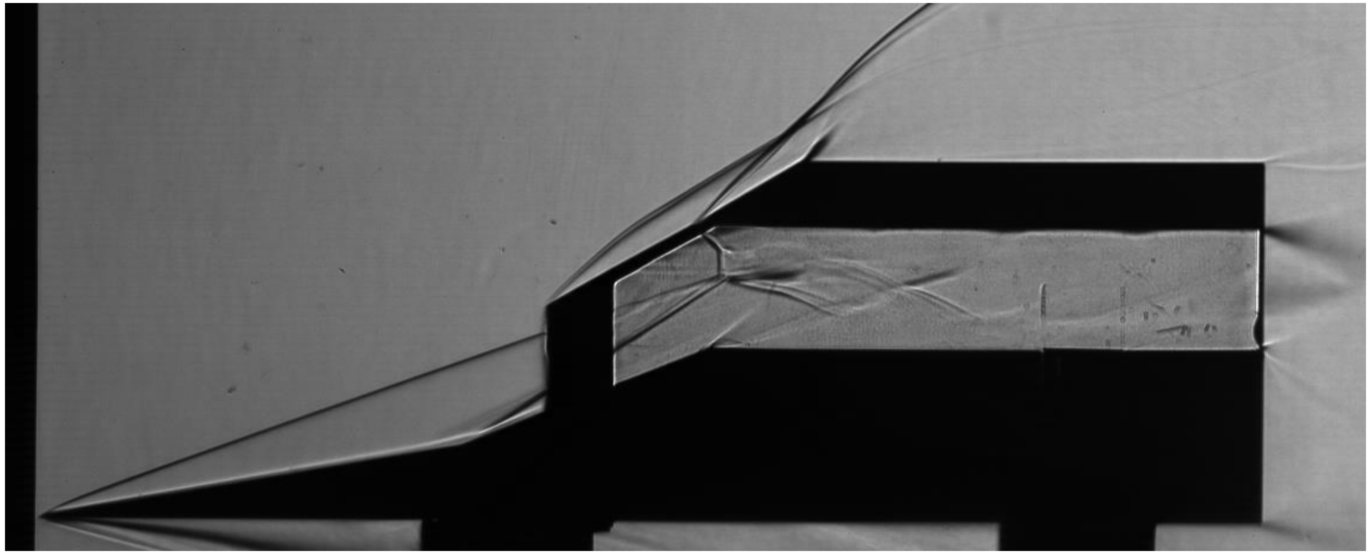


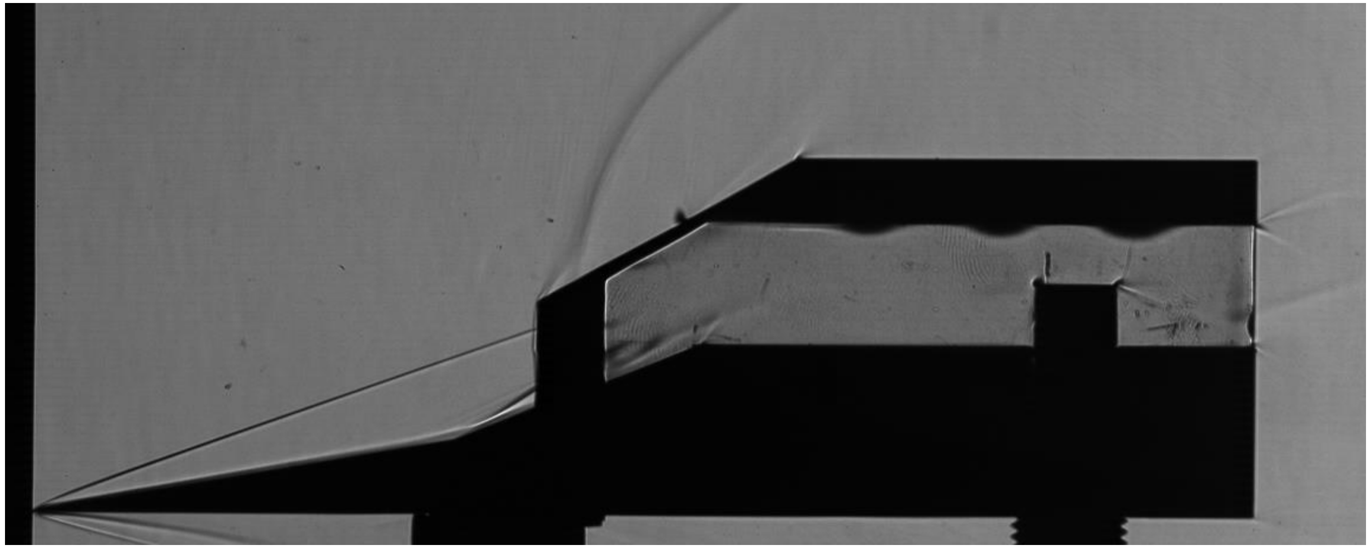
Schlieren

- Time averaged / long exposure

- Without any blockage
  - Shock impingement inside intake
  - Flow pattern well defined
  - Internal shock reflection

- With blockage
  - Large external bow shock
  - Blurry image lacking definition



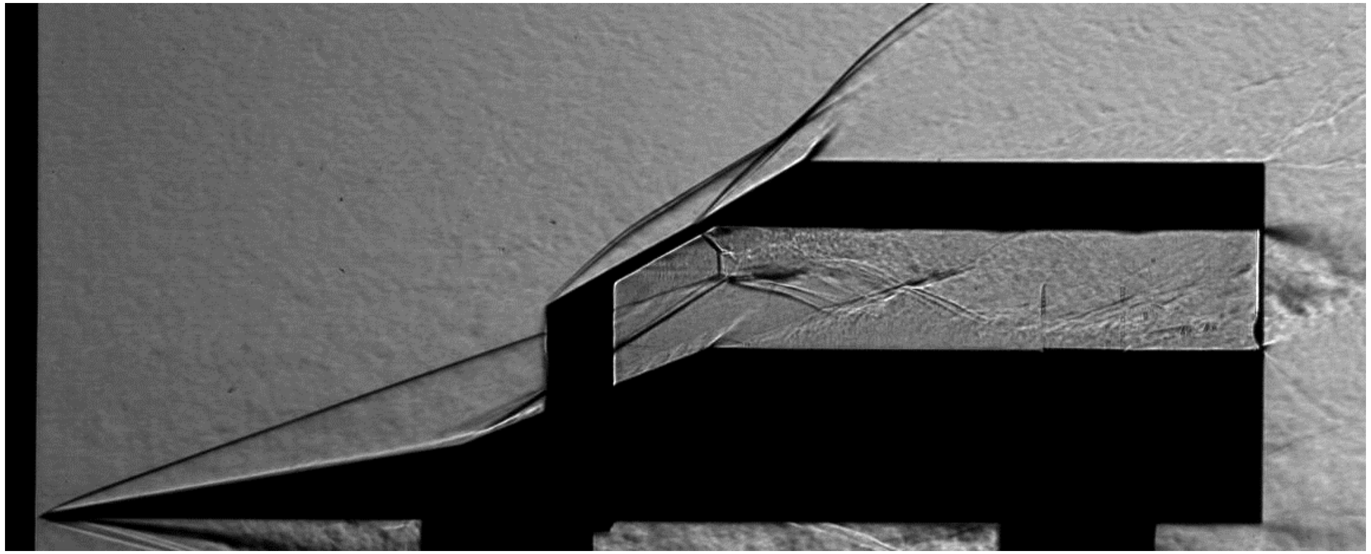


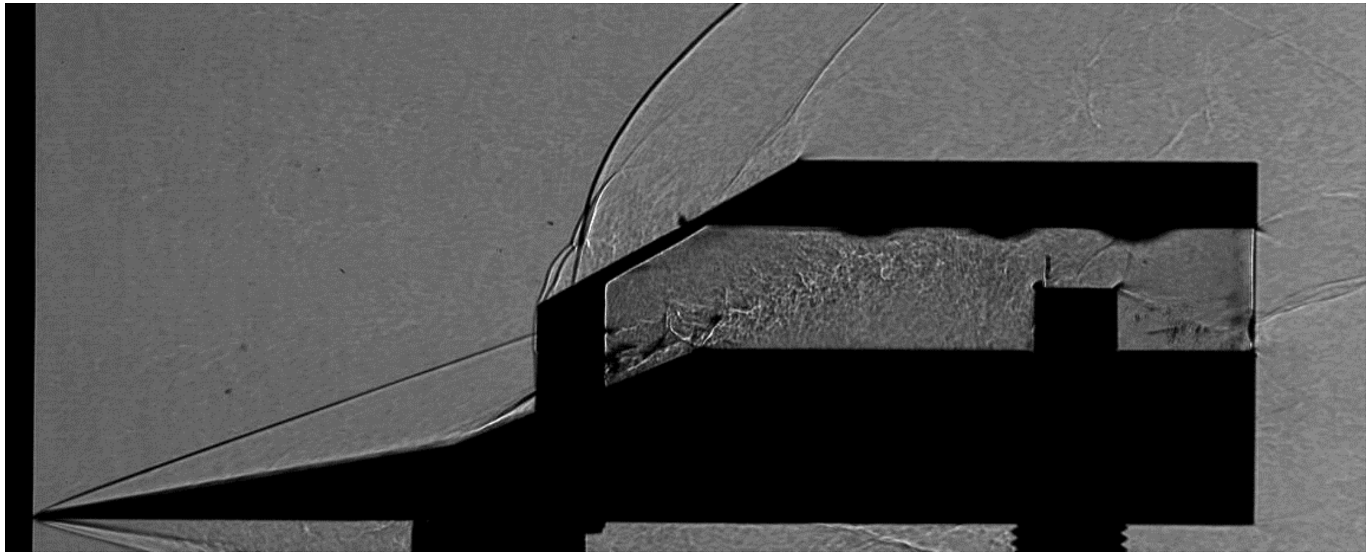
Schlieren

- Video slowed down 3000 times (30kHz played at 10fps)

- Without blockage
  - Shock structures are stable
  - Producing turbulent but quasi-steady flow

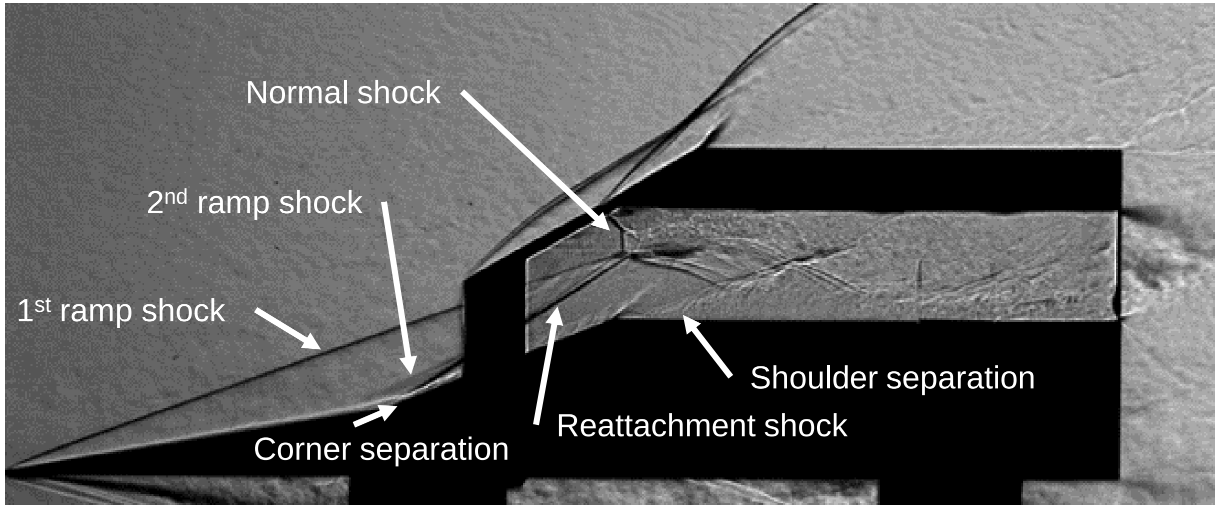
- With blockage
  - Significant movement of the external shock system
  - Intake is highly subcritical with large flow spillage
  - *buzzing*

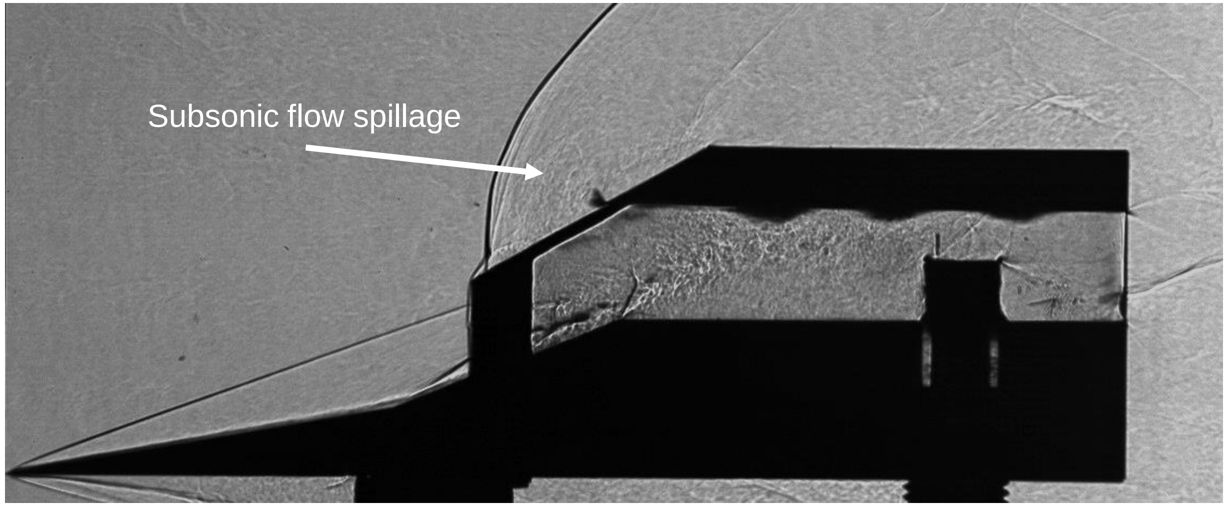


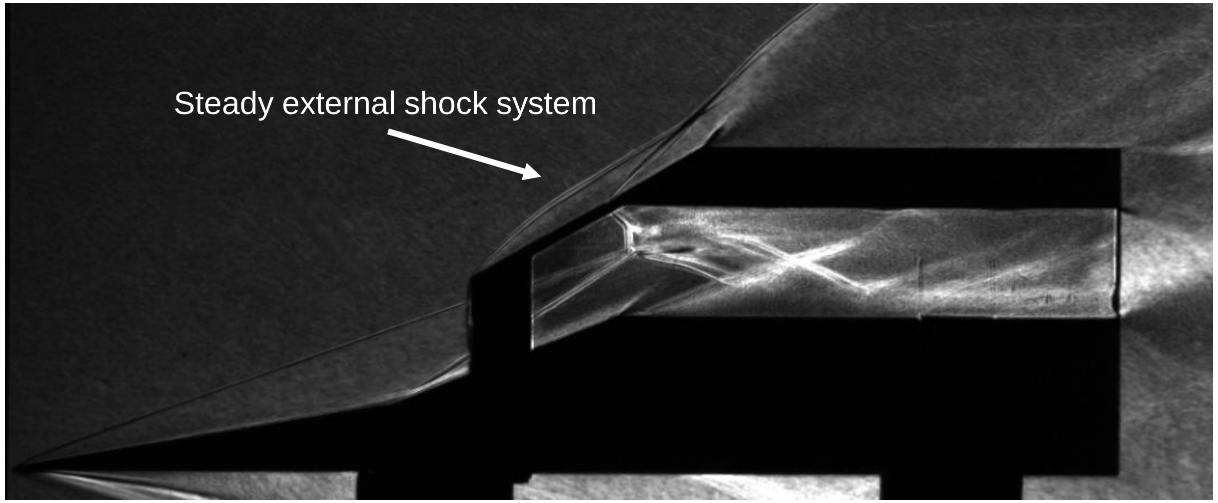


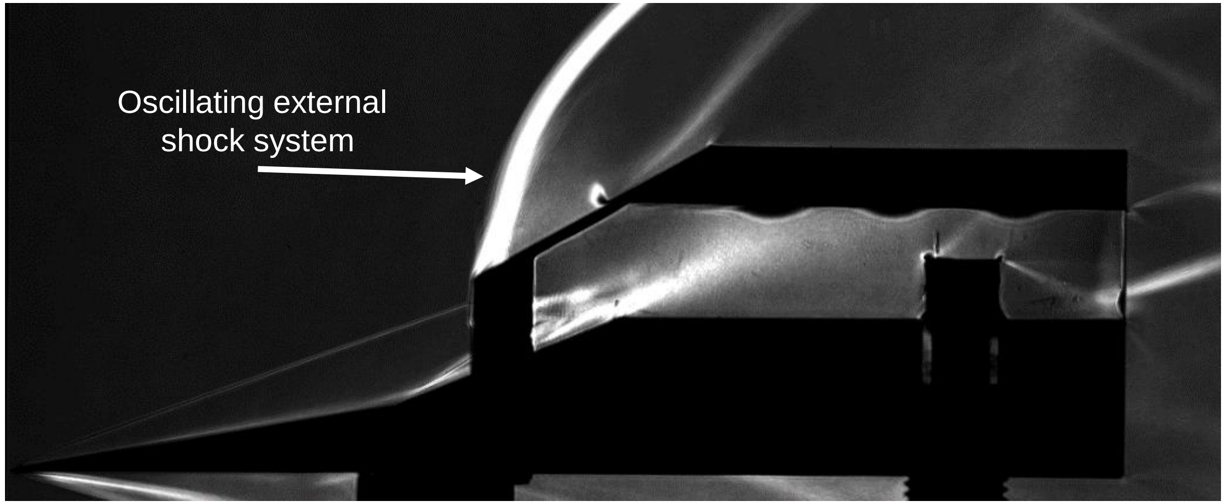
Barrier-down, Critical mode

Barrier-up, Subcritical mode → Buzz









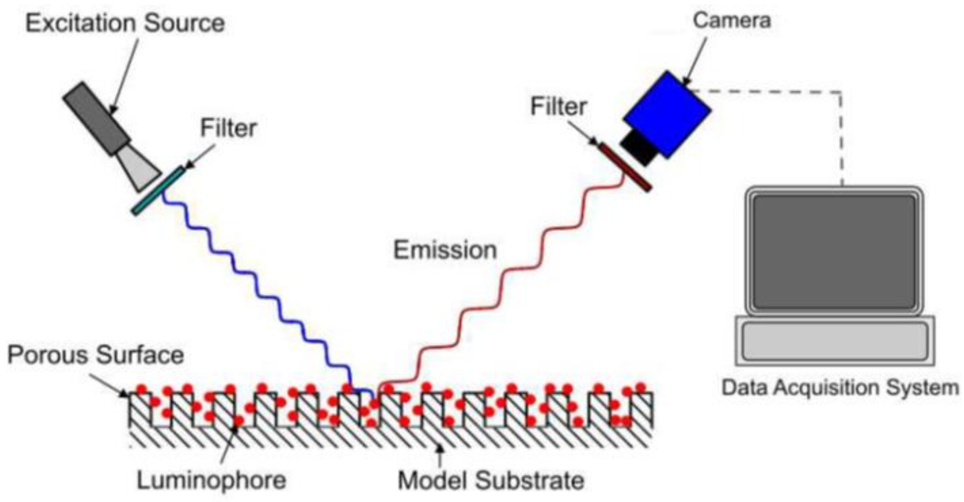
Standard deviation of all the frames captured by the high-speed camera

PSP - a brief overview

- A sprayable oxygen sensor
- Sensitive to concentration of oxygen
- Measurable with a camera relative to a reference condition
- Higher pressures reduce light output
- Application method sets response time

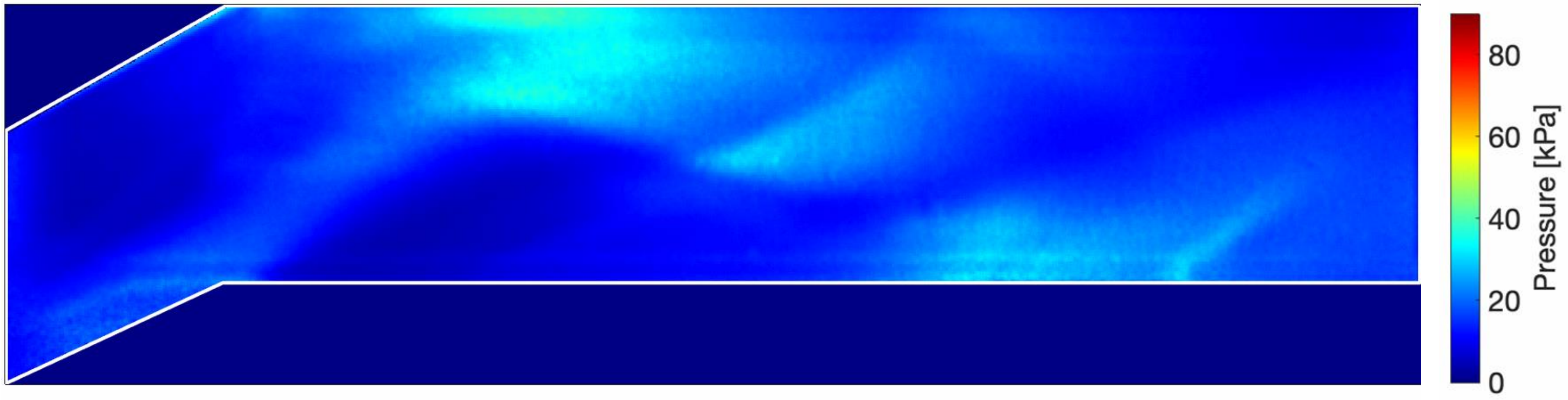
$$\frac{I_{ref}}{I} = A(T) + B(T)\frac{P}{P_{ref}}$$

$$\frac{I_{ref}}{I} = A(T) + B(T)\frac{P}{P_{ref}} + C(T)\left(\frac{P}{P_{ref}}\right)^2 + \cdots$$



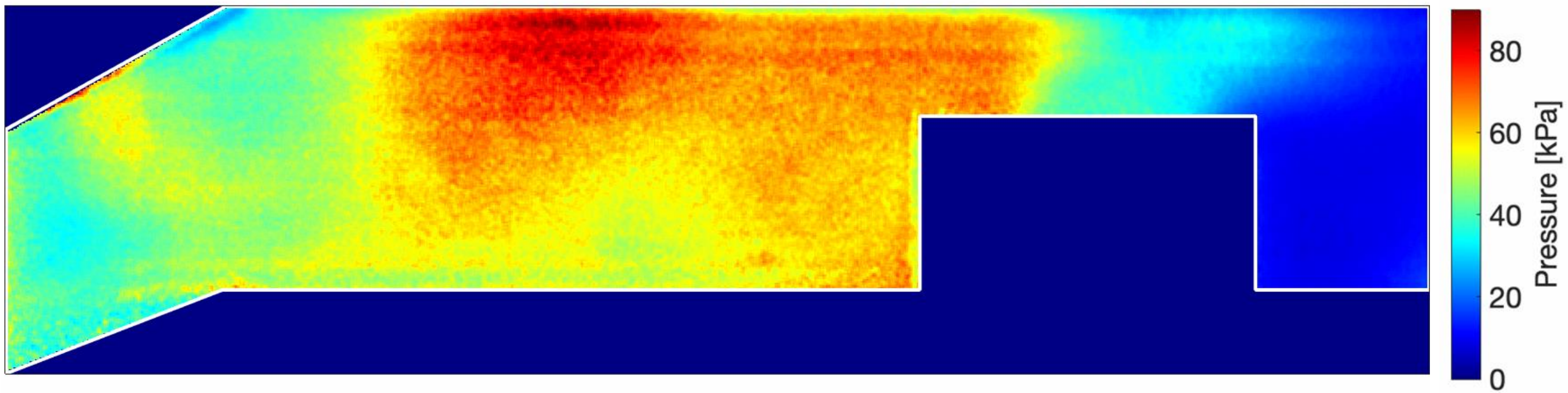
Unsteady Sidewall PSP

- Steady pressure-field features
- Pressure values consistent with 1D gasdynamics



Pressure-map, critical mode of operation (barrier-down)

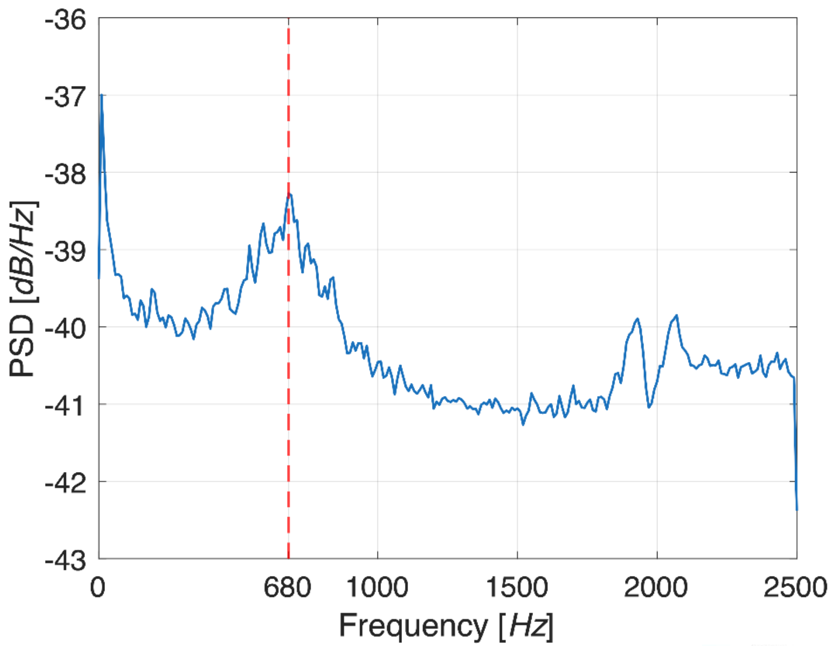
- Unsteady pressure-field features
- Higher pressure values compared to critical mode of operation

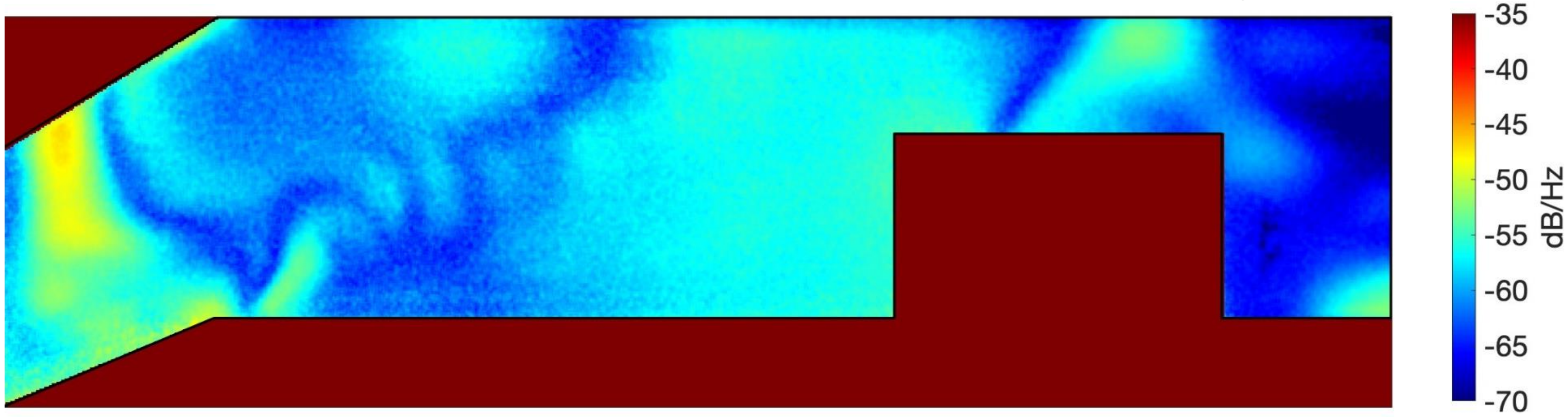


Pressure-map, subcritical mode of operation (barrier-up) → Buzz

Welch's method

- Frequency bin: $10\ Hz$
- Overlapping: 75%
- Number of DFT points: 500
- Window: *Hamming*
- Nyquist frequency: $2500\ Hz$
- I_{ref}: average of wind-on images





PSD-map of subcritical operation mode at $\mathbf{680\ Hz}$ *on sidewall*

Decomposition

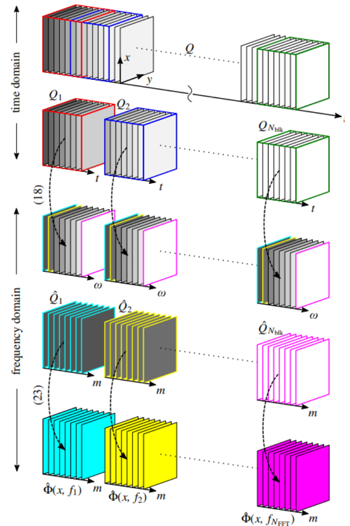
- Proper Orthogonal Decomposition (POD)
  - Very simple to implement
  - Useful for getting shapes correlated in space (overlapping temporal structures can get blurred together)

$$\boldsymbol{X} = \boldsymbol{U\Sigma V^T}$$

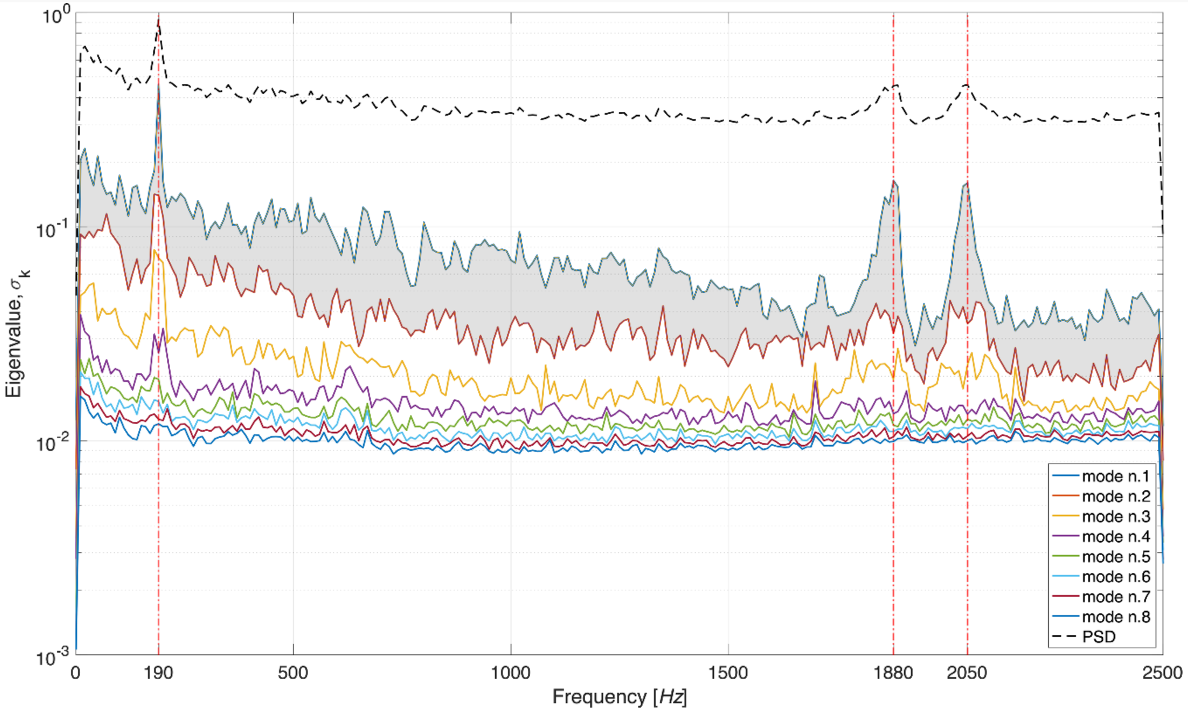
- Dynamic Mode Decomposition (DMD)
  - Approximates linear dynamics of the system
  - Useful for shapes coherent in space and time
  - Very susceptible to noise and transients

$$\boldsymbol{X}_{\boldsymbol{t=2\rightarrow N}} = \boldsymbol{AX}_{\boldsymbol{t=1\rightarrow N-1}}$$

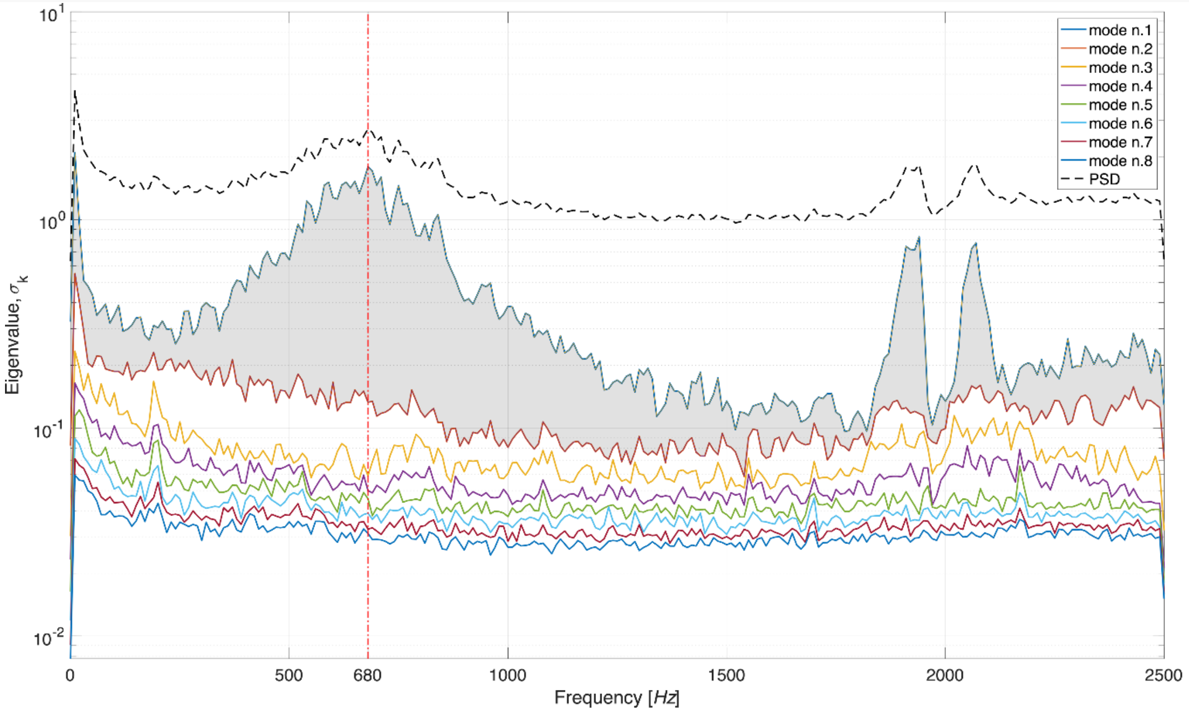
- Spectral POD (SPOD)
  - Similar to POD but utilising a Welch method of overlapping (like a PSD estimate)
  - Algorithmically more complex to understand
  - Much more robust for dynamics changing in space and time



Spectral PSP Content



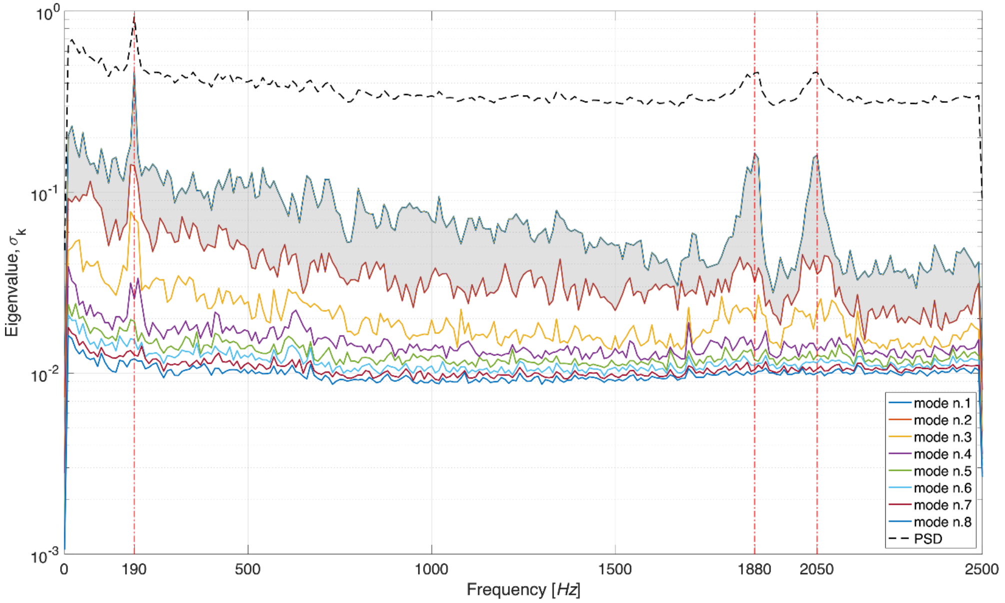
*SPOD energy spectrum for **critical mode**, sidewall-test case*

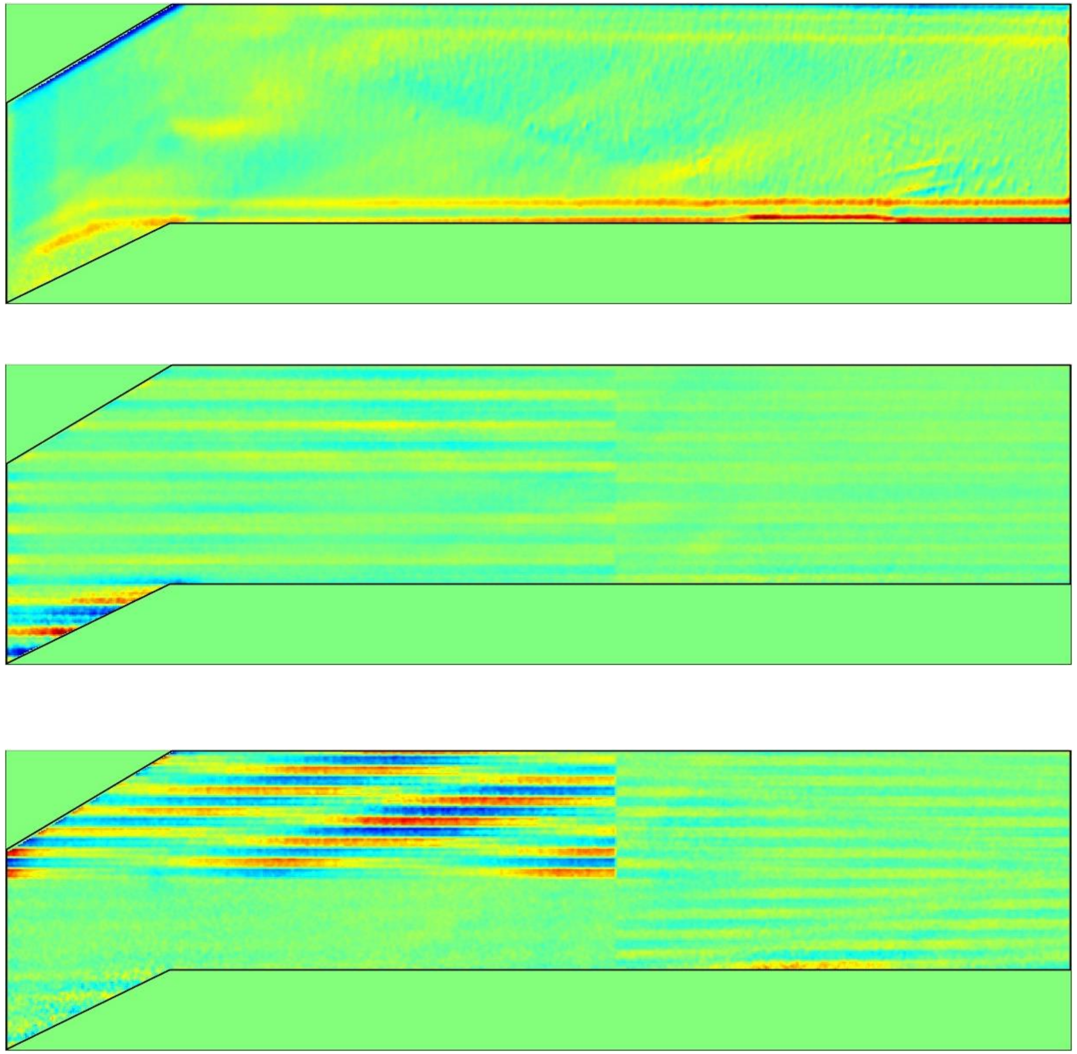


*SPOD energy spectrum for **subcritical mode**, sidewall-test case*

- *SPOD* is used to extract coherent structures of the flow in the form of *orthogonal modes* ranked by their energy
- Data that can be represented by a small number of basis vectors (*modes*): *low-rank behaviour*
- → **Mathematically**: corresponds to large separation between the SPOD modal energies (eigenvalues)
- → **Physically**: corresponds to the occurrence of a physically dominating mechanism
- The *low-rank behaviour* at 680 Hz is the result of one physical dominant mechanism: **inlet buzz**

Spectral PSP Content





- Three dominant tones:
  - 190 Hz
    - Model shake
  - 1880 Hz
    - Camera banding
  - 2050 Hz
    - Camera banding

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Spectral PSP Content

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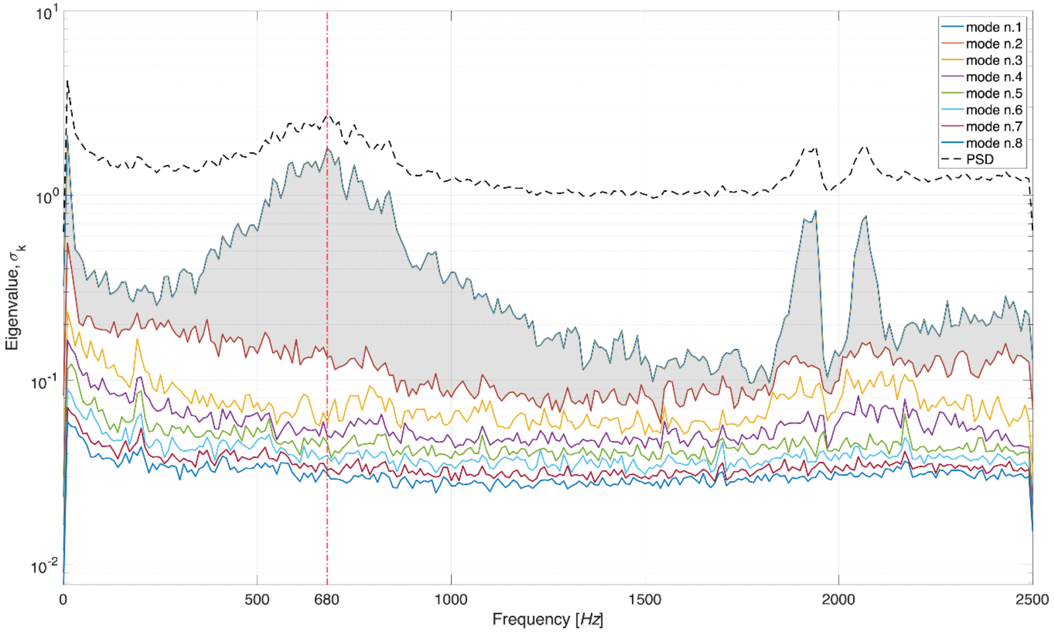
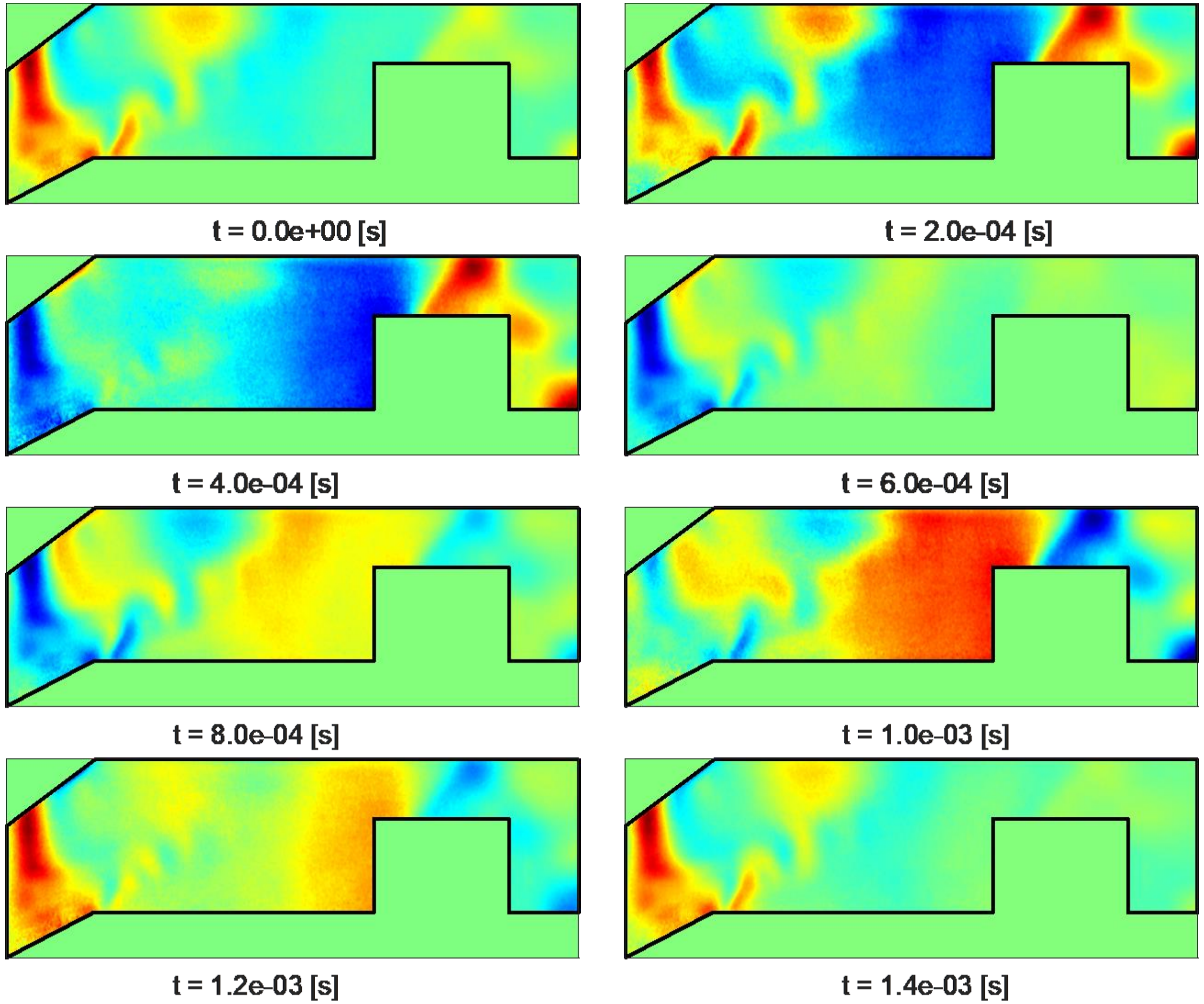
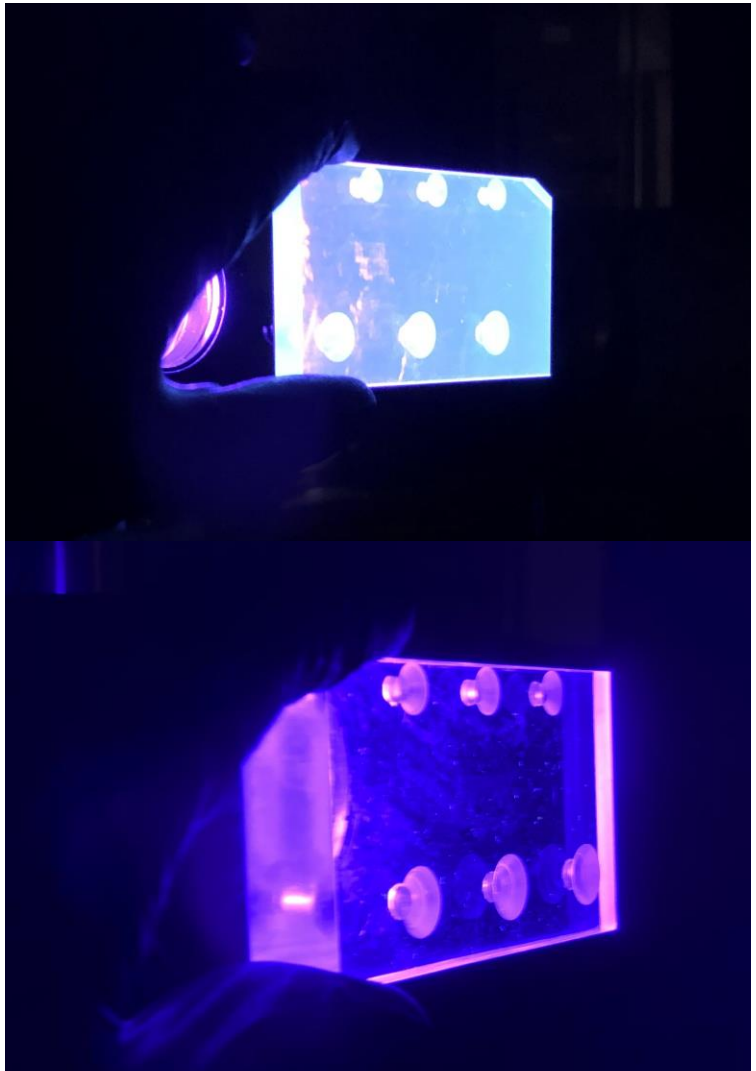




First SPOD mode at 680 Hz, over one period

A note on PSP testing

- The excitation light for PSP is 395nm (high UVA)
- This can be absorbed by some acrylic
- The acrylic may then emit this energy
- Make sure to get UVT acrylic/Perspex



Discussion

- Intake and unstart testing is easily conducted in this tunnel
- PSP + SPOD – very powerful way of extracting information
  - Possibly more information than we actually want…
- Data Fusion between techniques is the best way to understand performance
  - Challenging with unsteady dynamics