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Recent developments in the Oxford Cold-driven Expansion Tube CXT

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Monday 28th September 2026

International Workshop for Shock Tube Technology (IWSTT) 2026

Toulouse, France.

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Introduction



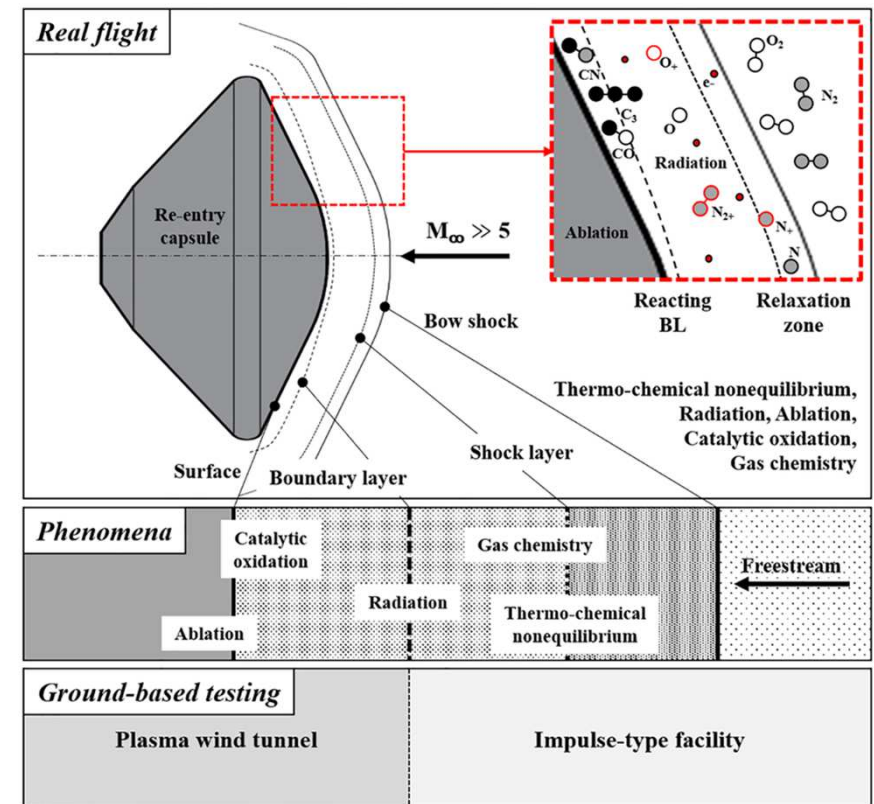
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Qualification of material response in hypersonic flight regimes

Large thermal loads: $\sim 1\text{-}10 \text{ MW/m}^2$

Complex, highly coupled heat transfer mechanisms:

- Non-equilibrium flows
- Pyrolysis gas blowing
- Surface roughness
- Surface reactions



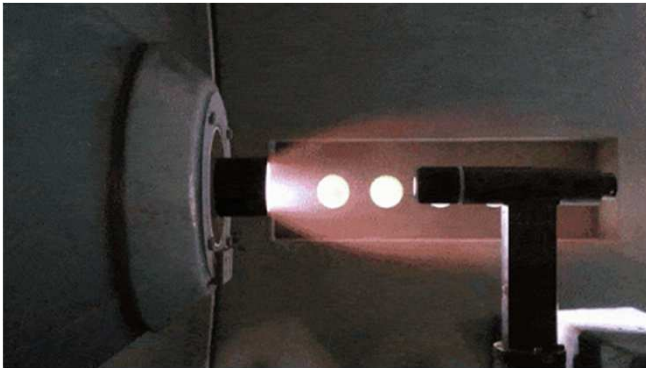
Flowfield around a re-entry vehicle [1]

Introduction (adapted from [2])



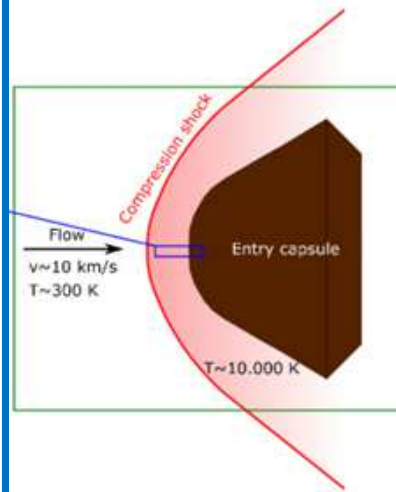
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Plasma wind tunnel (hot)

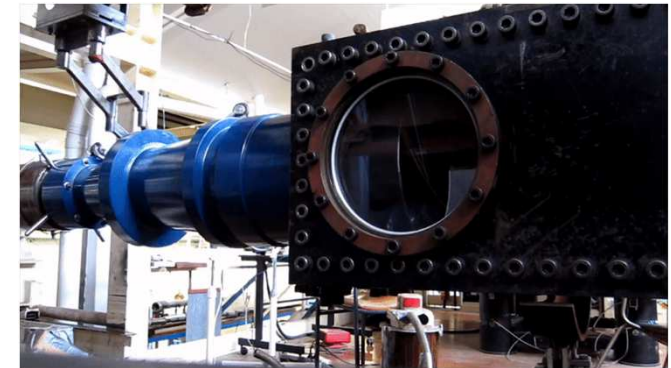


PWK1 arcjet testing [IRS]

- Electric energy to heat the test gas
- Continuous test duration (mins to hrs)
- **Material reaches flight T_w**
- Post-shock stagnation streamline is replicated (LHTS scaling)



Impulse facility (fast)



T4 shock tunnel Mach 10 run [UQ]

- Rapid release of stored energy to create impulsive flow conditions
- Short test duration (μs to ms)
- **Total enthalpy, velocity, and pressure are matched**
- Requires preheating to match flight T_w

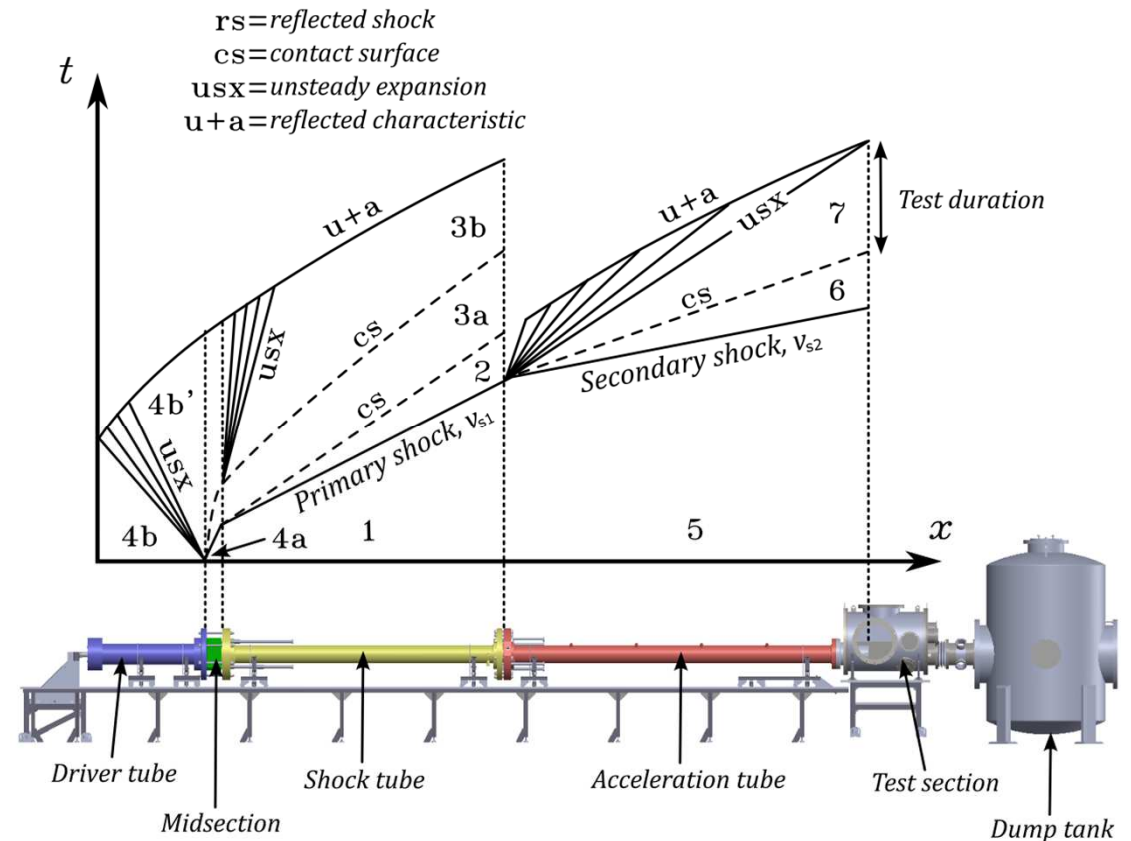
CXT: Facility overview



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CXT: Cold-driven eXpansion Tube

- Approx. 8.6m total tube length, 177.8mm bore diameter
- Cold, double diaphragm driver
- Air/helium driver and expansion gases



CXT facility with illustrative (x-t) diagram

CXT: Facility overview



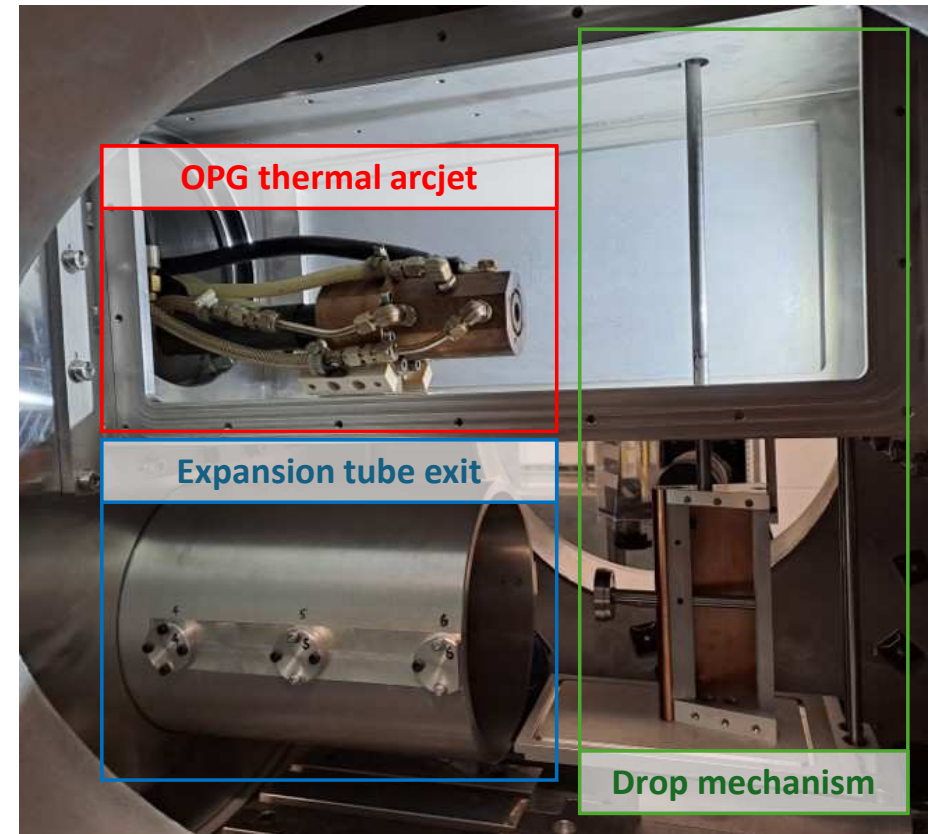
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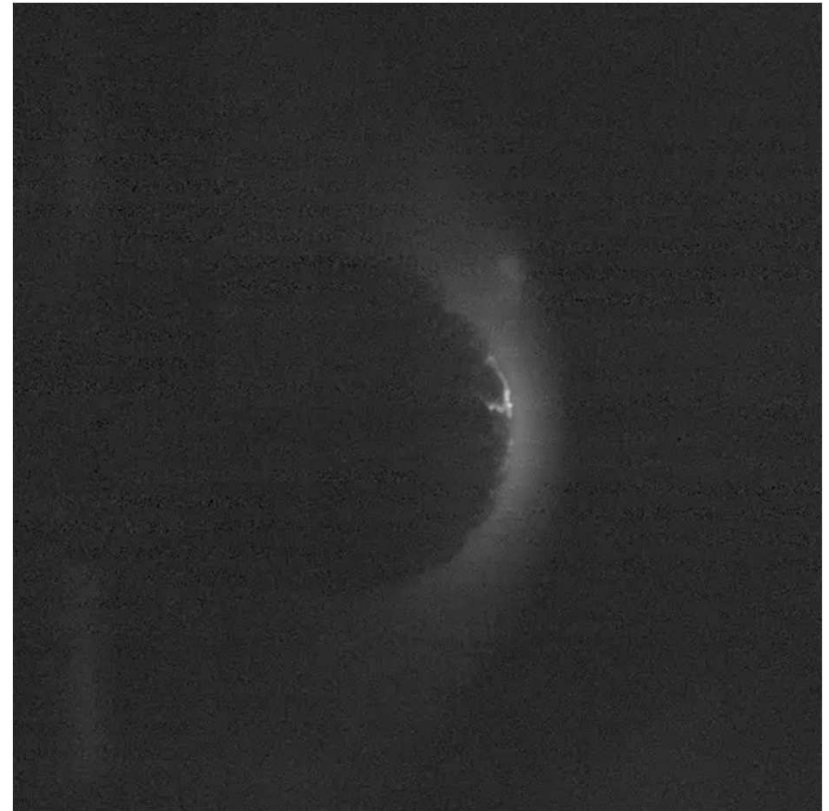
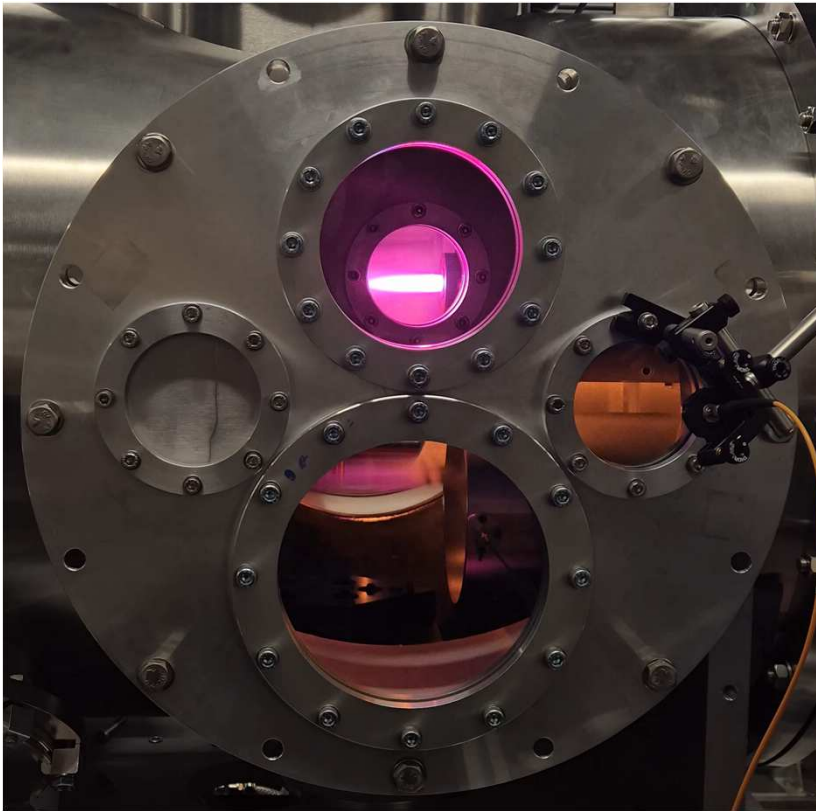
APEx: Arcjet Preheating within an Expansion Tube

- **Aerothermal preheating using OPG thermal arcjet**
 - Small-scale thermal arcjet (21.5 kW)
 - Steady supersonic jet conditions (Argon, N₂, Air) up to 0.2 g/s
- **Rapid traversal with piston-driven drop mechanism**
 - Trapdoor sealing to prevent leakage into main test section
 - 150ms travel time achieved
- **Arrival of high-speed flow from expansion tube**
 - Model cooling for ~400 ms prior to shockwave arrival



OPG nozzle and drop mechanism in CXT test section

CXT: Facility overview



Ablation of heated P50 cork model in high-speed flow [2]
Footage from phone camera, slowed down **(left)** and Phantom TMX7510 **(right)**

[2] E. W. K. Chang et al. "Development of an Arc-Jet Preheating System within an Expansion Tube Facility (APEX) for Hypervelocity Flow Testing of Ablating Test Models". 15th Ablation Workshop, 2025

Recent developments

January – September 2026

Double-diaphragm driver



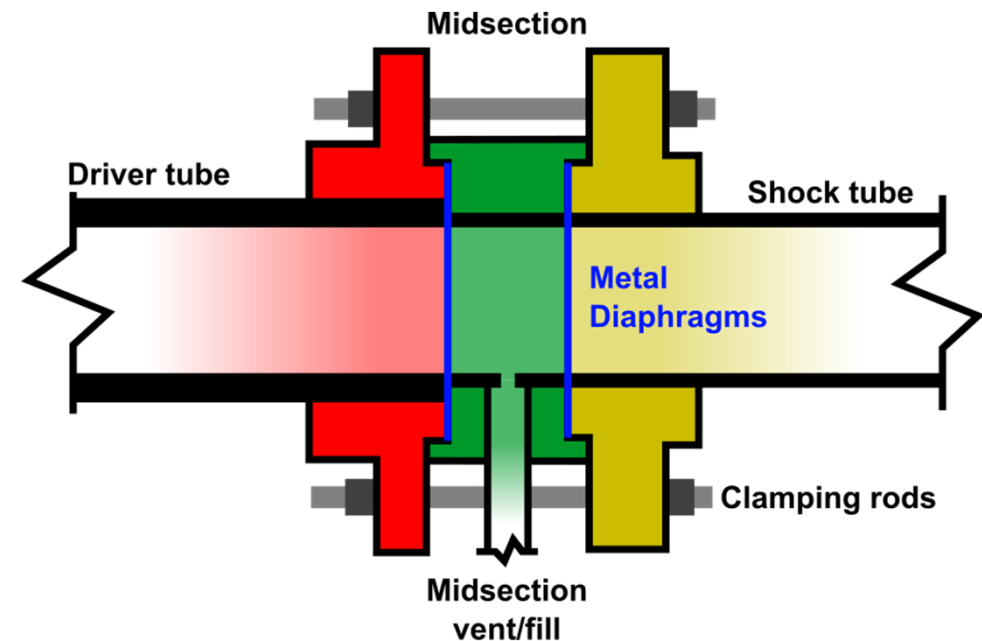
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Some examples in other facilities:

- [3] University of Oxford, UK: Cold-driven Shock Tube (CDST)
- [4] NASA Langley, USA: Langley 6-inch Expansion Tube
- [5] KAUST, Saudi Arabia: High-Pressure Shock Tube (HPST)
- [6] Texas A&M University, USA: Hypervelocity Expansion Tunnel (HXT)
- [7] Stanford University, USA: Mach 8-12 Expansion Tunnel

Other facilities with similar drivers:

- [8] Purdue University, USA: HYPULSE
- [9] CalTech, USA: High-Enthalpy Tunnel (HET)
- [10] University of Queensland, Australia: X2



Sketch of double-diaphragm driver for the CXT facility

- [3] J. Camm et al. "The Oxford Cold Driven Shock Tube (CDST) for Fuel Spray and Chemical Kinetics Research." *SAE Technical Papers* 2018-01-0222, 2018.
- [4] J. A. Moore. "Description and initial operating performance of the Langley 6-inch Expansion Tube using heated helium driver gas". *NASA TM X-3240*, 1975.
- [5] T. A. Kashif et al. "Double-Diaphragm Induced Shock Velocity Variation and Its Effects on Shocked Gas." *AIAA Journal* 63(12), 2025.
- [6] T.S. Dean et al. "On the Initial Characterization of a Large-Scale Hypervelocity Expansion Tunnel." *AIAA SciTech Forum*, 2022.
- [7] A. Ben-Yakar, R. Hanson. "Characterization of Expansion Tube Flows for Hypervelocity Combustion Studies." *Journal of Propulsion and Power* 18(4), 2002.
- [8] R. Bakos et al. "Expansion of the Scramjet Ground Test Envelope of the HYPULSE Facility." *AIAA Space Planes and Hypersonic Systems and Technologies Conference*, 1996.
- [9] A. Dufrene et al. "Design and Characterization of a Hypervelocity Expansion Tube Facility." *Journal of Propulsion and Power* 23(6), 2007.
- [10] S. Gu et al. "Study of the Afterbody Radiation during Mars Entry in an Expansion Tube." *55th AIAA Aerospace Sciences Meeting*, 2017.

Double-diaphragm driver



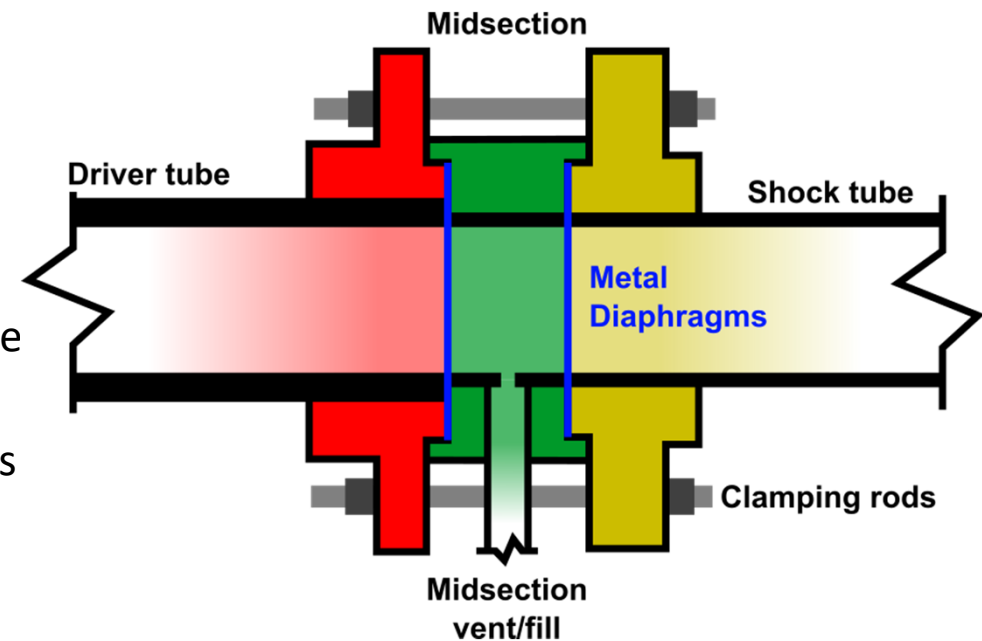
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Advantages for the CXT:

- Consistent rupture timing – synchronisation for APEx drop mechanism
- Simple operational principle with fast turnaround

Some difficulties encountered:

- **Low driver pressures (up to 80 bar)** – driver pressure limited by other aspects of facility
- **Relatively large bore diameter (177.8mm)** – reduces pressure for a given bending force/moment
- Aluminium tube sections – susceptible to scratching from diaphragm fragments



Sketch of double-diaphragm driver for the CXT facility

Diaphragm design

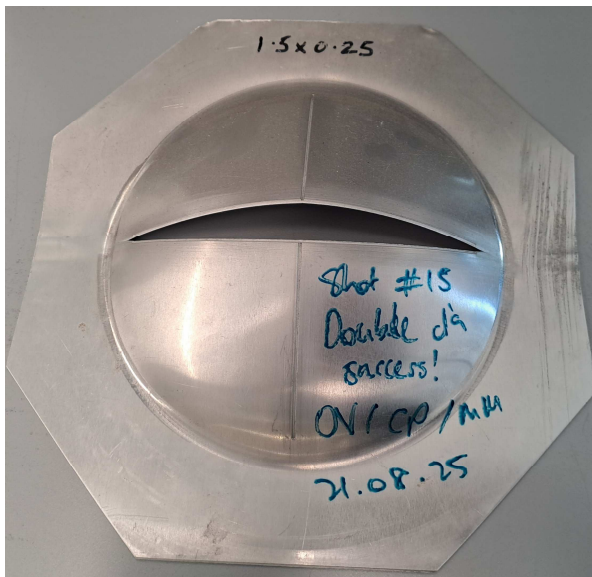


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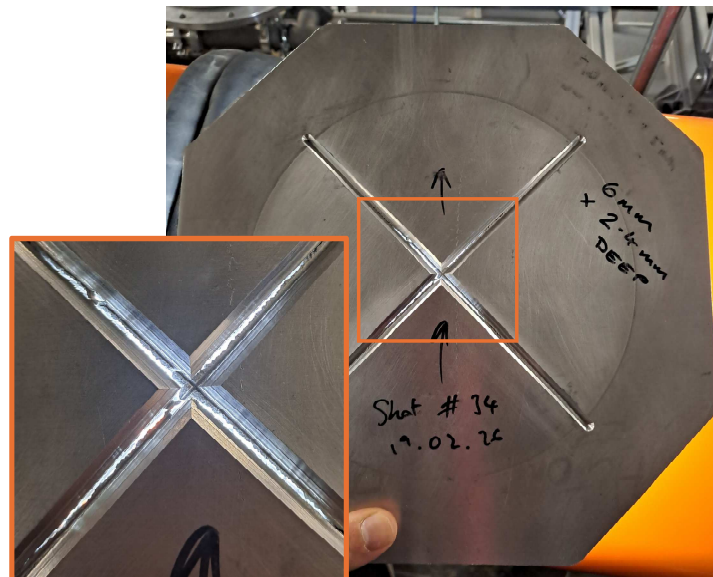
Has been a long process for us!

Started with materials on other Oxford facilities:

- **CDST** – Aluminium 1050-H14
- **T6** – 304 Stainless Steel, DCO1 CR4 Mild steel



Aluminium 1050-H14, 1.5mm thickness
No petalling, very low burst pressure



Aluminium 1050-H14, 6.1mm thickness
Fracture from groove through the plate



Mild Steel DCO1 CR4
Some unpredictable behaviour?

Diaphragm design



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Current working design:

Aluminium 1050-H14, 5.0mm thick

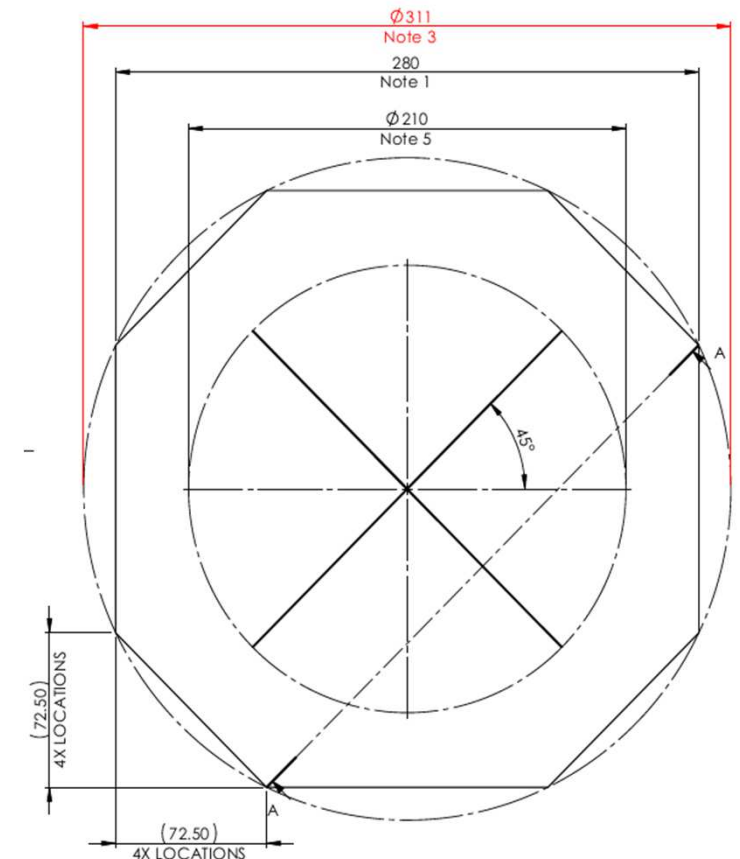
Blanks previously machined/filed to size - now laser cut

Grooves machined using 90° engraving bit

Torque wrench to control clamping force (180Nm)



Aluminium 1050-H14. 5.0mm thickness, 2.0mm score depth
First fully open petals on downstream diaphragm (right)

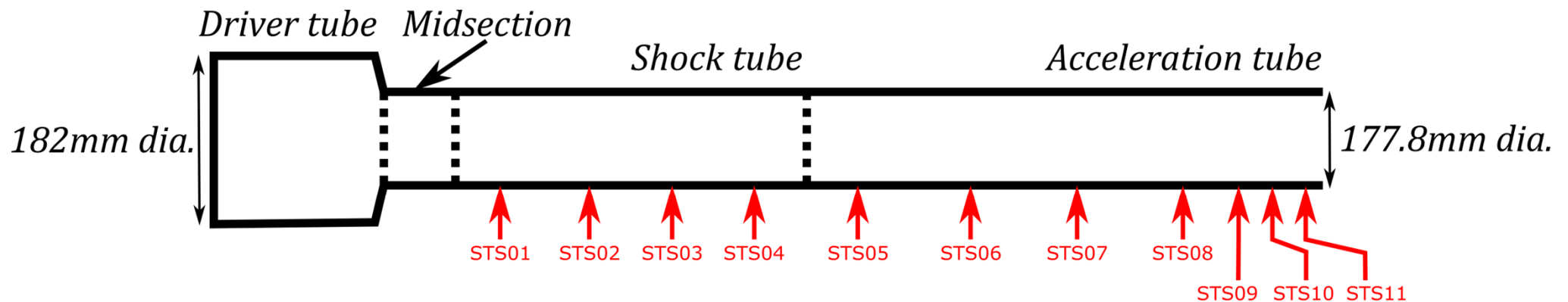


Current diaphragm geometry

Shock timing

Diagnostics:

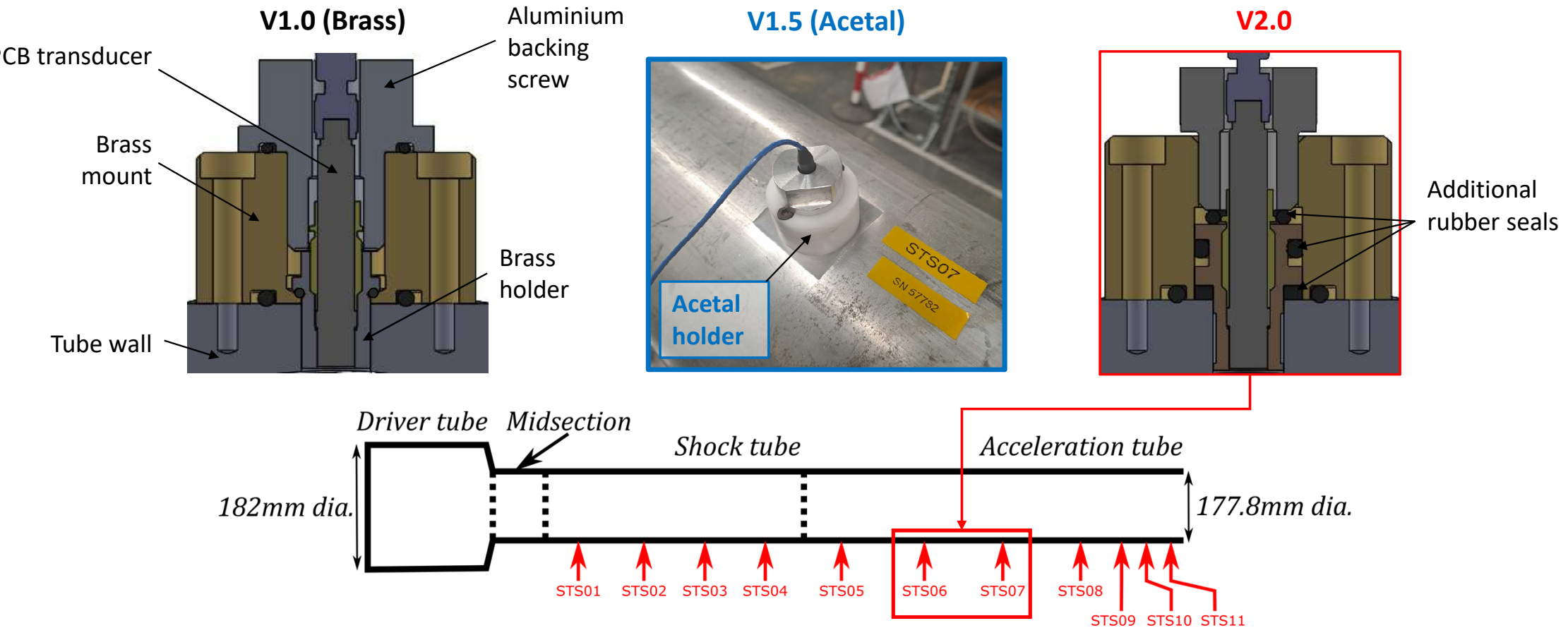
- Wall-mounted pressure transducers – 11 locations along facility
113B27 (PCB Piezotronics)
- Data acquisition with PicoScope 4824a PC Oscilloscopes (Pico Technology)



** not to scale*

Locations of timing stations on facility

Shock timing



* not to scale

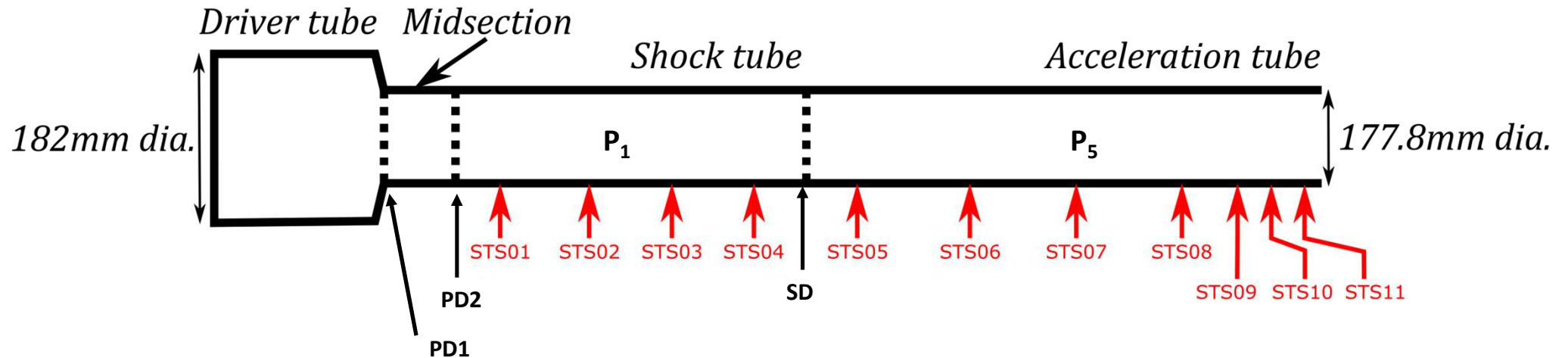
Shot #60: Example data



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Shot Number	PD1		PD2		SD, μm	P_4 , bar	P_1 , kPa	P_5 , Pa
	Score depth, mm [%]	Burst pressure, bar	Score depth, mm [%]	Burst pressure, bar				
60	0.75 [15%]	40.9	0.75 [15%]	42.1 $\pm$ 6.5*	5	69.7	5.32	19.8

* Estimate only, based on nominally identical diaphragms. Error band shown is 2 standard deviations.

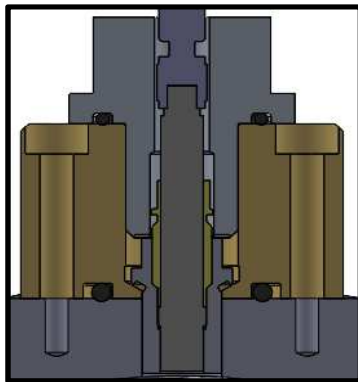


Shot #60: Shock timing



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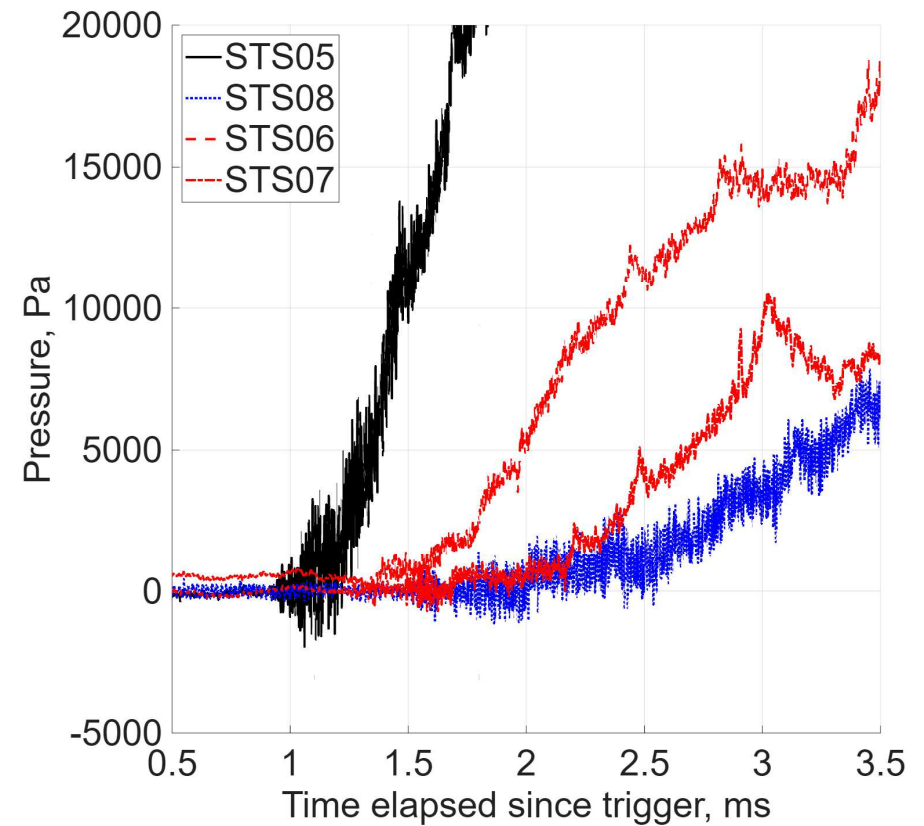
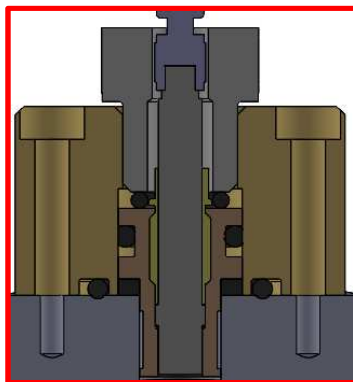
V1.0 (Brass)



V1.5 (Acetal)

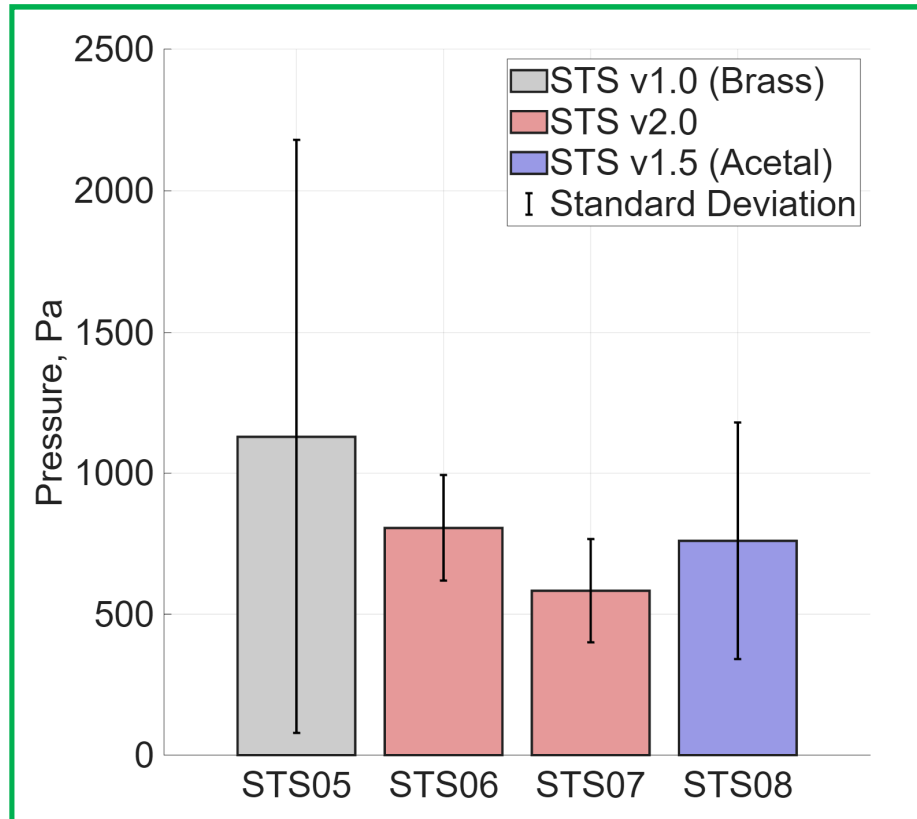


V2.0

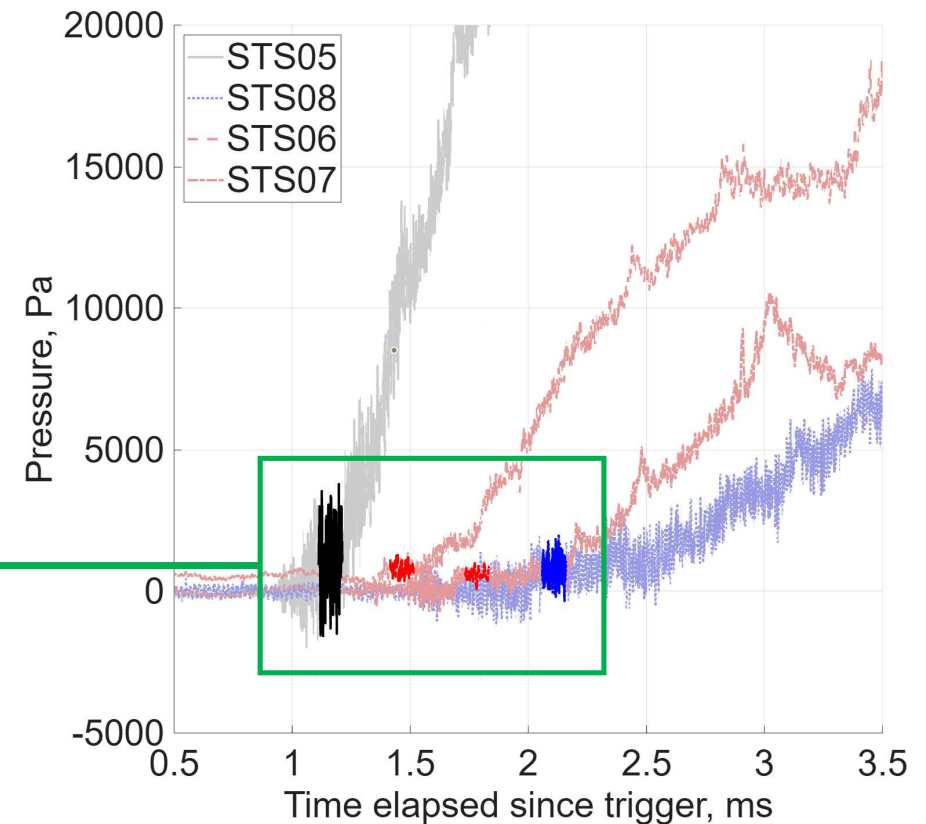


Pressure data from acceleration tube
(20-point moving mean filter)

Shot #60: Shock timing



Statistical distribution of filtered data, between 50-150 μ s post shock arrival. Bars indicate mean values.



Pressure data from acceleration tube
(20-point moving mean filter)

Shot #60: Test condition



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Measured shock speeds:

Primary shock: $V_{s_{2-4}} = 1006 \text{ m/s}$

Secondary shock: $V_{s_{6-11}} = 2260 \text{ m/s}$

Velocity uncertainties:

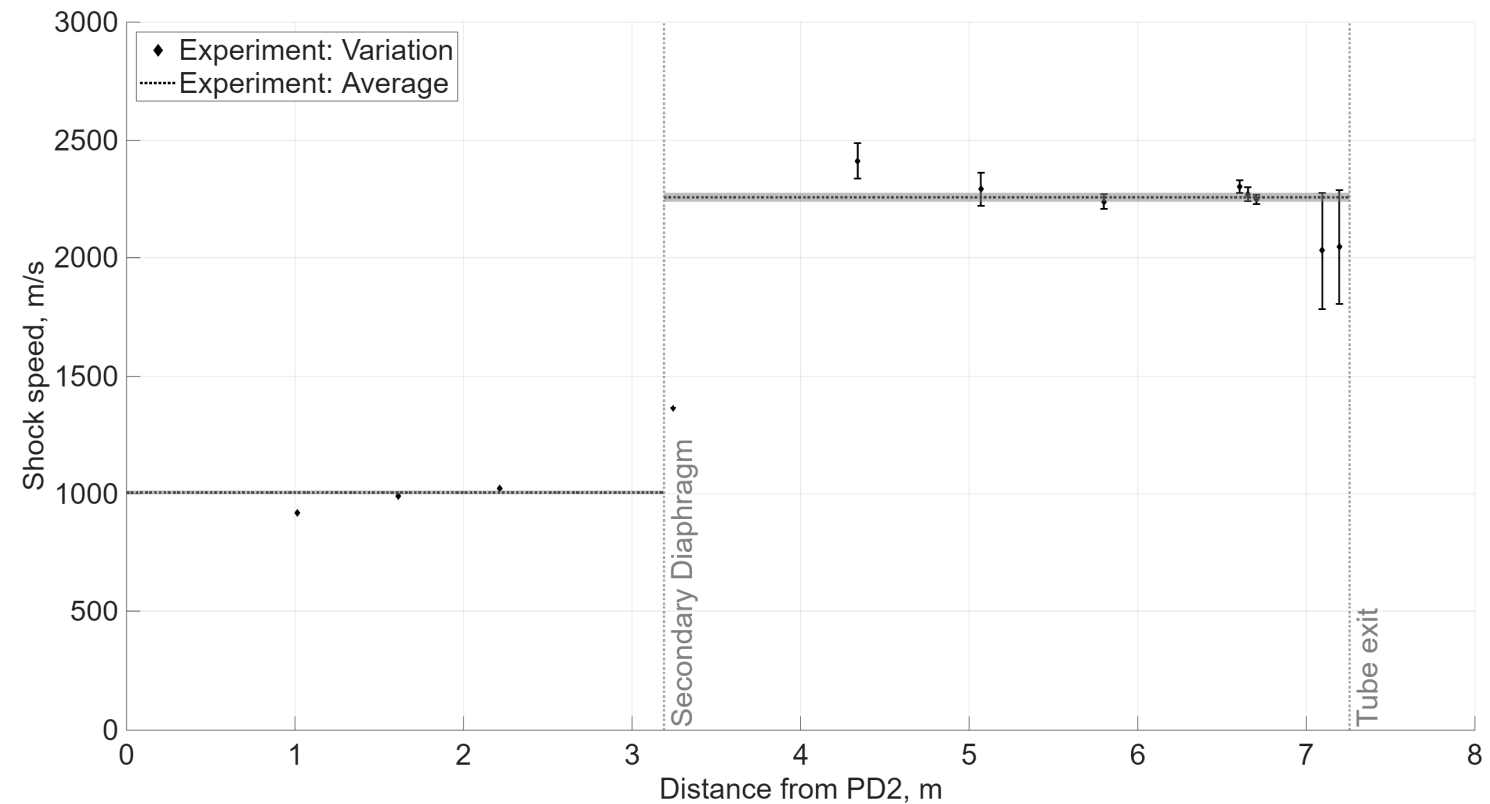
STS 01 to 04: 3%

(Error bars omitted for clarity)

STS05 to 08: 2 - 6%

STS09 to 11: 24%

(Small spacing of 90mm apart)



Shock speed variation along facility

Shot #60: Test condition



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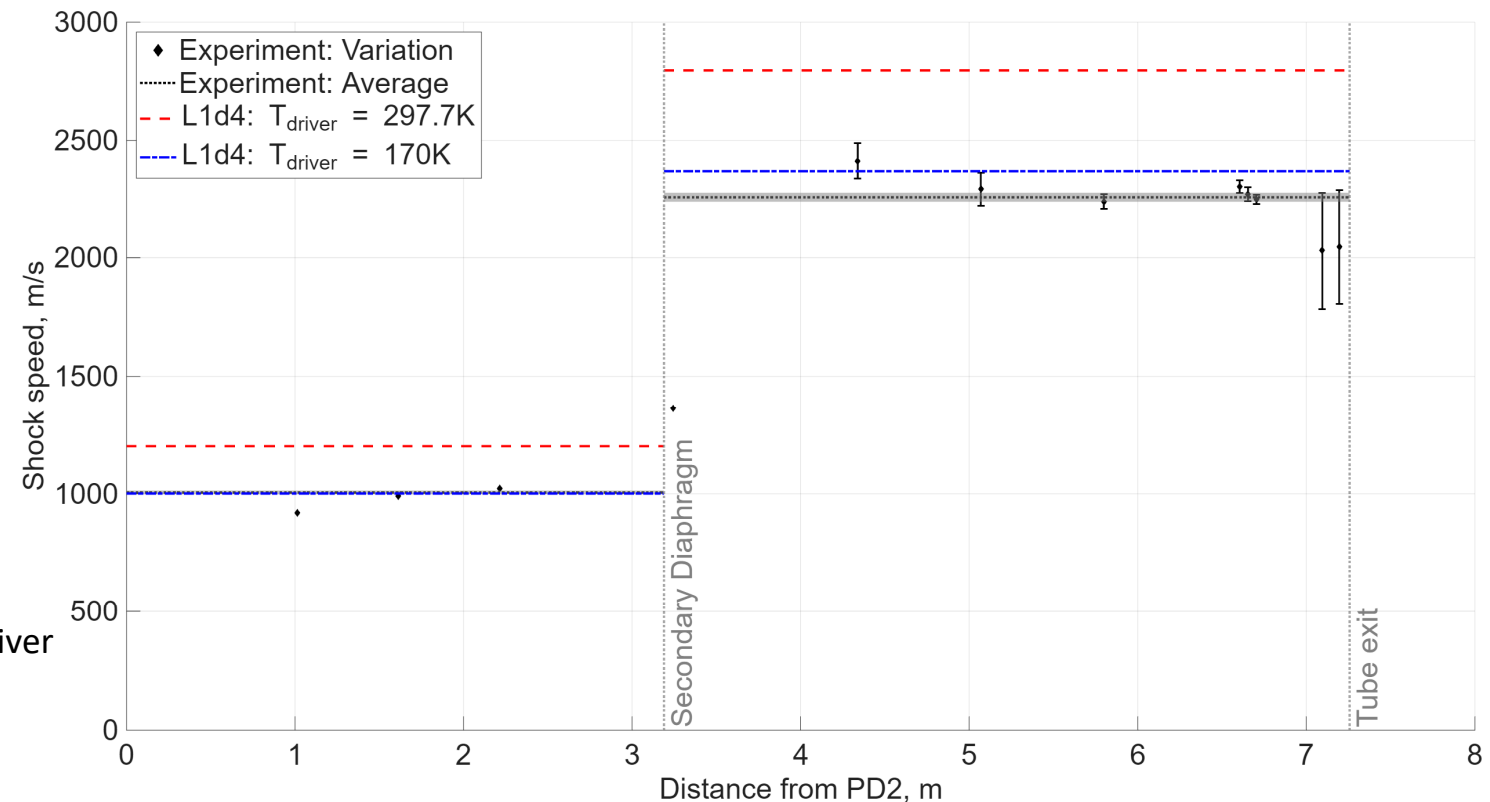
(Small spacing of 90mm apart)

L1d4 [11] analysis:

Good fit to shock tube data for 170K driver temperature.

(Method of Gildfind et al. [12])

Simulation of acceleration tube data requires further work.

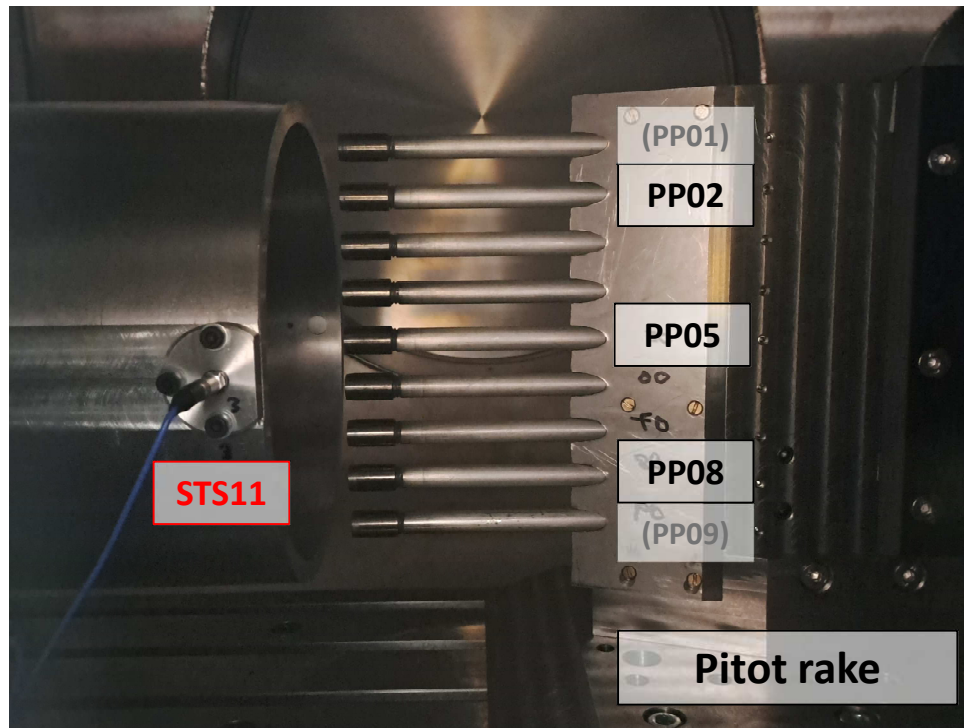


Shock speed variation along facility

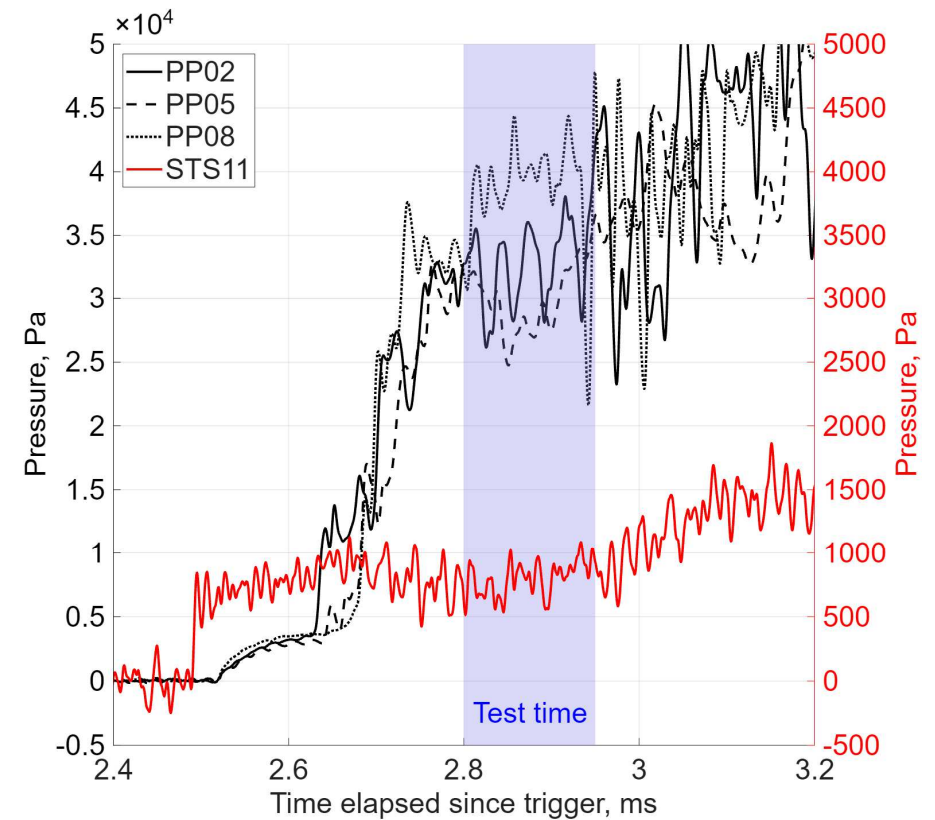
Shot #60: Test condition



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Pitot rake and STS 11 in test section



Pressure data from Pitot probes and STS 11
(Butterworth filter, 100kHz)

Shot #60: Test condition



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Steady test time: $\sim 150\mu\text{s}$
(2.8ms – 2.95ms)

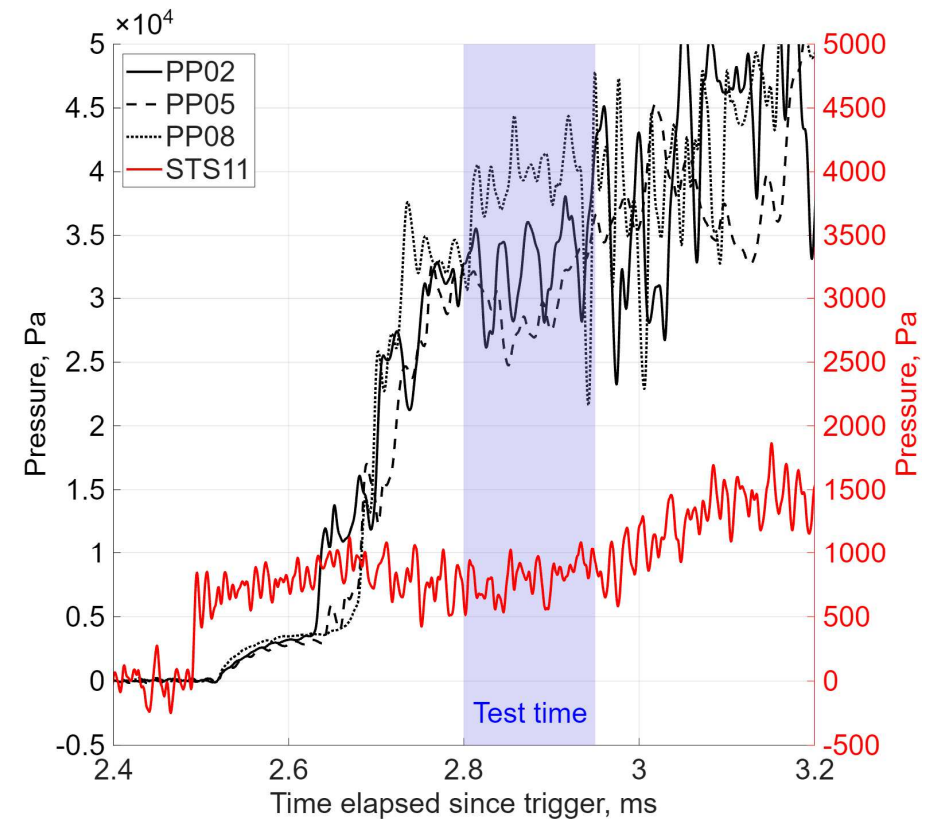
P_6 pressure: **820 Pa**

Pitot pressure (PP02-08): **32.1 kPa**

PITOT3 [12]: ‘Fully empirical’ mode

P_6 pressure: **1023 Pa**

Pitot pressure: **31.4 kPa**



Pressure data from Pitot probes and STS 11
(Butterworth filter, 100kHz)

Summary



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Successful diaphragm design achieved – up to 70 bar driver condition
Low plate thickness generally less successful - edge deformation

Improved data quality from facility diagnostics

V2.0 mounts for shock timing stations – reduced noise from vibration

Good agreement between simulations and facility data

With reduced driver temperature of 170K for L1d4

Next steps:

- Establish diaphragms for 80 bar driver condition
- Improved simulations of facility
- **Second APEx mode campaign – est. December 2026.**

Acknowledgments



We extend gratitude to our project sponsors:

- UKRI Future Leaders Fellowship scheme (grant number MR/T041269/1)
- ESA Open Space Innovation Platform (contract number 4000143016)

Additional thanks to the staff/students at the Oxford Thermofluids Institute for their advice at various stages of the facility development.

Special thanks to our technical staff for their continued support:

Matthew Todd, Hal Surtell, William Godfrey, Lee Stevens, Ambrose Kehoe,
Leo Verling, Duncan Blake, Shinu Toms, Dominic Harris, David O'Dell,
Andreea Dabija, Gabriel Tansley



Thank you for listening!

Any questions?