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Design and Commissioning of the Cold-Driven Expansion Tube CXT

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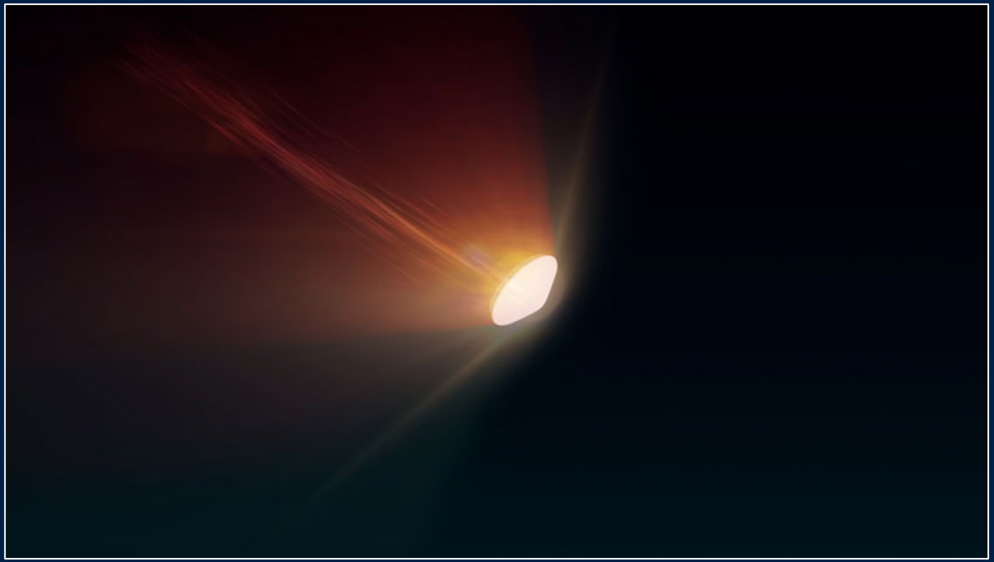
Overview

Part I: Introduction



NASA MSR Earth Entry System [NASA]

Background

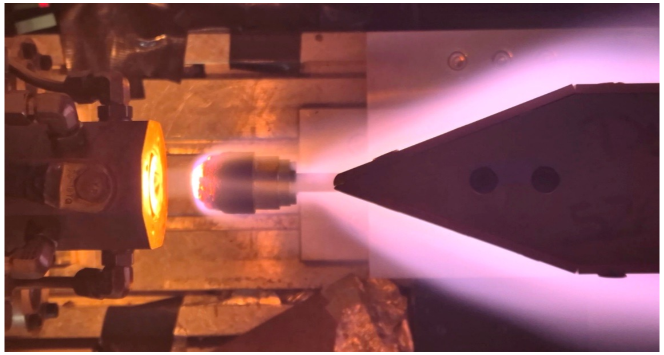
Motivation: Improved understanding of the thermal response of ablative materials

Complex, highly coupled heat transfer mechanisms:

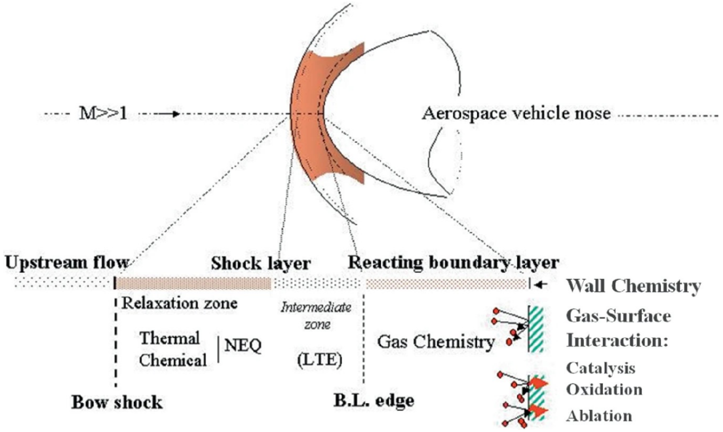
- Pyrolysis gas blowing
- Surface roughness
- Surface reactions
  (oxidation/nitridation, catalysis, etc)

High uncertainties in TPS design

Aim: Experimental investigation using hypervelocity flows in a ground testing facility



P50 cork in nitrogen plasma, OPG facility



Re-entry environment along stagnation line [1]

Methodology

Plasma wind tunnels:

- Hot models
- Stagnation streamline
- Equilibrium thermochemistry

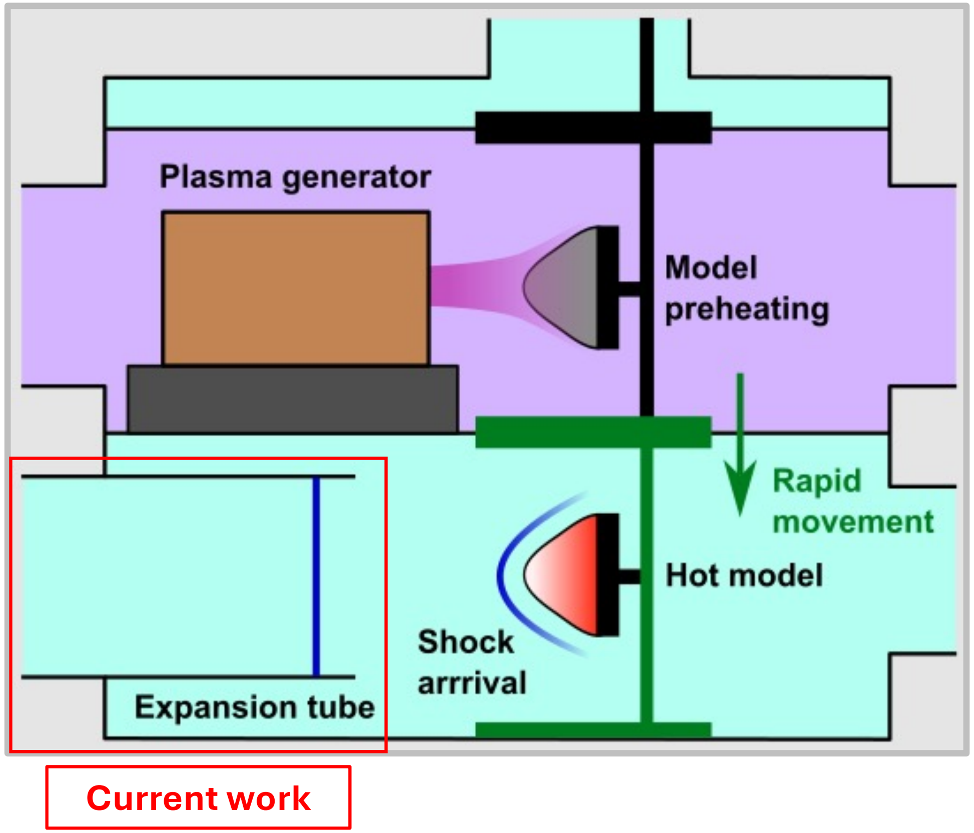
Impulse facilities:

- Cold models
- Full post-shock aerodynamics
- Non-eq. thermochemistry

Proposed hybrid methodology:

- Hot models
- Full post-shock aerodynamics
- Non-eq. thermochemistry

Proposed hybrid facility concept



Part II: Facility Overview

Photograph of the CXT facility build

Summary

Cold-driven
Xpansion
Tube

(not *the* CXT [3-6])

Shock/acceleration tubes recommissioned from R.A.E. Pyestock MCF facility

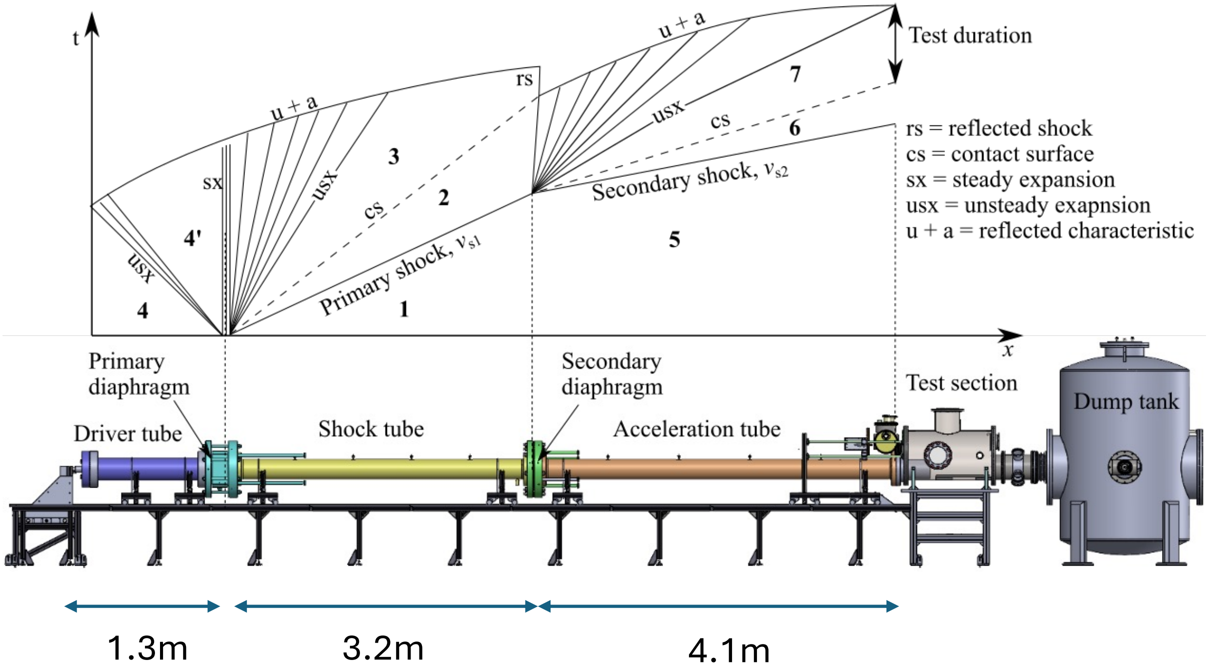
8.6m total length

177.8 mm (7”) internal diameter

(T6: 96mm)

‘Cold’ helium/air driver gas

Helium/air in acceleration tube



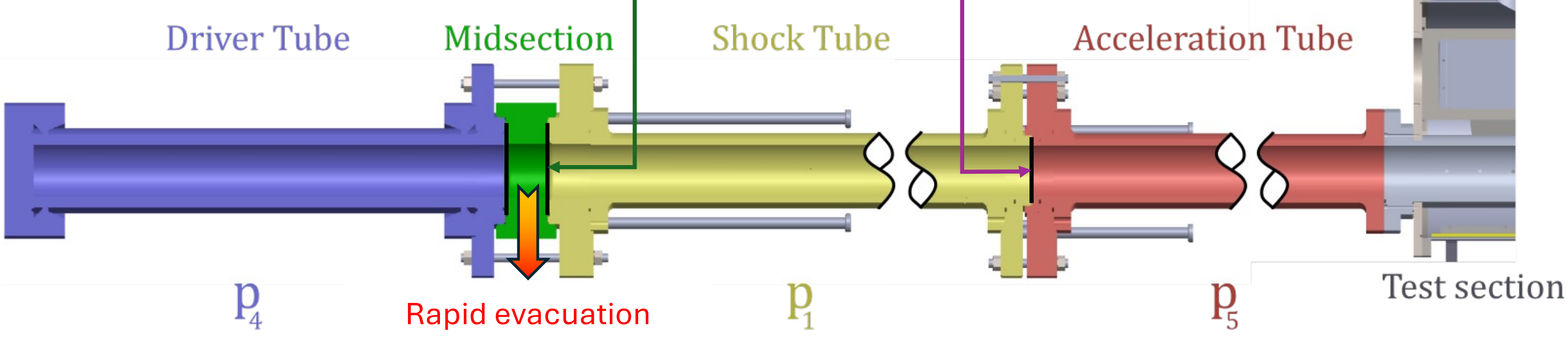
*Expansion tube distance-time diagram (**top**) and schematic of the CXT facility (**bottom**) [2]*

Cold driver

2x aluminium diaphragms separating driver tube/midsection/shock tube

- Driver tube fill pressure, $P_4 = 0.5$ to 8 MPa
- Shock tube fill pressure, $P_1 \sim 1 - 10$ kPa
- Fill midsection to intermediate pressure – rapidly evacuate to fire shot.

Secondary mylar diaphragm:
Ruptures upon shock arrival → unsteady expansion.
Can remove to run in shock tube mode.



Shot initiation procedure

Hard stops

Recoil suppression:

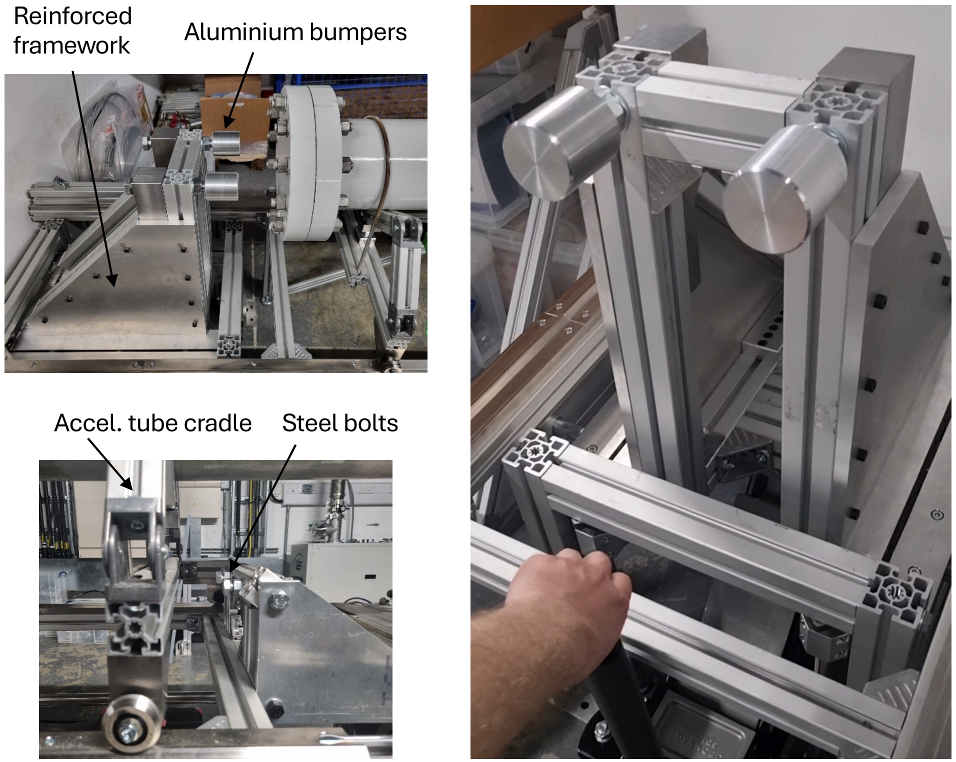
Max recoil force = 200 kN

Facility designed to eliminate recoil:

- Hard stops at driver/test section ends.
- Support frame bolted to floor.

Turnaround procedure:

1. Lower driver hard stop with trolley jack
2. Unfasten diaphragm station flanges
3. Open diaphragm stations on linear shafts
4. Replace diaphragms, clean etc
5. Close and fasten flanges, raise hard stop



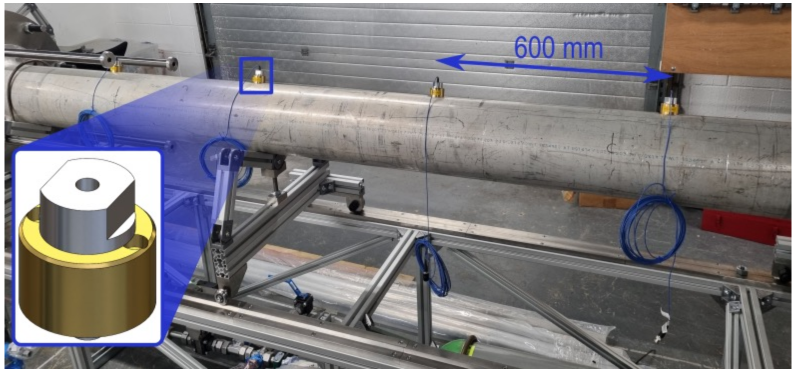
*Driver (**top**) and test section (**bottom**) hard stops.*

Shock timing

Instrumentation:

PCB113B piezoelectric transducers

- Measure static pressure at different locations
- Observes shock arrival time vs distance – calculate shock speed

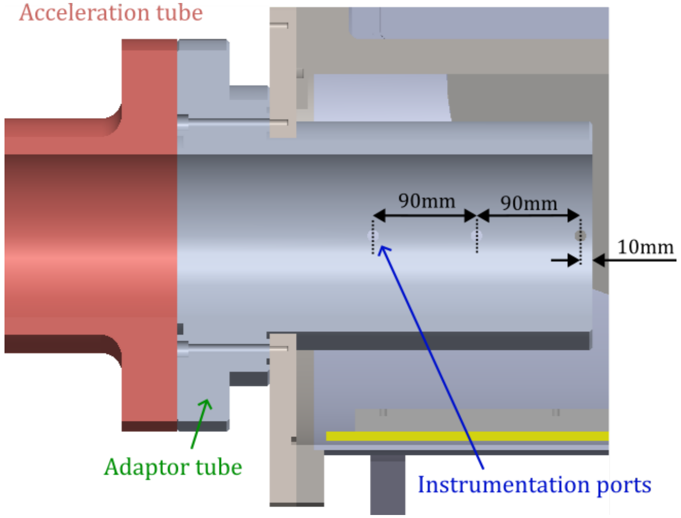


Shock tube with timing stations

Adaptor tube:

- 3x instrumentation ports per side (6 total)
- Spacings of 10, 100, 190 mm from tube exit

→ Good spatial resolution



Schematic of adaptor tube

Dual facility mode

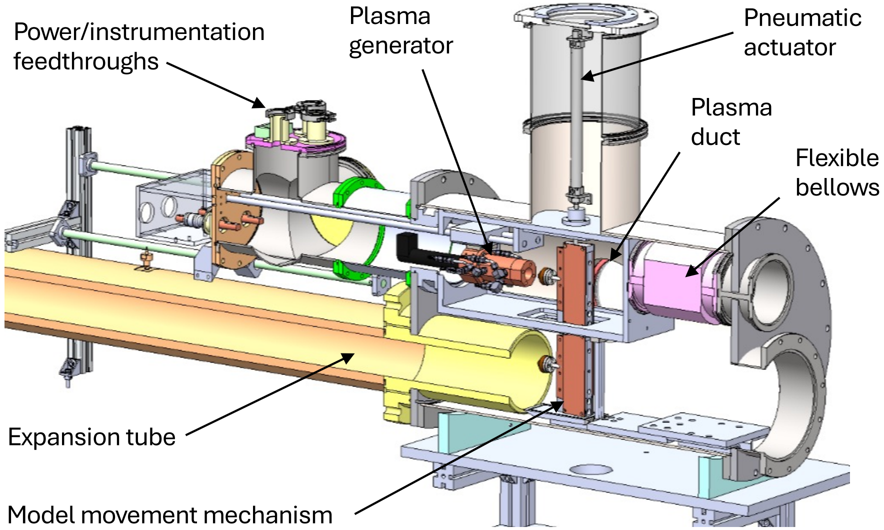
Separate vacuum systems in test section:

- Plasma duct: Busch R5 Combi
- Expansion tube: Edwards GXS.
- Volumes briefly unseal during model actuation.

Foreseen challenges:
Synchronising model movement with shock arrival:

- Temperature drops during movement
- Leakage from OPG to CXT → **rise in P_5**

Flight extrapolation: matched conditions for both halves.



Schematic of the test section in dual facility mode

Fast acting piston: movement timescales ~ 50-100 ms.

Double diaphragm: precise control of rupture time.

Sealed vacuum systems: minimised gas leakage.

Part III: Flow characterisation

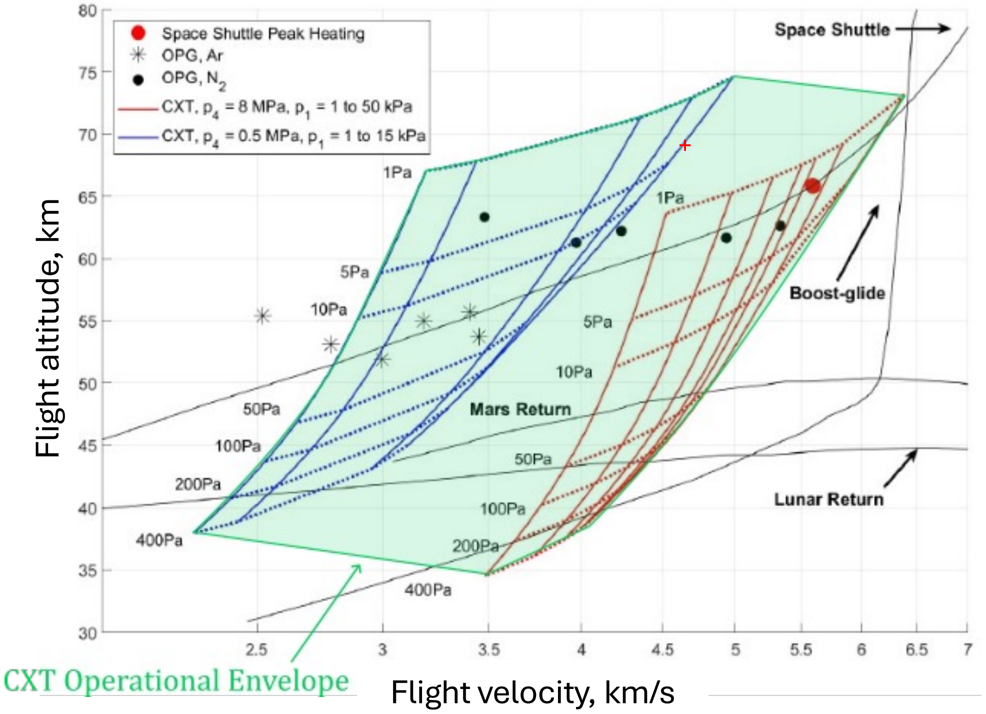
Preliminary numerical characterisation

University of Queensland Gas Dynamics Toolkit (GDTk):

Condition design in PITOT3 (0-d solver)

Recent work: L1d4 (1-d solver)

	He	Air	He			
Properties	**p_4, MPa**	**p_1, kPa**	**p_5, Pa**	**$H_{t,\,cxt}$, MJ/kg**	**U_e, km/s**	**ρ_{7e}, kg/m^3**
Condition A	0.5	0.5	3	11.0	4.682	0.0081
Condition B	1	1	5	11.2	4.733	0.0144
Condition C	8	5	63	11.2	4.727	0.1198



PITOT3 conditions [2]

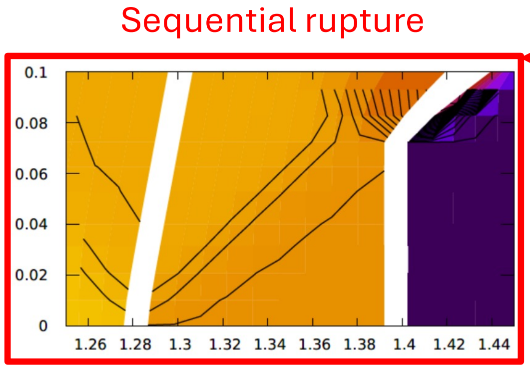
L1d results

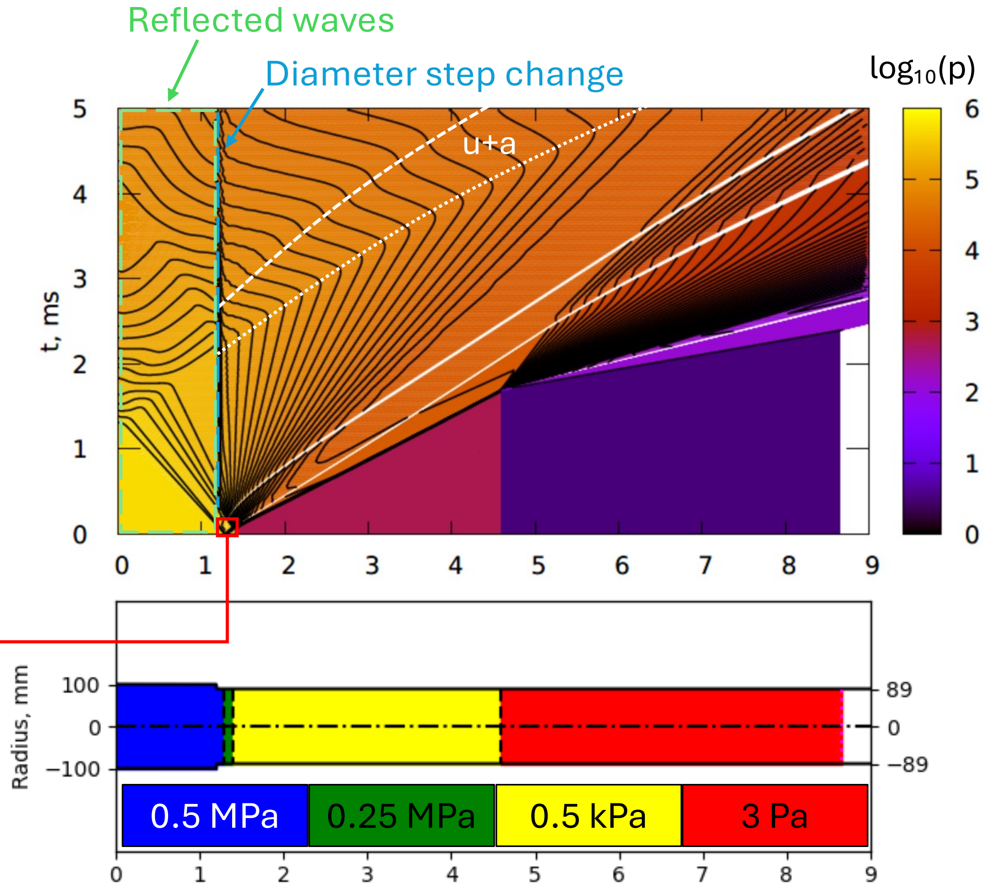
Midsection: He at $\frac{1}{2}p_4$= 0.25 MPa

Rupture pressures:

- PD1: 0 (instant rupture)
- PD2: 101% of 0.25 MPa

  = 0.2525 MPa
- SD: 1.0 kPa





L1d4: example xt diagram (top), with geometry used (bottom)

Shock speed = 180 mm/(31 μs) = **5.8 km/s**

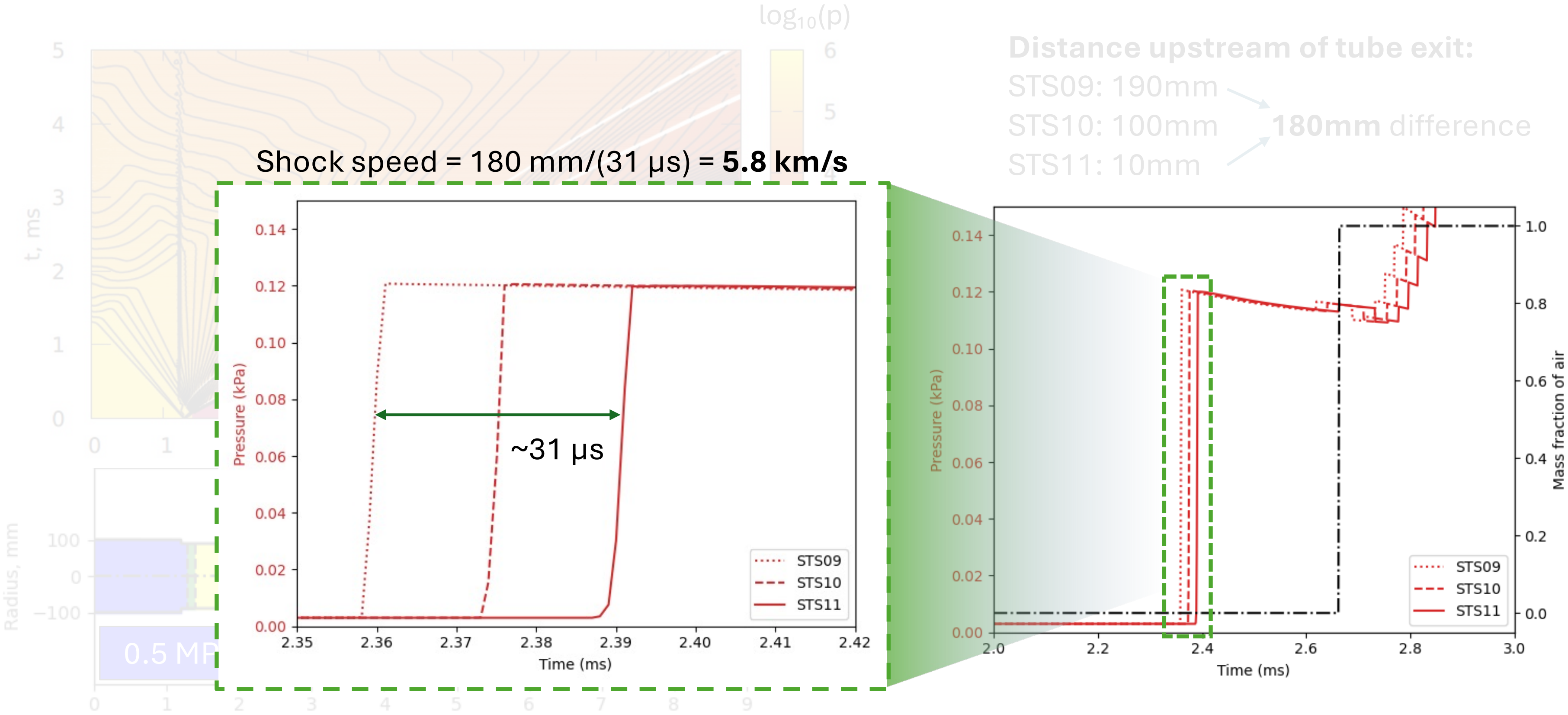
Distance upstream of tube exit:

STS09: 190mm

STS10: 100mm

STS11: 10mm

180mm difference



L1d4: example xt diagram (top), with geometry used (bottom)

L1d4: pressure traces in adaptor section

Rake campaign plans

Vacuum leak tests ongoing

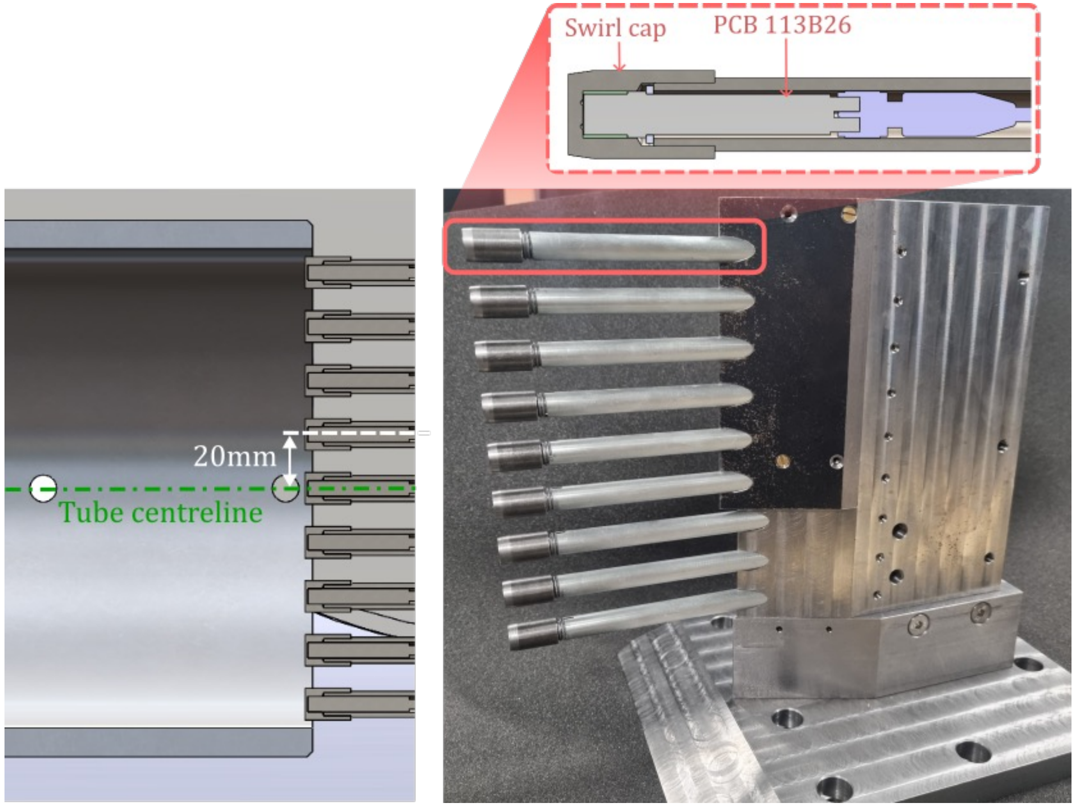
Pitot rake:

- P_{07} (radial): linear array of PCB113B
- 9 probes total
- 20mm spatial resolution

→ **89% coverage.**

Can infer flow properties (M_7, u_7, ρ_7 etc).

Estimation of core flow region



CXT Pitot rake model

Concluding remarks

Conclusion

New expansion tube facility at the Oxford Thermofluids Institute:

- Ablatives testing in hypervelocity flows
- Standalone/hybrid-mode operation
- Facility build nearing completion

Preliminary numerical work: shock speeds up to ~6.5 km/s

Next steps

- Completion of pipework: **Q4 2024 ?**
- Vacuum leak testing: **ongoing**
- Rake campaign
- Further numerical work

Hot model studies:

- Achievable wall temperatures with OPG?
- Temperature drop during model movement?

Surface temperature at shock arrival?

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[4] Abul-Huda, Y. M., Gamba, M. (2017). *Flow Characterization of a Hypersonic Expansion Tube Facility for Supersonic Combustion Studies*. Journal of Propulsion and Power 2017, 33:6, 1504-1519.

[5] Heltsley, W., et al. (2006). *Design and Characterization of the Stanford 6 Inch Expansion Tube*. In: 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 2006.

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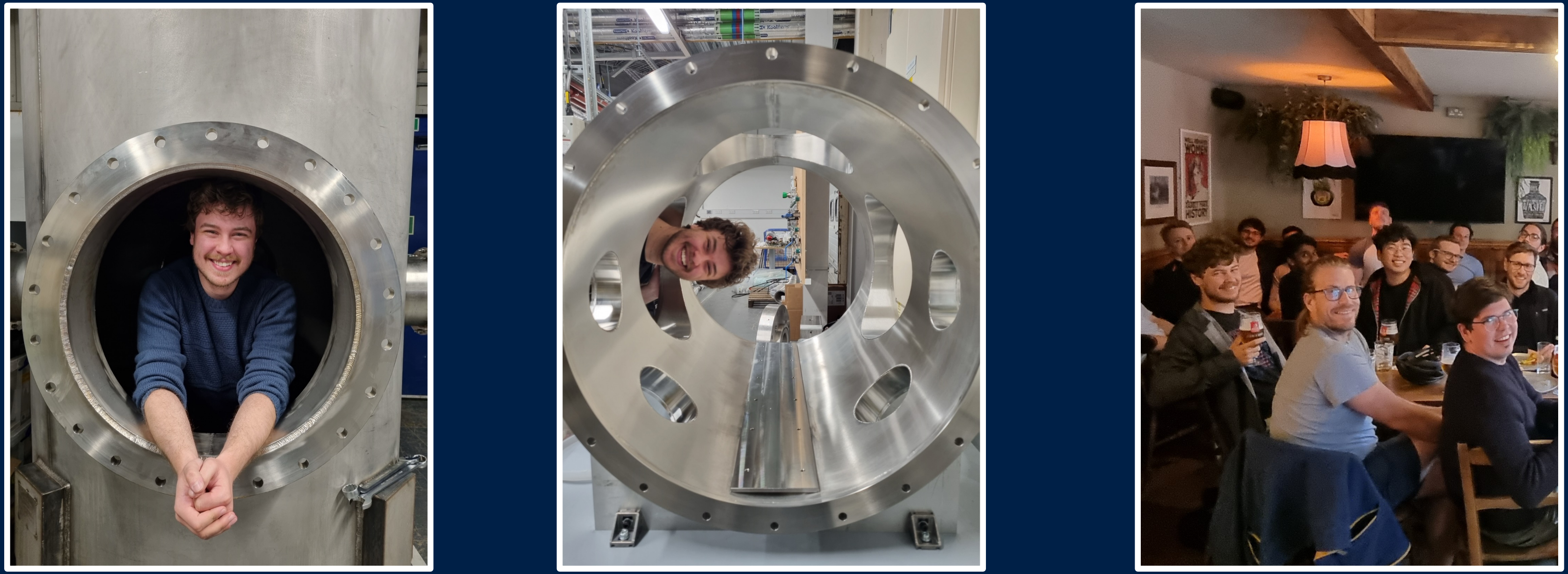
Thank you for listening!



Author in a dump tank (left), test section (centre) and pub (right)