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Sustained Hypersonic Flight – It's harder than Rocket Science

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Sustained Hypersonic Flight: It's harder than Rocket Science!

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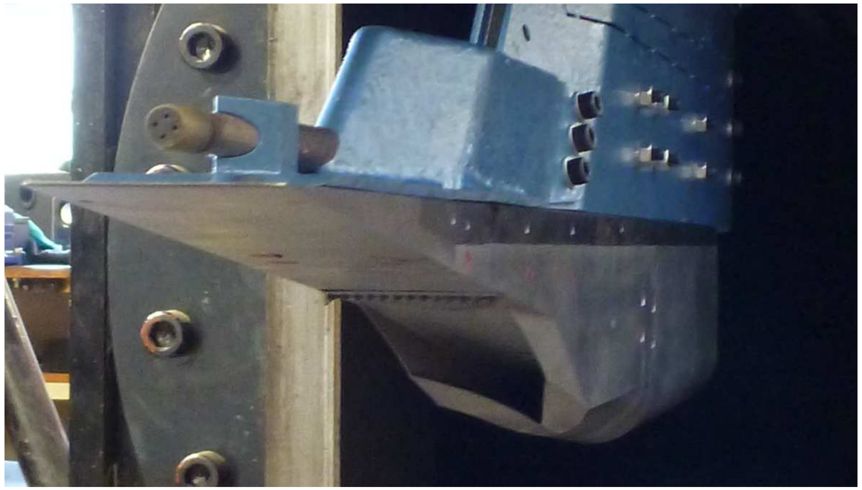
Summary

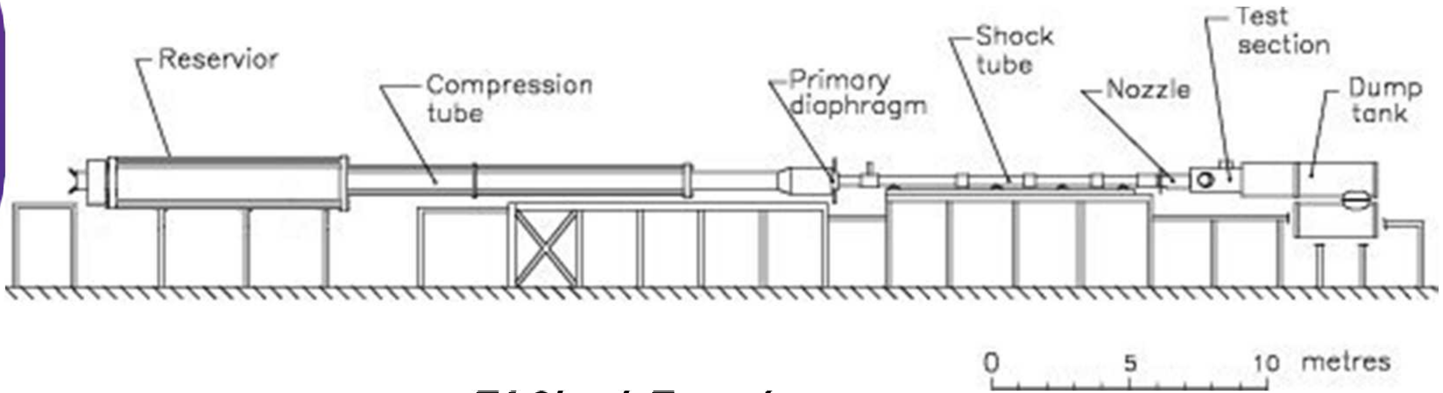
- UQ Centre for Hypersonics
- Sustained hypersonic flight: Scramjets
- HIFiRE: Australia's hypersonic flight program
- Key Challenges for sustained hypersonic flight
- Hypersonic Environment
- Materials solutions – DMTC
- New Structural Thermal Test Facility: HGG
- Future Challenges



Airframe-Integrated scramjet ground test model

UQ Centre for Hypersonics

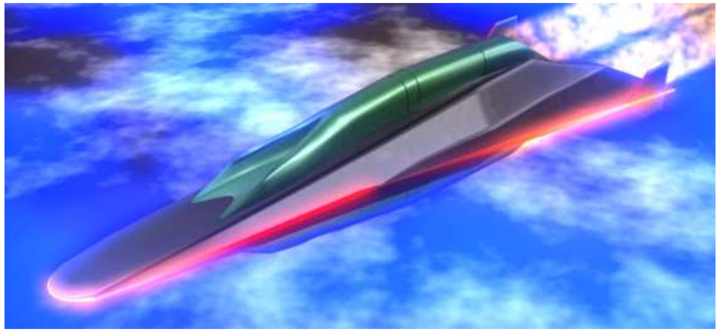
- **Diverse group of 30 academics, researchers and students performing hypersonics research**
- **The T4 shock tunnel and expansion tubes**
- **Track record of taking ground tests to flight (HyShot: 1998-2005; HIFiRE:2007-2017)**



T4 Shock Tunnel

Sustained Hypersonic Flight: Rockets versus Scramjets

- Scramjets (Supersonic Combustion Ramjets) can have higher specific impulse (fuel efficiency) than rockets, as they do not have to carry and pump oxidiser.
- Rockets have higher thrust-to-weight.
- Scramjets must fly within the atmosphere to have large thrust-to-frontal area.
- Hypersonic flight within the atmosphere induces high heat loads and drag; but also allows manoeuvring through the use of aerodynamic lift.



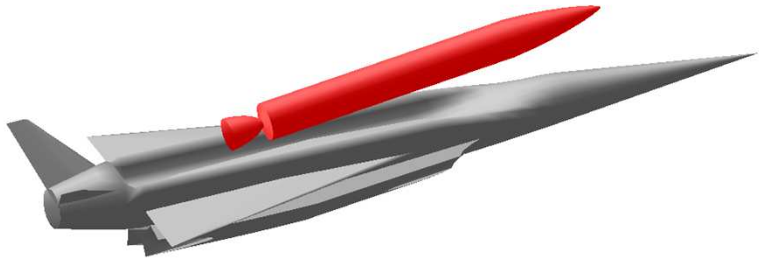
→ *Scramjets have particular advantages over rockets for sustained hypersonic flight in the atmosphere*

Scramjet Applications

There are two key applications for scramjets:

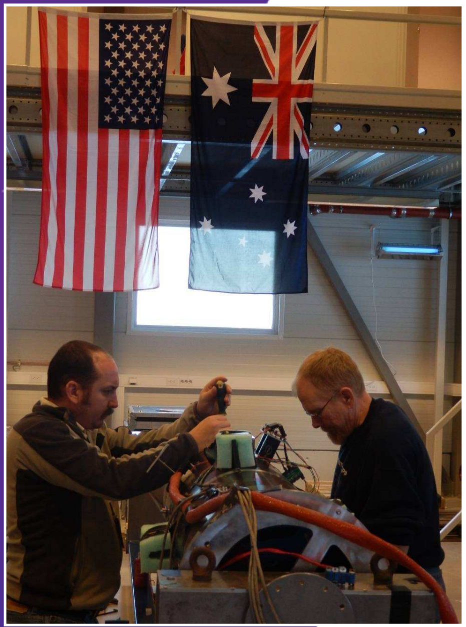
1. **Hypersonic Cruise**
    - **Flight speeds of Mach 4-8**
    - **Long range aircraft (Sydney to London in 2-3 hrs)**
    - **Military**
    - **Motivation for the *HIFiRE Program***

2. **Reusable access-to-space**
    - **Multi-stage rocket-scramjet-rocket systems**
    - **Scramjet operation from Mach 6-10**
    - **Possibility of reusable satellite launch systems**



HIFiRE Program

"The main goal of the HIFiRE Program is to develop the science and technology for hypersonic flight with air-breathing propulsion"



Organisational Structure:

- **Joint Australian/USA program administered by DSTO and US Air Force**
- **UQ and Boeing Phantom works are core partners**
- **Recently extended to 2017**

Methodology:

- **Low cost, sounding rocket based launches**
- **9 flights (first flight was in March 2009 – HIFiRE 0)**
- **Combination of fundamental hypersonic flow experiments and scramjet flights**
- ***Culminating in a sustained/powered flight (30 second engine operation) of an autonomous vehicle: HIFiRE 8***

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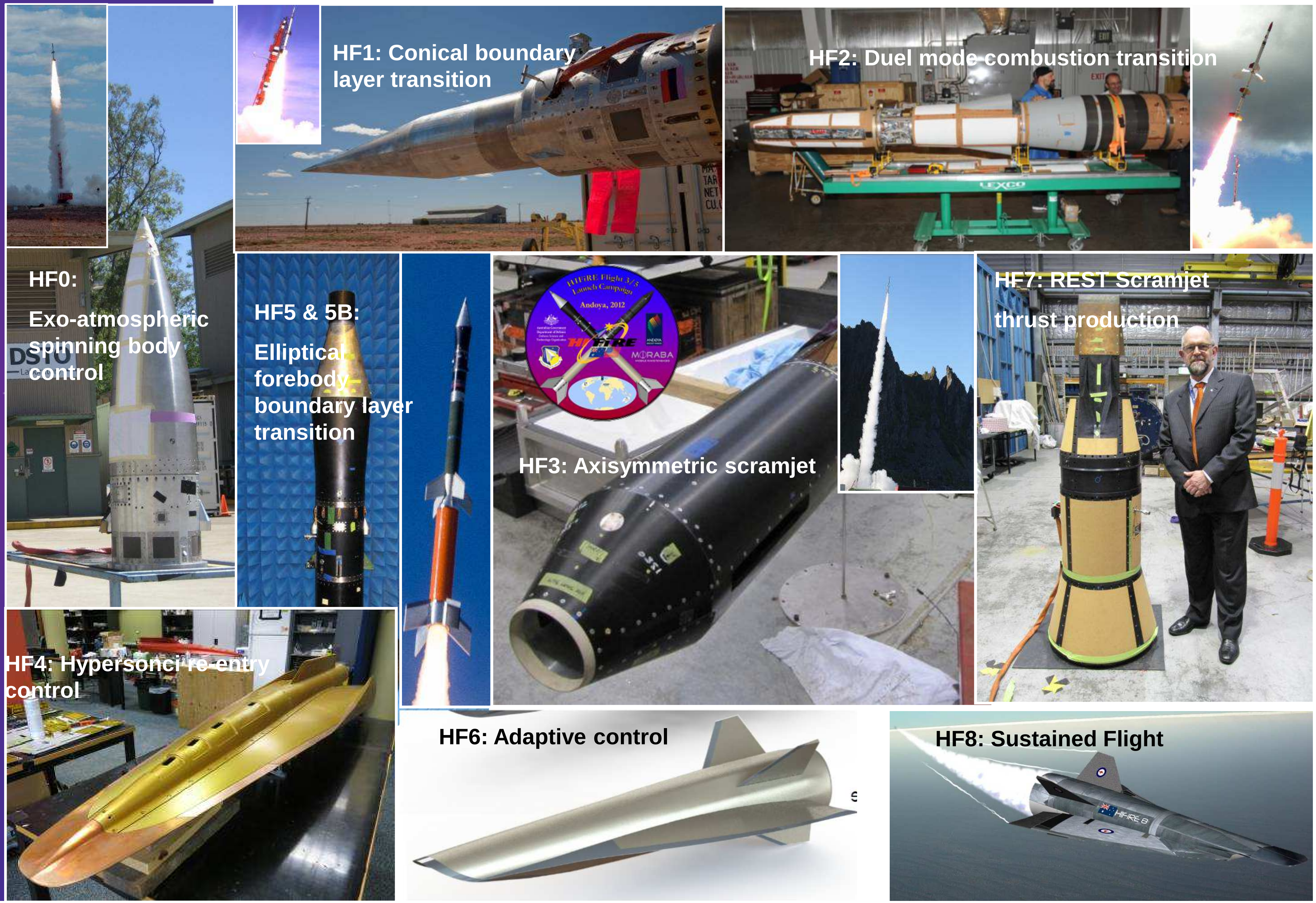
The HIFiRE FLEET



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HIFiRE MANIFEST

Flight	Description	Launch Date
HIFiRE 0	**Software Development (DSTO)**	**March 2009 (successful)**
HIFiRE 1	**Hypersonic Cone (USAF)**	**March 2010 (successful)**
HIFiRE 2	**Scramjet Combustor (USAF)**	**April 2012 (successful)**
HIFiRE 3	**Axisymmetric Scramjet (DSTO)**	**September 2012 (successful)**
HIFiRE 4	**Hypersonic Glider (DSTO-UQ-Boeing)**	**December 2015**
HIFiRE 5	**Hypersonic Elliptical Cone (USAF)**	**April 2012 (2^{nd} stage rocket failure)**
HIFiRE 5B	**Repeat of HIFiRE 5 (USAF)**	**July 2015**
HIFiRE 6	**Adaptive Control (USAF)**	**2016**
HIFiRE 7	**Free flying 3-D Scramjet (DSTO-UQ-Boeing)**	**March 2015**
HIFiRE 8	**Sustained 3-D Scramjet (DSTO-UQ-Boeing)**	**2017**

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2015 Flights: HIFiRE 4 and 7

HIFiRE 4 – Hypersonic Glider

HIFiRE 7 – Free-flying 3-D Scramjet

Key Challenges for Sustained Hypersonic Flight

(1) Aerodynamics and propulsion:

- **High flowpath efficiency needed for positive thrust (3-D engines show significant promise).**
- **Synergistic vehicle-engine integration (net thrust).**
- **Engine operation over a large Mach range.**

HIFiRE 8

Key Challenges for Sustained Hypersonic Flight

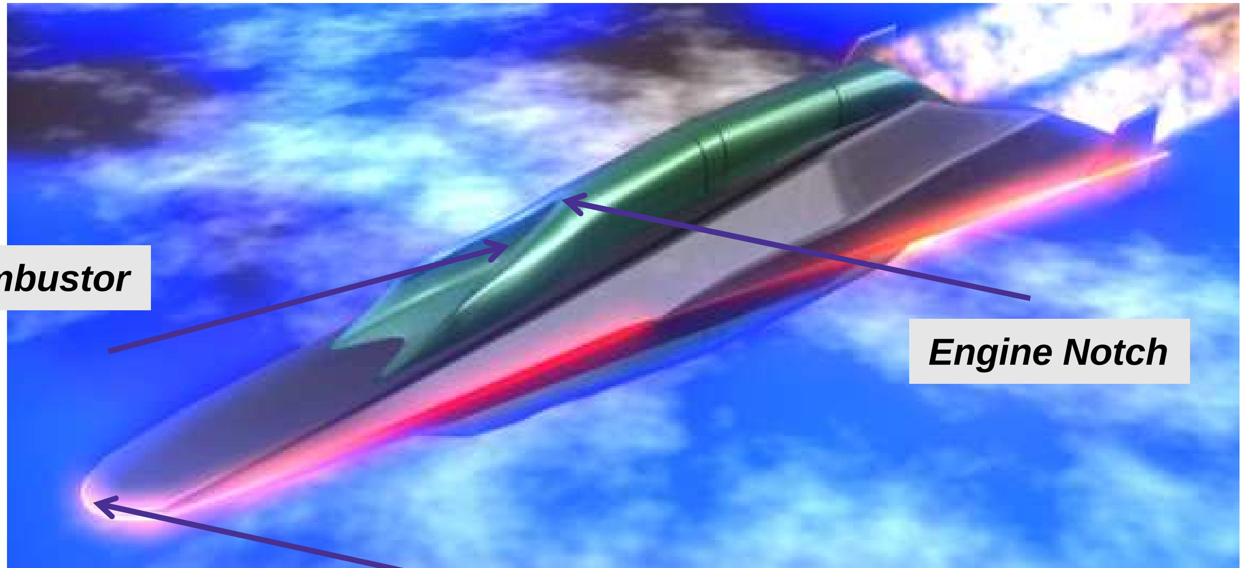
(2) Materials technology:

- **Heating, heating, heating!**
  - **Heating rates increase at the "cube" of Mach number.**
  - **Maximum temperatures depend on many factors.**
- **Weight, weight, weight!**
  - **High weight requires high lift which creates high drag which necessitates high thrust. High thrust needs more fuel which has greater weight!**

(3) Structural/thermal design:

- **Engineering required to deal with differential thermal expansion between hot and cold components.**

Hypersonic Materials Challenge

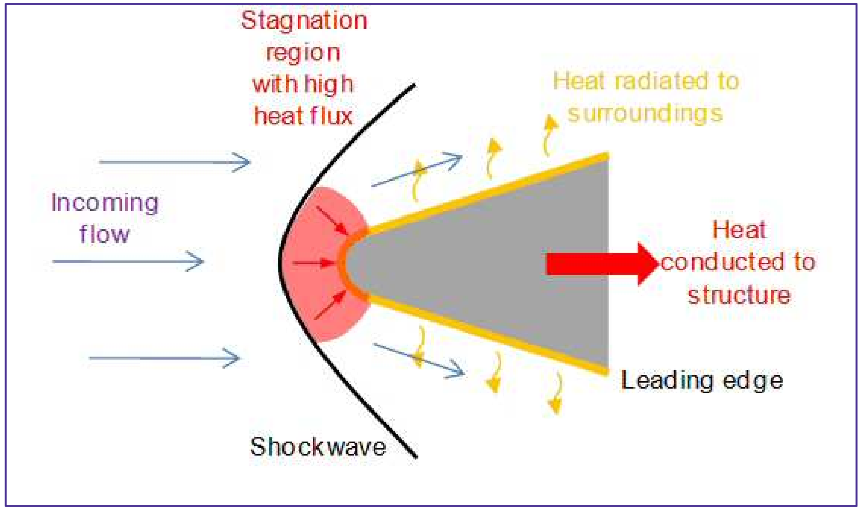


Key Components:

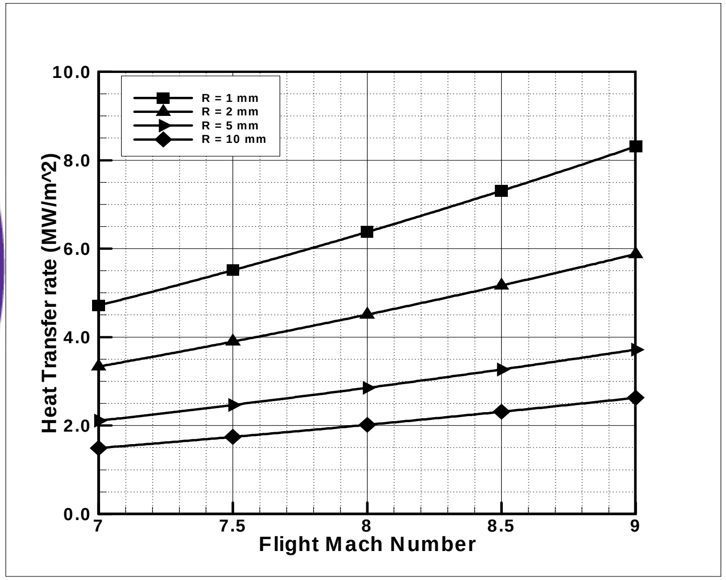
- **Vehicle/wing/fin leading edges**
- **Engine closure notch**
- **Scramjet combustor (internal flowpath)**

Leading Edge Environment

- Bow shock forms ahead of leading edge
- High convective heating from airflow
- Maximum temperature depends on radiation and internal cooling



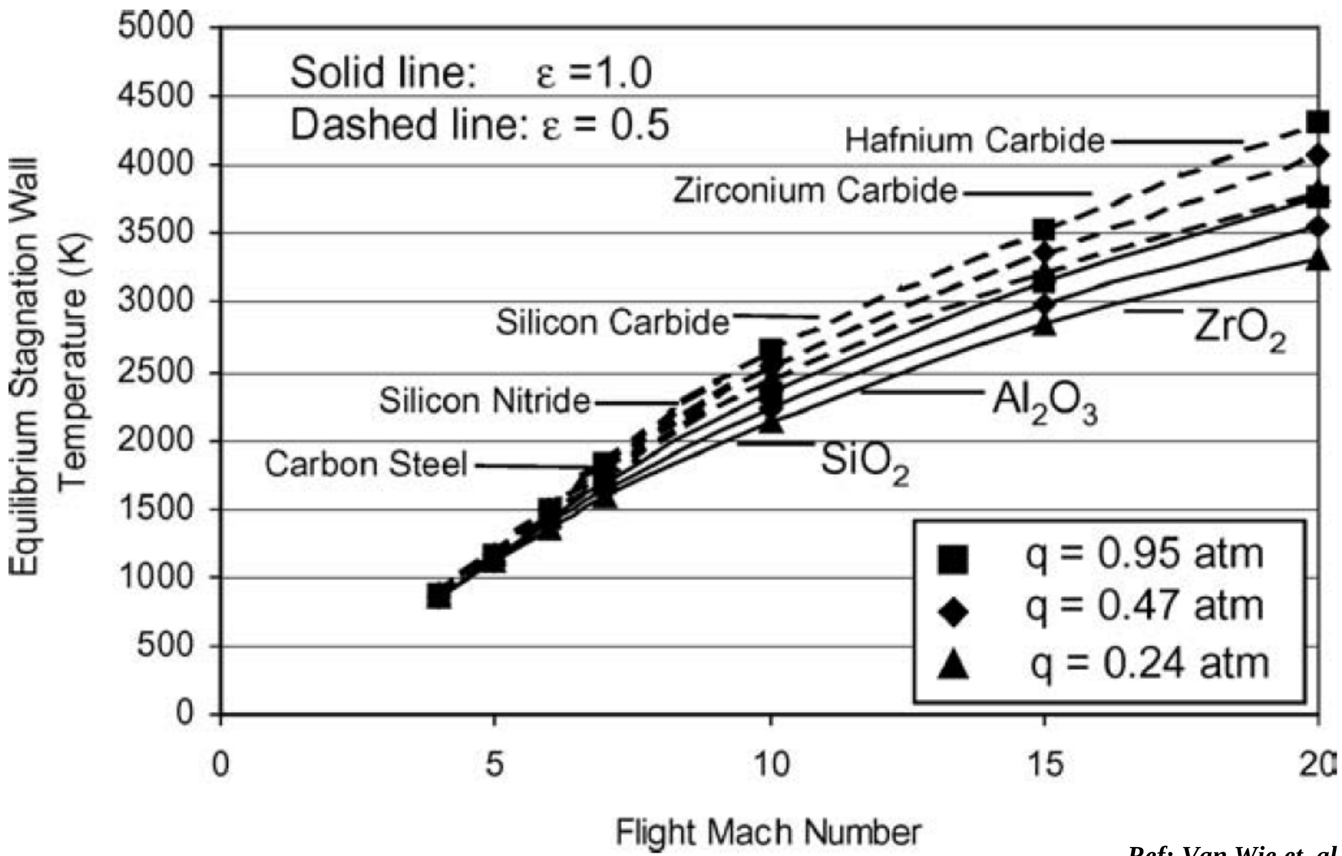
Ref: Tallon et. al., 2011



Heating rates increase with:

- Increasing Mach number
- Decreasing leading edge radius

Leading Edge Environment

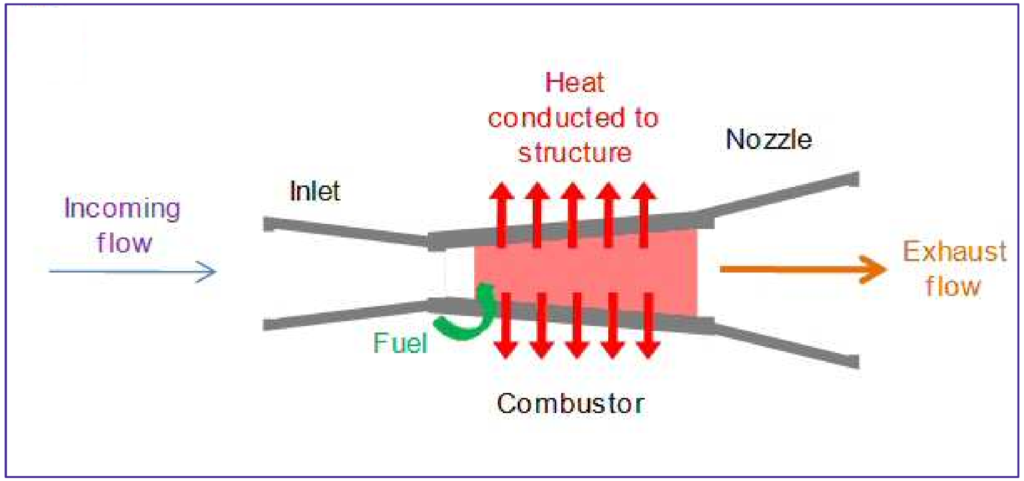


Ref: Van Wie et. al., 2004

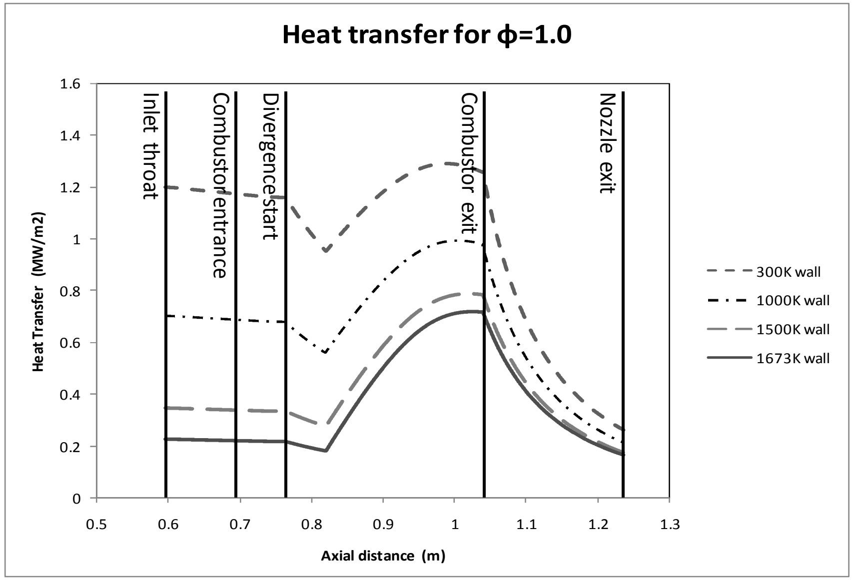
ε: surface emissivity

q: flight dynamic pressure

Combustor Environment



Ref: Tallon et. al., 2011



- **Convective heating from hypersonic flow through engine**
- **Heat transfer depends on rate of combustion and engine area distribution**
- **Hot wall decreases heat transfer rate and drag: "hot structures desirable"**

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Defence Materials Technology Centre

BAE SYSTEMS

Australian Government
Department of Defence
Defence Science and Technology Organisation

Australian Government
ansto

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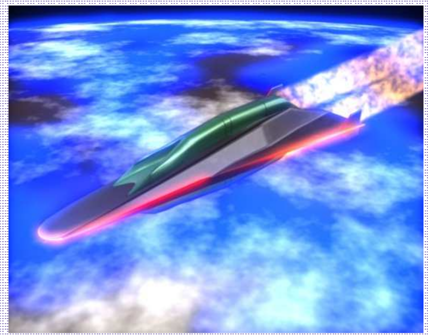

HIFiRE

ESSM

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Project 4.2: High Temperature Materials for Hypersonic Flight

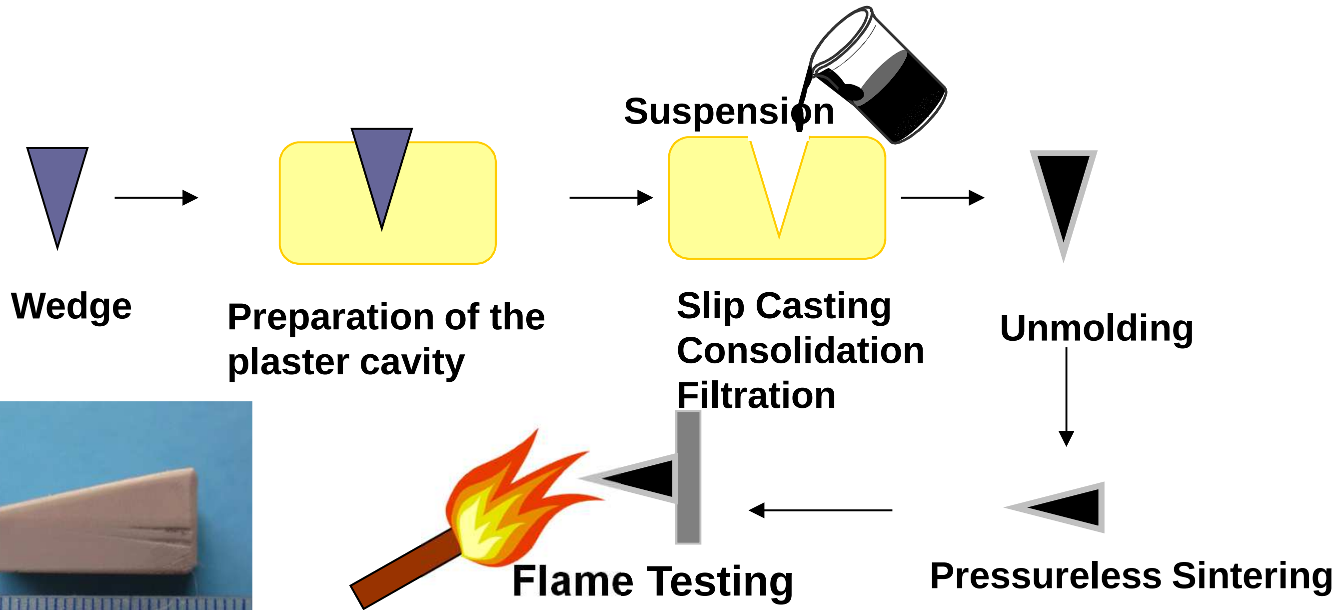
Hypersonic Leading Edge Solutions

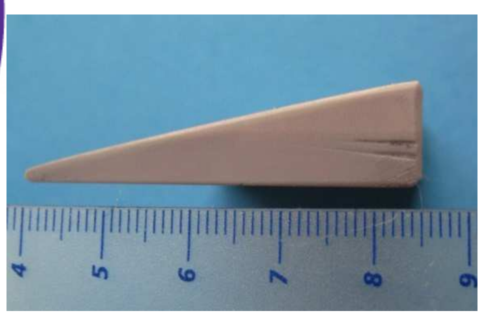
HIFiRE 8 Requirement:

- 60 second life at Mach 8

Materials solutions:

- Single and multi-phase Carbides and Diborides manufactured using colloidal processing





Near net shape

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Hypersonic Leading Edge Solutions

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Space Access Requirement:

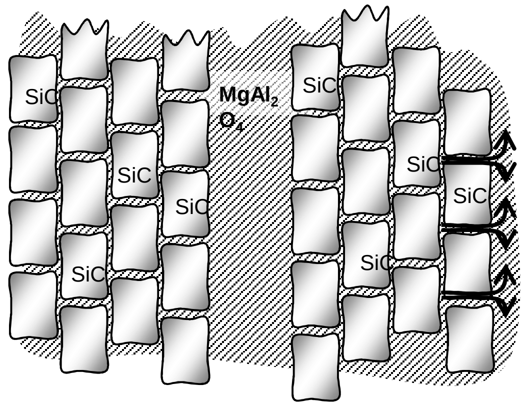
- **Single use to Mach 10 for 10 minutes**

Materials solutions:

- **Replenishable two-phase ablatives**

Replenishable Two-phase Ablatives:

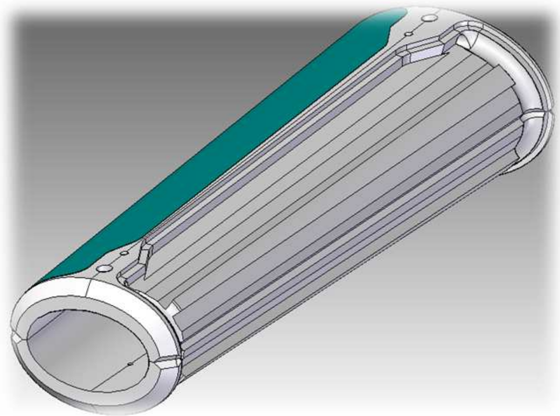
- **Leading edge cooled by ablation of lower temperature second phase**
- **Very high cooling performance**
- **Maintains leading edge shape**
- **Reservoirs of low temperature phase placed close to the surface to extend life**



Combustor Solutions for Sustained Hypersonic flight

Rationale:

- **"Hot Structures" required: 1600 ~ 2000º C.**
- **Possible candidates: Refractory metals, Ultra High Temperature Ceramics (UHTC) and Carbon Matrix Composites (CMC).**
- **Accurate material properties needed for structural/thermal analysis in the hypersonic environment.**
- **Fabrication/processing must be considered as part of the design from the outset.**
- **Ground qualification of full scale combustors is essential before flight.**



Liquid Cooled Inconel Combustor

Scramjet Combustor Solutions

Ceramic Matric Composite Tubes with variable shape

- **Research conducted at DSTO Melbourne**
- **Processing methods adapted from low temperature CFRP**
- **Extension to C/C over last 4 years**
- **Components suitable for short (< 1minute) flights planned for HIFiRE**
- **Oxidation remains problem for longer flights**

Full Scale Combustor Testing

DMTC/DSTO/UQ Hot Gas Generator

- Ground testing of combustor solutions required before transition to flight
- Vitiated heating added to existing electrically heated DSTO Combustion Test Facility (CTF)
- Can simulate thermal conditions of a scramjet combustor during flight at Mach 8.
- First test May 2015
- Constructed under DMTC; operated by DSTO/UQ

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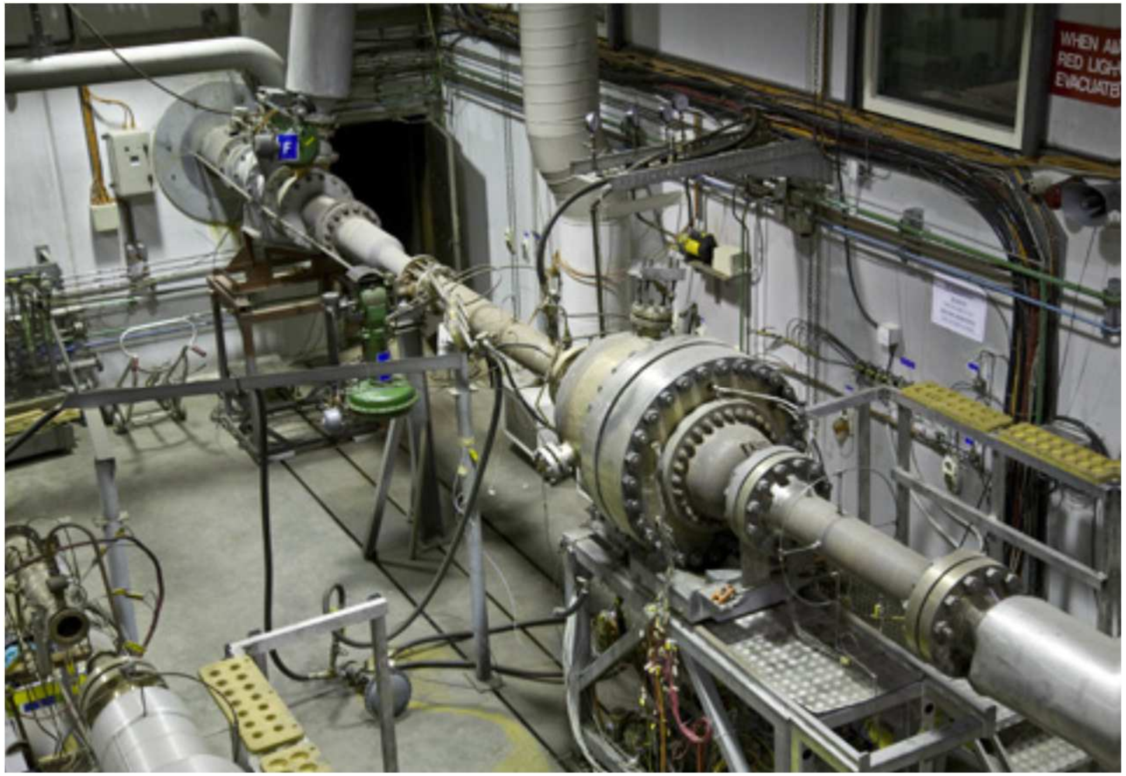
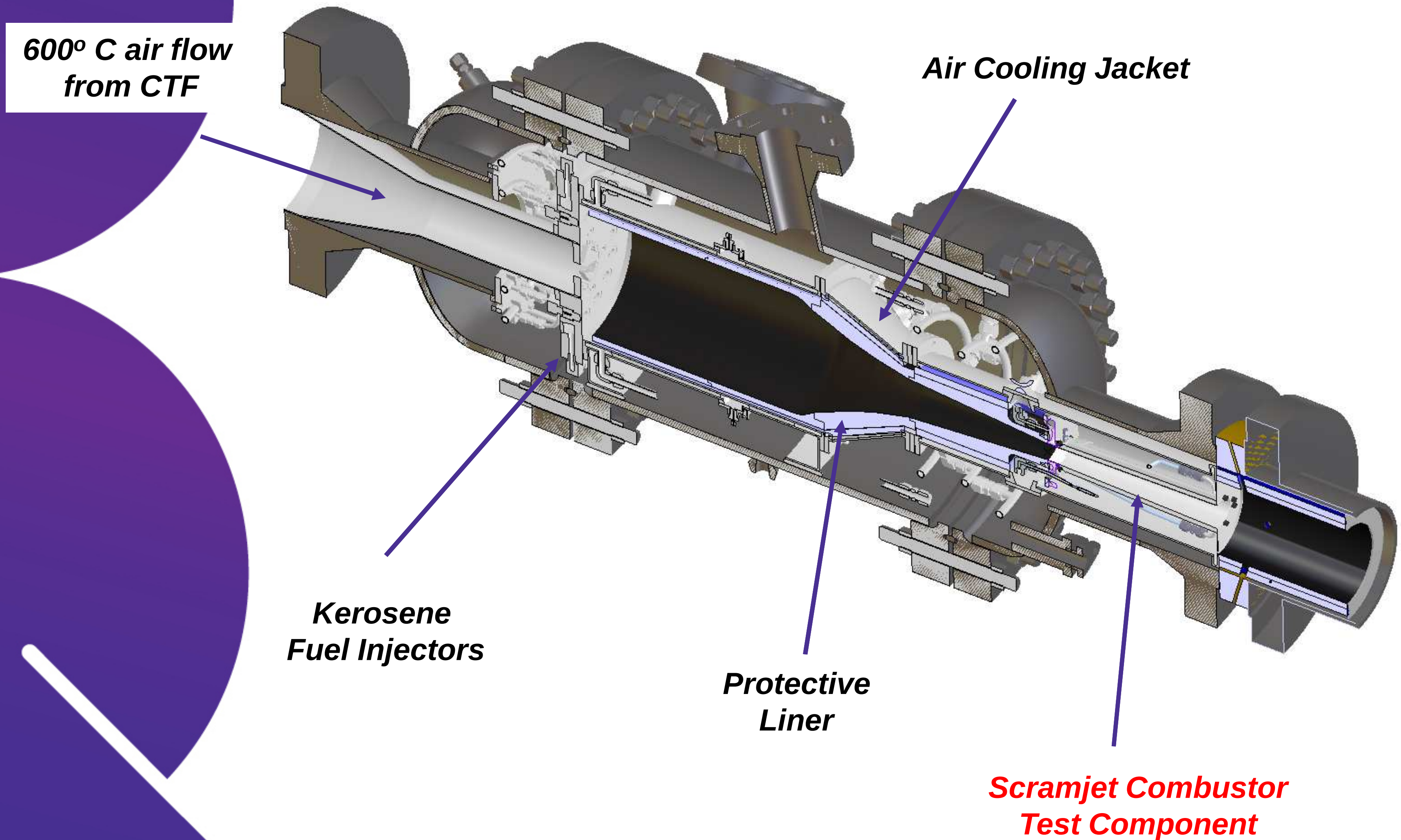
DSTO Combustion Test Facility (CTF)

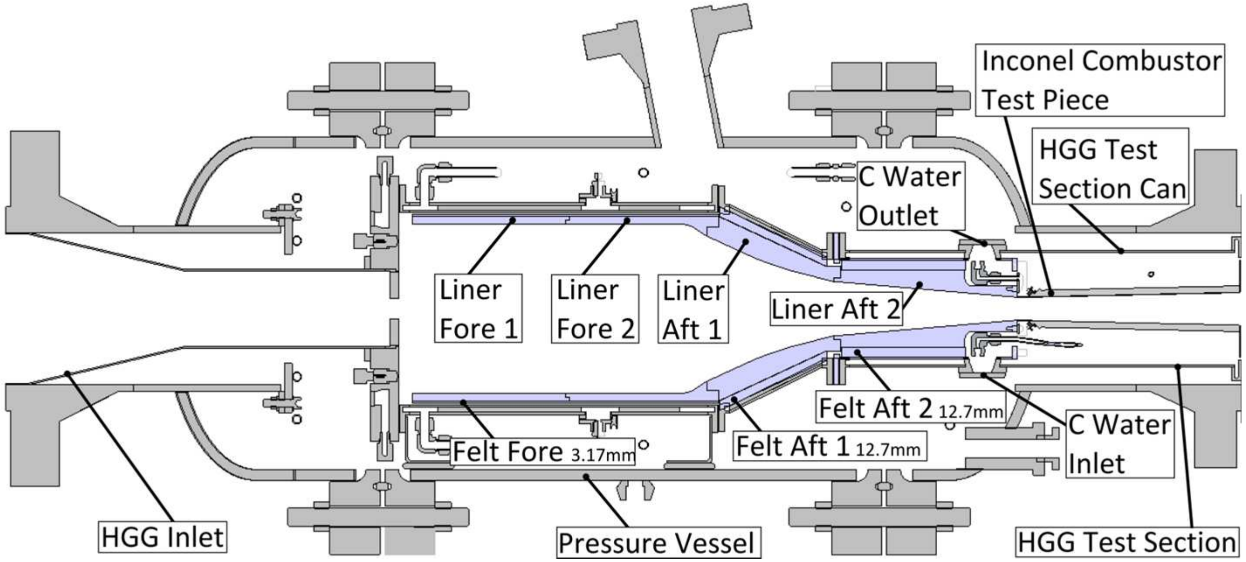


- **Significant defence infrastructure**
- **Built for gas turbine combustor testing**
- **Generates high pressure air flow up to 600°C**
- **Flow rate 1-7 kg/s**
- **Clean inflow to the HGG**

Hot Gas Generator

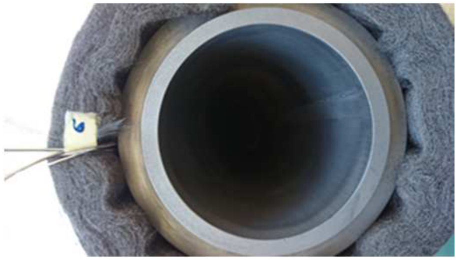


HGG Protective Liner



Two part liner:

- **Solid graphite machined to shape (used to shape inflow to test hardware)**
- **Outer layer of graphite felt for insulation**



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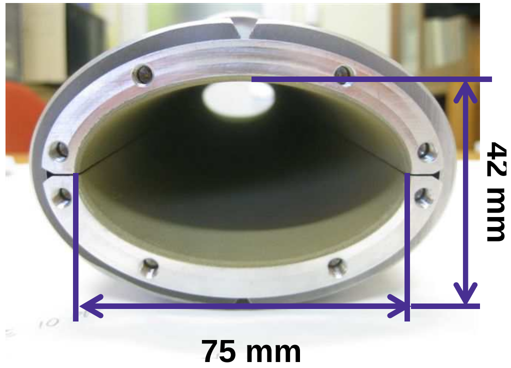
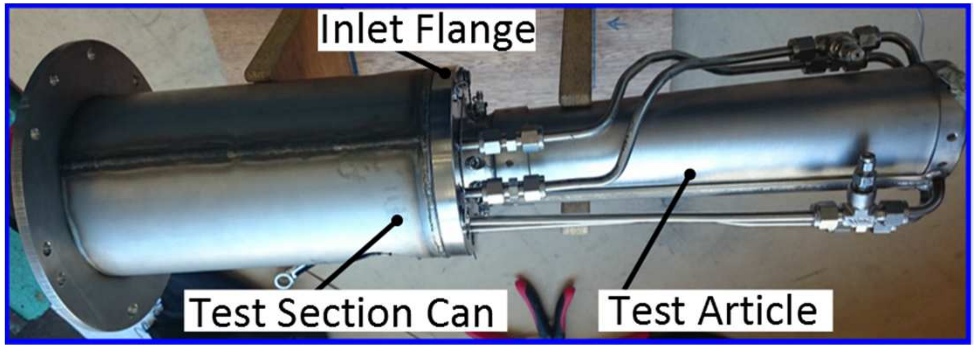
HGG Commissioning: Water cooled Inconel combustor

- Liquid cooled Inconel combustors are the current state-of-the-art
- DMTC designed and manufactured test component to be used for HGG commissioning
- Welded Inconel construction
- Plasma sprayed Zirconia internal surface
- Water cooled
- L = 275 mm; approximately 1/3 full flight scale





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A call to Materials Researchers

- **Sustained hypersonic flight requires high temperature materials for its progress.**
- **The ability to construct “real” components is far more important than maximizing materials properties.**
- **We want your contribution!**