THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

FROM HIGH-TEMPERATURE MATERIALS TO HIGH-RATE PRODUCTION

A./Prof. Michael Heitzmann

Who is UQ?

4
campuses

5
faculties

40+
teaching and research sites

8
research institutes

60,000+
total students

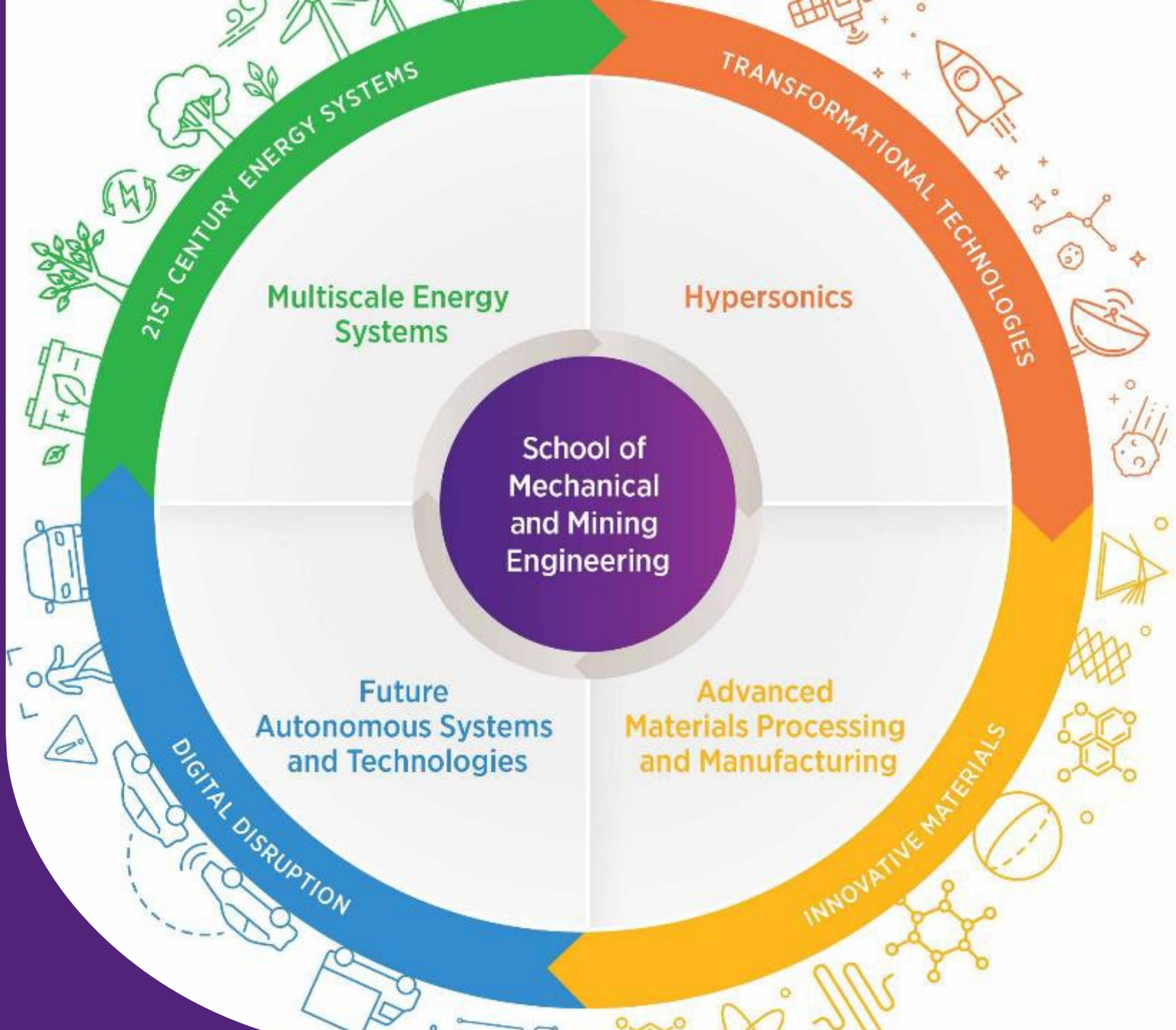
8,680
staff



School of Mechanical and Mining Engineering

The School of Mechanical and Mining Engineering advances research and innovation from discovery to impact by tackling big-picture challenges in:

- ✓ Sustainable materials and manufacturing (AMPAM)
- ✓ Hypersonics (CfH)
- ✓ Future energy systems (CMES)
- ✓ Trusted autonomy (FAST)



Centre for Advanced Materials Processing and Manufacturing (AMPAM)



Materials and manufacturing for a more sustainable world



Digital fabrication and design



Materials and processes for extreme environments

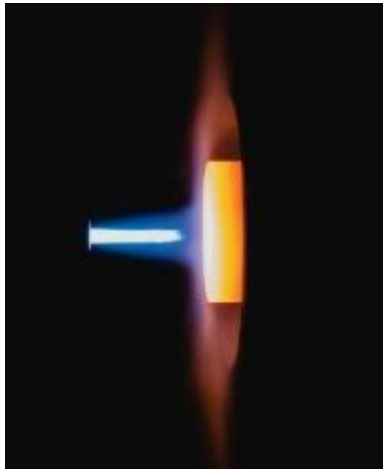




- Focal point for applied materials and manufacturing at UQ
- ~ 60 researchers, ~100+ PhD students
- ~ 30-40 active industry collaborations

Unique high temperature materials capability

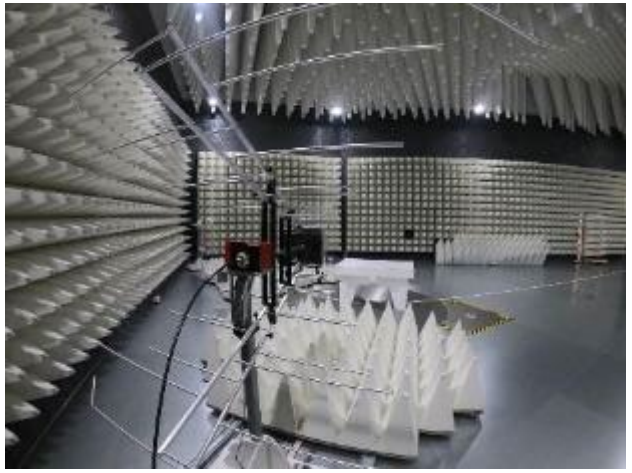
Characterisation



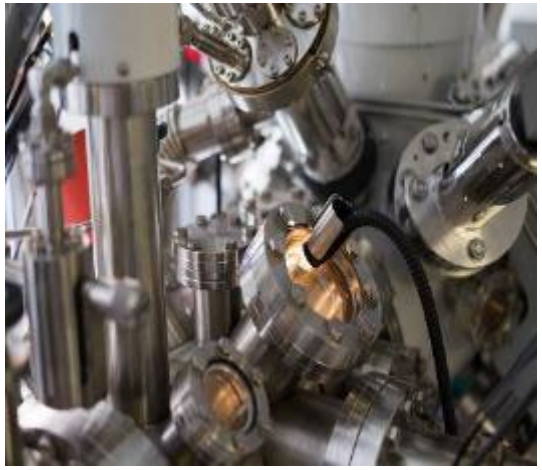
Instrumented & automated Oxy-acetylene testing



High temperature materials characterisation lab (thermal conductivity, phase change, expansion, dynamic properties)



Anechoic chamber



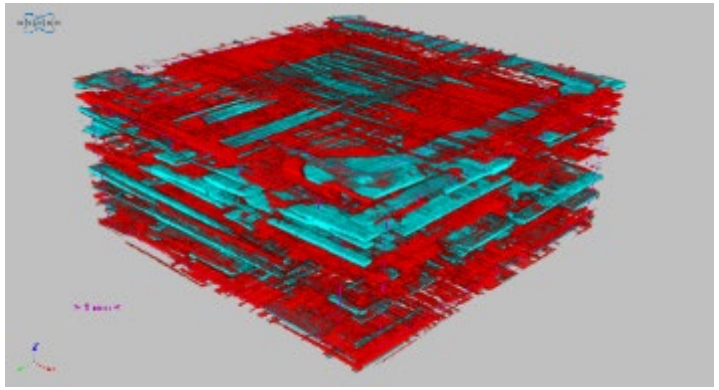
Microscopy and micro-analysis, including SAX, WAX XRD, XRF, SEM, TEM, EDS



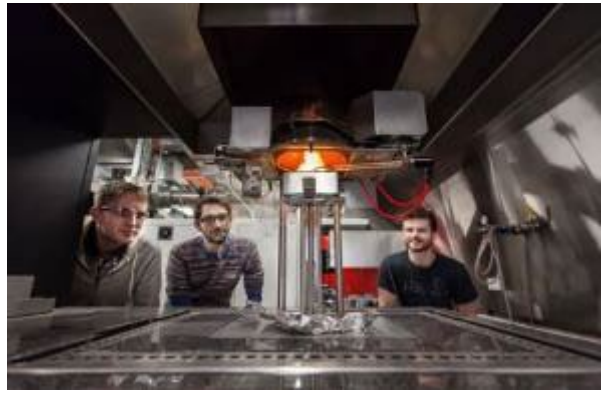
Mechanical testing up to 1MN



3-axial and 2-axial plus impact testing



Micro-CT



Fire testing

High temperature materials capability

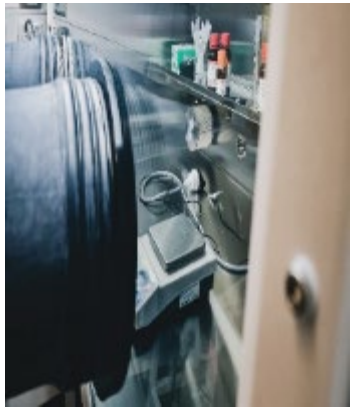
Materials processing and manufacturing



Large Arc plasma furnace 3000 °C



4-axis filament winder



Resin synthesis inert glove box and Schenk line



Kinetic metallisation system



High energy nano materials mill



Ultra-high temperature graphite and debinding furnace 3000 °C



Selective laser melting 3D printer



AML3d Arcemy System Electric Arc Welding



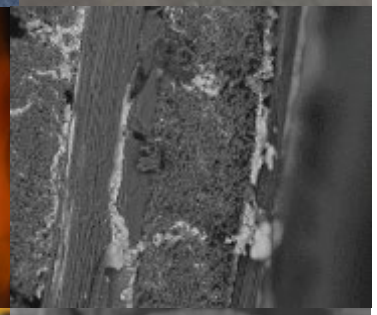
Polymer processing facility

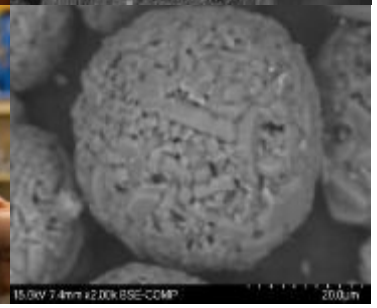
Composite Materials for Extreme Environments

The University Of Queensland
AUSTRALIA

Air

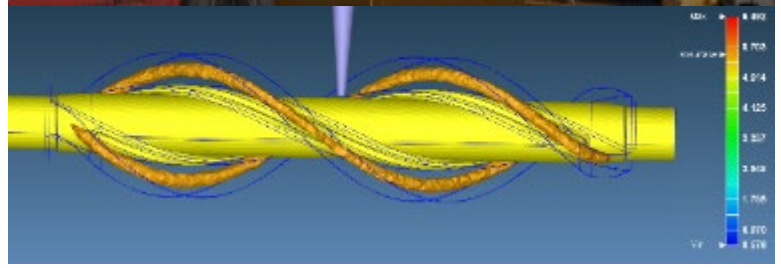


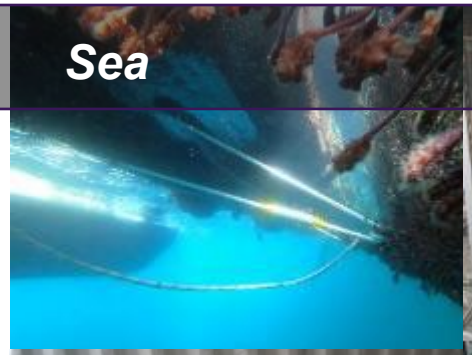


Land



Sea







THALES
HYPERSONIX
GUNDOUR SPACE
DST GROUP
LOCKHEED MARTIN
cascade
OILFIELD PIPING Systems
Santos
origin
Carnegie CLEAN ENERGY
ACS AUSTRALIA
tassal

Outline

OVERVIEW OF EXISTING RESEARCH EFFORTS AND OUTLOOK

- **Part 1: Manufacture of a CMC scramjet inlet insert**
- **Part 2: Lessons learned form a decade in CMCs**
- **Part 3: ARC Research Hub for Australian Mass Manufacturing of High Temperature Composites**

Acknowledgments:

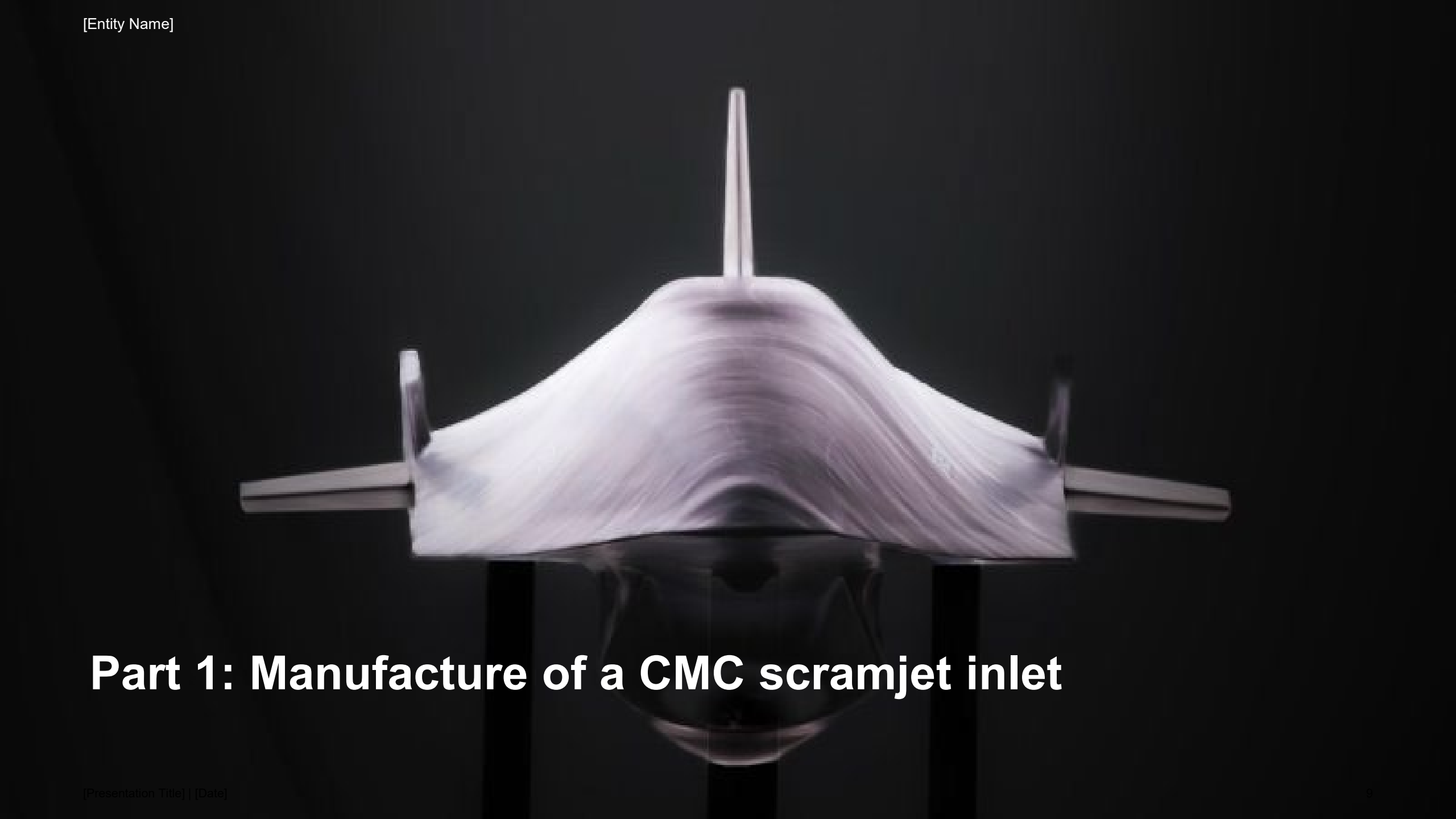
Team

- Dr. Christin Kudisonga
- Dr. Asanka Basnayake
- Dr. Andrew Murray
- Dr. harry Chrisholm
- Mr. Roan Moorwood-Portoles
- Mr. Stephen Joseph
- Mr Sam Sutcliff

Partners:

- DST
- Hypersonic Launch Systems
- Gilmour Space Technologies
- Lockheed Martin Australia



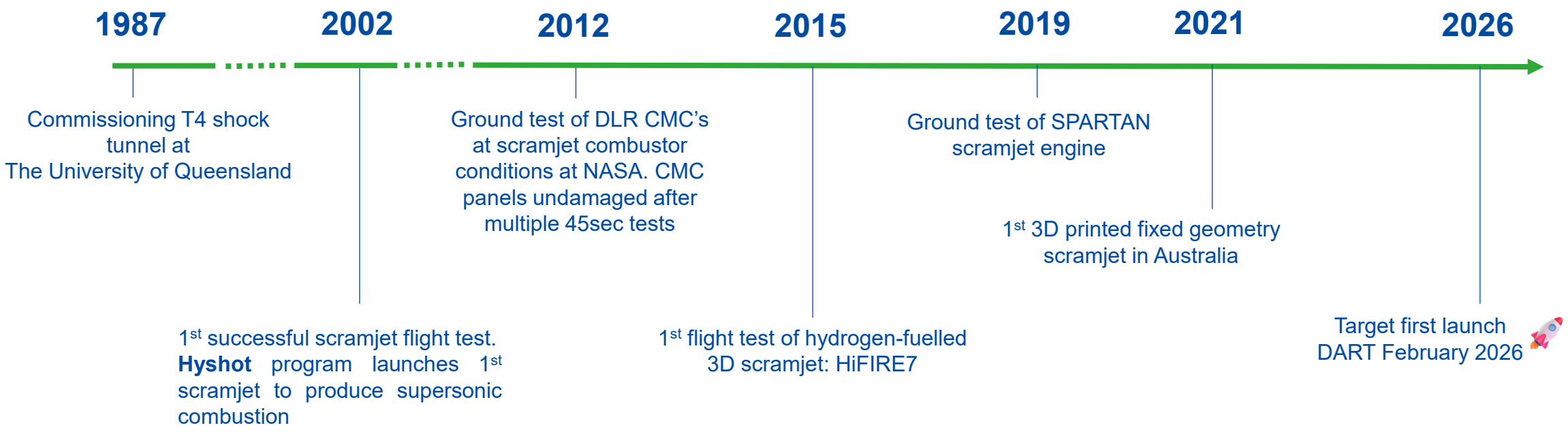


Part 1: Manufacture of a CMC scramjet inlet

HypersoniX Launch Systems

*Hypersonix Launch Systems (**HLS**)* Australia's leading aerospace engineering design and build company, specializing in hypersonic technology and scramjet engines.

Australia has a long history with Hypersonic flight:



The integration challenge

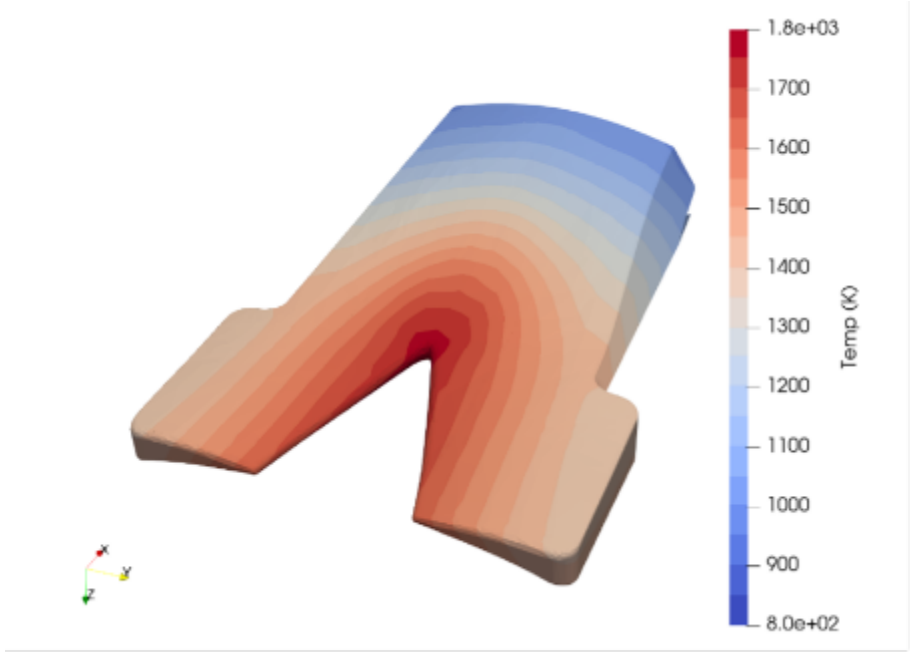
Engine inlet

- Critical for flight and engine performance
- Stagnation point resulting in high heat loads
- Heat loads exceeding the resistance of the 3D printed in high temperature alloy
- Transient problem



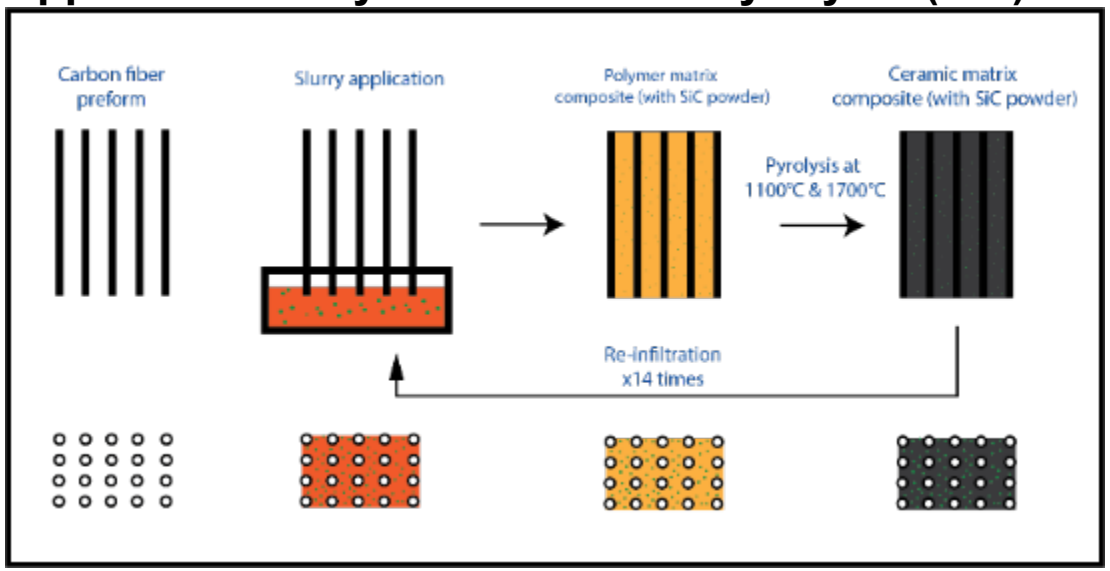
Requirements:

- Integration with rest of inlet
- High thermal resistance
- Minimal/no ablation



Material selection

Approach 1: Polymer Infiltration Pyrolysis (PIP)



- Carbon fiber: PAN-derived
- Preceramic polymer: Polycarbosilane (SiC)
- Powder: β-SiC

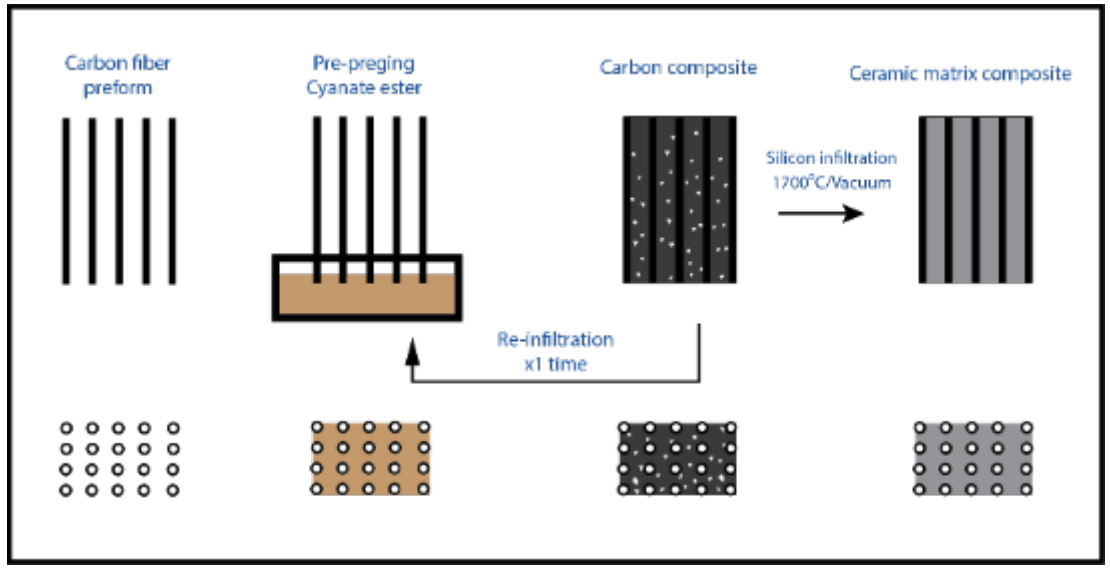
Advantages:

- Ease of green-body manufacture
- Robustness of process

Disadvantage:

- Cost of precursor
- Processing time

Approach 2: Liquid Silicon Infiltration (LSI)



- Carbon fiber: Pitch-derived
- Preceramic polymer: Cyanate Ester

Advantages:

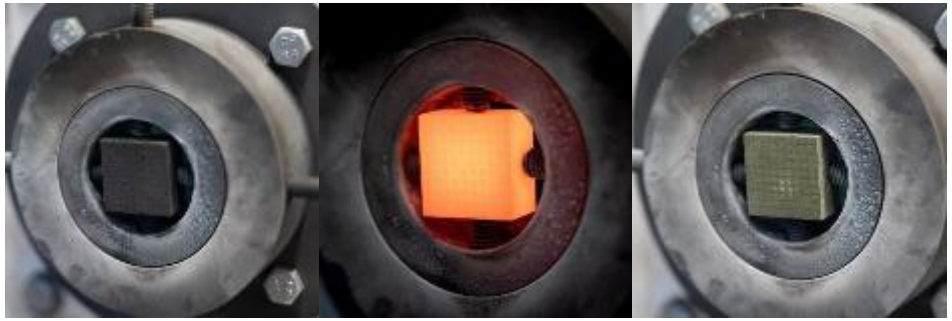
- Processing time
- Low void content

Disadvantage:

- Process control
- Risk of free silicon

Ablation performance

Approach 1: Polymer Infiltration Pyrolysis (PIP)



C/SiC	MAR (mg/s)	Mass loss (%)
Oxytorch	1.248	0.811

Test
- 5.1 MW/m^2
- 1 min
- O_2 flow: 11L
- C_2H_2 flow: 8L
- Ratio: 1.35
- Oxidizing flame

- Less than 1% mass loss
- No evidence of ‘transpiration’

Approach 2: Liquid Silicon Infiltration (LSI)

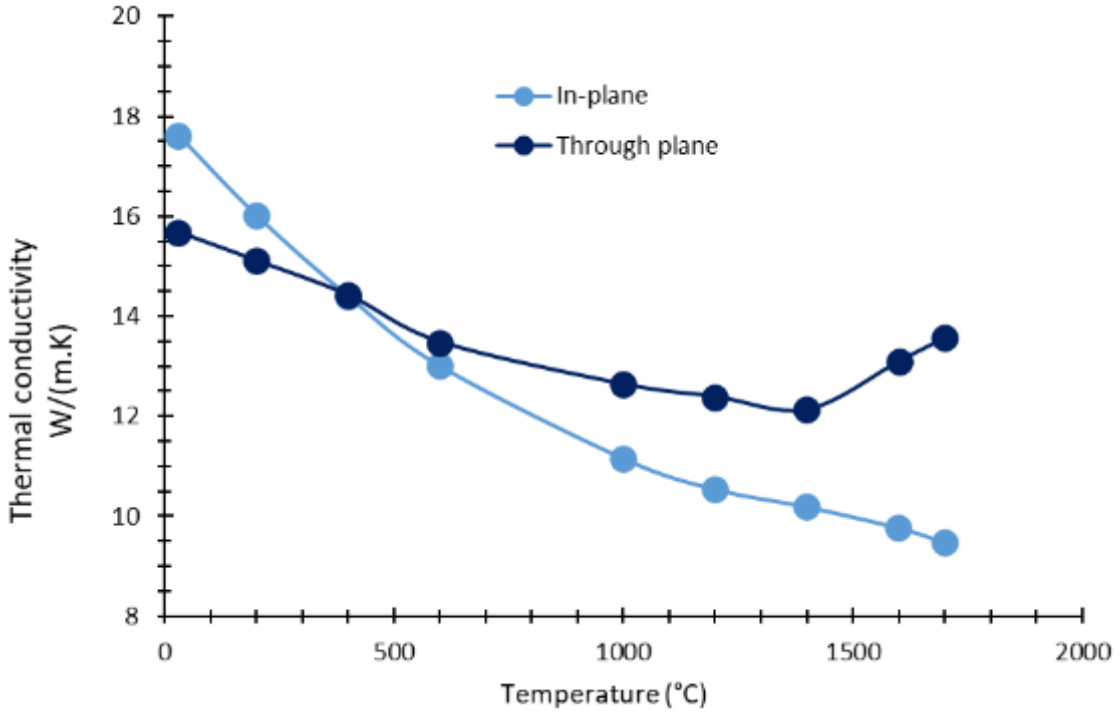


C/C-SiC	MAR (mg/s)	Mass loss (%)
Oxytorch	0.290	0.139

- Ablation rate and mass loss are significantly lower than PIP sample
  - Pitch fibres
  - Free silicon
  - Lower porosity
- Silicon/Silica transpiration

Thermal properties

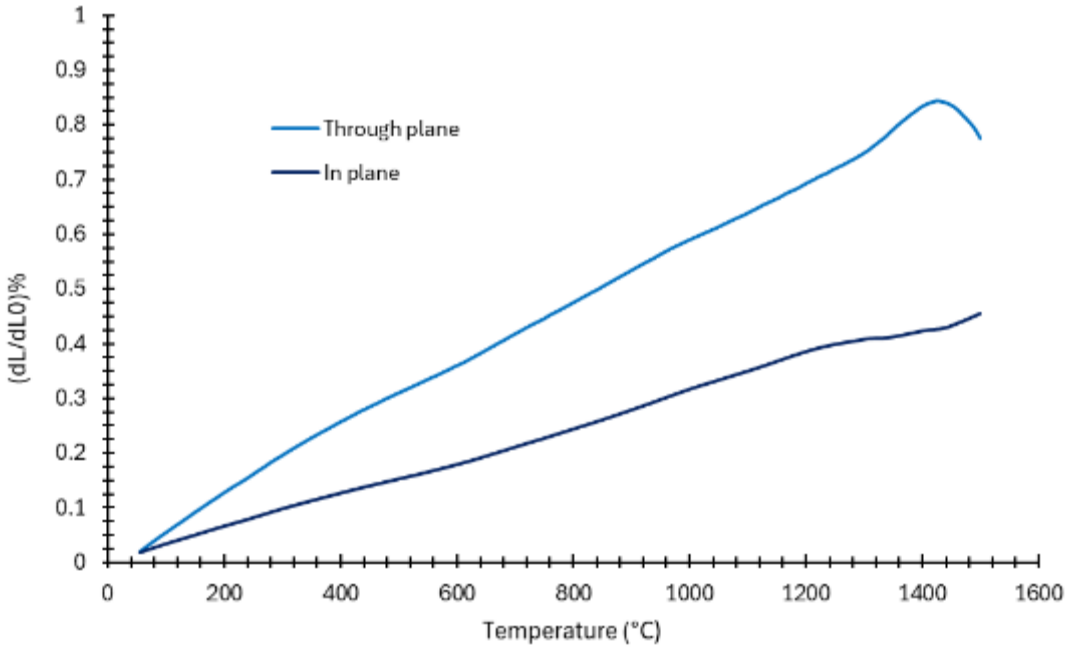
Importance of thermal properties for design and integration



Temperature	In-plane ($\sigma_{\parallel}$)	Through plane ($\sigma_{\perp}$)
29°C	17.63	15.70
1400°C	10.18	12.12
1700°C	9.50	13.56

Carbothermal reduction:

$SiC(O)_{(s)} + C_{(free)} \rightarrow SiC_{(s)} + CO_{(g)}$



CTE values (50-1500°C):

- $\lambda_{\perp}$: $5.33 \times 10^{-6}.K^{-1}$
- $\lambda_{\parallel}$: $3.02 \times 10^{-6}.K^{-1}$

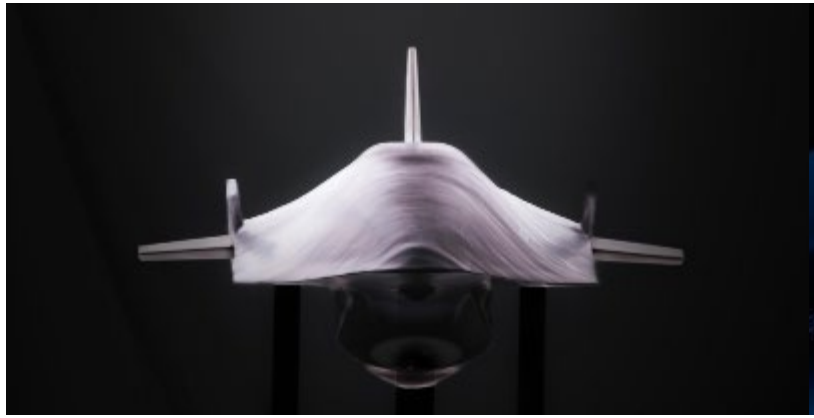
Result

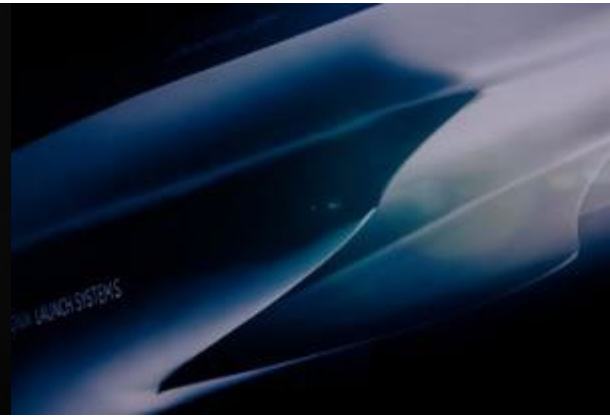
- **HypersoniX Launch Systems Dart VE**
  - In-house R&D:
    - Materials concept
    - Tooling concept
    - Thermomechanical testing
    - Manufacture and delivery of test and flight hardware
  - Collaborative R&D
    - Structural integration
    - Thermo-structural simulations





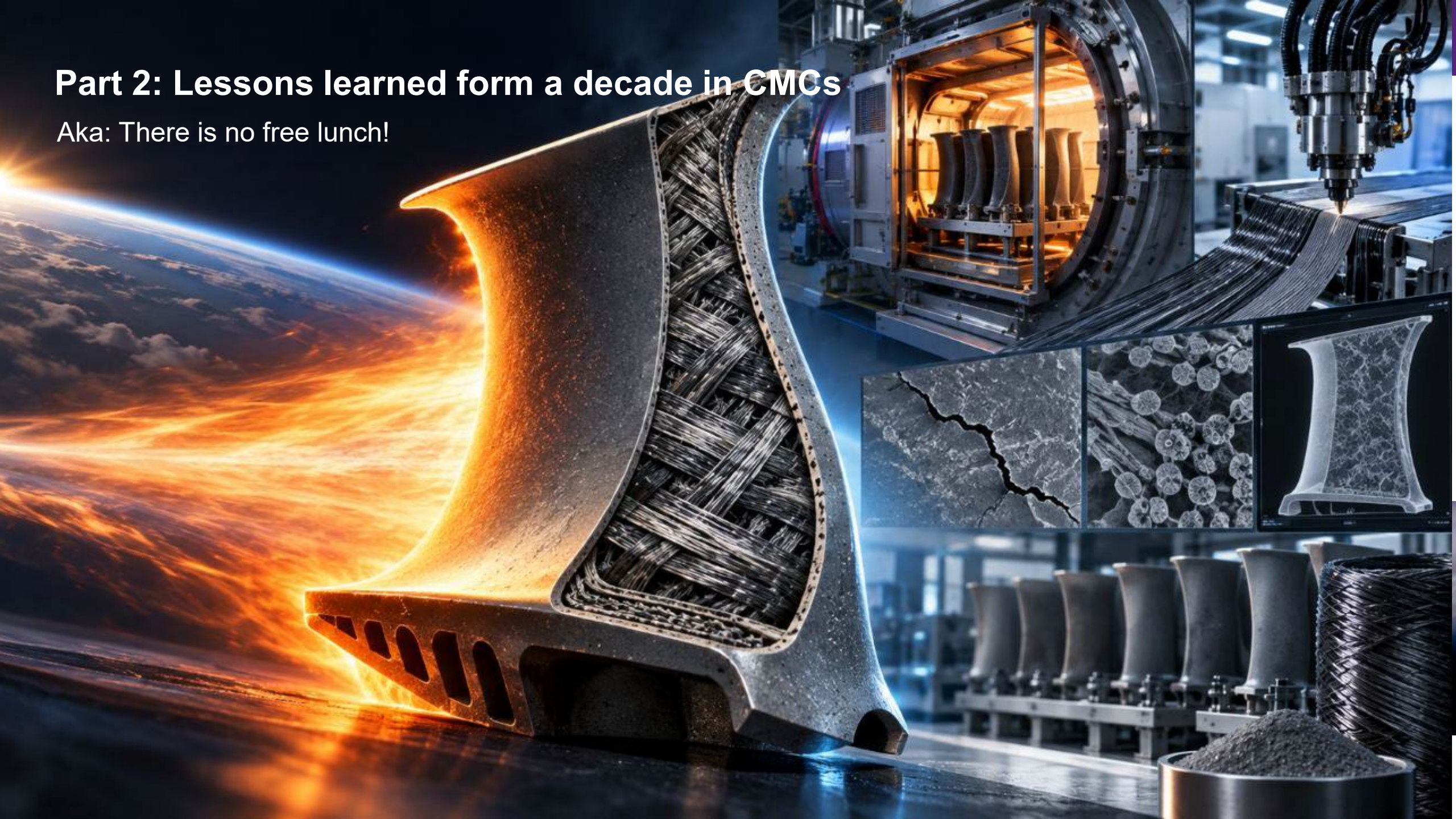
Successful MACH7+ flight test conducted with our component February 2026





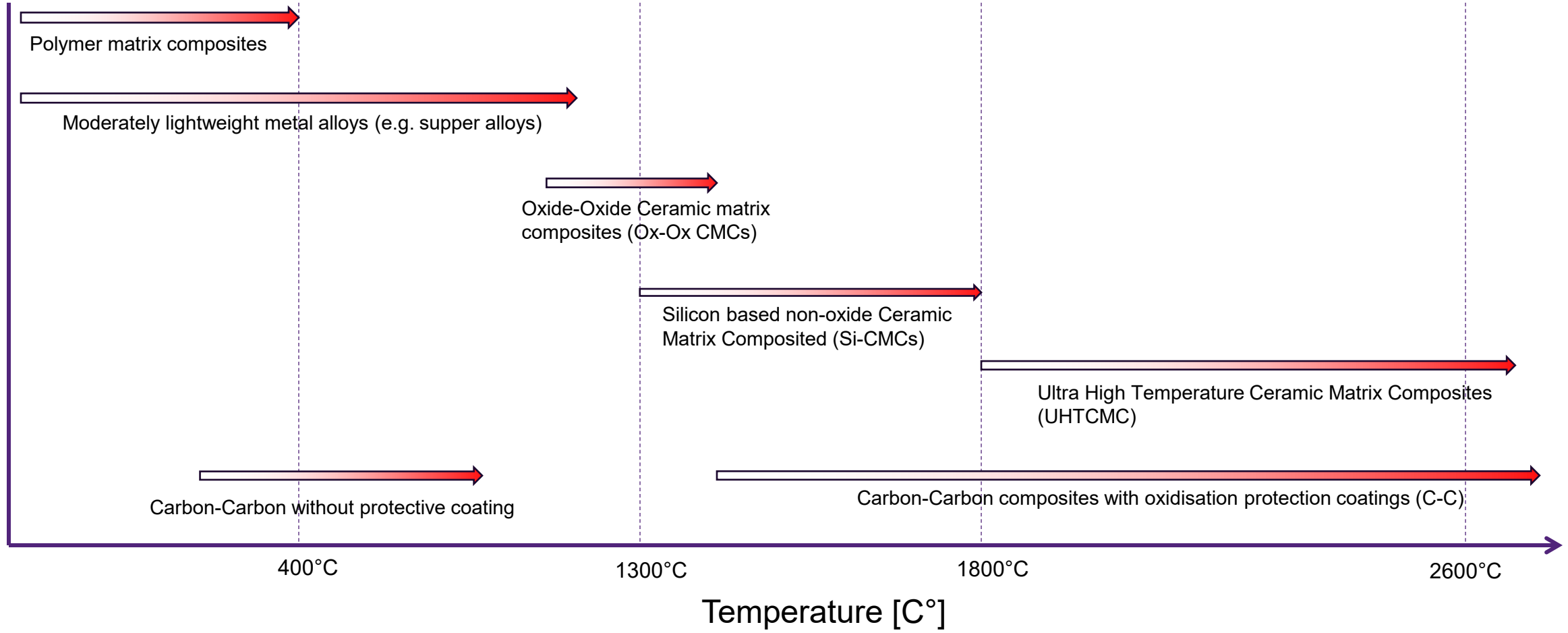
Part 2: Lessons learned form a decade in CMCs

Aka: There is no free lunch!



High temperature composites map

Material categories and their operation limits in oxidising flows



Note: Material operation temperatures and application scenarios are grossly generalised. Exact usability limits are subject to complex interactions, incl design, altitude, trajectory duration, etc.

Critical gaps: Supply chain

Availability and cost of preceramic polymers for PIP

- Costs have increased by x 4
- Often single origin

→ Opportunity in Siloxane chemistries

Fibre interface coatings

- Required for both high temperature polymer and thermoplastics
- Requirement for non-CVD coatings

→ Opportunity to develop low coast bulk coatings that can be applied to fabrics

→ Fibre coatings that inhibit rection with metalloids

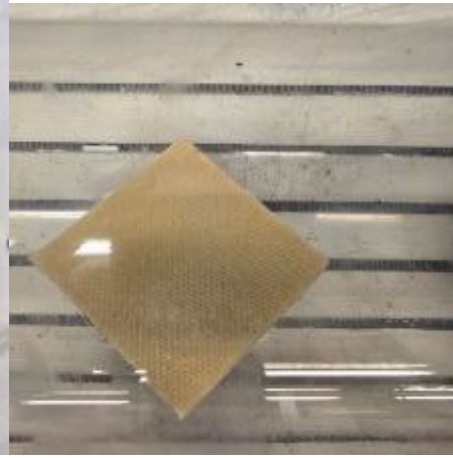
Accessibility of fibres

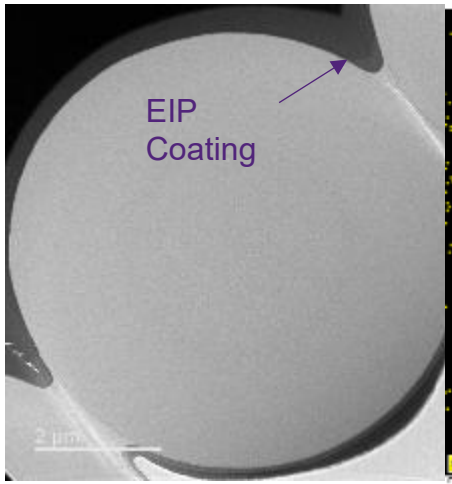
- High strength fibres (hard to access beyond T800)
- High graphite fibres (expensive and hard to source, big compromise with strength)
- Oxide fibres (expensive part in an Ox-Ox CMC
- Non-oxide fibres (availability and cost)

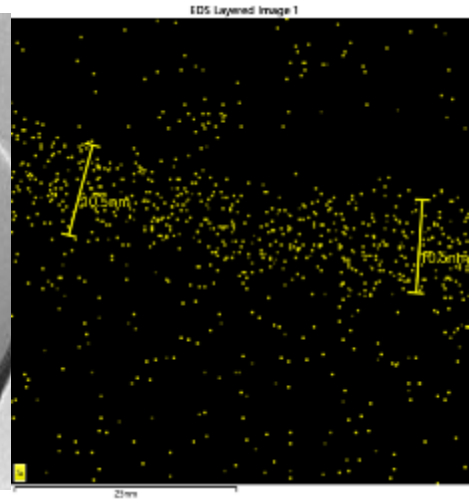
→ Opportunity for bespoke CMC carbon fibres

→ Opportunity for hybrid fibres









Critical gaps: Manufacturing

Manufacturing rates for PIP and CVI

- Manufacturing times of weeks to month
- Batch processes

→ Opportunity for Reactive Melt Infiltration processes

→ Opportunity for thermoplastic precursors instead of thermosets



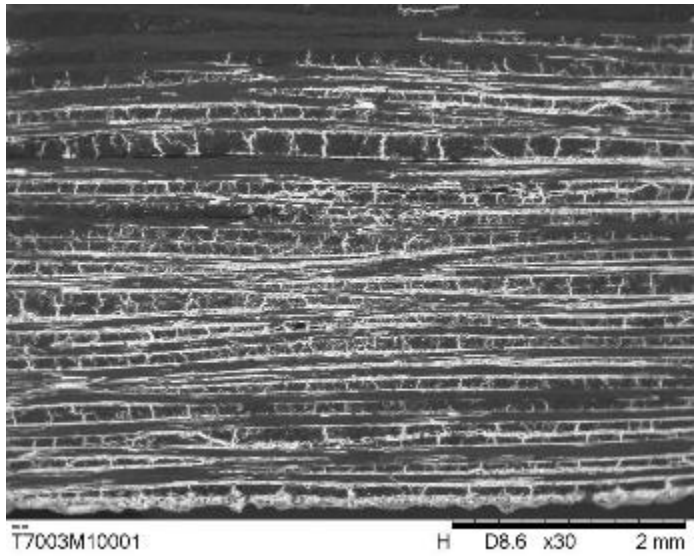
The 2000° C + barrier

- MACH 7+ applications likely require passive resistance at temperatures greater than 2000° C
- CMCs ‘fall of a cliff’ if temperature resistance is exceed

→ Active/Semi-active cooling integration into CMCs

→ Ultra high temperature CMCs





Critical gaps: Integration

How good is ‘good enough’

- Need for integration cases
- Realistic flight condition testing
- Consistency in datasets

→ Opportunity for a Team Australia approach

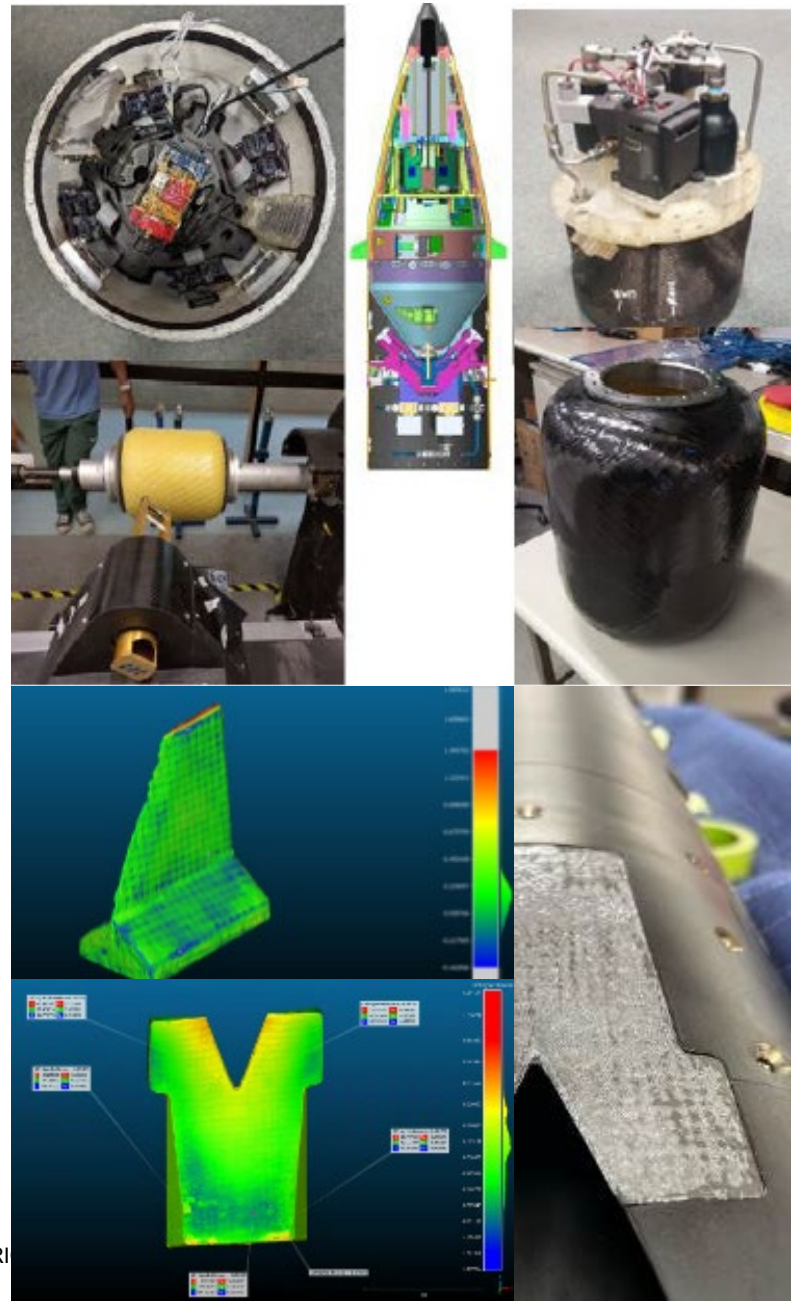
→ Opportunity for new testing methods and flight tests

Airframe architecture

- Complex nexus between materials, manufacturing and design
- Hot structure vs. cold structure approaches

→ Opportunity to let manufacturing be the main driver

→ Opportunity to test out different approaches on the same vehicle



Part 3: ARC Research Hub for Australian Mass Manufacturing of High Temperature Composites



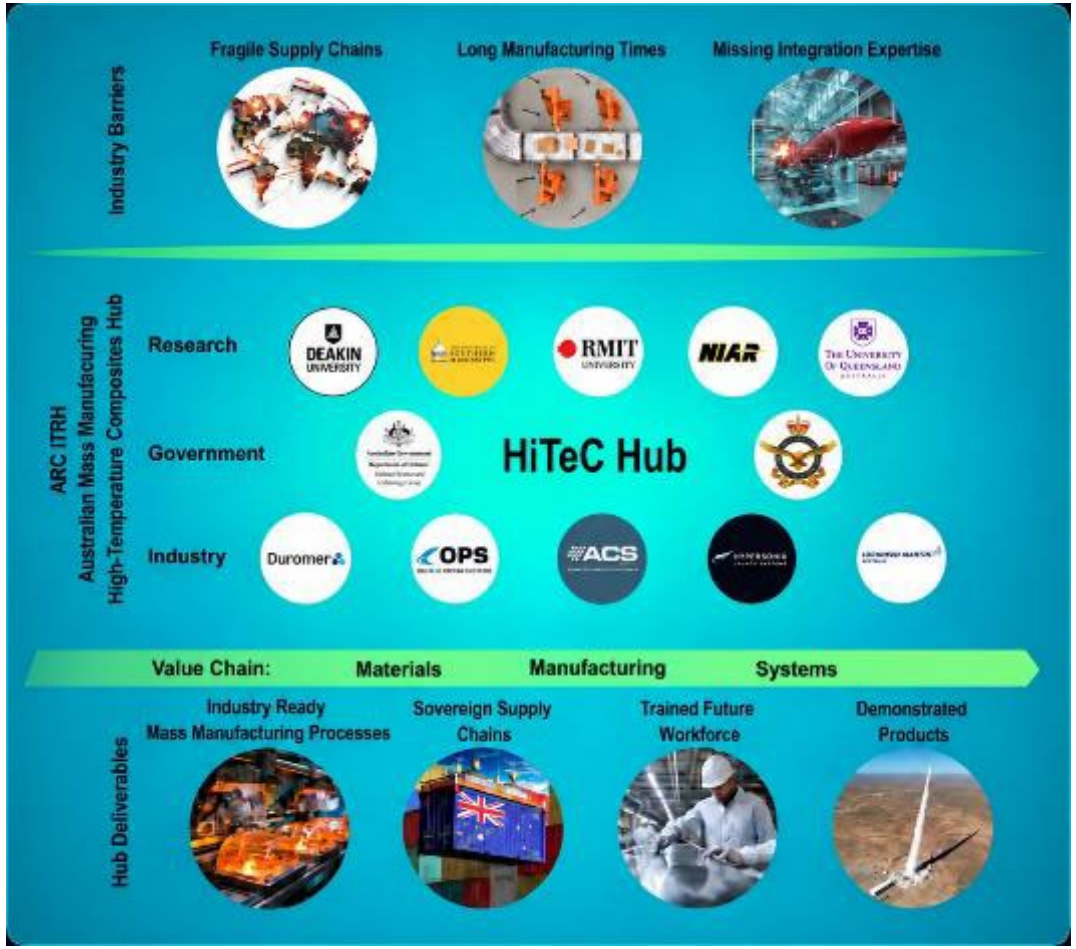
Introduction

Problem statement:

- High-temperature composites are critical enablers for next generation high-speed flight.
- However, they suffer from:
  - Long manufacturing times
  - Fragile supply chains
  - Missing integration expertise

The HiTeC Hub will develop **mass manufacturing methods** for high temperature composites and **demonstrate** these through integration in hypersonic flight hardware (STAjE).

- Hub is a 5 year, $18M ($8 M cash, $8M in-kind) program with funding provided by Australian Research council and co-investment from industry and academia.
- End goal is translation into an industrial capability



Hub Activities

Pillar 1: Mass manufacturing Technologies

- Pioneer Compression-Injection overmoulding
- Rapid reactive melt infiltration

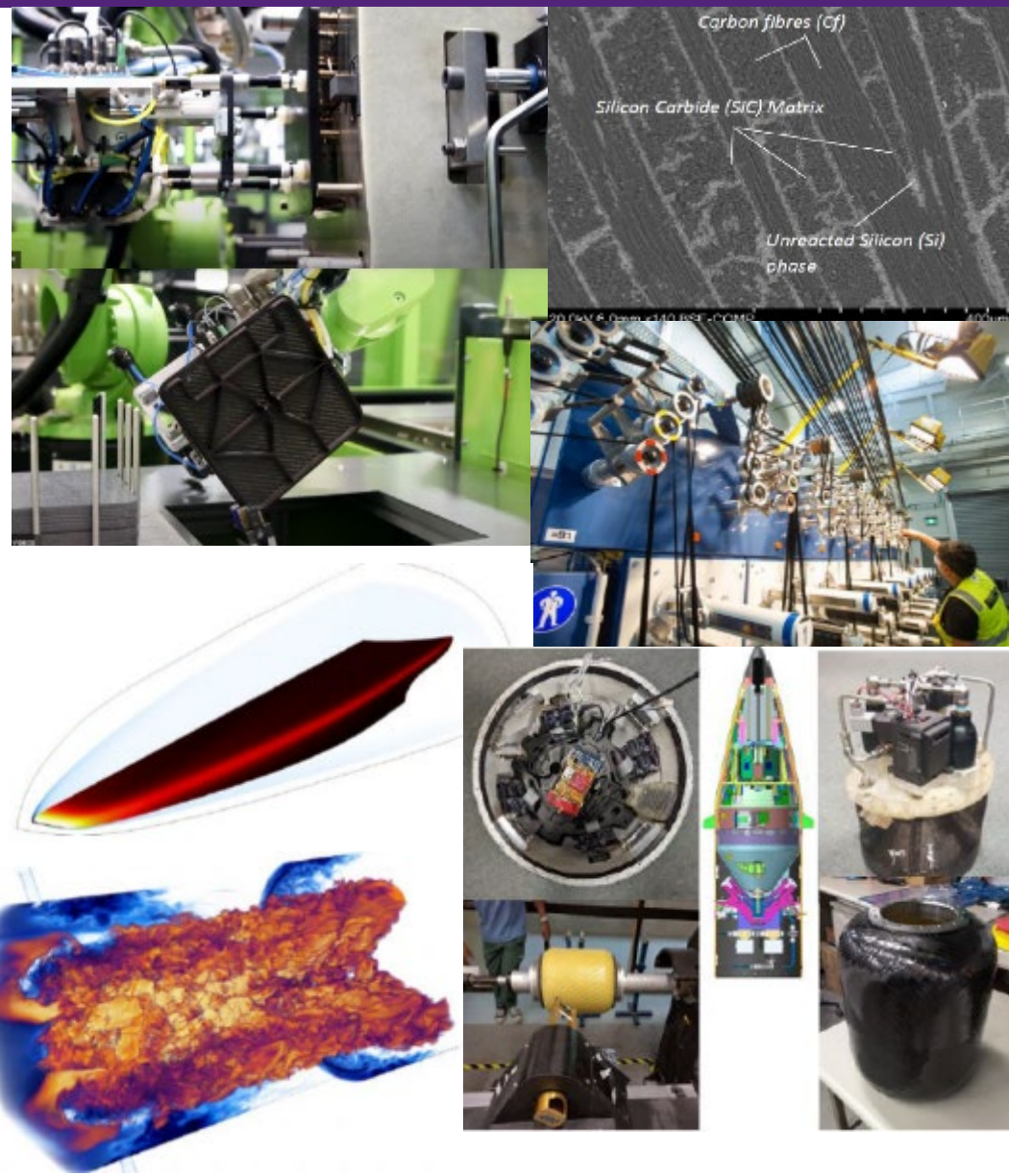
Pillar 2: Enabling Technologies

- Sovereign precursors and resins
- Fibre and fibre coatings

Pillar 3: Product Integration and Realisation

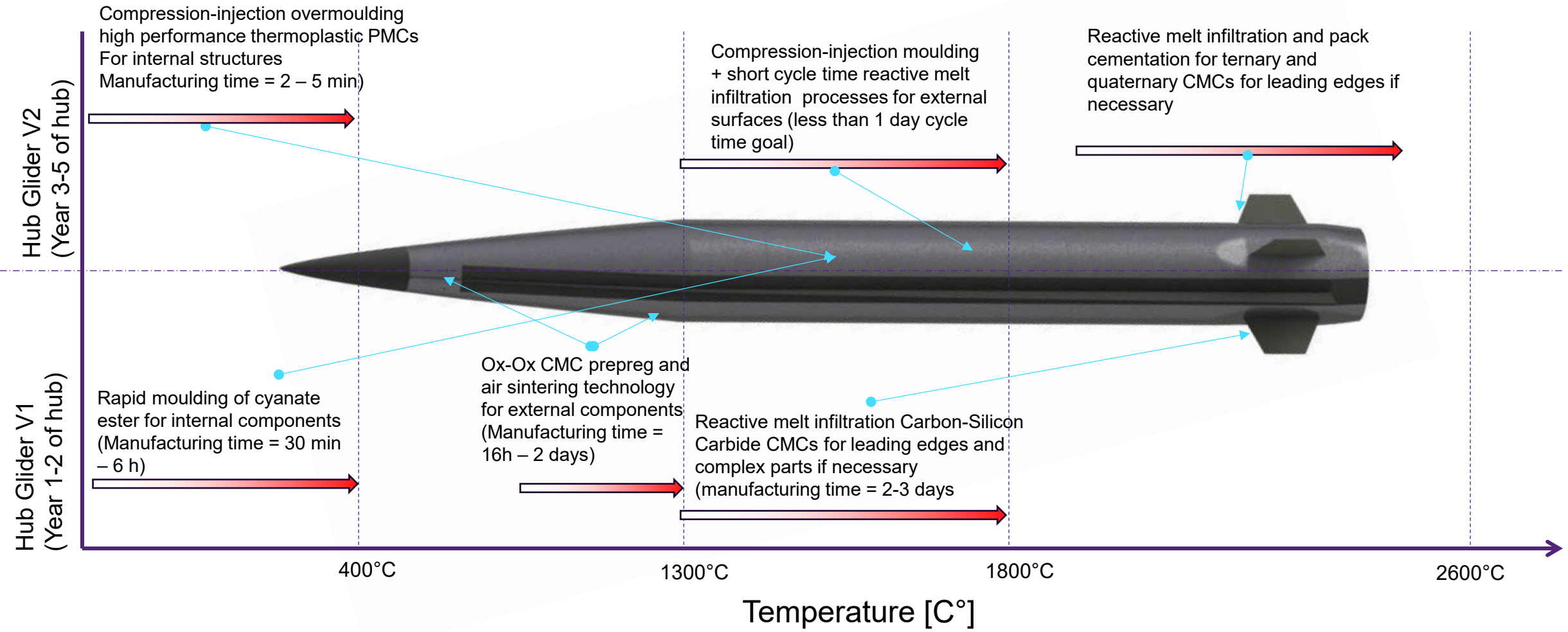
- M4E2 electric propulsion ground test and prototype glider development
- Low cost sovereign launch technology
- HypersoniX Launch System ox-ox integrated wing prototype
- Enabling simulation and testing capability

Collaboration with AUKUS+ partner organisations



High temperature composites map

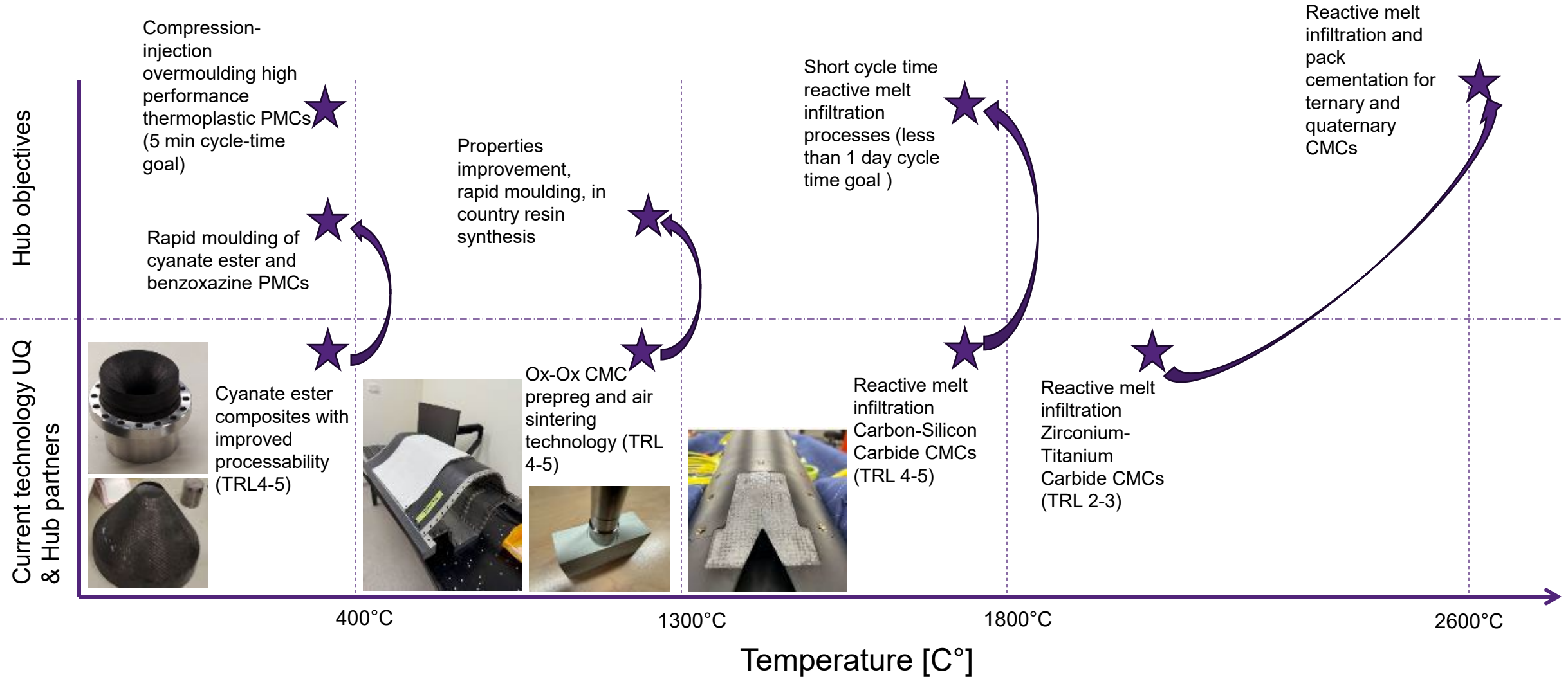
Materials for glider



Note: Material operation temperatures and application scenarios are grossly generalised. Exact usability limits are subject to complex interactions, incl design, altitude, trajectory duration, etc.

High temperature composites map

Existing materials technology and hub road map



Note: Material operation temperatures and application scenarios are grossly generalised. Exact usability limits are subject to complex interactions, incl design, altitude, trajectory duration, etc.

Thank you

Michael Heitzmann
Director Research SMME
School of Mechanical and Mining Engineering
University of Queensland, St Lucia

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