University of BRISTOL
Bristol Composites Institute

Thermal characterisation of actively cooled CFRPs via embedded channel networks

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UKRI Engineering and Physical Sciences Research Council

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EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing

LEONARDO

Project outline

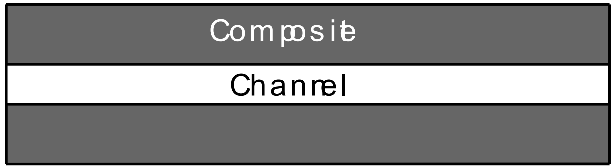
Carbon-fibre reinforced polymers (CFRPs) have ever increasing uses in modern aircraft structures but are currently unsuitable for service in and around temperature critical components

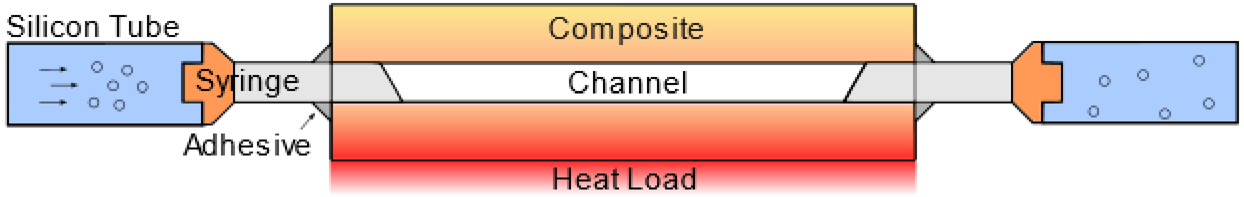
Improved thermal performance could be the key to unlocking a whole new design space within the industry and Leonardo wanted to investigate and characterise a potential method to achieve this

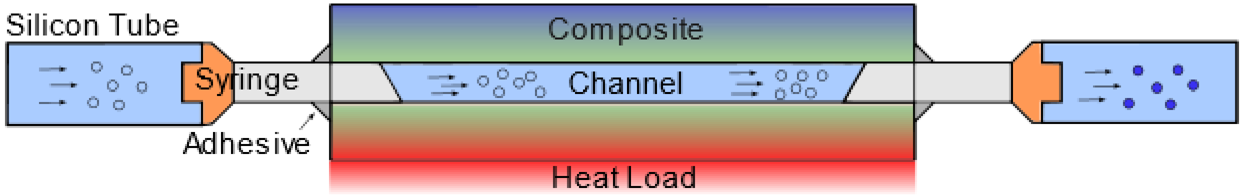
Active cooling in CFRPs is a proven but underexplored method to achieve huge thermal performance improvements

The project has three aims:

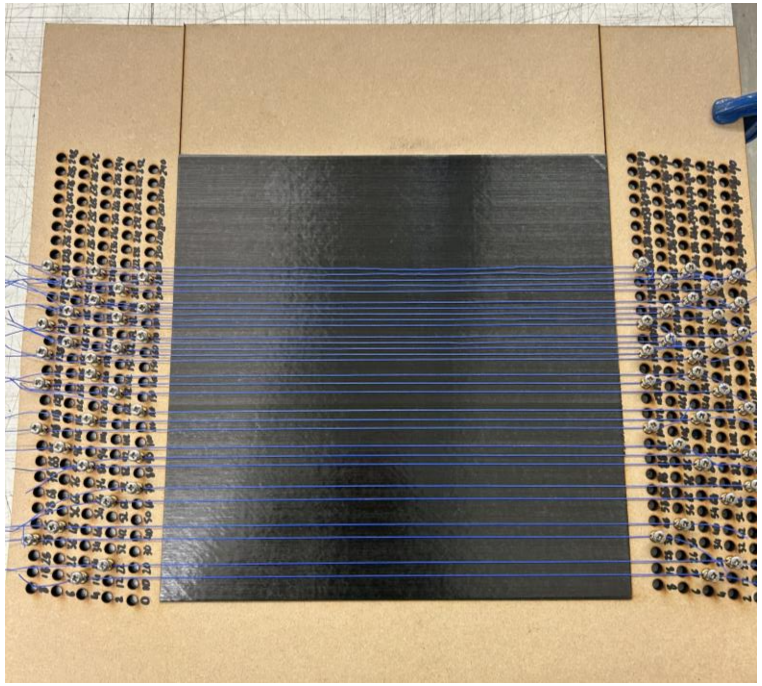
1. Characterisation
2. Optimisation
3. Application



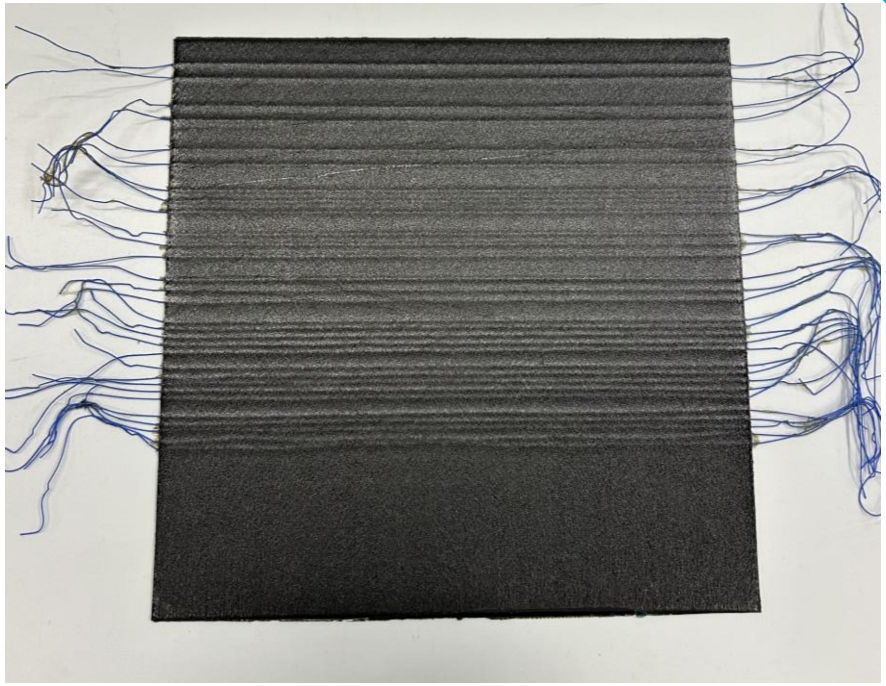




Manufacturing



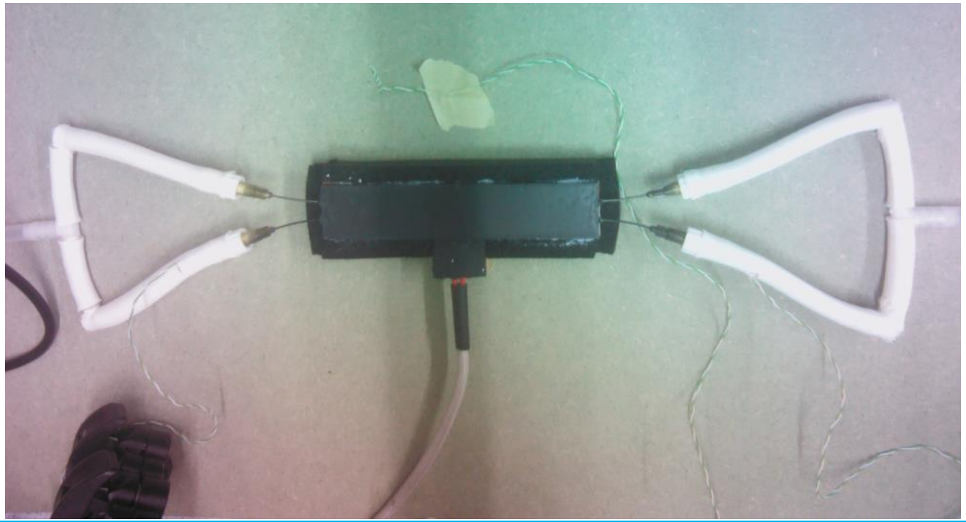
Metallic wires are embedded in the mid-plane of a composite laminate during hand layup using a bespoke jig to hold the wires in the desired position



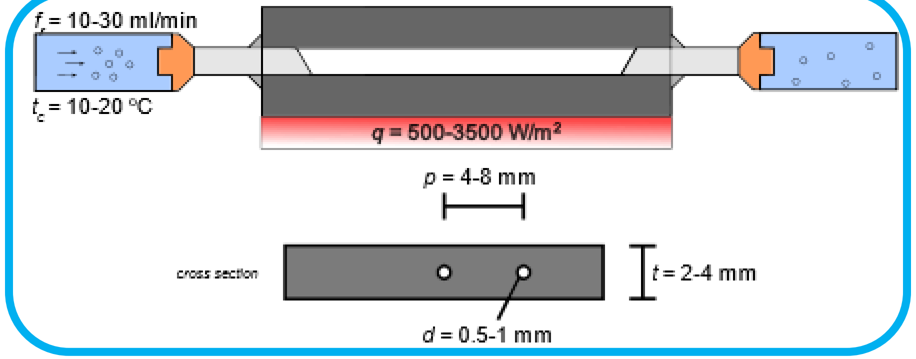
The laminate is cured and wires are removed manually, leaving a series of hollow channels

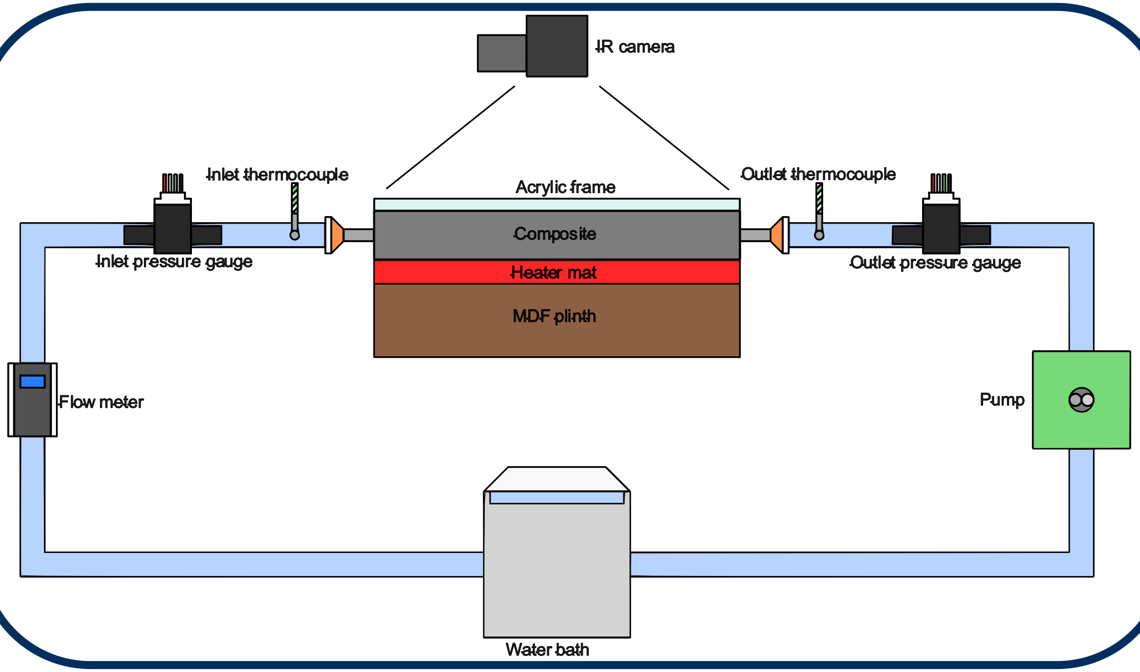
The laminate is cut into smaller samples and syringe tips are glued into the exposed channel ends

Testing



Samples are tested for various parameters





A custom conduction set up is used to test each sample

Samples are placed on a heater mat and heated at a set heat flux

Coolant fluid is pumped into the channels at a set flow rate and temperature

The resulting decrease in temperature is captured using an IR camera

Effect of flow rate

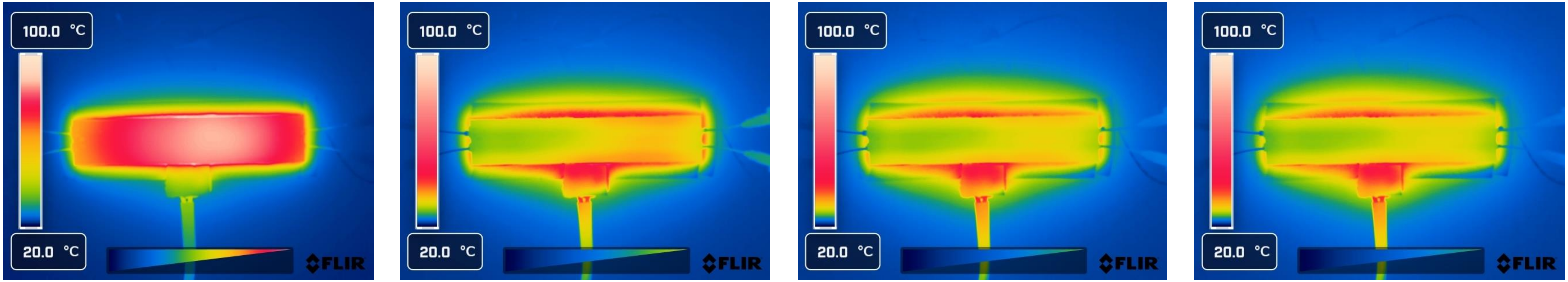
t = 4 mm | d = 1 mm | p = 8 mm (2 channels)

t_c = 20°C (water) | q = 500 W/m^2

Surface temperature is reduced by 55-63% in this configuration and by up 80% across all tests

The cooling effect begins to plateau at higher flow rates

f_r = 0 ml/min → f_r = 10 ml/min → f_r = 20 ml/min → f_r = 30 ml/min



T_{max} = [redacted] → T_{max} = [redacted] → T_{max} = [redacted] → T_{max} = [redacted]

Effect of pitch

t = 4 mm

d = 1 mm

f_r = 20 ml/min

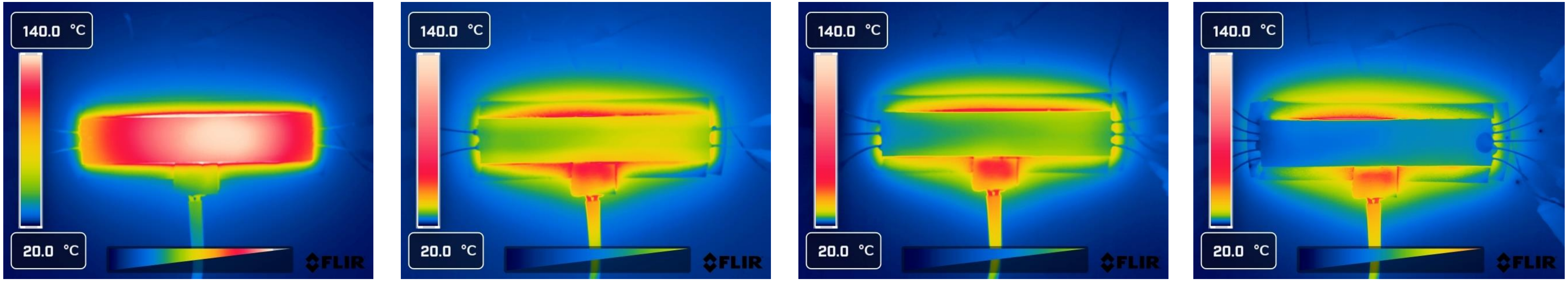
t_c = 20°C (water)

q = 2000 W/m²

Decreasing pitch increases the reduction in surface temperature

A denser network of channels leads to a more uniform temperature profile

p = 8 mm (2 channel) → p = 6 mm (3 channel) → p = 4 mm (5 channel)



T_{max} = [redacted] → T_{max} = [redacted] → T_{max} = [redacted] → T_{max} = [redacted]

T_{avg} = [redacted] → T_{avg} = [redacted] → T_{avg} = [redacted] → T_{avg} = [redacted]

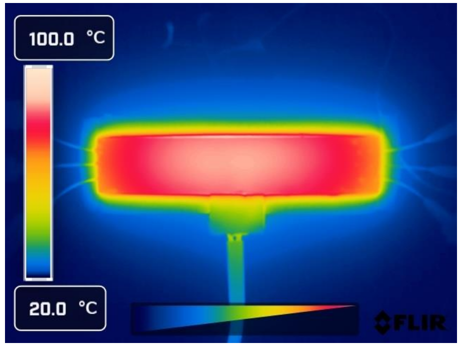
Heat flux

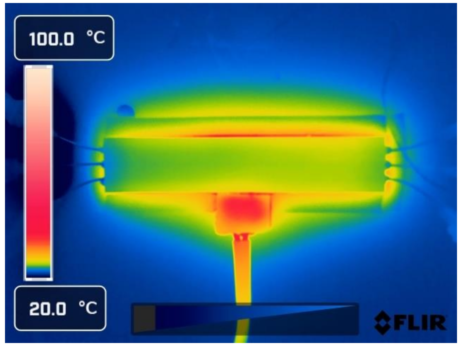
q = 500 W/m^2 → q = 1250 W/m^2 → q = 2000 W/m^2

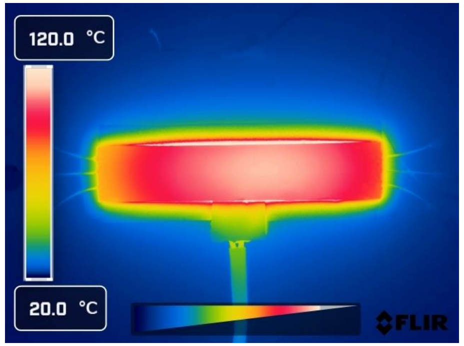
T_{sur} = [redacted]

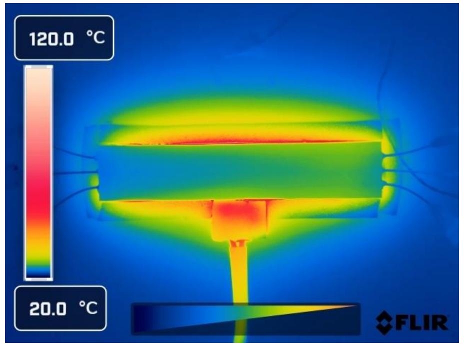
T_{sur} = [redacted]

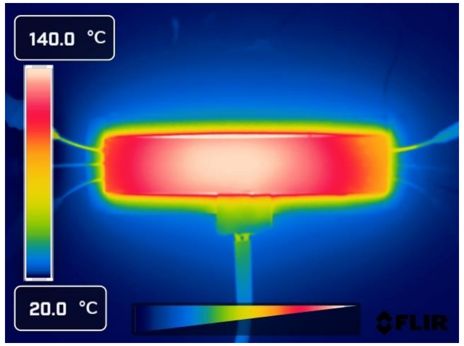
T_{sur} = [redacted]

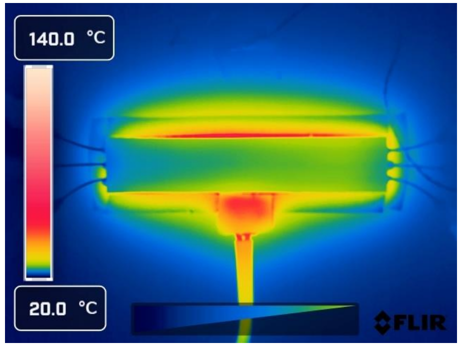












T_{sur} = [redacted]

T_{sur} = [redacted]

T_{sur} = [redacted]

t = 4 mm

d = 1 mm

p = 6 mm (3 channels)

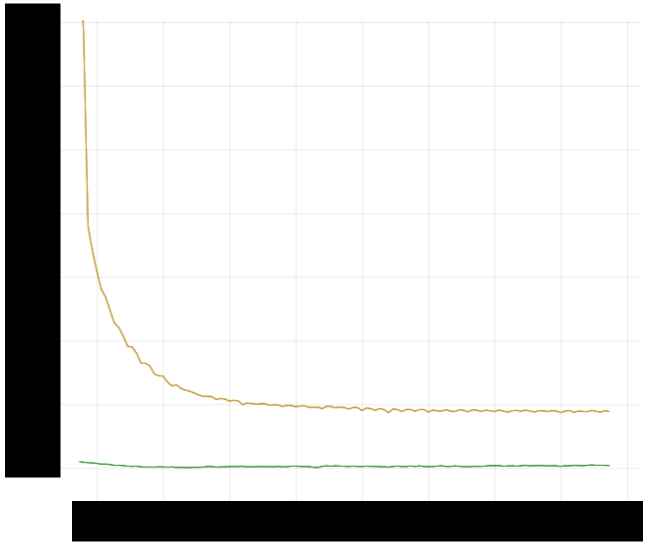
t_c = 20^{o}C (water)

f_r = 30 ml/min

Even at the highest heat flux the temperature can be reduced to a safe and maintainable level

There is scope for even higher heat fluxes in this configuration

Other considerations



Inlet and outlet temperatures can be used to calculate the heat removal from the sample

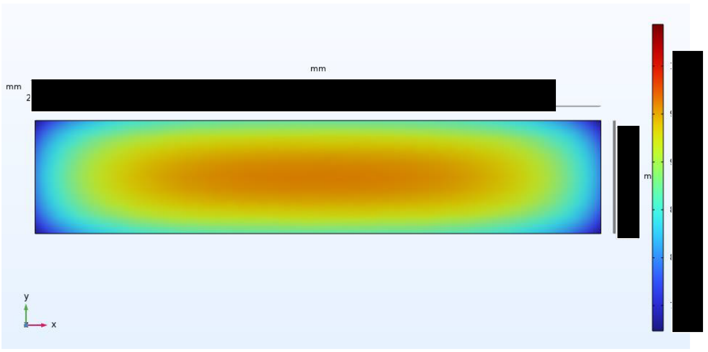
Up to 70% heat removal has been measured

Pressure gauges are used to determine pressure across the channels

Experimental results have been validated with modelling in COMSOL

$T_{max,e}$ = 89.6°C

$T_{max,s}$ = 96.5°C



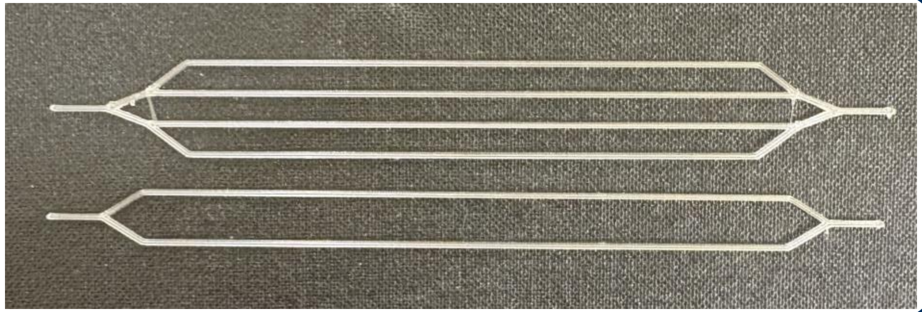
Tensile testing has been carried out to determine the effect of the channels on mechanical performance

97% retention in ultimate tensile strength in five channel sample

93% agreement

Optimisation and application

Instead of straight and flat '2D' channels created by wire extraction, more complex '3D' channels involving branches and junctions can be manufactured using a process called vapourisation of sacrificial components (VaSC)



Several suitable '3D' channel networks have been identified in COMSOL models, manufactured and thermally tested with the same set up

The findings from the characterisation and optimisation experiments can be applied to a potential use in industry – an intermediate gearbox (IGB) in a helicopter

Due to the much higher thermal loads involved (3000-3500 W/m^2) in this application, work has instead been done in COMSOL Multiphysics

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Questions

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