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SUSTAINABLE & COST EFFICIENT
HIGH-PERFORMANCE COMPOSITE STRUCTURES
DEMANDING TEMPERATURE
AND FIRE RESISTANCE

Composite Inner Fixed Structure Use Case

Spirit AeroSystems, Belfast
Daniel Breen

Public Workshop

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SuCoHS project, Grant Agreement N° 769178

Spirit AeroSystems Inc. – Company Overview

SuCoHS Partner - Spirit AeroSystems Belfast, N.Ireland

Spirit AeroSystems is one of the world's largest manufacturers of aerostructures for commercial airplanes, defense platforms, and business/regional jets. With expertise in aluminum and advanced composite manufacturing solutions, the company's core products include fuselages, integrated wings and wing components, pylons, and nacelles. Also, Spirit serves the aftermarket for commercial and business/regional jets. Headquartered in Wichita, Kansas, Spirit has facilities in the U.S., U.K., France, Malaysia and Morocco.

Nacelle Inner Fixed Structure

Overview of Use Case Component

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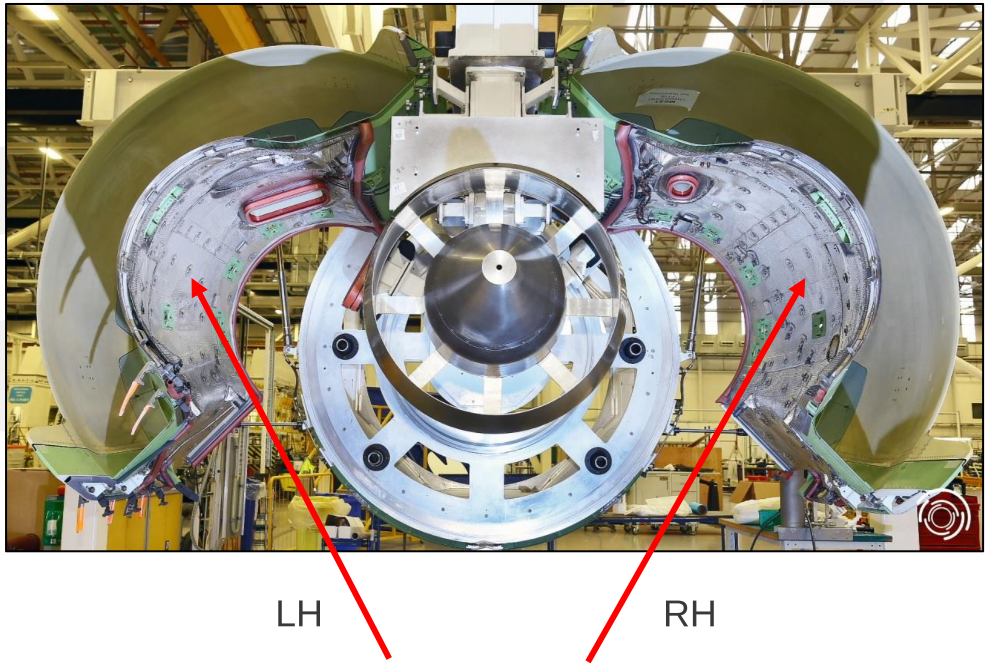
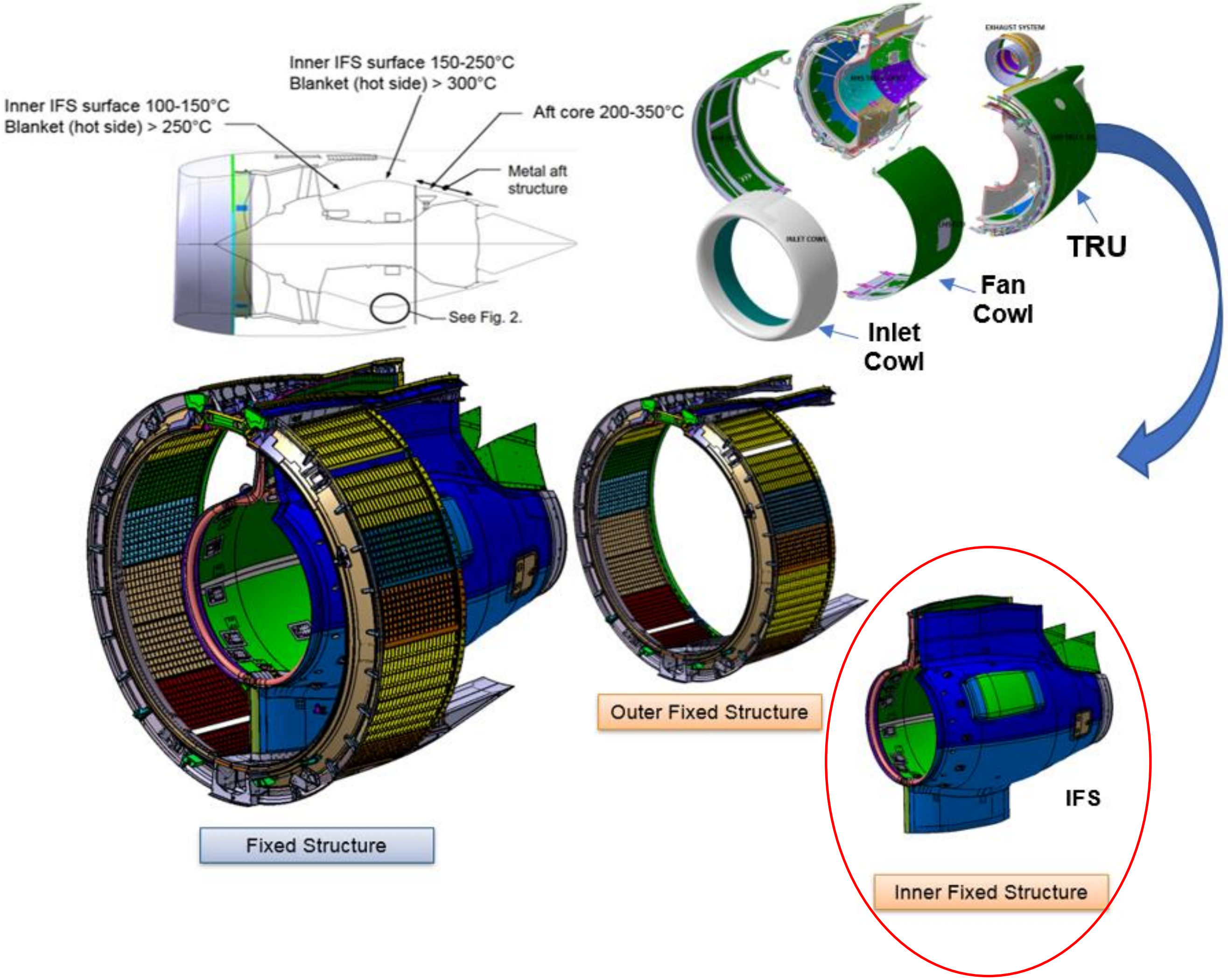
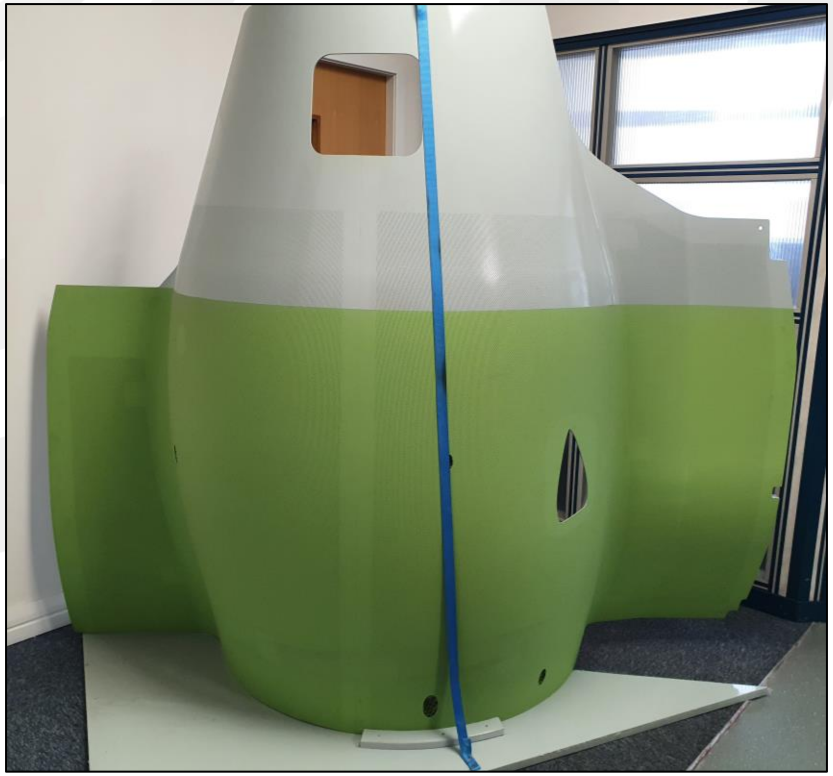
Spirit AeroSystems Use Case: Composite Inner Fixed Structure



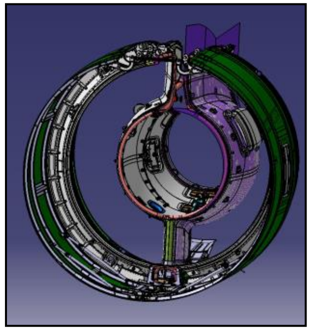
'Inner Fixed Structure' (IFS)



Spirit AeroSystems Use Case: Composite Inner Fixed Structure



- **IFS Functionality**;
  - Structural Integrity whilst minimising weight
    - Honeycomb stiffened structures have excellent specific strength to weight ratios
  - Excellent fatigue and vibration resistance
  - Heat resistance
    - The higher the heat resistance the lower the requirement of thermal blankets
  - Excellent thermal conductivity
    - Assist cooling by transferring heat from hot engine side to cool bypass duct
  - Noise attenuation
    - Honeycomb stiffened structure with perforated facing skin provides excellent acoustic dampening properties
  - Provide aerodynamic inner wall for bypass duct to enable streamlined air flow



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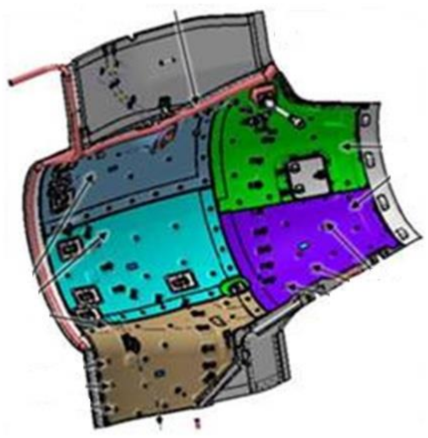
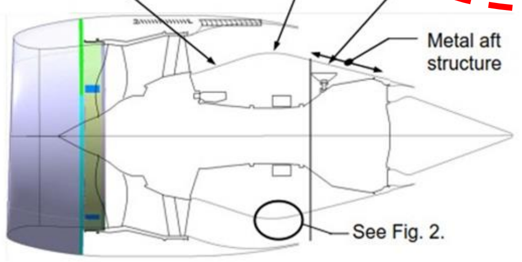
Spirit AeroSystems Use Case: Composite Inner Fixed Structure

- **Key Project Objective**: Develop capability of manufacturing an automated fibre placed composite inner fixed structure which will satisfy a complex set of requirements whilst providing the following benefits over the traditionally manufactured metallic IFS;
  - Reduced part count
  - Improved fatigue resistance
  - Improved noise attenuation
  - Potential weight savings
  - Potential cost savings

- **Main Project Activities**:
  - Evaluate multi-functional materials and methodologies to process them together
  - Evaluate automated fibre placement of high temperature resistant materials to improve process efficiency and reduce thermal blanket requirements
  - Design and manufacture low cost tooling suitable for layup and autoclave curing
  - Manufacture a Risk Mitigation Panel
  - Manufacture full scale Composite IFS Manufacturing Demonstrator
  - Validation of integrated cure monitoring sensors for quality control and process optimisation





NB: Temperatures on the IFS structure are dependent on blanket sizing, which in turn is dependent on selected material temperature capabilities. The blanket is sized to maintain a certain interface temperature with the backing sheet of the honeycomb assembly. In turn the thicker the blanket is, the higher the temperature on the hot side of it will be.

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Material Selection Process

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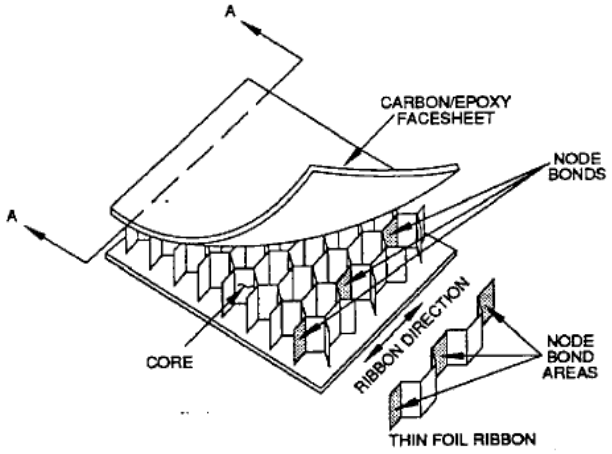
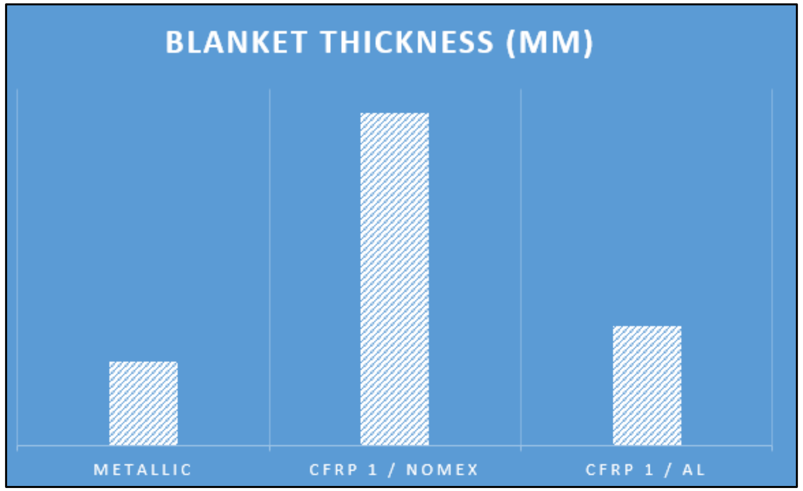
Material Makeup: CFRP-Honeycomb Stiffened Structure

- The IFS is required to be a honeycomb sandwich reinforced structure
- Multiple CFRP’s were evaluated in terms of max service temperature, mechanical performance and thermal conductivity
- Typical aerospace grade honeycomb cores such as Nomex (aramid paper with phenolic resin) and Aluminium were also evaluated
- Thermal conductivity trials concluded that Nomex had to be eliminated due to poor conductivity and hence significantly increased thermal blanket requirements





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Galvanic Corrosion and Springback

- Bonding CFRP facing skins to aluminium honeycomb poses a serious risk in terms of galvanic corrosion degradation
- Isolating the CFRP and Aluminium cores with GFRP is a proven solution <u>however</u> it creates a new problem in terms of Springback
  - CFRP's have a close to zero CTE meaning they expand/contract very little when subjected to temperature changes
  - GFRP's on the other hand have a positive CTE meaning their fibres expand when heated and contract again when cooled
- A Risk Mitigation Panel of representative shape and size to the full IFS had to be produced to demonstrate a processing solution to overcome the springback issue

GALVANIC SERIES
In Flowing Seawater

Alloy		*Voltage Range of Alloy vs. Reference Electrode**
Magnesium	**Anodic or Active End**	-1.60 to -1.63
Zinc		-0.98 to -1.03
Aluminum Alloys		-0.70 to -0.90
Cadmium		-0.70 to -0.76
Cast Irons		-0.60 to -0.72
Steel		-0.60 to -0.70
Aluminum Bronze		-0.30 to -0.40
Red Brass, Yellow Brass, Naval Brass		-0.30 to -0.40
Copper		-0.28 to -0.36
Lead-Tin Solder (50/50)		-0.26 to -0.35
Admiralty Brass		-0.25 to -0.34
Manganese Bronze		-0.25 to -0.33
Silicon Bronze		-0.24 to -0.27
400 Series Stainless Steels**		-0.20 to -0.35
90-10 Copper-Nickel		-0.21 to -0.28
Lead		-0.19 to -0.25
70-30 Copper-Nickel		-0.13 to -0.22
17-4 PH Stainless Steel †		-0.10 to -0.20
Silver		-0.09 to -0.14
Monel		-0.04 to -0.14
300 Series Stainless Steels ** †		-0.00 to -0.15
Titanium and Titanium Alloys †		+0.06 to -0.05
Inconel 625 †		+0.10 to -0.04
Hastelloy C-276 †		+0.10 to -0.04
Platinum †	**Cathodic or Noble End**	+0.25 to +0.18
Graphite		+0.30 to +0.20

* These numbers refer to a Saturated Calomel Electrode.
** In low-velocity or poorly aerated water, or inside crevices, these alloys may start to corrode and exhibit potentials near -0.5 V.
† When covered with slime films of marine bacteria, these alloys may exhibit potentials from +0.3 to +0.4 V.

- Galvanic corrosion textbook definition;

  An electrochemical process in which one metal corrodes preferentially when in contact with a different type of metal and both metals are contained in an electrolyte

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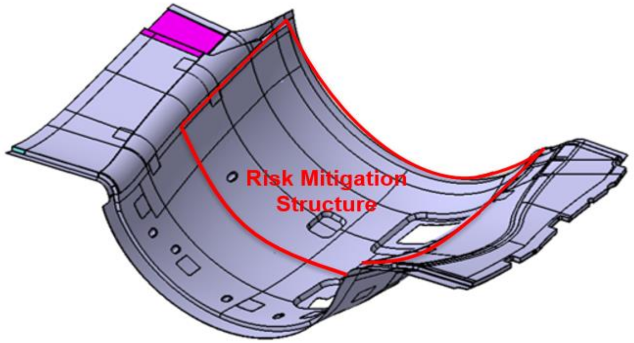
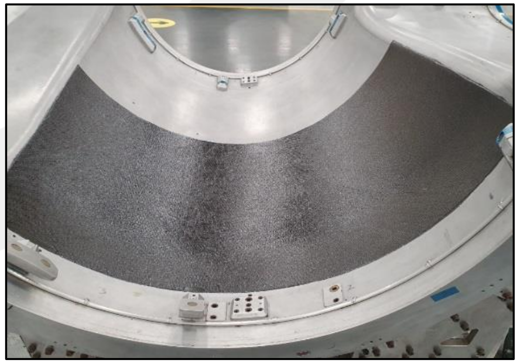
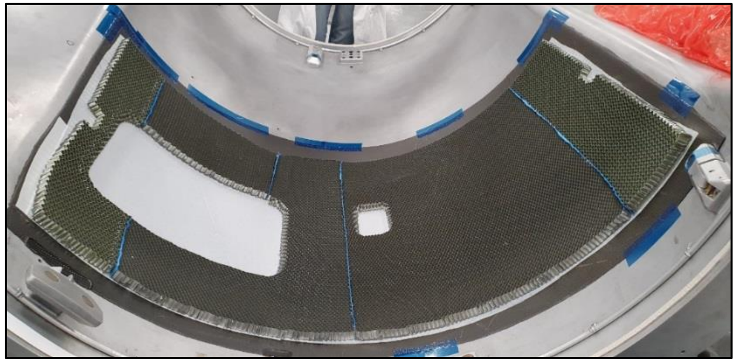
Risk Mitigation Structure

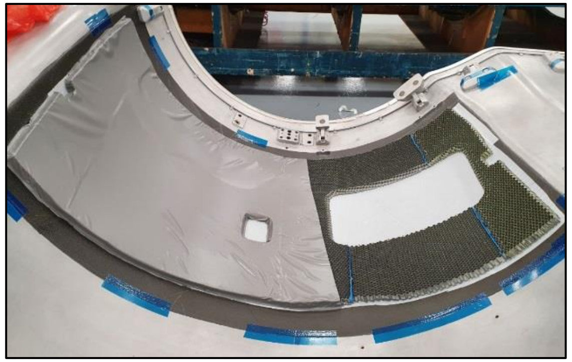
Risk Mitigation Structure Manufacturing Activities

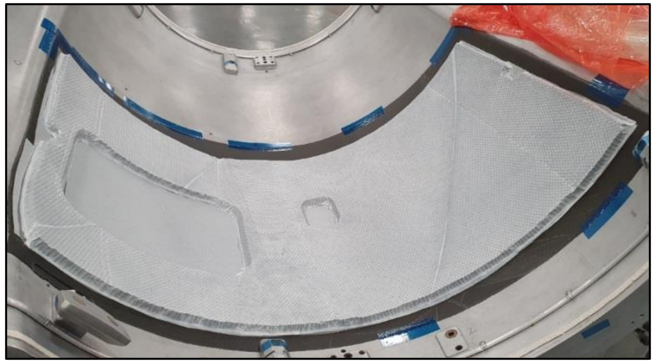
- It is important that the RMS shape incorporated similar extreme curvature to that of the full IFS demonstrator since this will crucially influence the counteracting forces of the contracting GFRP layers

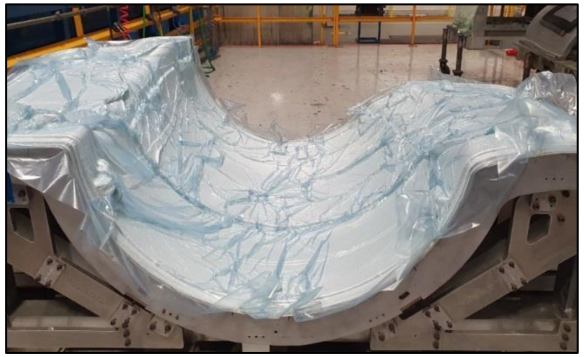




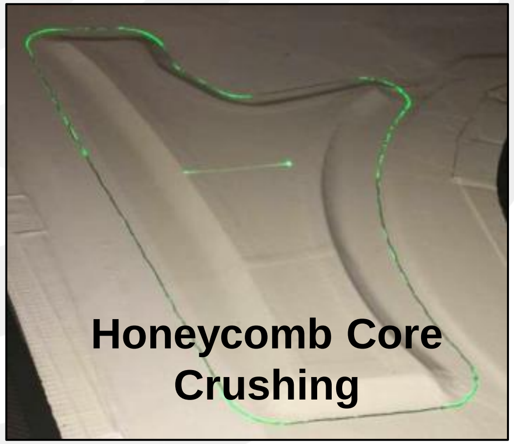


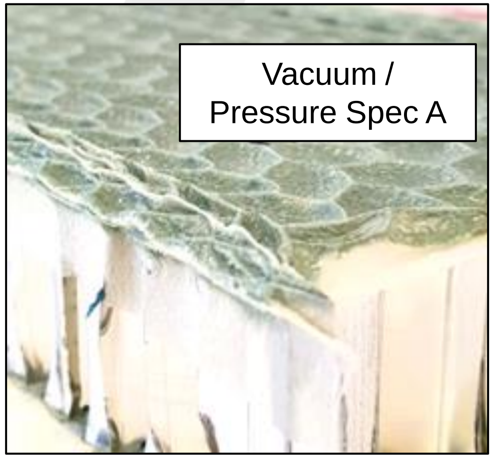


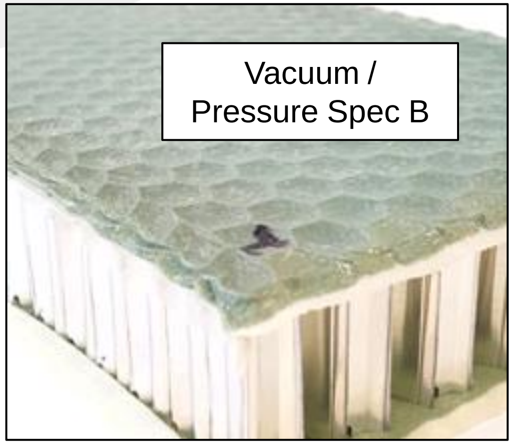


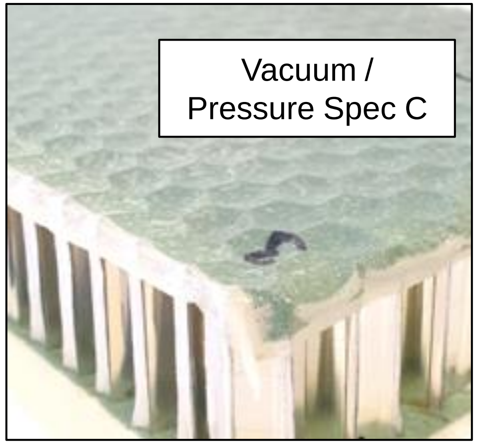


Optimised Cure Parameters to Support AFP over Honeycomb

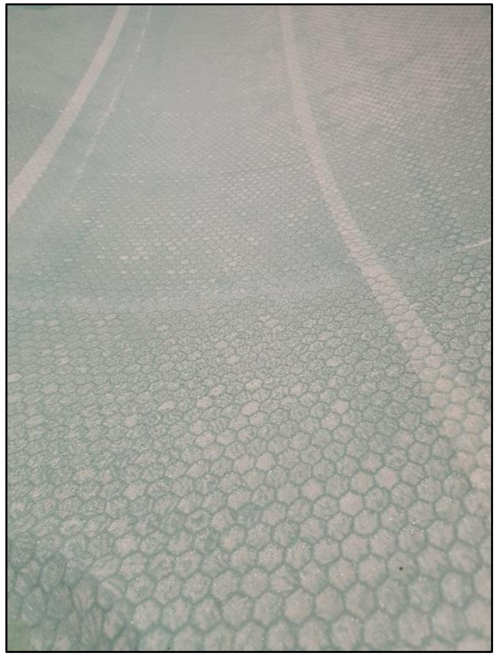








- Honeycomb is susceptible to crushing under excess pressure due to vacuum and autoclave pressure
- Optimum vacuum and autoclave pressure levels needed to be evaluated to minimise the surface telegraphing effect and additionally ensure as smooth a surface as possible to support the automated fibre placement process



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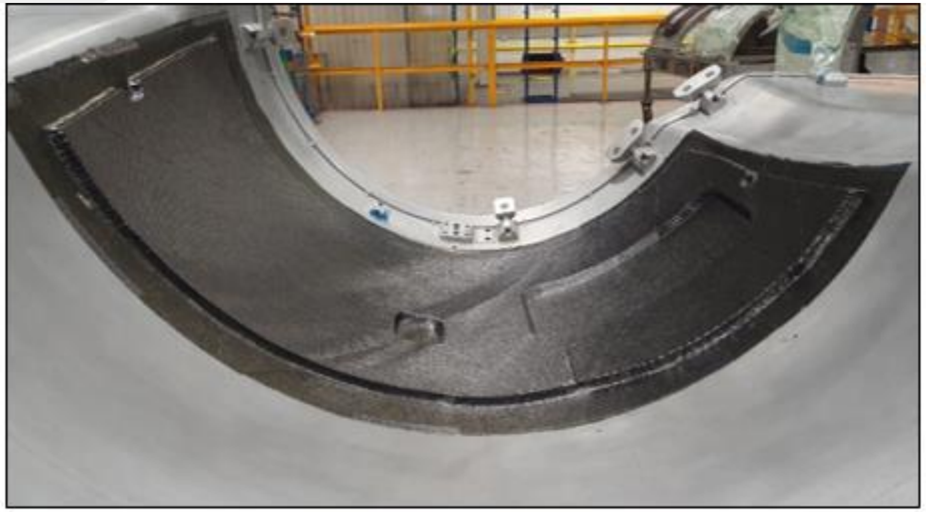
Risk Mitigation Structure – Successfully Complete

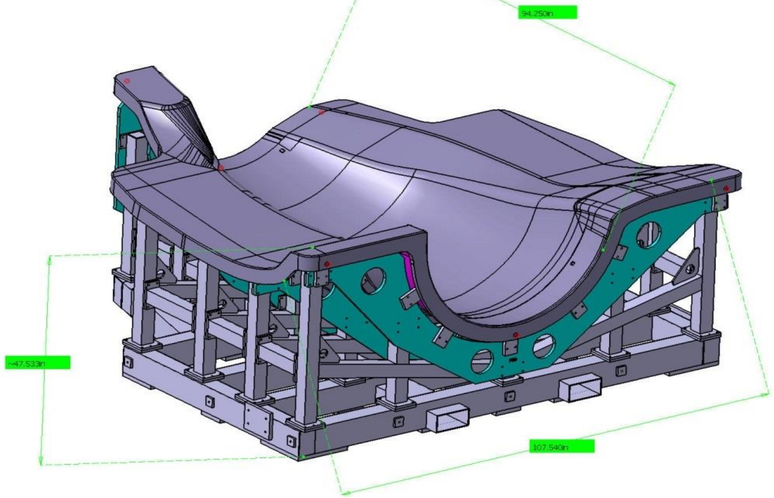


Successful Outcome – No Springback

Outer Mould Tool Manufacturing

IFS Mould Tool Manufacture

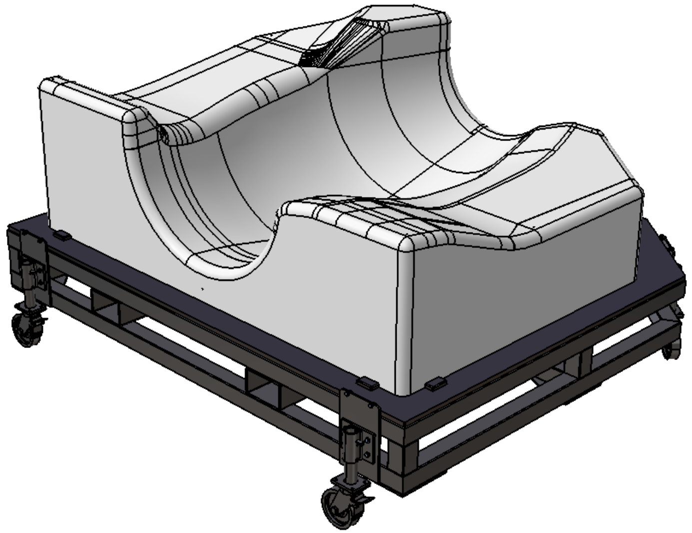
- To produce the composite demonstrator Spirit Belfast needed to produce an outer mould tool for layup & cure
- The tool must be strong enough to withstand autoclave cure pressures as high as 6bar and temperatures as high as 180ºC whilst ensuring the mould surface maintains its shape profile. The tool surface must also be vacuum tight for composite fabrication.
- A metallic tooling solution would be expensive and therefore inefficient for a one off demonstrator.
- Fabricating a composite demonstrator on a metallic tool also brings complications due to differences in CTE. Other solutions needed to be evaluated.

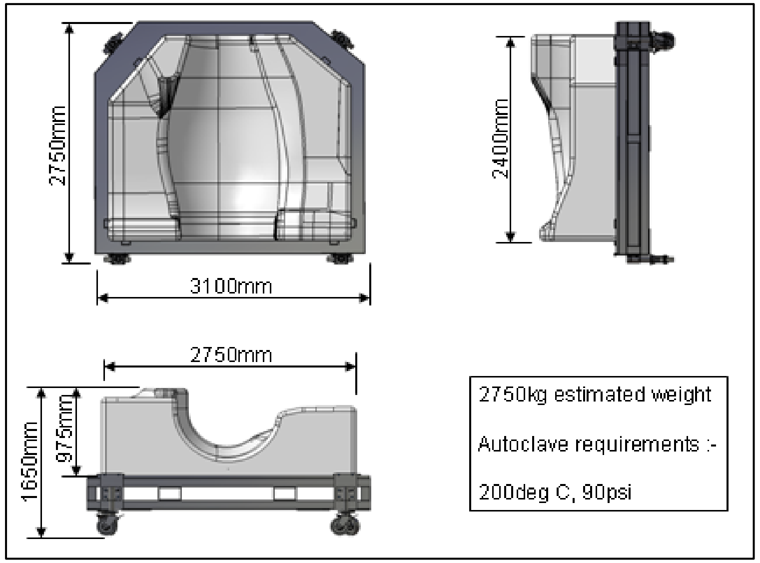


Metallic Tool Solution

IFS Tooling Concept 1 – Ceramic Tooling Block

- Tooling block is widely used within aerospace to produce short run tooling prototypes.
- It is easily machined to a very high tolerance in a CNC milling machine
- Tooling block was considered to produce the layup & cure tool.
- These materials are high temperature resistant, have a very low CTE and are capable of withstanding at least multiple autoclave cure cycles.
- This production however would need to be sub-contracted at high cost. The material is also quite brittle and can be easily damaged if not handled carefully.
- It was decided this concept would not be pursued.





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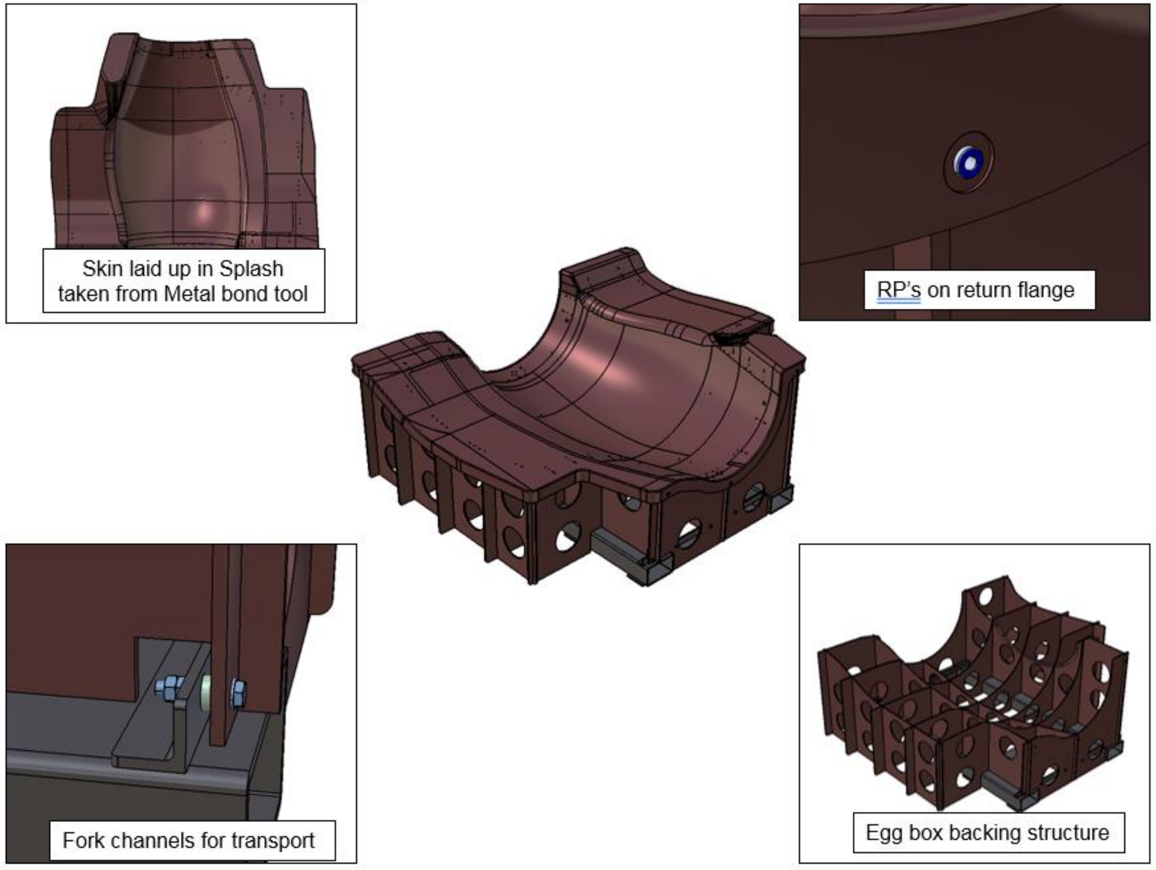
IFS Tooling Concept 2 – Carbon Fibre Cure Tool



- Spirit Belfast has vast experience in producing CFRP tooling in house.
- CFRP tooling is extremely robust, eliminates any CTE issues and manufacturing in house would save on cost
- The process would involve initially producing a 'master tool'. The master tool would then be used to manufacture the layup & cure tool surface.
- The lightweight materials would result in a total mass of approximately 300kg; 2450kg lighter than the tooling block concept.
- The decision was therefore made to manufacture the carbon fibre tooling concept

CFRP Tooling Manufacture – Master Tool

- Multiple layers of tooling prepreg were layed up and cured in an autoclave to produce the master tool surface
- 2D templates of the CAD model eggbox backing structure boards were printed and used to produce a timber backing structure to support the master tool surface
- Finally the tool was bagged up and vacuum drop tested to ensure vacuum integrity

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CFRP Tooling Manufacture – Cure Tool Surface and Backing Structure

- A dry preform was layed up onto the Master tool using recycled fabric from our wing factory and was subsequently infused and cured OOA
- Using the 2D templates of the eggbox structure printed from the CAD model, carbon fibre boards were cut to shape and assembled together to produce a backing structure
- The cured tool surface was then bonded to the backing structure and surface sealed ready for use

IFS Use Case Manufacturing

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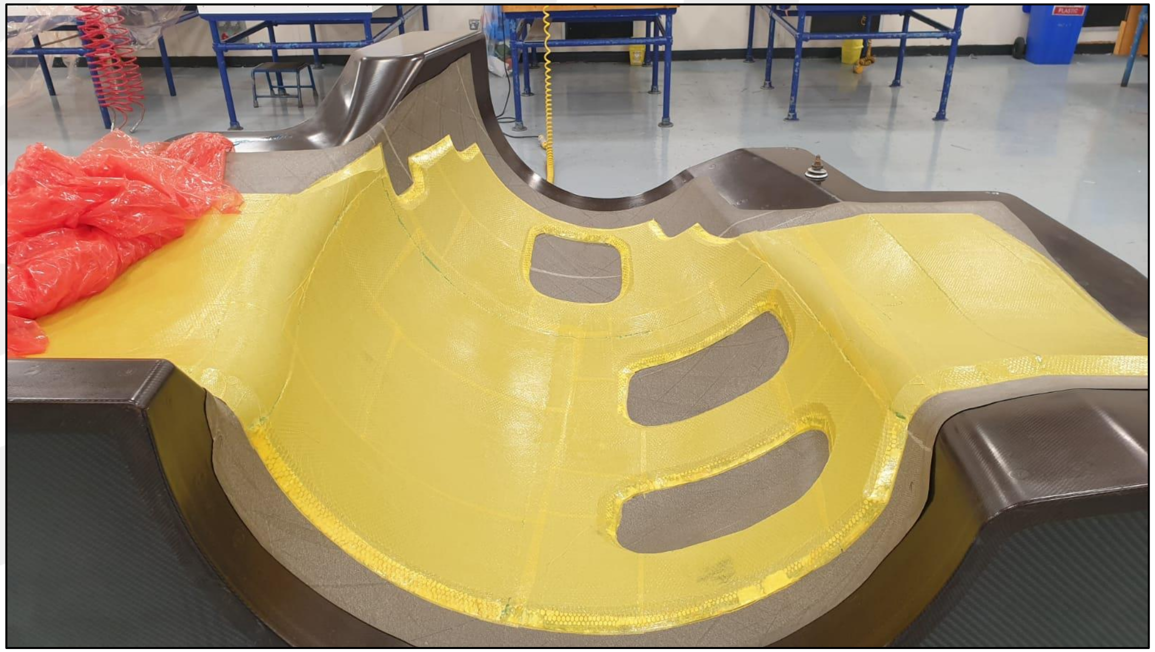
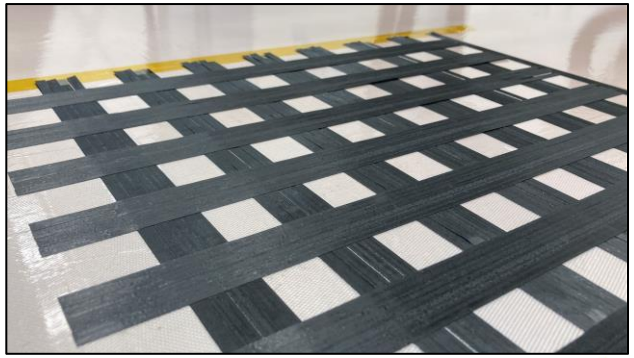
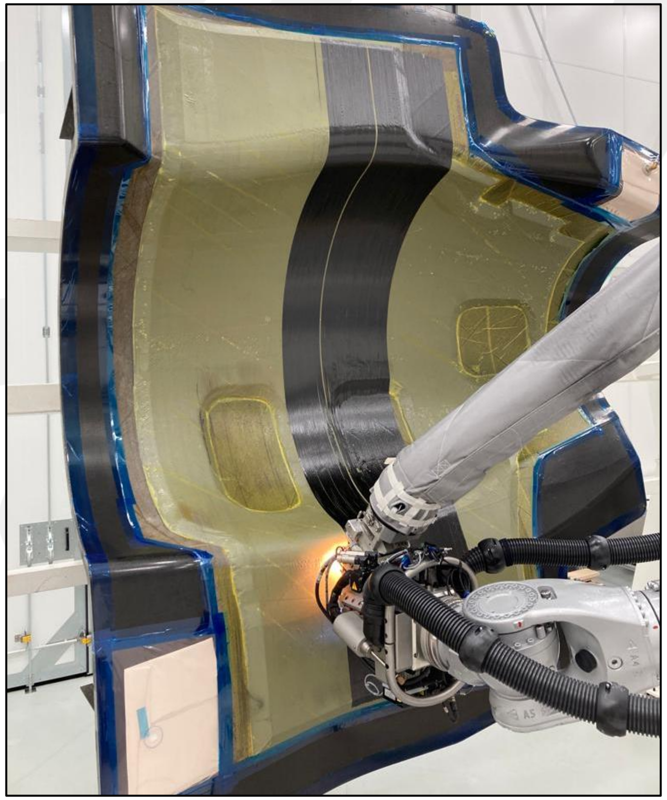
Initial Component Layup and Prep for AFP

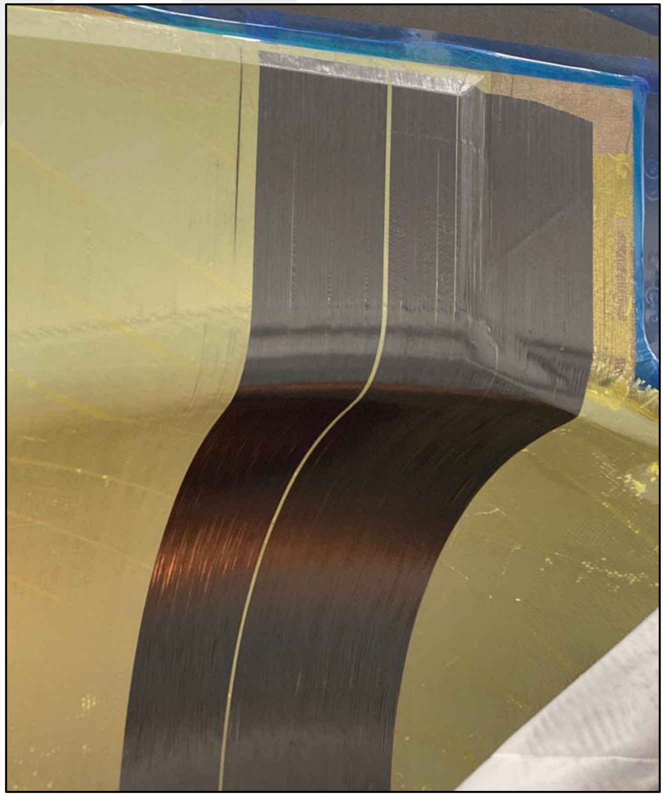


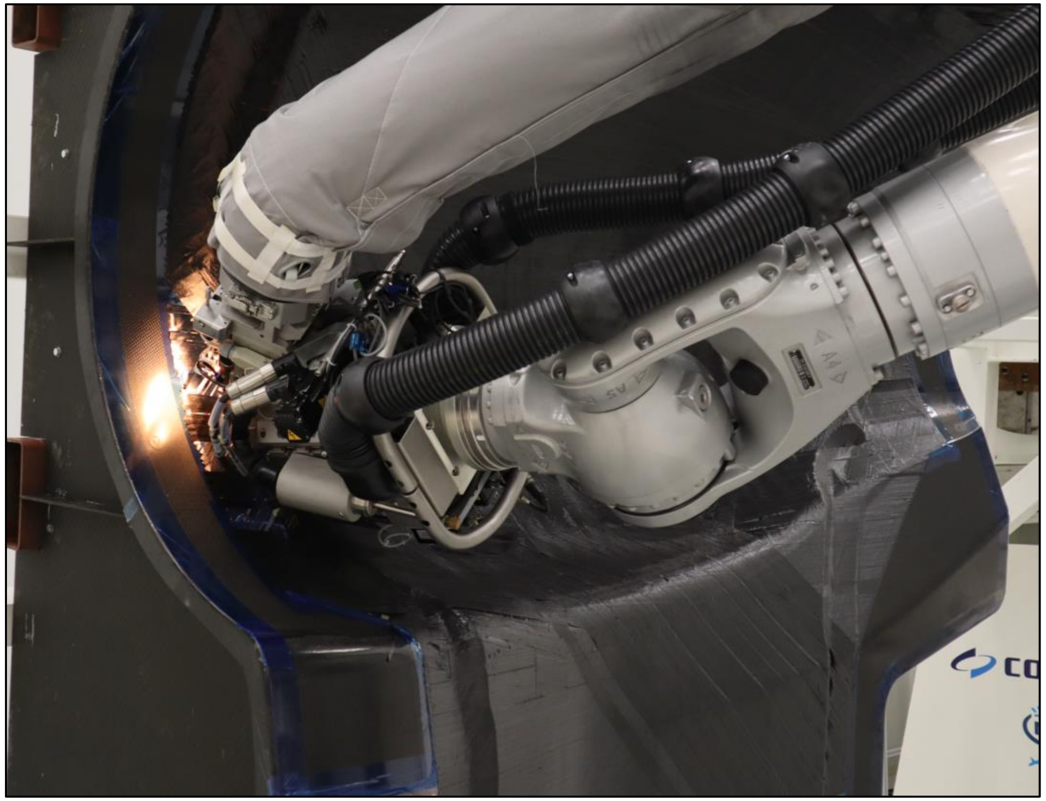


- Hand layup of the facing skin and bonding of the honeycomb core kit was carried out at Spirit Belfast
- AFP of the backing skin was the responsibility of NLR, Marknesse, NL
- NLR initially performed flat trials to evaluate optimum temperature and humidity conditions for the material

Automated Fibre Placement of Backing Skin







- Excellent Deposition accuracy and Material Tack

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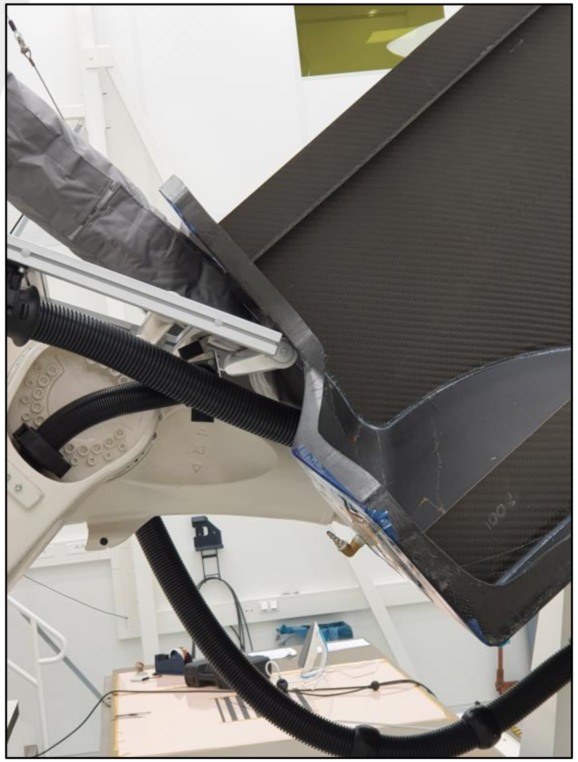
Automated Fibre Placement of Backing Skin



- Mould was extremely challenging in terms of space
- Removal of rectangular bracket was required as it became a collision risk (Not included in Coriolis Virtual Simulation)

Automated Fibre Placement of Backing Skin

- The component layup was successfully completed in full and on schedule

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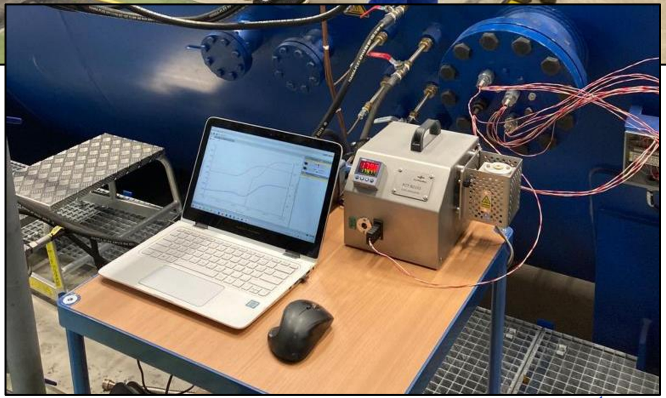
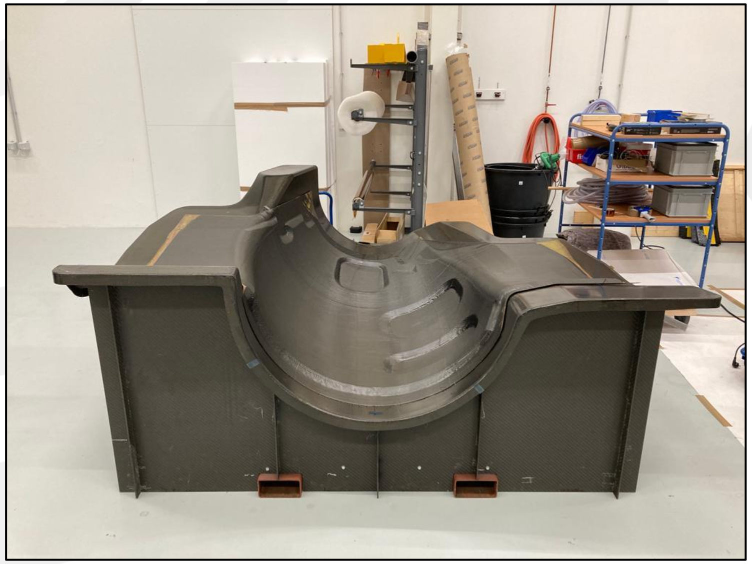
Autoclave Curing and Online Cure Monitoring

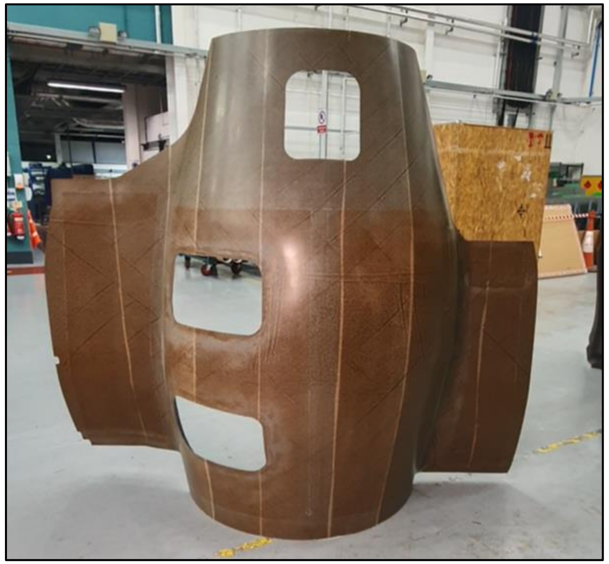


- Component was transported to Fokker-GKN for Cure
- Synthesites Cure Monitoring Technology was used to provide live feedback of the material degree of cure throughout
- Component was cured successfully

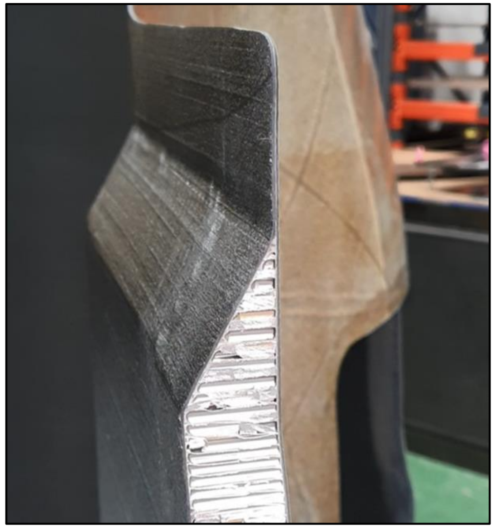
synthesites

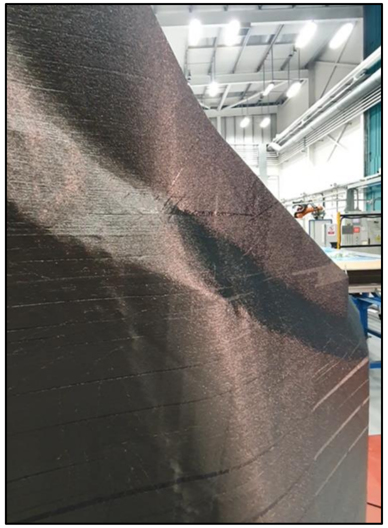
Successful Completion of Composite IFS Use Case





- Successful Completion of the Composite Inner Fixed Structure Use Case Demonstrator
- Finally, component was trimmed and inspected;
    - No Distortion
    - No Disbonds
    - No Porosity





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