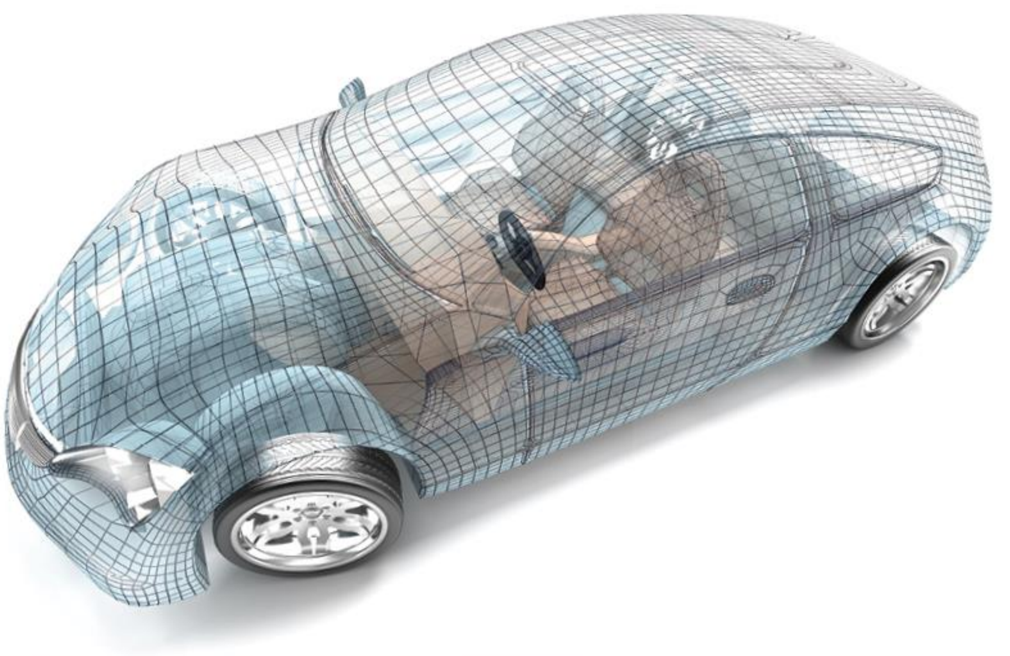
TCC 2020
THERMOPLASTIC COMPOSITES CONFERENCE

A VIRTUAL EVENT
APRIL 29 – MAY 1, 2020



Advancements in Process Automation and High Rate Manufacturing

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NATIONAL COMPOSITES CENTRE

Our ambition

Our vision: The NCC is a world leading authority on composites, bringing together the best minds and the best technologies, to solve the world's most complex engineering challenges

Our purpose: To accelerate the adoption of high value, sustainable engineering solutions in composites in order to stimulate global growth and enhance capability for the benefit of the UK

The National Composites Centre in numbers

2011
officially opened

£200m+
invested in capabilities

£36.7m
of the £200m invested in iCAP

10
New tailor-made technologies

2
NCC locations

17,500m²
at NCC HQ

4,250m²
at NCC Filton

350
composites engineers

150
engineers at ACCIS

55+8
members + major sectors supported

725
organisations engaged

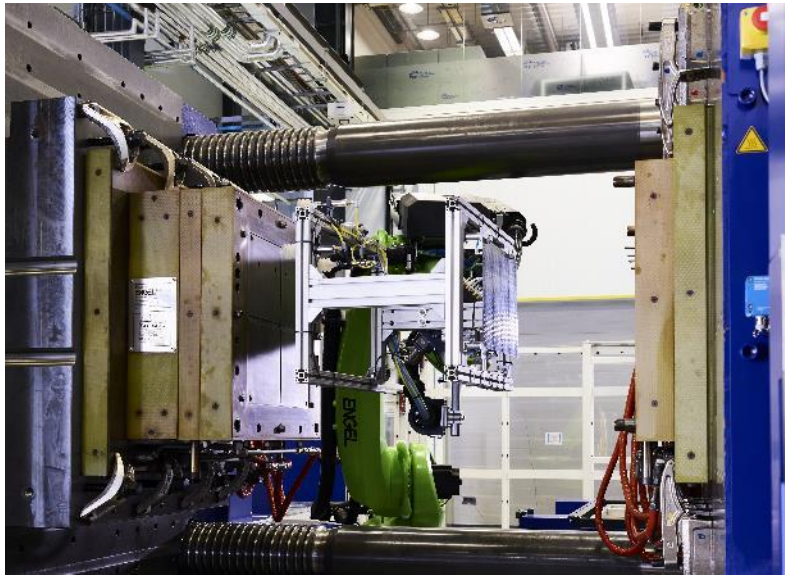
46%
of those are SMEs

Advancements in Process Automation and High Rate Manufacturing

AGENDA

Chapter 1

- NCC Braiding capability introduction
- Braiding automation (process monitoring)
- Commingled thermoplastics
- EB Auto - Commingled thermoplastic - Industry Case-study



Chapter 2

- NCC Overmoulding capability introduction
- Overmoulding automation and digital focus
- IR camera monitoring for processing thermoplastics laminate
- OBStruct - Overmoulding in Aerospace - Industry Case-study
- Conclusions/Summary
- Questions

Chapter 1

NCC Braiding Capability Introduction

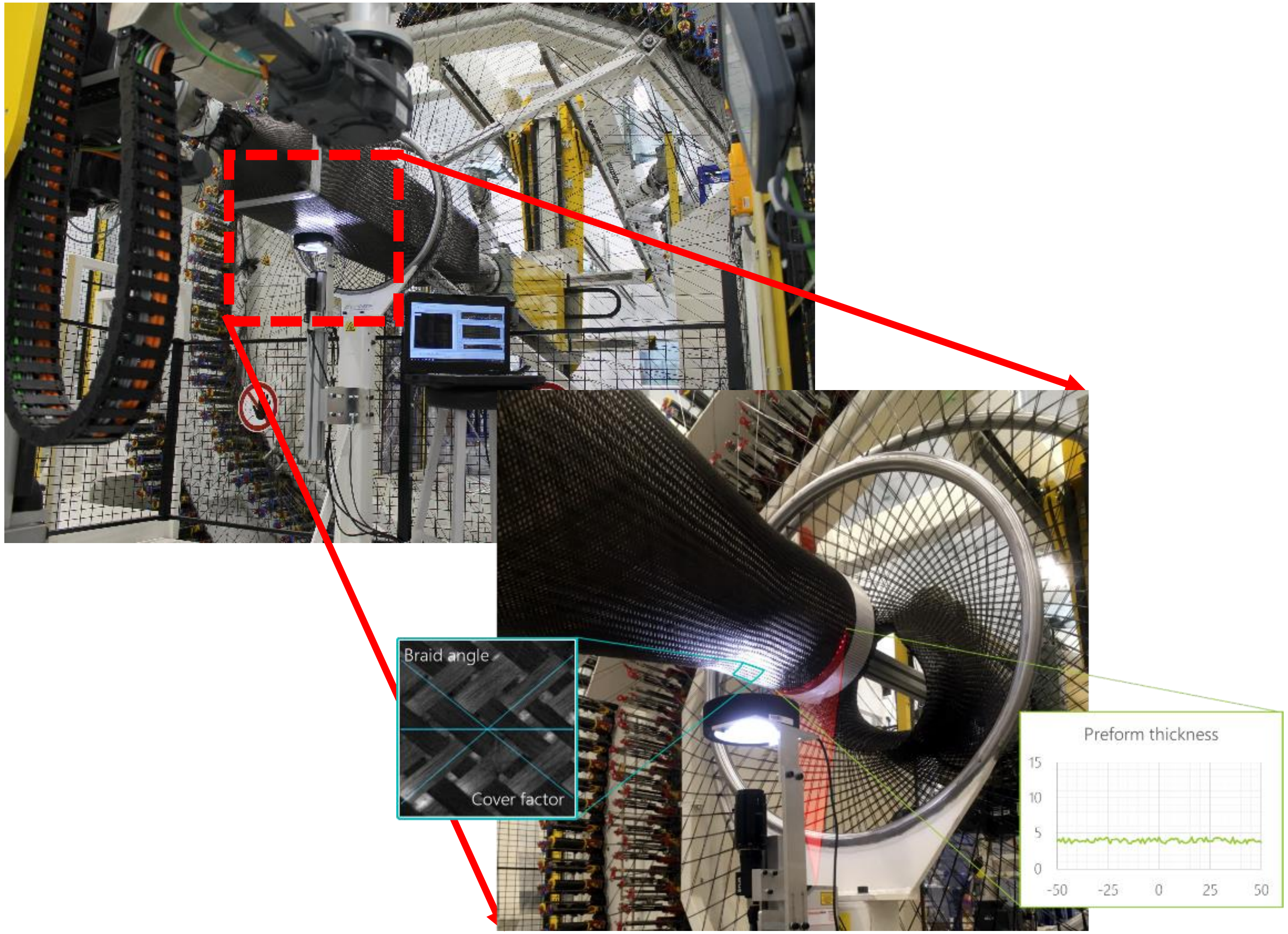
- The NCC has the only two ring braider in the UK
- Comprising 288 and 192 spools
- Two rings and a 10m long gantry enables us to braid complex circular, rectangular and convex sections
- Biaxial and triaxial, 3 patterns (diamond = 1/1, Regular = 2/2, Hercules = 3/3) are possible
- This process can achieve under normal operation fibre deposition rates of 50kg/h
- In theory up to several hundred kg/h is possible with larger FAW and additional axial tows
- Direct tow-to-preform deposition, near net-shape preforming, high rate production, high quality and repeatability, low material waste and post-braiding shaping are possible

Braiding automation (process monitoring)

- NCC's bespoke process monitoring platform developed for the over-braiding capability
- Enables layer-by-layer acquisition of data relevant to the quality of the deposited preform, e.g. braid angle, thickness
- Facilitates a greater understanding of relationships between material, process and product

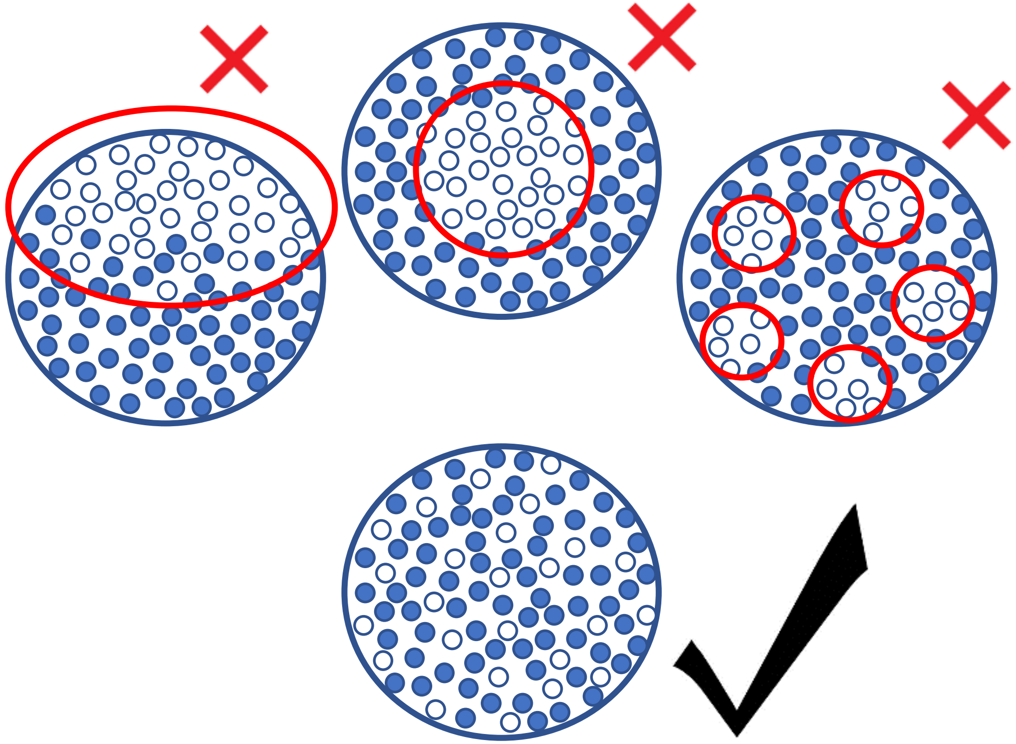
FUTURE ADVANCEMENTS

- Data-warehouse and data analytics
- Improve link between data generation and FE modelling of braiding process
- Improve braiding simulation: e.g permeability, structural FE



Commingled Thermoplastics

A commingled thermoplastic is a fibre tow/bundle composed of both thermoplastic and reinforcing fibres, produced in 'endless' length



BENEFITS

- Thermoplastic is in intimate contact with the reinforcement: low resin flow needed to achieve good consolidation
- In woven form is a more 'drapable' material compared to pre-pregs (semi-pregs), enables complex forming
- Cost-effective materials option for thermoplastic composites

CHALLENGES

- Maintaining even fibre distribution within bundle (during manufacture and processing), commingling tows is difficult
- Tow-to-tow friction and fibre entanglement
- Smaller tows are harder to process so 3K harder than 12K
- Material is more bulky than dry fibre so bulk management is harder, especially for a thick preform

Basalt Fibre Composites for the Automotive Industry (EB-Auto)

COMPOSITE BRAIDING mafic COATS NISSAN RGU ABERDEEN M.Wright & Sons Ltd. Engineered Textile Structures (Established 1860) IHI

Challenge

Lack of supply chain for basalt fibre and thermoplastic composite material formats, limited data availability for manufacturing processes parameters and mechanical/physical data to support manufactured parts. Basalt fibre composites combined with thermoplastic matrix materials such as polyamides have great potential for reducing cost in future automotive structures

Project Aim

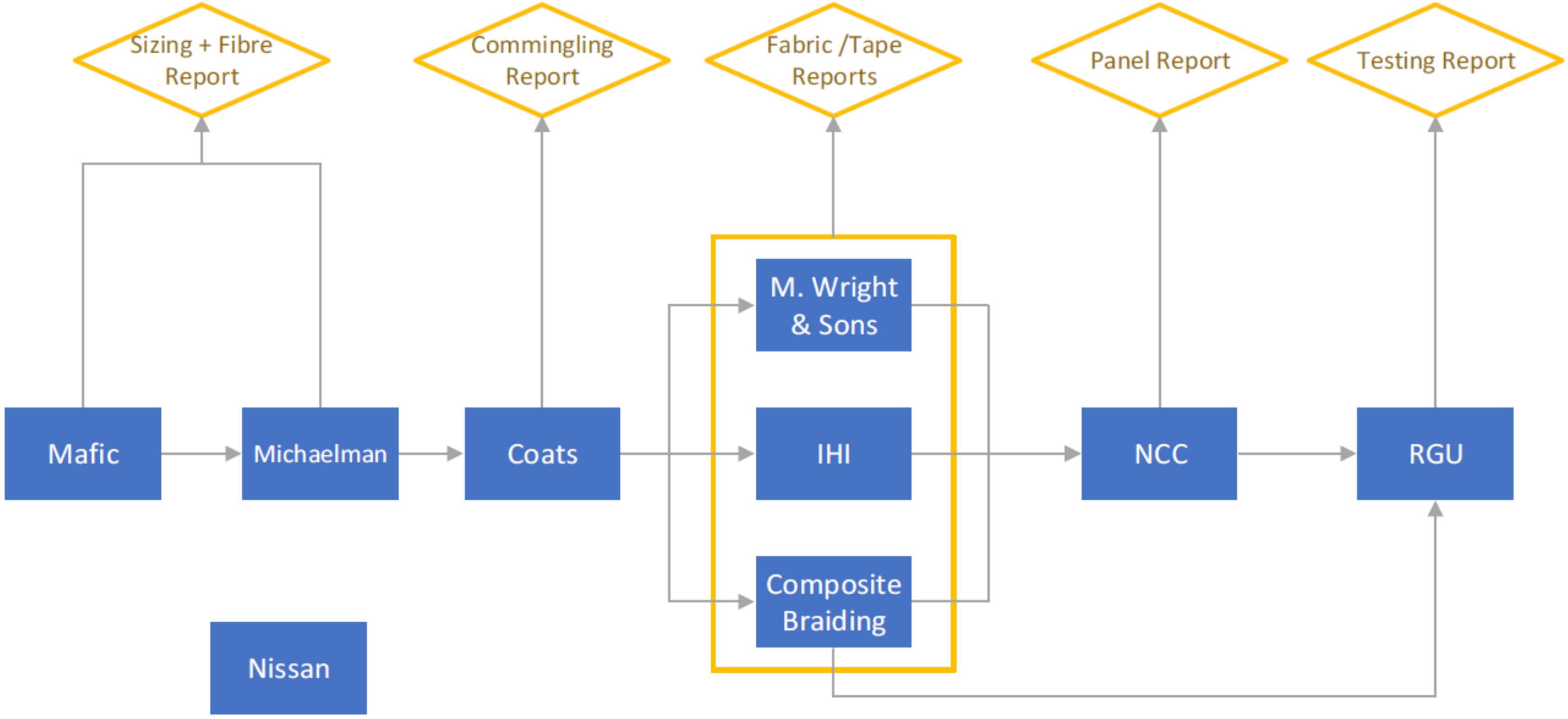
1. Manufacture basalt fibre(BF)/PA6 intermediate materials in a variety of formats. Including the use of commingled yarns in 3D-weaving and braiding
2. Use these materials for a variety of different deposition/manufacturing techniques to manufacture test panels/tubes
3. Characterise the mechanical and physical performance of manufactured tubes & panels and compare test data to similar architecture S2 glass/PA6 formats

Benefit

Provide data to support the use of BF/PA6 composites for automotive applications, increase confidence in manufacturing composites with this potentially cost beneficial material format, develop the supply chain for intermediate material formats including commingled yarns

Basalt Fibre Composites for the Automotive Industry (EB-Auto)

Work Breakdown Structure



Deliverables;

- Sizing and fibre analysis
- Commingling data
- Fabric/tape prototypes
- Panel manufacturing guide
- Coupon testing data

Material Formats

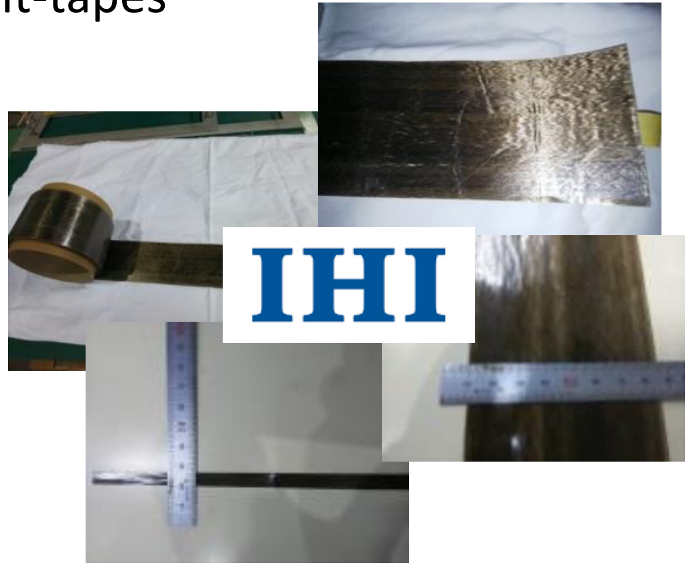
- Manufacture of basalt fibre yarns

Commingling with PA6 thermoplastic dry fibre

COATS

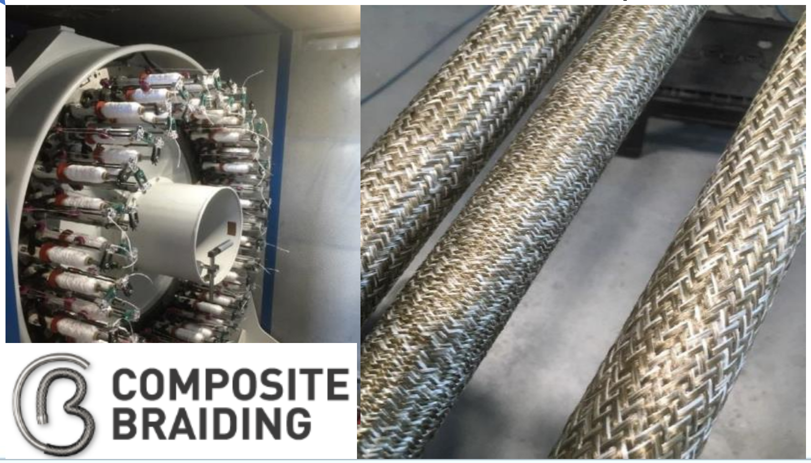
Commingled Yarns

Film laminating into 75mm (ATL) and 6.35mm (AFP) slit-tapes



3D woven fabric architecture

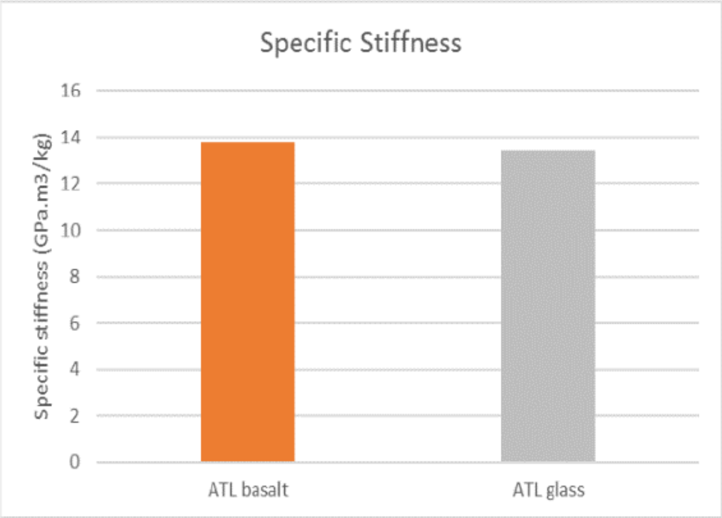
Braided tube architecture (30, 45 and 60°)

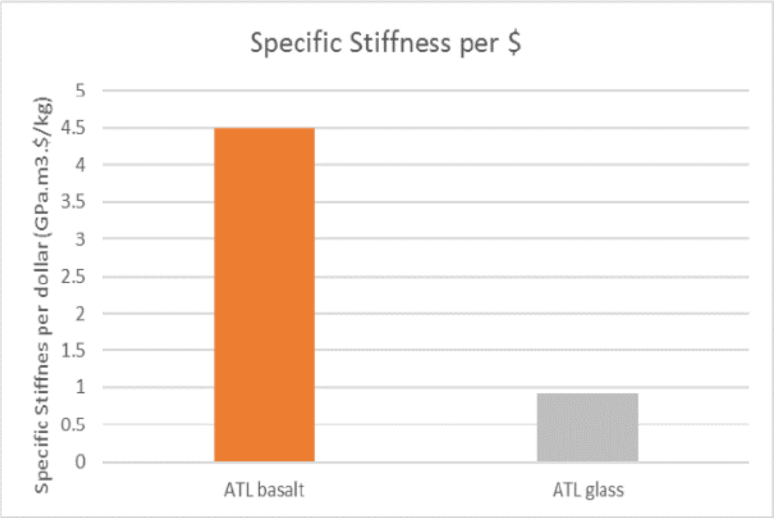


Conclusions

NISSAN · M.Wright & Sons Ltd. Engineered Textile Structures (Established 1860) · RGU ABERDEEN · IHI · COMPOSITE BRAIDING · mafic · COATS

- Commingling of basalt fibre and PA6 is possible and has been achieved within EB-auto
- ATL Basalt PA6 has been shown to exhibit stiffness properties superior to that of S2 glass at a fraction of the cost



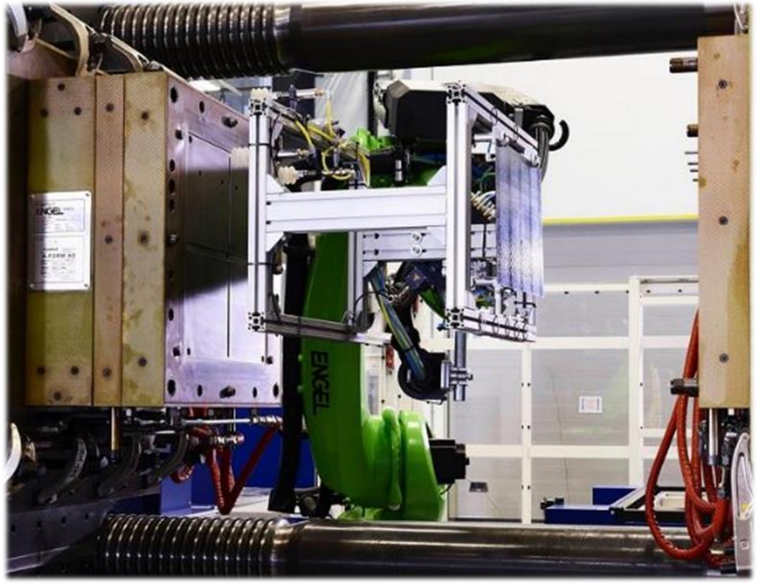


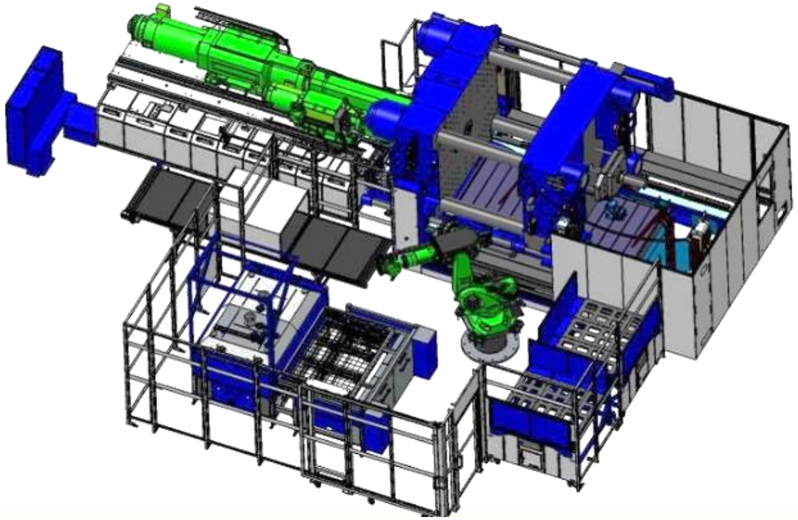
- There are now multiple supply chains for a wide range of BF/PA6 material formats (commingled braid, commingled 3D fabric, UD tape) coupled with increased interest in using basalt fibre composites

Chapter 2

NCC Overmoulding Capability Introduction

- Engel Duo overmoulding production cell
- 1700T Engel clamp unit (horizontal)
- Usable platen size: 1.8 x 1.4 m
- Two injection units
- Polymer injection shot volume: 135 to 6450 cm^3
- Barrel heating up to 425 °C
- Infra-red heating for blank/laminate
- KUKA 6-axes material handling/transfer automation
- Compound dryers and vacuum loading hoppers
- Gravimetric blending for pigment, powder additives and regrind
- Material granulator for pellet recyclate production





Processing thermoplastic laminate (organosheet) – Infra-red camera monitoring

- The NCC is developing a predictive model for part quality via thermoplastic degree-of-healing during overmoulding
- A critical input for modelling the overmoulding is the initial surface temperature map of the organosheet
- In designing experiments to validate the model, the NCC identified this as a critical blind-spot; the last witness of organosheet temperature was inside the IR oven, via spot pyrometer
- Subsequently, a number of operations occur which likely have a significant effect on the sheet temperature:
  - Oven tray moves out
  - Robot makes contact with sheet at a few distinct locations
  - Sheet is transferred at speed through free space
  - Sheet is hung on metallic pins in the horizontal press
- “Eyes on” sheet surface temperature was therefore required, at a point closer to the tool
- This data used to inform process modelling and simulations to improve predictive accuracy

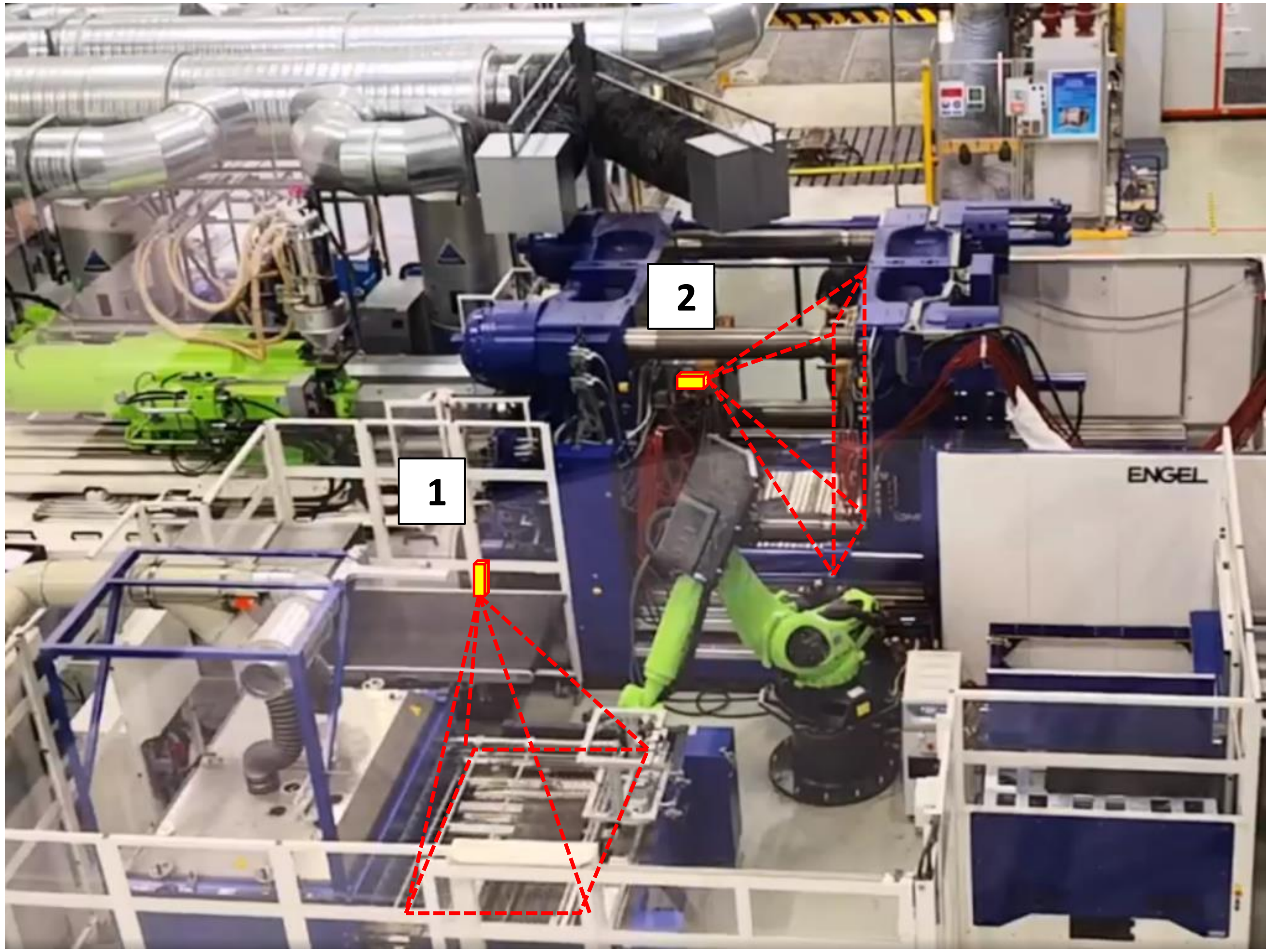
Thermography Setup: 1/2

Twin IR camera arrangement:

- Camera 1: above organosheet at oven
- Camera 2: in front of sheet immediately prior to insertion into tool

Considerations for camera positioning:

- Lens FoV; must capture whole sheet
- Lens incidence on sheet; normal preferred
- Line-of-sight obstructions, e.g. robot end-effector framework, IMM clamp unit tie bars, tool body, etc.
- IR reflection avoidance; incorrect triggering, e.g. off high-polish metallic tool cavity surface



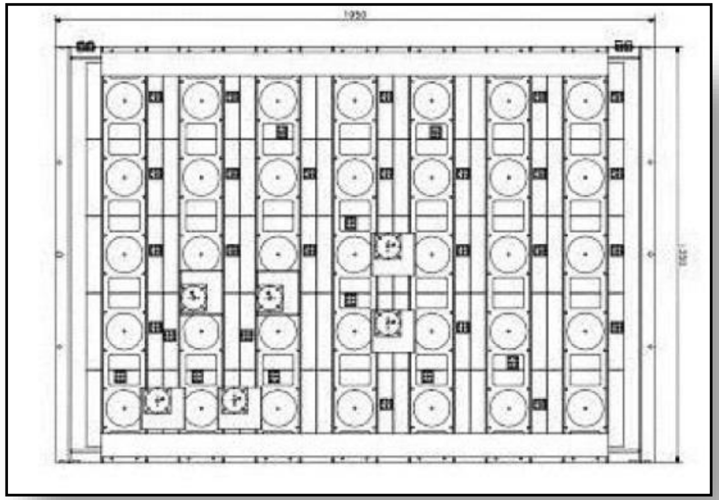
Thermography Setup: 2/2

- Single image captured for camera 1 and 2 every "cycle", i.e. per-part
- Camera control and raw data capture via Micro-Epsilon "TIMConnect" software on user HMI
- Image capture enabled by setting up a temperature alarm for a specific zone-of-interest on each camera feed; when a hot organosheet passes through this area, the software exports IR data
- Operator also sees both images from the last part, for online process monitoring information purposes
- Thermal data, in .csv format, exported to NCC Data Warehouse for automatic post-processing via a Python script plug-in


```python
#%%  Extract temperature data from IR camera CSV


def extract_temperature_data(camera, program_number, shot_number, heightwise_pixels, lengthwise_pixels):

    #Extract temperature data from csv
    temperature_data = pd.read_csv(os.path.join(root_path,
                                                r"Overmoulder\Data warehouse\2 - Primary data\Thermal Camera "+str(camera)-
                               header=None, sep=';')

    #Remove columns of empty values
    temperature_data = temperature_data.dropna(axis=1)

    #Transform dataframe into a numpy array
    temperature_array = temperature_data.values

    #Initiate a maximum average for organosheet extraction loop
    max_average=1

    #Slide window through numpy array to find set of values with the dimensions of the organosheet
    #and the highest temperature average
    for row in range(np.size(temperature_array,0)-lengthwise_pixels+1):
        for column in range(np.size(temperature_array,1)-heightwise_pixels+1):
            array = temperature_array[row:row+lengthwise_pixels, column:column+heightwise_pixels]
            array_average = np.mean(array)
            if array_average > max_average:
                max_average = array_average
                max_array = array

    return max_array
```

Example of Data Interrogation: 1/3

- IR oven has a pixelated heating control zone arrangement, each zone having its own separate bulb array
- The incumbent positioning of the organosheet, when the twin camera system was setup, straddled 9 zones in the corner

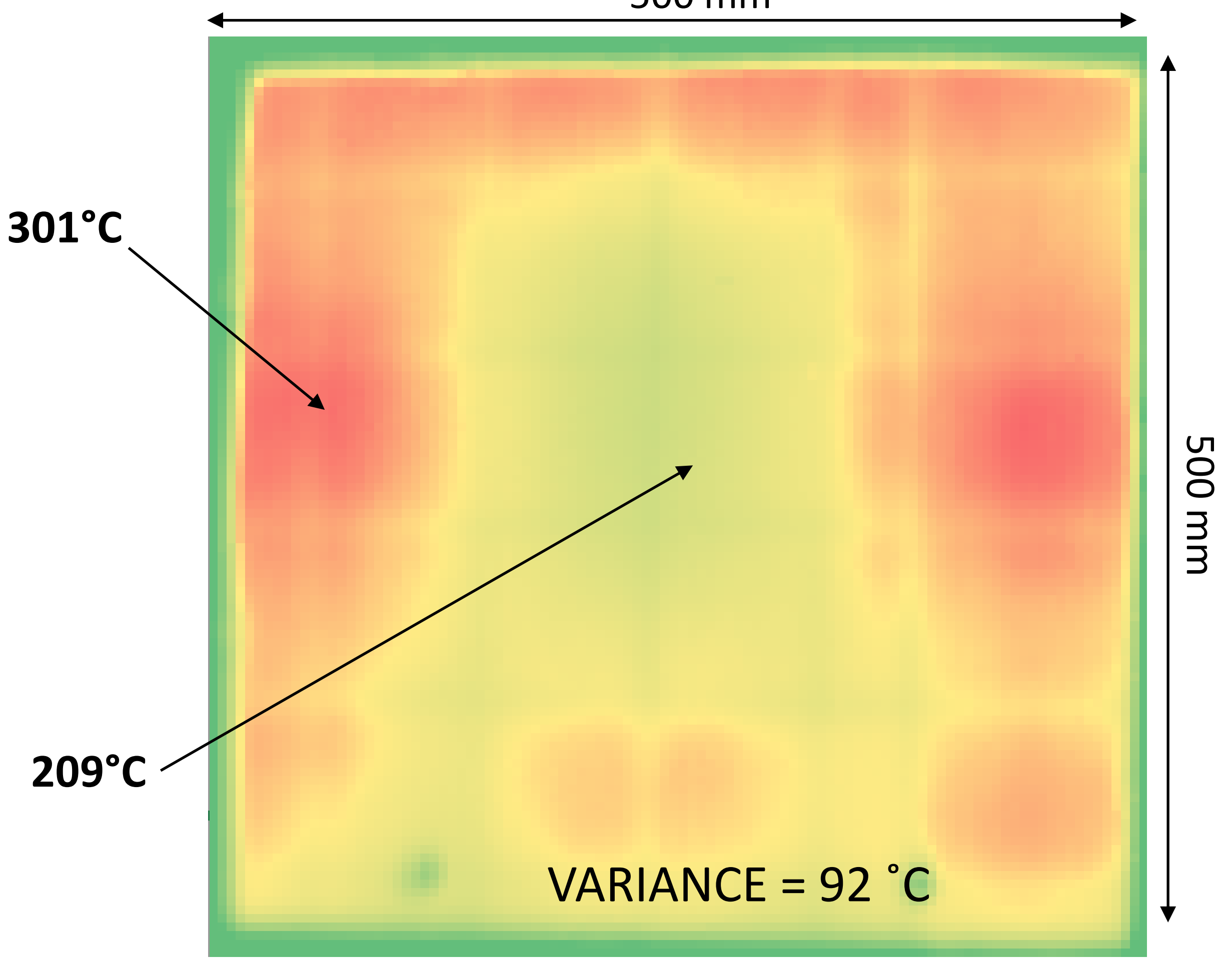


1 +RA01 -E561	2 +RA01 -E563	3 +RA01 -E566	4 +RA01 -E568	5 +RA01 -E571	6 +RA01 -E573	7 +RA01 -E576
8 +RA01 -E578	9 +RA01 -E581	10 +RA01 -E583	11 +RA01 -E586	12 +RA01 -E588	13 +RA01 -E591	14 +RA01 -E593
15 +[illegible] -[illegible]596	16 [illegible] -E598	17 [illegible]01 -E[illegible]1	18 +RA01 -E603	19 +RA01 -E606	20 +RA01 -E608	21 +RA01 -E611
[illegible]2 +[illegible]A01 -[illegible]613	23 +RA01 -E616	2[illegible] +R[illegible]01 -E[illegible]8	25 +RA01 -E621	26 +RA01 -E623	27 +RA01 -E626	28 +RA01 -E628
[illegible]9 +[illegible]A01 -E631	30 [illegible] -E633	3[illegible] +R[illegible]01 -E636	32 +RA01 -E638	33 +RA01 -E641	34 +RA01 -E643	35 +RA01 -E646

Example of Data Interrogation: 2/3

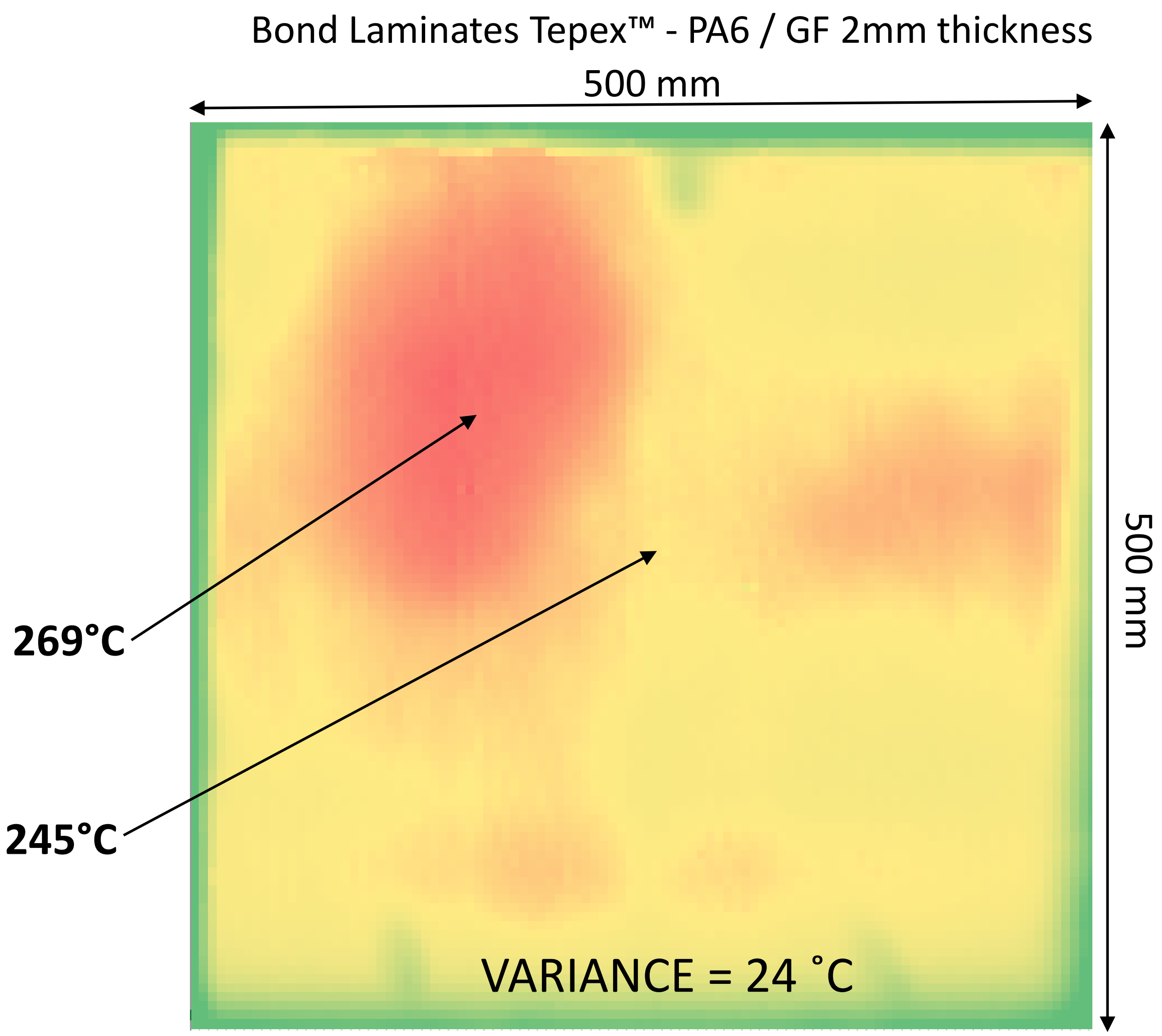
- The thermal-image taken from Camera 1 drew attention to a large variability in sheet surface temperature
- Approaching 90-100°C, this variability is of high significance for model validation accuracy
- The central "cold spot" exactly corresponds to one array of IR bulbs, suggesting a defect or failure that was not flagged by any other monitoring method
- Also perceptible is a grid pattern. This is the heat-sink witness of the steel wires that the organosheet rests on during heating and transfer

Bond Laminates Tepex™ - PA6 / GF 2mm thickness



Example of Data Interrogation: 3/3

- Using the thermal-image over a short test run, a more optimal position over the IR array was established
- This new arrangement was validated by interrogation of the new thermal-image, achieving a much more even temperature distribution and tighter range
- 20-30˚C more acceptable variation
- This enables greater confidence in validation of the overmoulding simulation
- Further part and process development at the NCC now utilises the twin camera system at an early stage to plan and model an optimal process



Overmoulding for Butt-Joined Aerostructures (OBStruct)

Challenge

Low maturity and confidence in the application of high volume thermoplastic overmoulding processes in the aerospace industry. High cycle times currently limits the adoption of butt jointed thermoplastic technologies in higher volume aerospace and defence programmes

Project Aim

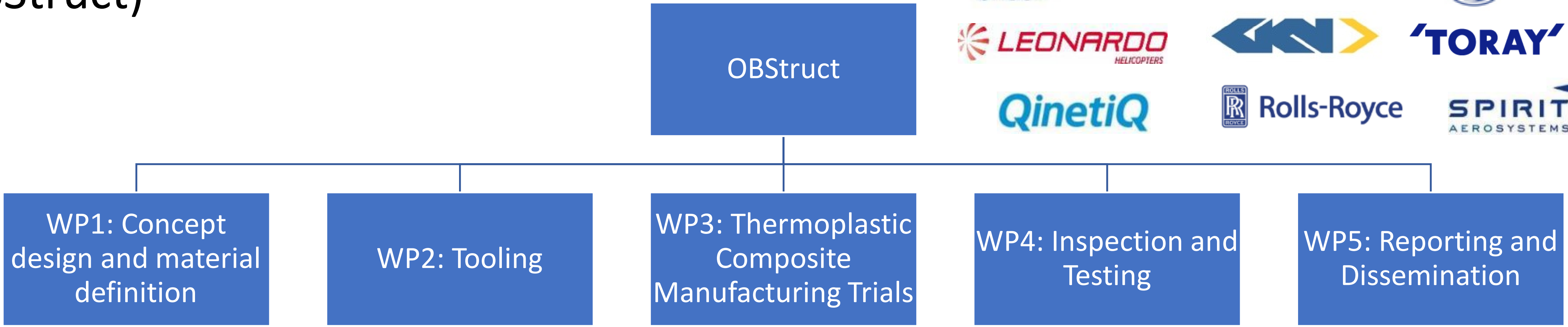
Show that a stiffened panel, fabricated with overmoulded butt joints can conform to both repeatability and quality control expectations to meet aerospace requirements. Demonstrate an improvement to cycle time, provide NDT and mechanical testing validation of manufactured demonstrators

Benefit

Higher volume manufacture and reduced costs

Increased maturity of overmoulding technology through better process knowledge, how to scale up to larger components and reduction of part count through fabricated overmoulded butt joints

Overmoulding for Butt-Joined Aerostructures (OBStruct)



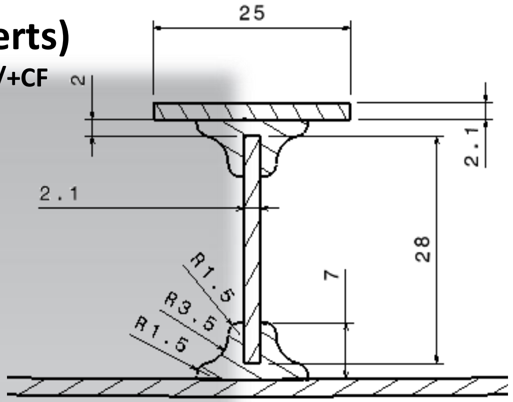
Deliverables

- Overmoulded component design
- Tool design and manufacture
- New production methodology
- Technology demonstrator of a stiffened panel fabricated with overmoulded butt joints
- Route to scale up to large components

Overmoulded ‘butt-joined’ stiffened panel demonstrator

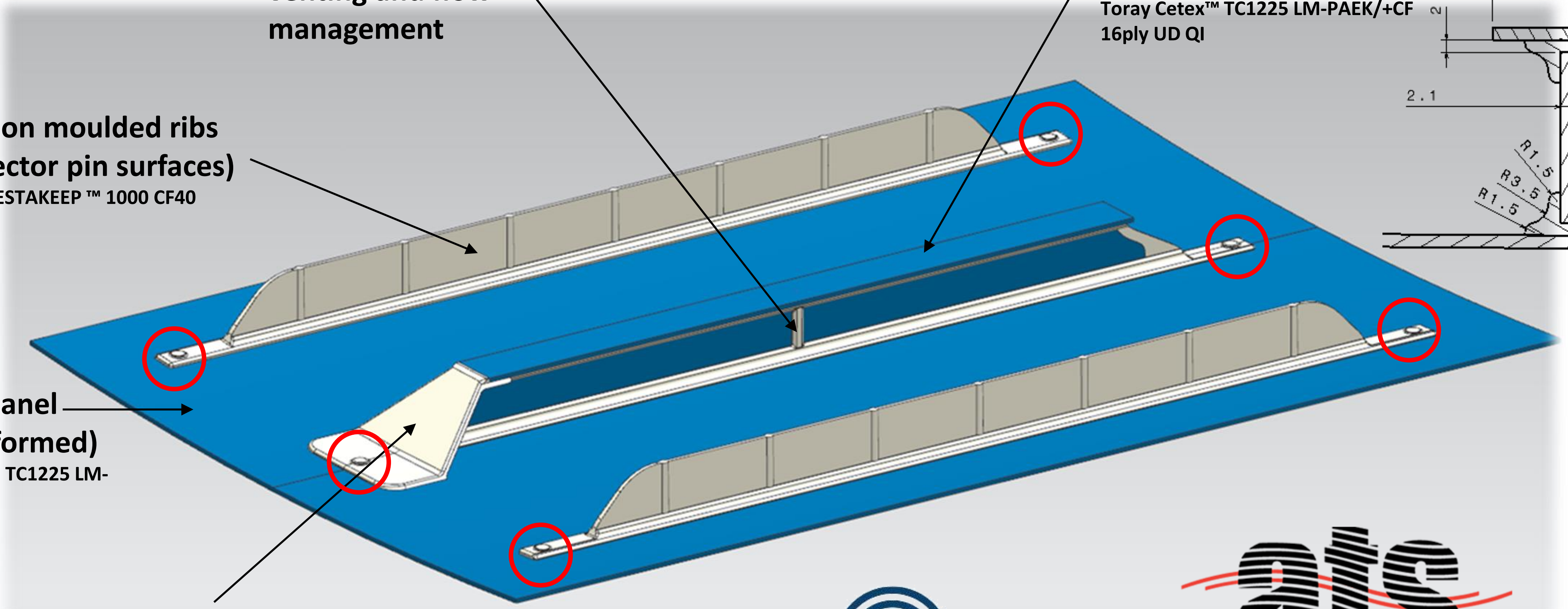
Concept central venting and flow management

Integrated T-Stringer (solid embedded inserts)
Toray Cetex™ TC1225 LM-PAEK/+CF 16ply UD QI



Injection moulded ribs (w/ejector pin surfaces)
Evonik VESTAKEEP ™ 1000 CF40

Curved panel (thermoformed)
Toray Cetex™ TC1225 LM-PAEK/CF 16ply UD QI



Injection moulded z-cover (reducing stringer peel) (removing secondary assembly)
Evonik VESTAKEEP™ 1000 CF40

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Considerations - Tooling design

- Initial geometry cross-section
- Suggested materials combination
- Riser blocks in tool to withdraw from undercut and demould the part

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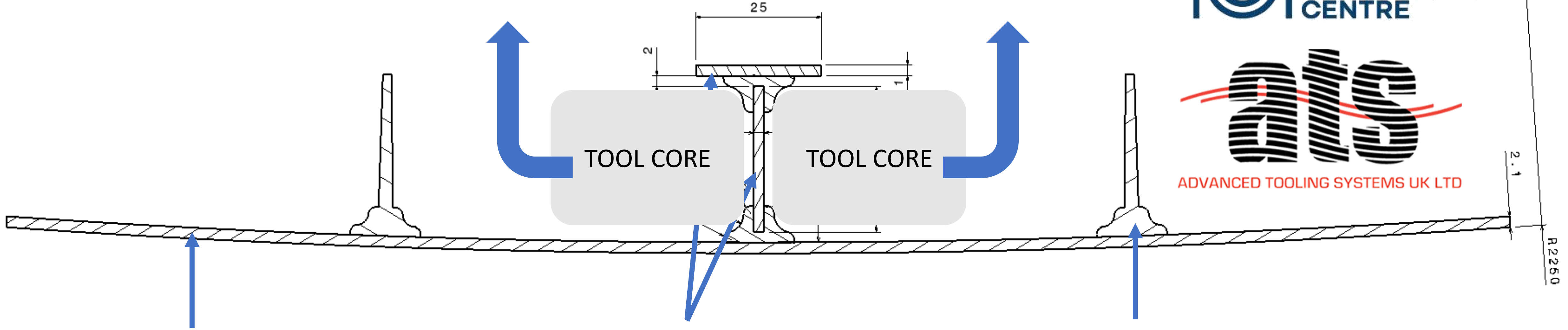

Laminate 16ply QI UD LM-PAEK (eg. Toray TC1225)

Melt temp; 305 ˚C Process temp; 325 ˚C

Laminate QI UD LM-PAEK (eg. Toray TC1225)

Melt temp; 305 ˚C Process temp; 325 ˚C

IM compound CF/PEEK

Process temp; ~385 ˚C

SUMMARY

- NCC is operating and researching some world-leading technologies for thermoplastic composites processing
- NCC is developing new automation, process modelling and data capture technologies for a variety of composite manufacturing processes
- Including thermoplastic composite methods such as overmoulding and the processing of commingled thermoplastic yarns by braiding
- NCC has developed a process monitoring system for braiding which can assess fibre angle and preform thickness
- Commingling and braiding of basalt fibre and PA6 is possible and has been achieved within consortia project EB-auto
- NCC experienced team with partner ATS and members are demonstrating new applications for overmoulding stiffened aerostructres within the OBStruct project
- The above NCC overmoulding research (and other overmoulding/forming projects) are supported by a new automated IR camera process monitoring system for data capture of organosheet temperature uniformity