NATIONAL COMPOSITES CENTRE

Welcome to the Technology Pull-Through Launch Webinar

We will start shortly after 13.00

4 October 2023

Agenda

13.00	Welcome and introduction to the NCC	Matt Scott
13.05	Introduction to TPT and the TPT process	Roger Walker
13.15	Our Sustainability Strategy	Tim Young
13.25	Our Hydrogen Strategy	Marcus Walls-Bruck
13.35	Our Digital Strategy	Marc Funnell
13.45	Our High-Temp / Defence Strategy	Konstantina Kanari
13.55	Break and poll	Matt Scott
14.10	Voice of an academic	Lee Harper
14.20	Questions, including poll results	Roger Walker
14.35	Conclusions and thanks	Roger Walker
14.45	End	-

NATIONAL COMPOSITES CENTRE

Brief introduction to the National Composites Centre

Matt Scott NCC Chief Engineer for Capability

4 October 2023

High Value Manufacturing Catapult

CATAPULT
High Value Manufacturing

7 centres	**17** locations
27 technologies	**3500+** people
£800m assets	**Over 2000** projects per year
1/3 government funded	**2/3** industry funded

£500m
industry R&D linked to HVMC per year

1. AFRC – ADVANCED FORMING RESEARCH CENTRE – UNIVERSITY OF STRATHCLYDE
2. cpi
3. NUCLEAR AMRC
4. AMRC – ADVANCED MANUFACTURING RESEARCH CENTRE
5. mtc – Manufacturing Technology Centre
6. WMG – THE UNIVERSITY OF WARWICK
7. NATIONAL COMPOSITES CENTRE

Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center

Catapult Mission: Bridging the Valley of Death

Early innovation and research	Applied research and development	Technology implementation through to successful operations
TRL 1, TRL 2, TRL 3	TRL 4, TRL 5, TRL 6	TRL 7, TRL 8, TRL 9
Research establishments	NCC	*Private sector*

The National Composites Centre

Our Vision

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

Our Purpose

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

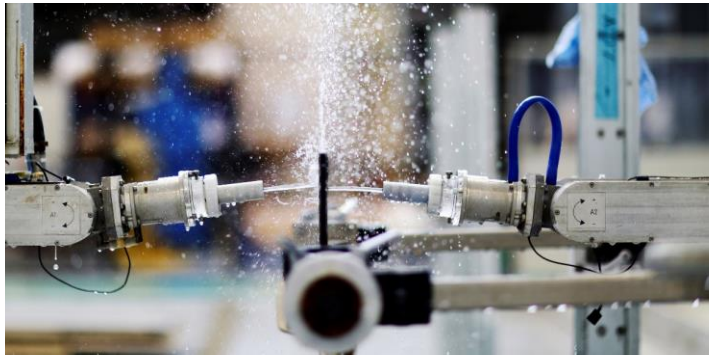
£200m invested in capabilities

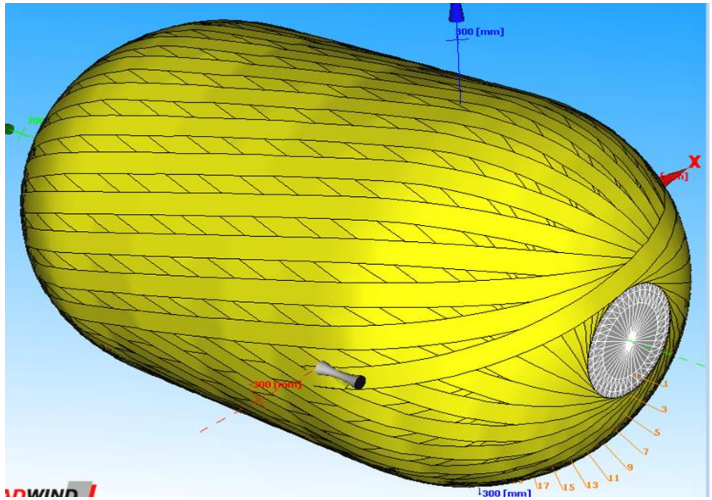
700+ organisations supported

600+ composites specialists

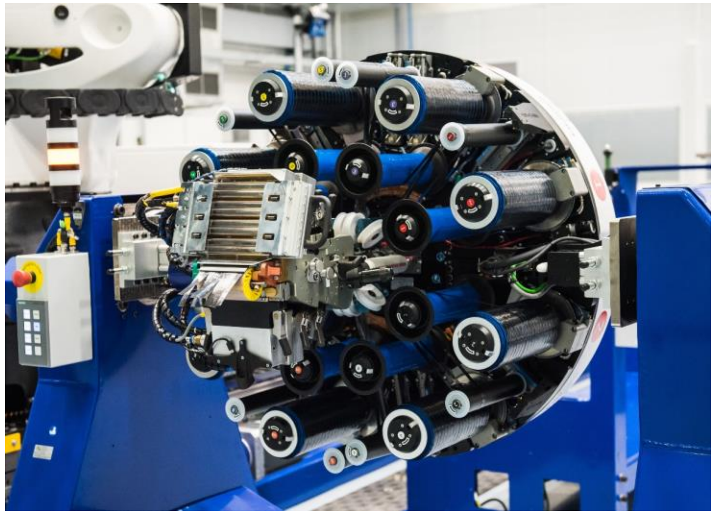
60+ university partners

Capabilities





Europe’s leading composite innovation centre



NATIONAL COMPOSITES CENTRE

NCC Technology Pull-Through Programme: Transitional Research in Action

Roger Walker NCC TPT Programme Manager

4 October 2023

Technology Pull-Through: What is it?

- A technology development programme to stimulate the transition of suitably mature technologies to industry
- Scope is technologies and methods ready to leave the lab environment (TRL3-4)
- Projects are 12 months long, are funded and managed by the NCC, and conducted primarily by NCC
- Background IP stays with the source universities, foreground IP is shared

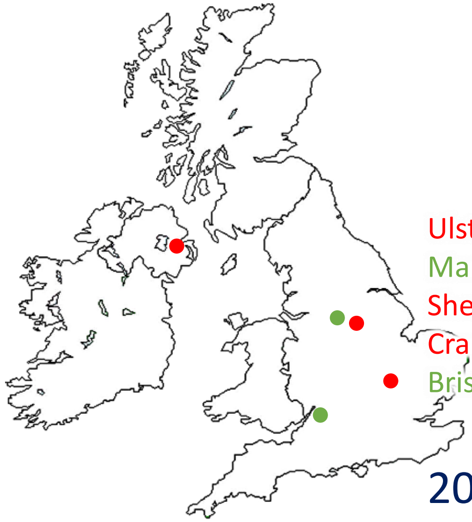
Technology Pull-Through: History

- First programme launched in 2017
- 23+ technologies matured – including:
  - Continuous Tow Shearing — University of BRISTOL
  - HiPerDif — University of BRISTOL
  - SimpleCure — University of BRISTOL
  - Dielectric sensors — Cranfield University
  - Dismantlable joints — OXFORD BROOKES UNIVERSITY
  - Bio-derived thermoplastics — UNIVERSITY OF BATH

Down-selection process includes CIMCOMP KEC

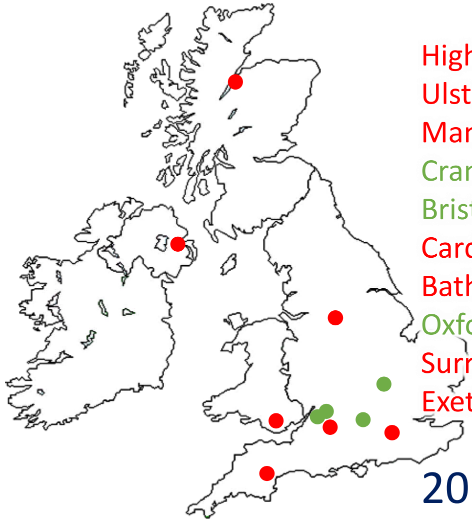
~£2.2m total invested in upcoming technologies over last 5 years

Geographic Spread



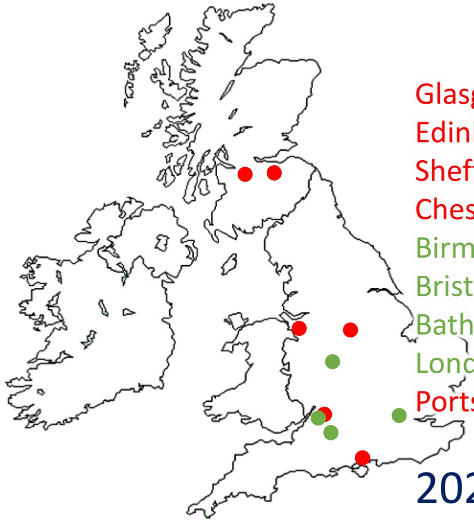
Ulster
Manchester
Sheffield
Cranfield
Bristol (UoB)

2018-19



Highlands
Ulster
Manchester
Cranfield
Bristol (UoB, UWE)
Cardiff
Bath
Oxford
Surrey
Exeter

2019-20



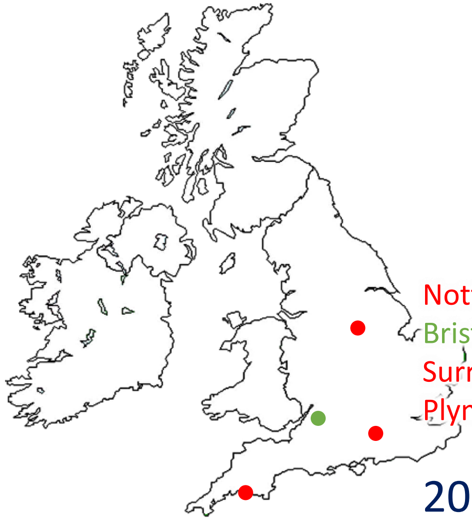
Glasgow
Edinburgh
Sheffield
Chester
Birmingham
Bristol (UoB, UWE)
Bath
London (UCL)
Portsmouth

2021-22

- Launched projects
- Applications received

Liverpool
Nottingham
Birmingham
Bristol (UoB, UWE)
London (UCL)
Portsmouth
Exeter

2022-23



Nottingham
Bristol (UoB)
Surrey
Plymouth

2023-24

Technology Pull-Through **2022-23**

- Two TPT projects kicked off for 2023-24
- Both directly aligned with NCC composites strategy

MARKET PULL

TECHNOLOGY PUSH

- Market drivers
- Sector trends
- Sector platforms
- Enabling products
- Technology challenges
- Technology themes
- Technologies

NCC's current
Technology Challenge THEMES

Digital

Sustainability

Hydrogen

Harsh Environments

Global-to-Local Forming Simulation

Digital

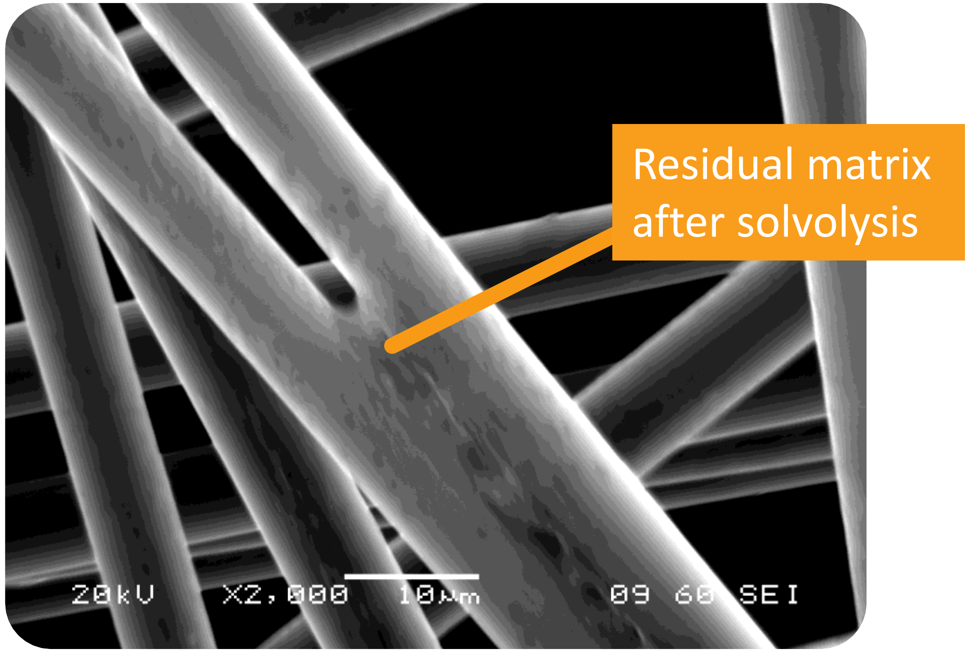
- ✓ Dr Lee Harper @ University of Nottingham working alongside Dr Jonathan Belnoue @ NCC/(UoBris)
- ✓ Key technology contributor to large aerospace manufacturing
- ✓ Directly supported national NCC CR&D project
- ✓ Off the shelf software benchmarking together with new software process development

The University of Nottingham

Solvolysis Recycling of Composites

Sustainability

- ✓ Prof Gary Leeke @ University of Birmingham
- ✓ National expert in solvolysis helped to build a strong NCC chemical recycling foundation



UNIVERSITY OF BIRMINGHAM

Technology Pull-Through **2023-24**

- Next year’s programme will CONTINUE with new academic proposals

- Selection criteria will include:
  - ✓ Technology Readiness Level (3-4)
  - ✓ Alignment with Technology Challenge Themes
  - ✓ Viability and impact for future industrial application
  - ✓ Intellectual Property and freedom to operate

Technology Pull-Through **2023-24**

- Application process to commence in TWO WEEKS: 16 October 2023

- Application page will be circulated on 16 October when call opens

NATIONAL COMPOSITES CENTRE

NCC Sustainability Outlook

Tim Young NCC Head of Sustainability

4 October 2023

Sustainability Vision and Missions

Sustainability

Our Vision: **Enable global sustainability initiatives through three core missions**

End goal: **Domestic sovereign technologies with a global market**

Create UK competitiveness in manufacture of re-imagined sustainable products essential to the delivery of net zero

Enable conditions for investment in green industries and technologies, delivering reduced cost, energy and waste and value to society

Secure and Protect resilient supply chains through circular, commercially viable exploitation of UK research and technology strengths

Sustainability Vision - background

Sustainability

Net Zero UK current emission stats

24 % Transport
Road Transport, Railways, Domestic aviation, Shipping, Fishing, Aircraft Support Vehicles

21% Energy
Fuel combustion (Gas/Coal), Nuclear, Renewables

18% Business
Combustion in industrial/commercial, industrial off-road machinery, refrigeration, aircon

16 % Residential
Fuel combustion for heating & cooking, aerosols, inhalers, garden machinery

11% Agriculture
Livestock, agricultural soils/fertiliser, stationary combustion, off-road machinery

9% Other
Waste management, industrial processes (cement, ammonia, lime), public buildings

Key Trends

Energy use
- Storage (H2, Electric)
- Transportation (H2)
Infrastructure
Carbon capture

Energy creation
- Wind & renewables
- Nuclear & fusion
- Alternative fuels

Reduction / Optimisation
- Insulation (new & retrofit)
- New heating systems
- Process optimisation (e.g. manufacturing)

Products from natural resources
- Bio-fuels
- Methane/hydrogen
- Natural feedstocks (e.g. bio-polymer, lignin)

Enabling products from waste
- Recycled product / materials / fuels
- Coal offsetting (plastics in cement kiln)

Challenge Interventions

Delivering sustainable product designs

Reducing impact, optimisation and adoption of state-of-art

Enabling products from CC, waste & natural resources

What does a Sustainability Innovation programme deliver?

Creating UK competitiveness in manufacture of re-imagined sustainable products essential to the delivery of net zero

Enabling the conditions for investment in UK competitive manufacturing through the reduction of cost, energy and waste and value to society

Secure and Protect competitive UK supply chains and the onshore of critical infrastructure and technologies through circular, commercially viable, local supply chains and utilise UK strengths in materials research and waste

Sustainability

Sustainability

Digital
- Make LCA easier & accessible
- Measure and tracking
- Manufacturing optimisation

Sustainable design
- Credibility assessment (is it greenwashing? / EOL viability assessment)

New Materials
- Sustainable materials for specific products (e.g. hydrogen tanks/pipes)
- Materials for end-of-life
  - Separation / disbonding / recyclability
- High performance Drop-in replacements
- Technologies that increase performance or durability
- Improved processability

Re-lifing technologies
- Requalification
- Post-process technologies – how to handle reclaimed fibres before manufacture
- Re-lifing / reforming of thermoplastic composites

Manufacture with recyclate into products
- Increased V_f & control of rFibre products
- Short bobbin use
- Prediction of short fibre
- “r”intermediates and “r”matrices

Sustainable manufacture
- Remove waste (e.g. consumables)
- Reduce harm (volatiles, toxicity, cleaning products)
- Quantify & reduce energy / costs
- Low energy heating technologies

Underpinning → Design for S → Future Materials → End of Life → Sustainable Manufacture → Product impact

Sustainable Design & predictive modelling
- Materials data & appropriate characterisation
- Recycling requirements 4 design
- Designs / disassembly concepts

Recycling Technologies
- Reclamation, of both fibre and matrix
- Waste product identification
- Post reclamation treatment of fibre
- Recyclate quality assurance & categorisation

End-of-life
- Disbonding/dismantling
- Fibre handling & chopping
- Separation & identification technologies

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NCC Hydrogen Outlook

Marcus Walls-Bruck NCC Head of Hydrogen

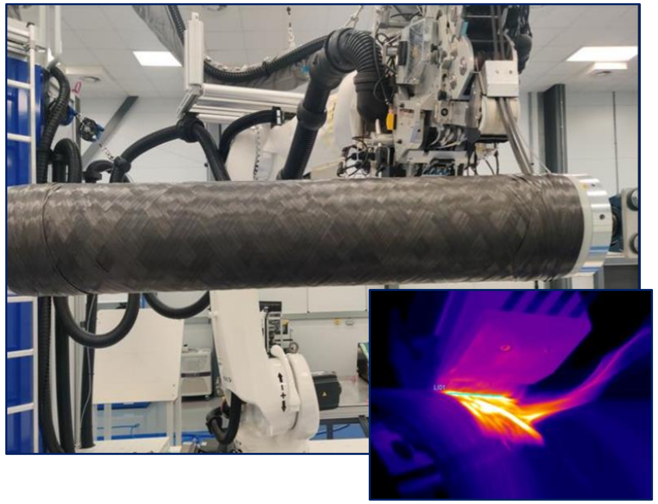
13 September 2022

Hydrogen focus areas at NCC

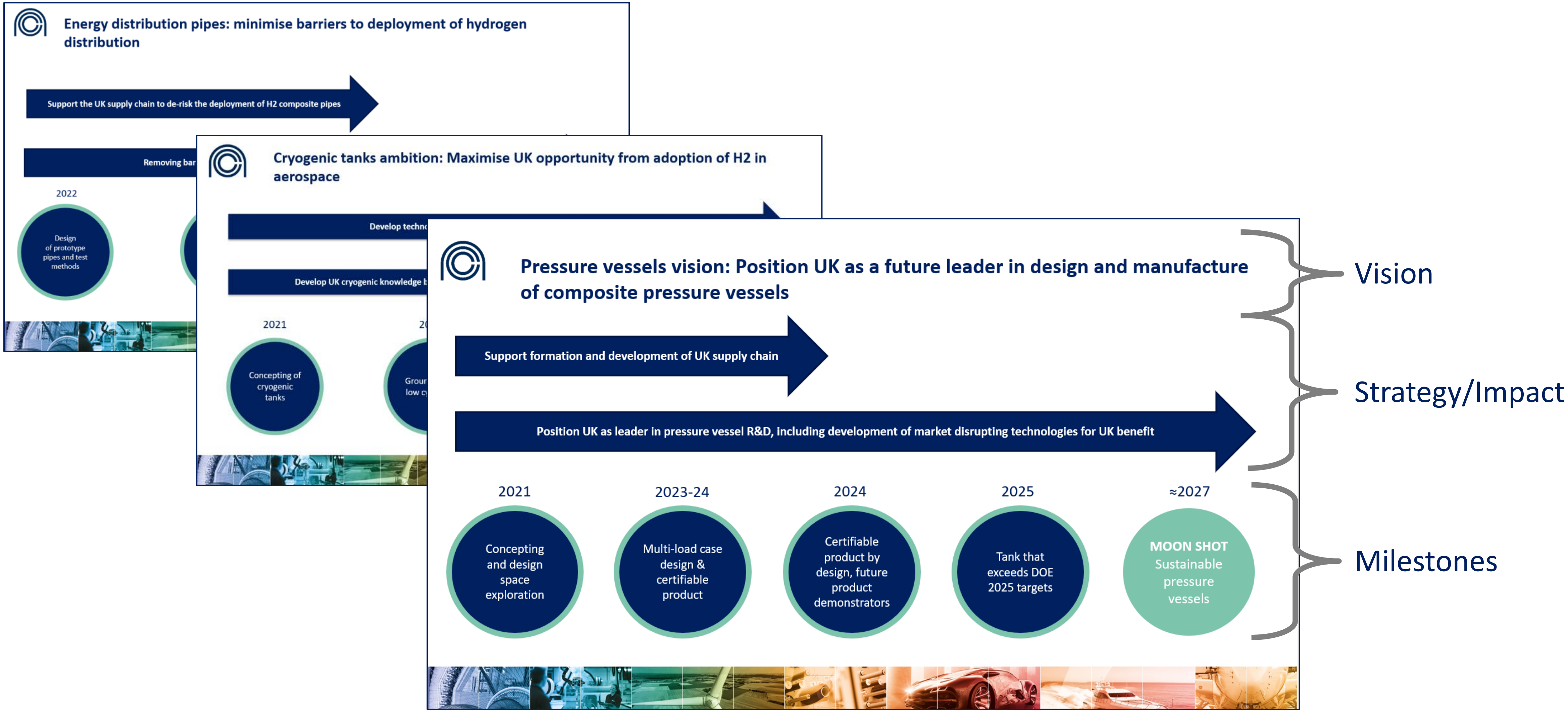
Pressure vessels

Cryogenic tanks

Distribution pipes



Multi- year strategy for each of the three priority products



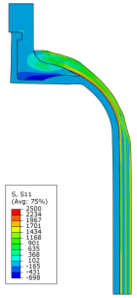
Pressure vessels – what are we doing?

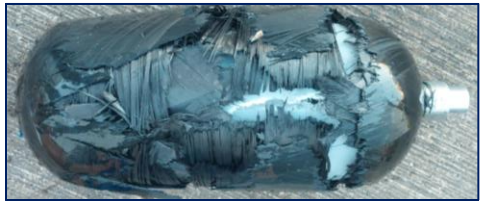
Developing ability to design pressure vessels to meet certification standards

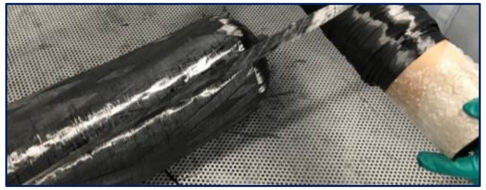
- Full product capability under development: **Design – Manufacture – Test**
- Partnering to develop UK Type 4 liner capability

Future technology

- Recovery of continuous fibre from end-of-life pressure vessels demonstrated
- Development of methods to monitor through life performance







Pressure vessels: TECHNOLOGY GAPS

2021 — Concepting and design space exploration

2023-24 — Multi-load case design & certifiable product

2024 — Certifiable product by design, future product demonstrators

2025 — Tank that exceeds DOE 2025 targets

≈2027 — **MOON SHOT** Sustainable pressure vessels

Challenge 1: Polymeric liners – process modelling

During pressure vessel manufacture the liner undergoes a series of processing steps. It is moulded, then acts as the mandrel for the filament winding process before being place in an oven for composite cure, and then plays a vital role in tank performance. ***Understanding the impact of processing conditions on in-service performance is key and currently not fully understood.***

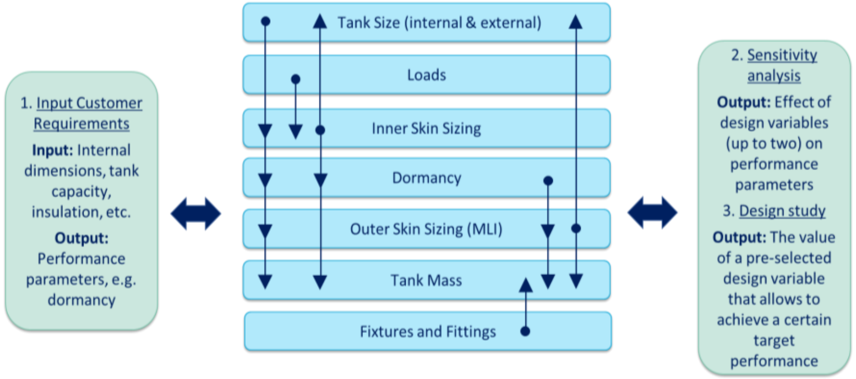
Challenge 2: Modelling damage growth and fatigue life

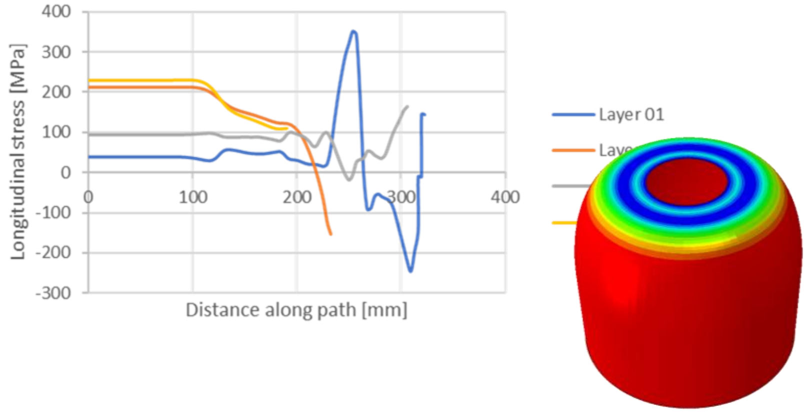
Efficient design of pressure vessels typically requires acceptance of some matrix cracking within their service life. Commercial tools are currently incapable of predicting this damage growth and its impact on fatigue life. ***Modelling of damage growth and prediction of fatigue life is key to optimise tank design.***

Cryogenic storage – what are we doing?

Design

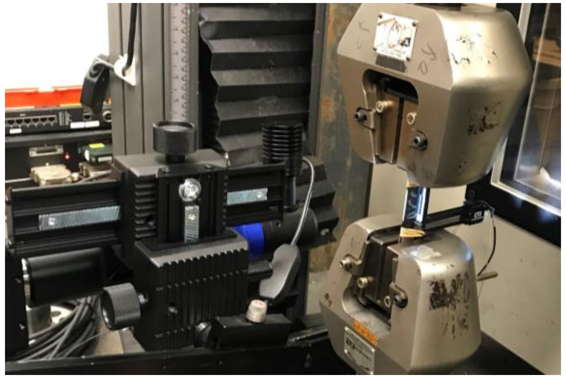
Generation of concepts against requirements, detailed design of inner containment tanks

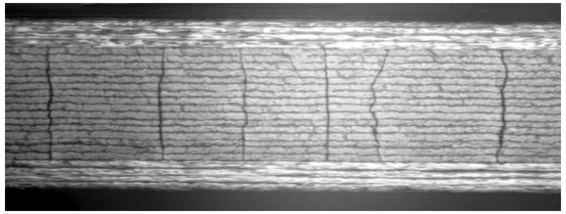




Materials

Development of test methods and understanding of material performance at cryogenic temperatures





Build and test

Small scale tank manufacture and test

Cryogenic tanks: TECHNOLOGY GAPS

2021	2023	2025	≈2030
Concepting of cryogenic tanks	Ground tested low cycle tank	Flight worthy low cycle tank	Flight worthy high cycle tank

Challenge 3: Thin ply materials for cryogenics

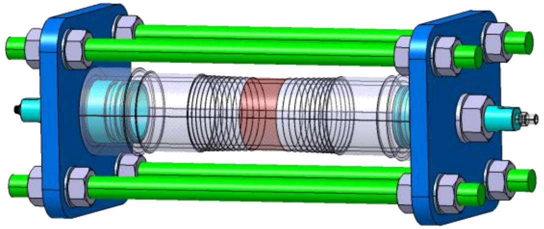
Thin ply materials offer advantageous microcrack resistance compared to traditional materials, however their performance when applied to products at cryogenic temperatures is not fully understood. ***Solutions in thin ply deposition and behaviour around features at cryogenic temperatures is required to enhance understanding and maturity of this technology.***

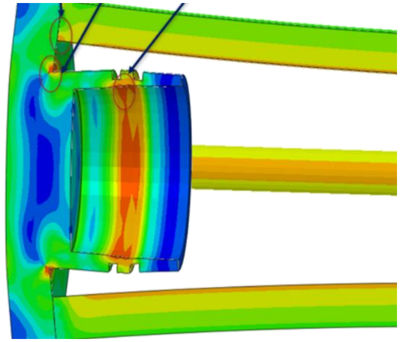
Challenge 4: Detection of microcracks in composite

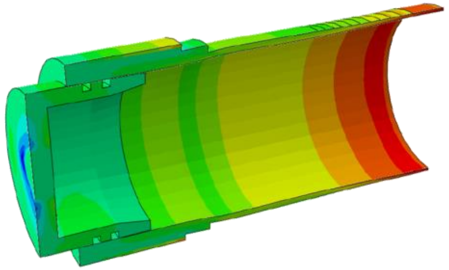
Composites are susceptible to microcracking when thermally cycled to LH2 temperatures. It is key to be aware if microcracking occurs, as this could impact the permeability and structural integrity of the tank. ***A solution is required to detect if a microcrack occurs during tank service and inform the operator about the location and magnitude of the microcrack(s).***

Energy distribution pipes – what are we doing?

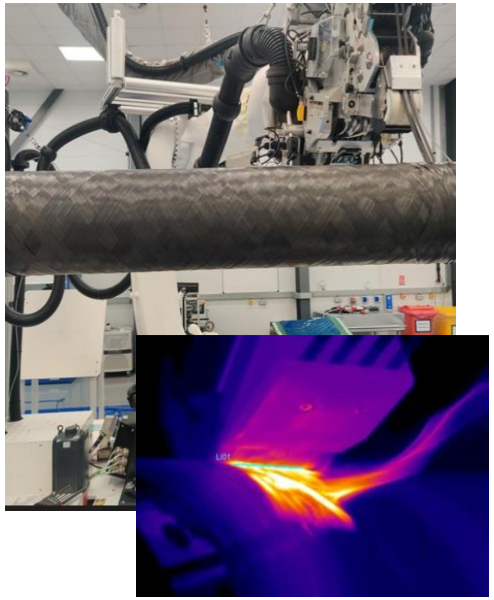
Design







Manufacture



Dedicated pipe winder coming soon!

Inspection and Test

Energy distribution pipes: TECHNOLOGY GAPS

2022
Design of prototype pipes and test methods

2023
Pipe prototyping and testing capability

2024
Material selection and predictive permeability cap abilities

≈2026
MOON SHOT
In-service repair

Challenge 5: Ageing in a hydrogen environment

The mechanical and permeation properties of polymers may change after long term exposure to hydrogen environments. ***Understanding of this behaviour is key for design and building confidence in long term performance***

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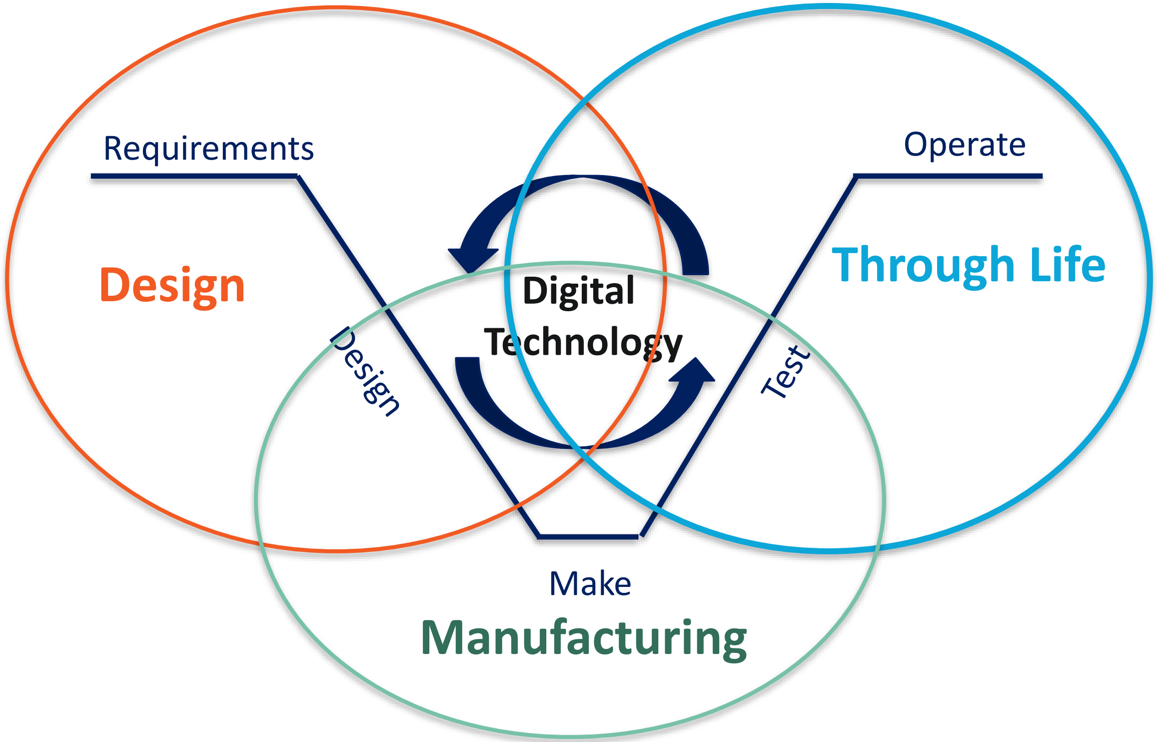
NCC Digital Outlook

Marc Funnell NCC Head of Digital

4 October 2023

Digital Engineering @ NCC

Exploiting digital Technology to transform the Product Life Cycle



Developing Digital People
Establishing Digitally enabled Ways of Working
Pulling through and Integrating Digital Technology

DIGITAL ENGINEERING TECHNOLOGY & INNOVATION

Phase 1 Completed

https://www.nccuk.com/what-we-do/digital/deti/

Testbed and Trails Completed

https://www.5g-encode.com/

MADE SMARTER
WEST OF ENGLAND

https://www.westofengland-ca.gov.uk/growth-hub/technology-innovation/made-smarter/

Digitalisation of Design

Amit Visrolia

Accelerating Design and Certification cycles of product development across distributed supply chain

Model Based Enterprise
Techniques enabling system agnostic CAD-CAM-Shopfloor Automation and x Supplier Traceability

Concurrent Design Systems
Enabling collaborative Multi Disciplinary simulations and design decisions across supply chains

Certification by Analysis
Building trust in CAE, mathematics and data science to reduce physical testing requirements (Material – System)

Generative AI
What can Chat GPT and other generative tools do for knowledge management and rapid concepting

Latest News Sept 23:

- NCC is developing the Engineering Transformation Network on behalf of IUK
- Forming proposal for Certification by Analysis Phase 2 (Phase 1 completed March 24)

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Digitalisation of Manufacturing

Jonathan Butt and Stephen McCartney

Reducing waste and cost of operation (striving for right every time manufacture)

Self-Adaptive Manufacturing

Exploiting AI for real time process control with defect detection Automation where appropriate

IIOT and Connectivity

IT Solutions to make your shopfloor smarter
Sensors and Dashboards enabling LEAN processes

Augmented Operations

Guided Instructions and In-Process Inspection techniques enhancing workforce capability

Waste Management

Asset Tracking and energy monitoring for Scope 1,2
Product Carbon Accounting and waste recycling

Latest News Sept 23:

- NCC forming a JIP for Digital Twinning of Composite Deposition (contact Jon Butt)
- NCC are deploying Asset Tracking and Energy Monitoring solutions as part on NCC Exemplar

Digitalisation Through Life

Marc Funnell and Stephen McCartney

Extending operation lifespans, safety of critical assets and cost of through life operation

Structural Heath and Usage Monitoring

Twinning and Data insights to enable predictive maintenance and relifing of critical assets in service

Augmented In-Field Servicing

Remote Expert Helper, Guided Instructions and automated inspection enhancing maintenance

Through Life Passports

Standards, pedigree and traceability circulatory, end of life and scope 3 assessments

Latest News Sept 23:

- NCC launching a Digitalisation for End to end H2 Infrastructure initiative through the Digital Twin Hub

Specific Areas of Interest

Digital

- Tracking distinct objects around a busy environment (like a factory/workshop) using various comms scenarios e.g. 5G 4G, Narrow band or WiFi signals — this hasn't really progressed beyond academia yet
- Human augmentation, visual (in- and post-process verification), audial (voice control) and physical — there are good examples of exo-skeletons that increase the strength of human operators, but not that significantly increase speed or dexterity
- Machine learning for manufacturing — general AI models for language, image generation etc. are becoming commonplace, but there hasn't been much progress on general AI for manufacturing. What should this look like, what kind of QHSE and ethical controls should be built in. Especially critical too for limited data sets.
- Interoperability, Resilience and Security in Data acquisition solutions and IOT devices inside the factory
- Manual dexterous task tracking and machine vision verification – hand tracking learning using AR headsets as opposed to laser line scanners, specific HD cameras and other in-process verification capabilities.
- Opportunity for "swarm" cobot mimicry – based off manual dexterous task tracking and monitoring to increase productivity and consistency
- Model-based Systems Engineering, Integration platforms and digital thread techniques — keeping traceability from material development — Design Make, Test and following through life (via digital twin in operations) and through recycling reuse phases.
- Bringing in attributes from supply chain and manufacture (e.g. manufacturing capability, energy usage and resilience) into the early design phases as part of the MDO solutions
- Structural Health Monitoring or condition-based monitoring solutions of in-service products using embedded or other sensor solutions e.g. fibre optics as support for H2 — detection of cracking etc. in service and other safety considerations
- ChatGPT for Engineering Knowledge Management

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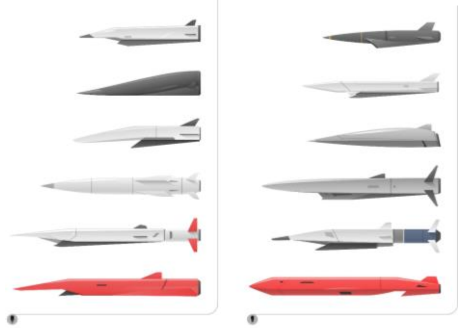
NCC Defence & Space Outlook

Konstantina Kanari Advanced Research Engineer

4 October 2023

Defence & Space Applications: Why composites?

Harsh Environments



Lightweight

Composites **reduce the mass** of military platforms, allowing **increased range and maneuverability**

Survivability

Composites help our assets and people to **survive conflict**. They are central to **next generation protective armour systems** and protecting from emerging threats

Corrosion resistance

Composites **replace metallic structures** susceptible to in-service corrosion and degradation and provide **additional fatigue resistance**

Functionality

Composites provide opportunity to **embed functionality**, they enable sensing, power transfer, healing and **low-observability** technology

High Temperature

Advance Ceramic Matrix Composite (CMC) technologies enable new ventures in **air combat propulsion** and are pivotal for the UK Hypersonic Programme

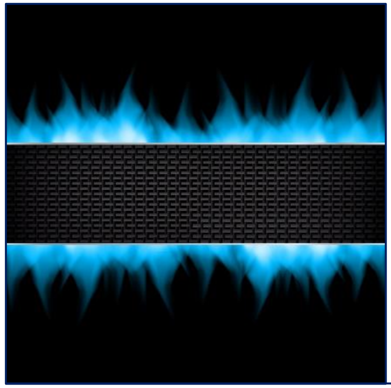
Defence Strategy 2022/2023

Harsh Environments

Survivability

- Low-velocity impact
- Blast and ballistic protection
- Shock loading
- Impact modelling and testing

Harsh Environments



- Marine environment
- Acoustic fatigue
- Fire retardancy
- Radiation hardening
- Durability testing
- Coatings and additives

High Temperature Performance

- CMCs for propulsion and hypersonics (> 1000 °C)
- High Tg polymers (> 250 °C)

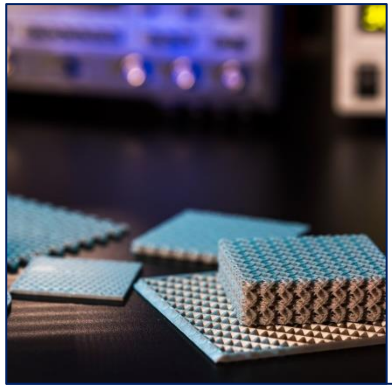
Sustainability & Cost

- Manufacturing automation
- Reducing development time
- Integrated structures
- Rapid prototyping
- Life-cycle assessment
- End-of life

Joining & Assembly

- Joint design
- Composite-to-composite joining
- Dissimilar material joining

Emerging Technologies & Digital



- Smart materials and structures
- Nanomaterials
- Metamaterials
- Digital tools and Industry 4.0

UHT CMCs for Hypersonics & Thermal Protection

Harsh Environments

Materials

- ✓ Carbon preform filled with Carbon and UHTCs
- ✓ UHTCMCs improve HT ablation performance
- ✓ Ultra High Temperature Ceramics: HfB_2, ZrB_2, HfC, TaC, etc.

Knowledge and Manufacture Partnerships

- ✓ Chemical Vapour Infiltration (CVI)
- ✓ Radio- Frequency Chemical Vapour Infiltration (RF-CVI)
- ✓ Polymer Infiltration and Pyrolysis (PIP)
- ✓ UK technology preferred

Programmes at NCC

- ✓ **Manufacturing with Graded CMCs** in partnership with Government and Academia
- ✓ Micro-scale CMC modelling and step change in **cost reduction for SiC/SiC composite** processing
- ✓ **Joining of Ceramic Matrix Composites** (brazing, bonding, mechanical)
- ✓ 3D Preforms and Designing for CMCs
- ✓ Thermal modelling and Ablation modelling

3D Fibre Composites Technology

Materials

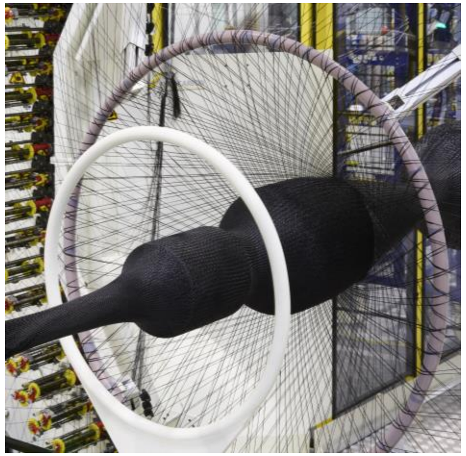
- ✓ Carbon, glass, aramid, thermoplastic (binder yarns) and functional filaments (metallised fibres)
- ✓ Reclaimed carbon fibre, commingled nylon, jute, sisal, basalt

Searching Knowledge and Manufacture Partnerships

- ✓ Braiding Technology
- ✓ 3D Jacquard Weaving
- ✓ Tailored Fibre Placement
- ✓ Through Thickness Reinforcement
- ✓ UK technology preferred

Programmes at NCC

- ✓ PV contracts with MoD and Private Sector OEMs (under NDA)
- ✓ 3D Fibre applications across aerospace, complex weapons, and land-systems platforms



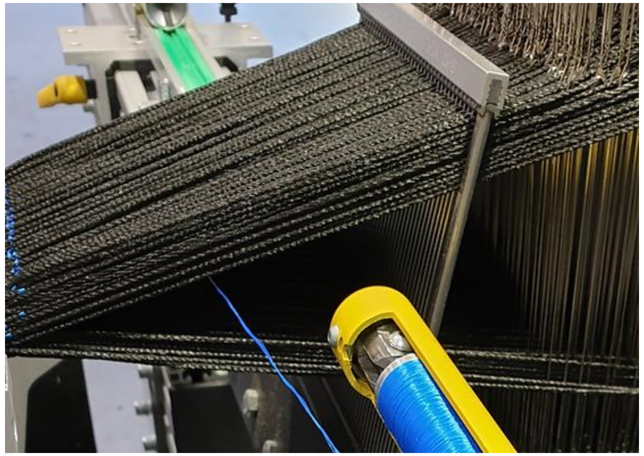


Image credit: Optima3D

Space Strategy 2022/2023

Harsh Environments

Launch Vehicle Structures

- Design and mass optimisation
- Manufacturing trials and process automation
- Market assessment and technology exploitation
- Novel materials and processes (AFP & LSRI)
- Design for reusability and recyclability vs demisability

Propellant & Pressurant Tanks

- Lightweight tank design
- Fatigue resistance
- Design for reusability or demisability
- Smart tanks with integrated fuel sensing and SHM
- Materials selection and testing
- Process modelling, manufacturing & verification

Advanced Materials for Space

- Atomic oxygen and radiation resistance
- Self-healing & Vitrimers
- CMCs for propulsion and space reactors
- Microgravity-enabled manufacturing
- Material manufacturing scale-up and demonstration

In-Orbit Manufacturing

- IOM composite material feedstock and process conceptualisation
- Design for robotic handling and robust assembly
- Enabling large-scale space structures

Advanced Materials for Space

New materials for the space environment

- ✓ AO/radiation-resistance, self-healing & vitrimers
- ✓ Temperature fatigue
- ✓ Thermally stable structures
- ✓ Novel materials – hosted on ISS Bartolomeo with University of Bristol

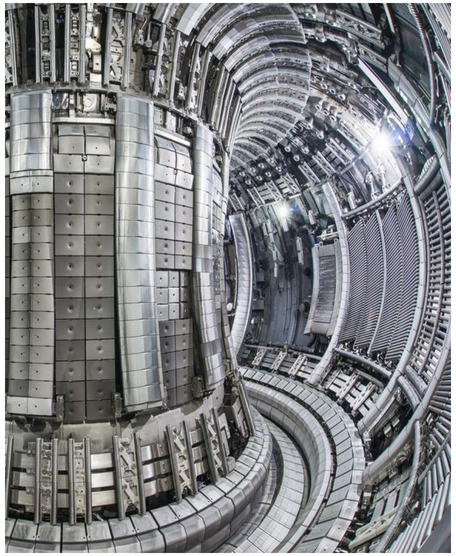
Enabling future technologies

- ✓ Nuclear reactors for exploration and habitation
  - Launch-resilient lightweight materials
  - Radiation shielding
  - Ultra-high temperature ceramic composites
- ✓ Propulsion
- ✓ LEO assets
- ✓ Microgravity-assisted manufacturing and in-orbit economy

Opportunities

We welcome projects on:

- CMCs
- CMC joining
- 3D fibre composites technologies
- Novel materials in extreme environments



NATIONAL COMPOSITES CENTRE

NCC: Other Challenges

Matt Scott NCC Chief Engineer for Capability

13 September 2022

… But that’s not all

Explorative

- The NCC has three strategic themes, and these are our main growth areas
- But composites research and development at the NCC happens across the board
- Our technology roadmap covers the full gamut of composites development

Materials

Application & Process Design

Manufacture

Validation & Certification

In-Service

End-of-Life & Circularity

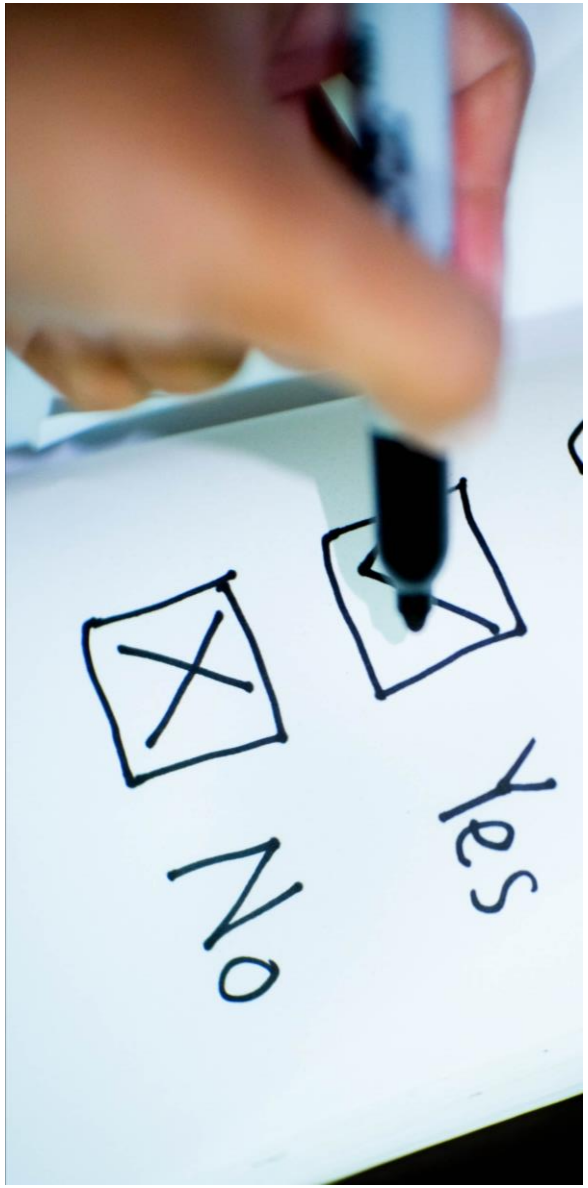
Agenda

13.00	Welcome and introduction to the NCC	Matt Scott
13.05	Introduction to TPT and the TPT process	Roger Walker
13.15	Our Sustainability Strategy	Tim Young
13.25	Our Hydrogen Strategy	Marcus Walls-Bruck
13.35	Our Digital Strategy	Marc Funnell
13.45	Our High-Temp / Defence Strategy	Konstantina Kanari
13.55	Break and poll	Matt Scott
14.10	Voice of an academic	Lee Harper
14.20	Questions, including poll results	Roger Walker
14.35	Conclusions and thanks	Roger Walker
14.45	End	-

Short Break and Poll

Please complete our poll and take a short break

We'll restart at 14.10 with some thoughts from Lee Harper from the University of Nottingham



NATIONAL COMPOSITES CENTRE

CATAPULT High Value Manufacturing

Global to local modelling for forming-related defect detection in aerospace parts

Lee Harper, University of Nottingham

4 October 2023

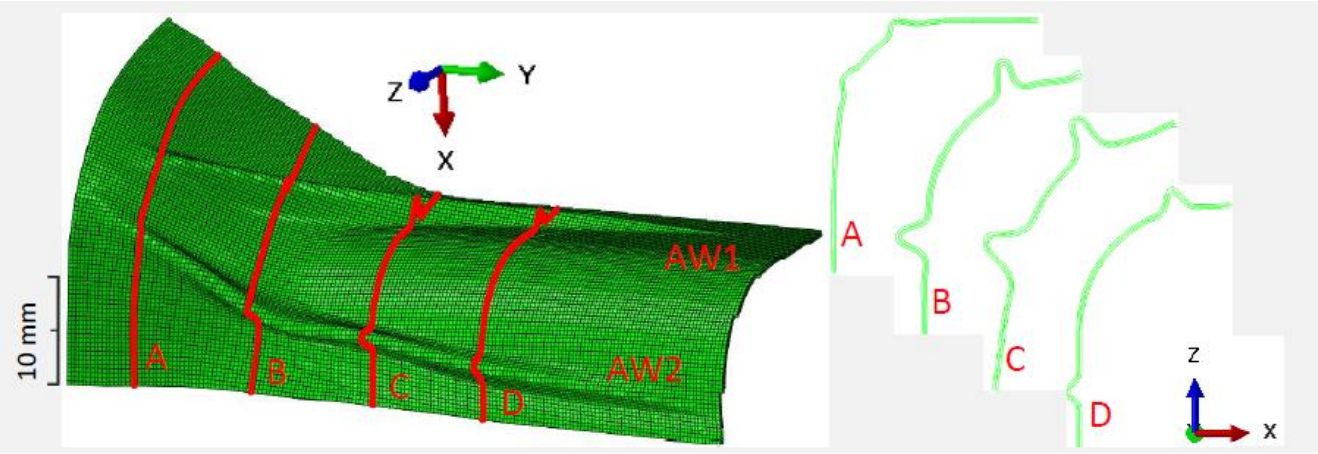
Global to local modelling for forming-related defect detection in aerospace parts

Primary Partner:	University of Nottingham	**Secondary Partner(s):**	

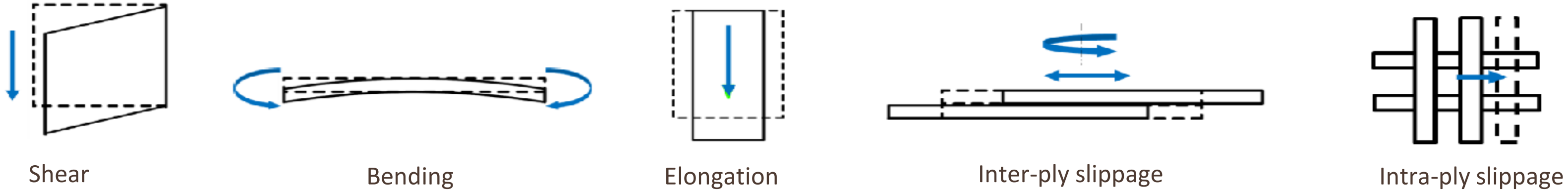
Challenge
State of the art forming simulations of dry textiles are either fast and inaccurate (i.e., unable to capture defects) or accurate but computationally prohibitive. Industry processes to set-up forming conditions are reliant on costly and wasteful physical trials and technicians' skills and expertise.

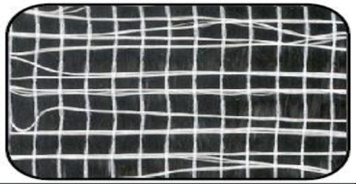
Project Aim
To explore how the global to local approach for dry textile forming (developed at the university of Nottingham) scales over 1 m and can offer **fast and accurate simulation of industrial-sized parts**.

Benefit
This has the potential to considerably reduce current part development time (and associated cost and material waste) in the composite industry. The developed tools can also help replace autoclave moulding processes currently dominant in the aerospace sector with infusion-based options.



NCF Deformation Modes

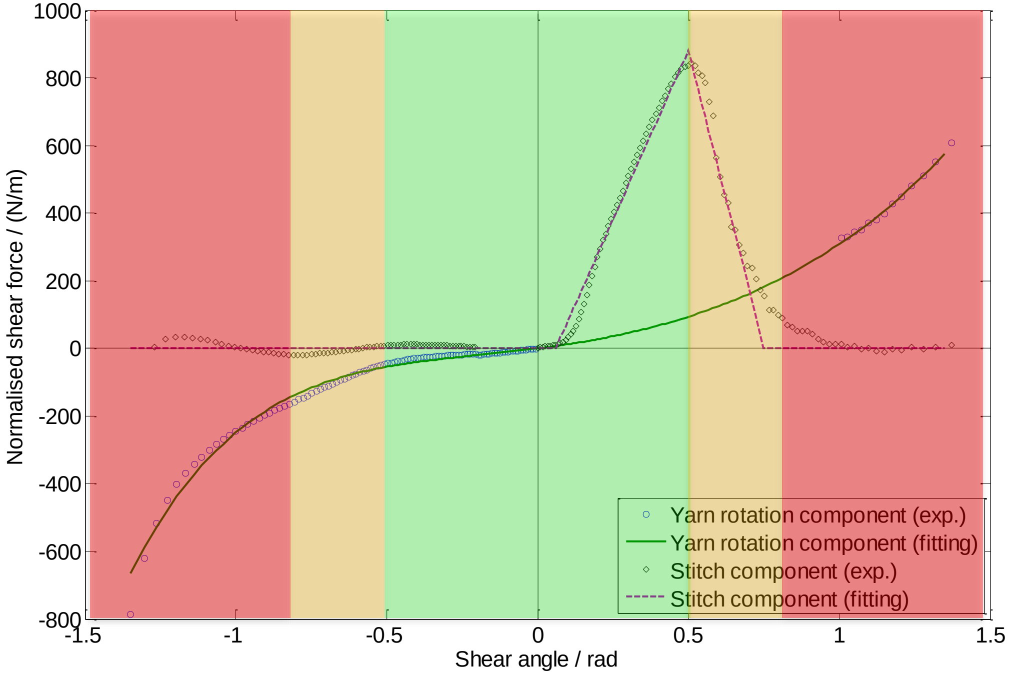


NCF Defects				
Phenomena	Macro-scale wrinkling (ply folds)	Meso-scale wrinkling (bundle loops)	Gaps / voids (laddering)	Stitch damage
Mechanism	Transverse yarn compaction (shear locking)	Longitudinal yarn compression (yarn buckling)	Intra-ply yarn spacing (intra-ply over-slippage)	Longitudinal stitch extension (stitch rupture)
Measure	Shear angle (locking angle)	Fibre compressive stress (critical buckling stress)	Fibre tensile strain (fibre spacing)	Stitch stress (stitch strength)

Assessment criteria:

- Global shear angle
- Local shear angles along a specified path
- Material draw-in (ply perimeter shape)
- Punch forces
- Qualitative criteria – onset of wrinkling, fibre buckling, inter-ply slippage

NCF Constitutive Model



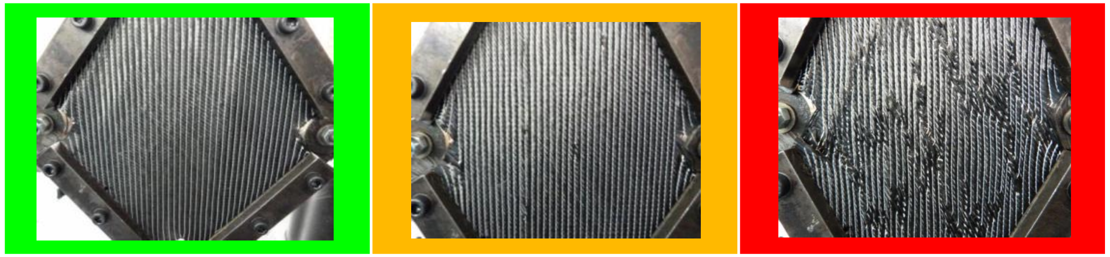
User-defined subroutine

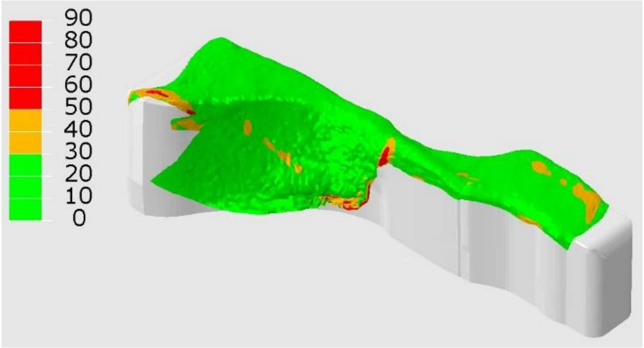
- Non-linear hypo-elastic model
- Non-orthogonal - Valid for materials that exhibit two structural directions, which may not remain orthogonal following deformation
- Based on Abaqus/Explicit and executed using membrane elements (plane stress)
- Superposition used to model the separate effects of stitch and yarn rotation
- Non-linear regression used to establish fitting parameters

$$F^{stitch}_{norm} = F_{norm} - F^{yarn\ rotation}_{norm}$$

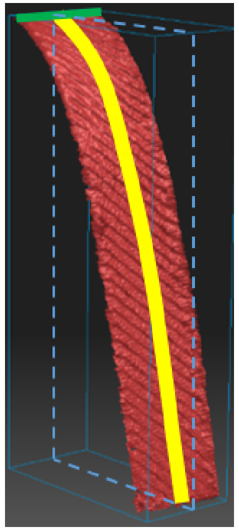
$$F^{stitch}_{norm} = \begin{cases} (2000\gamma_{12} - 120)\mathrm{N/m}, & 0.06 \leqslant \gamma_{12} < 0.50; \\ (-3520\gamma_{12} + 2640)\mathrm{N/m}, & 0.50 \leqslant \gamma_{12} \leqslant 0.75; \\ 0\mathrm{N/m}, & \text{else.} \end{cases}$$

$$F^{yarn\ rotation}_{norm} = (29.56\gamma^5_{12} - 65.56\gamma^4_{12} + 137.06\gamma^3_{12} + 94.73\gamma^2_{12} + 112.19\gamma_{12})\mathrm{N/m}$$

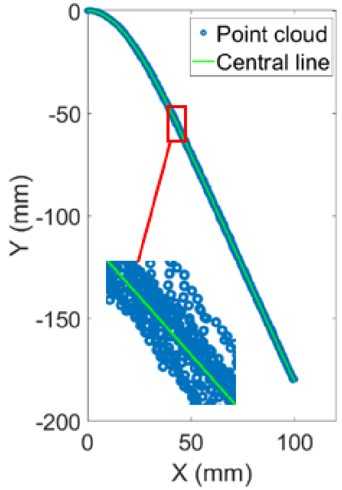




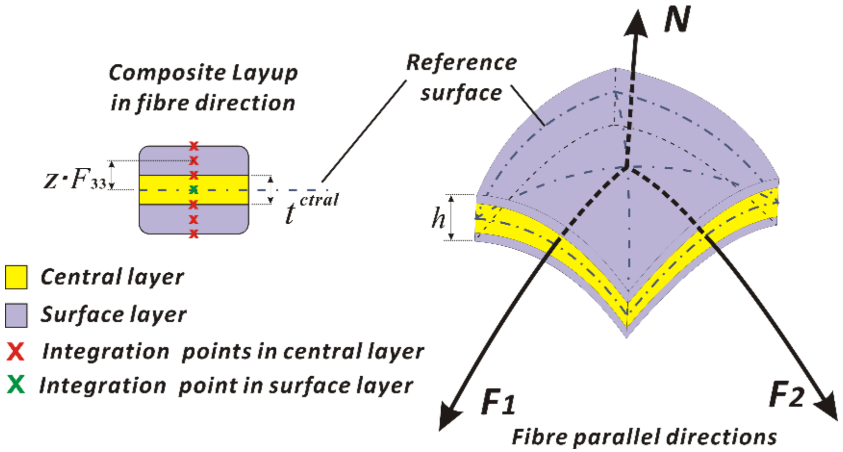
Non-Linear Bending Model



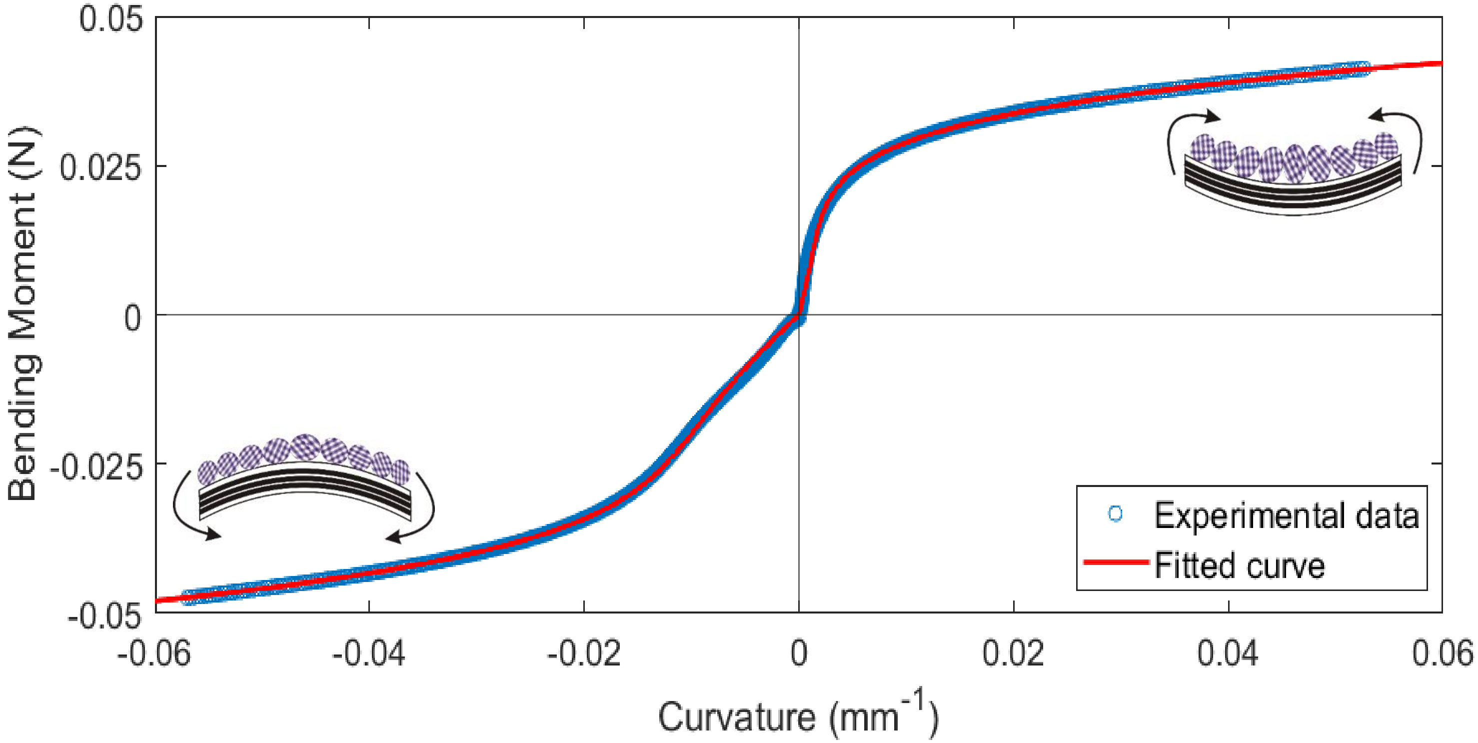
Data acquisition



Curve fitting

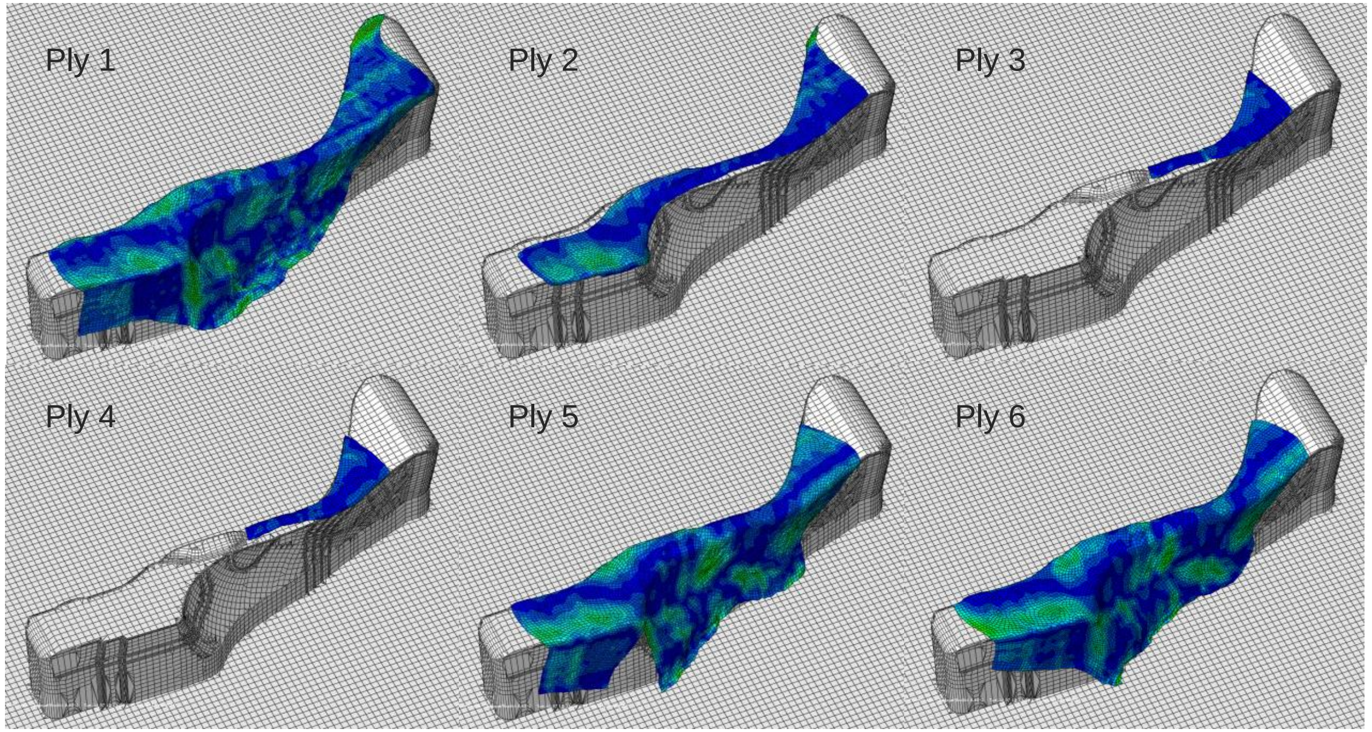


Validation based on cantilever simulation



Bending moment and curvature at points along the overhang of fabric specimen were calculated to plot the Moment-Curvature curve for both positive and negative bending.

Double Diaphragm Forming – Diaphragm Characterisation



Uniaxial mode

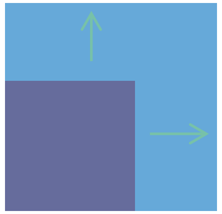
$$\lambda_1 = \lambda_U, \quad \lambda_2 = \lambda_3 = \lambda_U^{-\frac{1}{2}}, \quad \lambda_U = 1 + \epsilon_U$$

$$T_U = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i} \left(\lambda_U^{\alpha_i - 1} - \lambda_U^{-\frac{1}{2}\alpha_i - 1} \right).$$

Equibiaxial mode

$$\lambda_1 = \lambda_2 = \lambda_B, \quad \lambda_3 = \lambda_B^{-2}, \quad \lambda_B = 1 + \epsilon_B$$

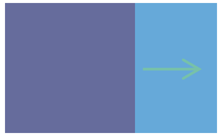
$$T_B = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i} \left(\lambda_B^{\alpha_i - 1} - \lambda_B^{-2\alpha_i - 1} \right).$$

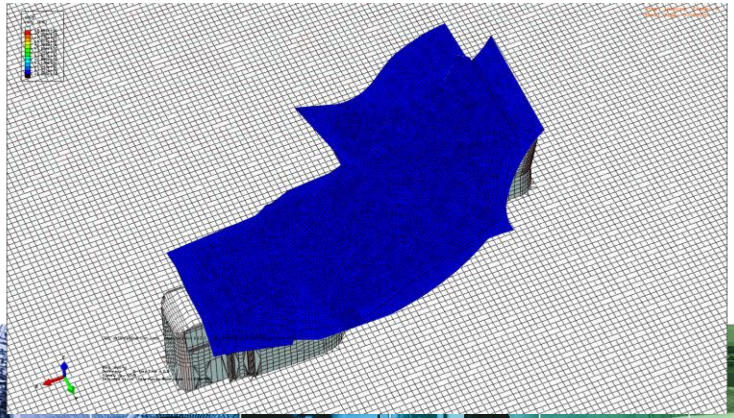


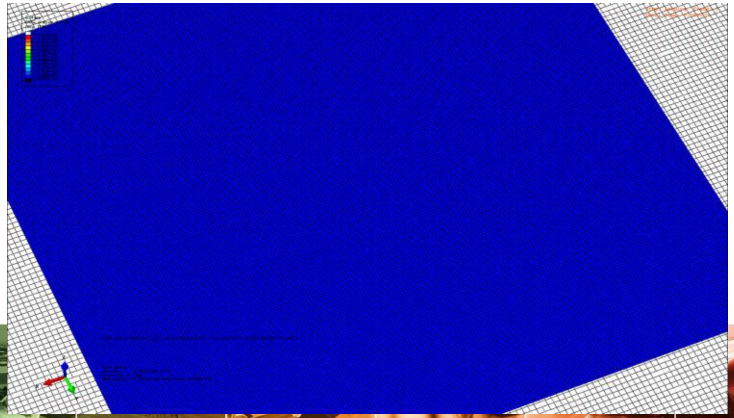
Planar (pure shear) mode

$$\lambda_1 = \lambda_S, \; \lambda_2 = 1, \; \lambda_3 = \lambda_S^{-1}, \quad \lambda_S = 1 + \epsilon_S$$

$$T_S = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i} \left(\lambda_S^{\alpha_i - 1} - \lambda_S^{-\alpha_i - 1} \right).$$







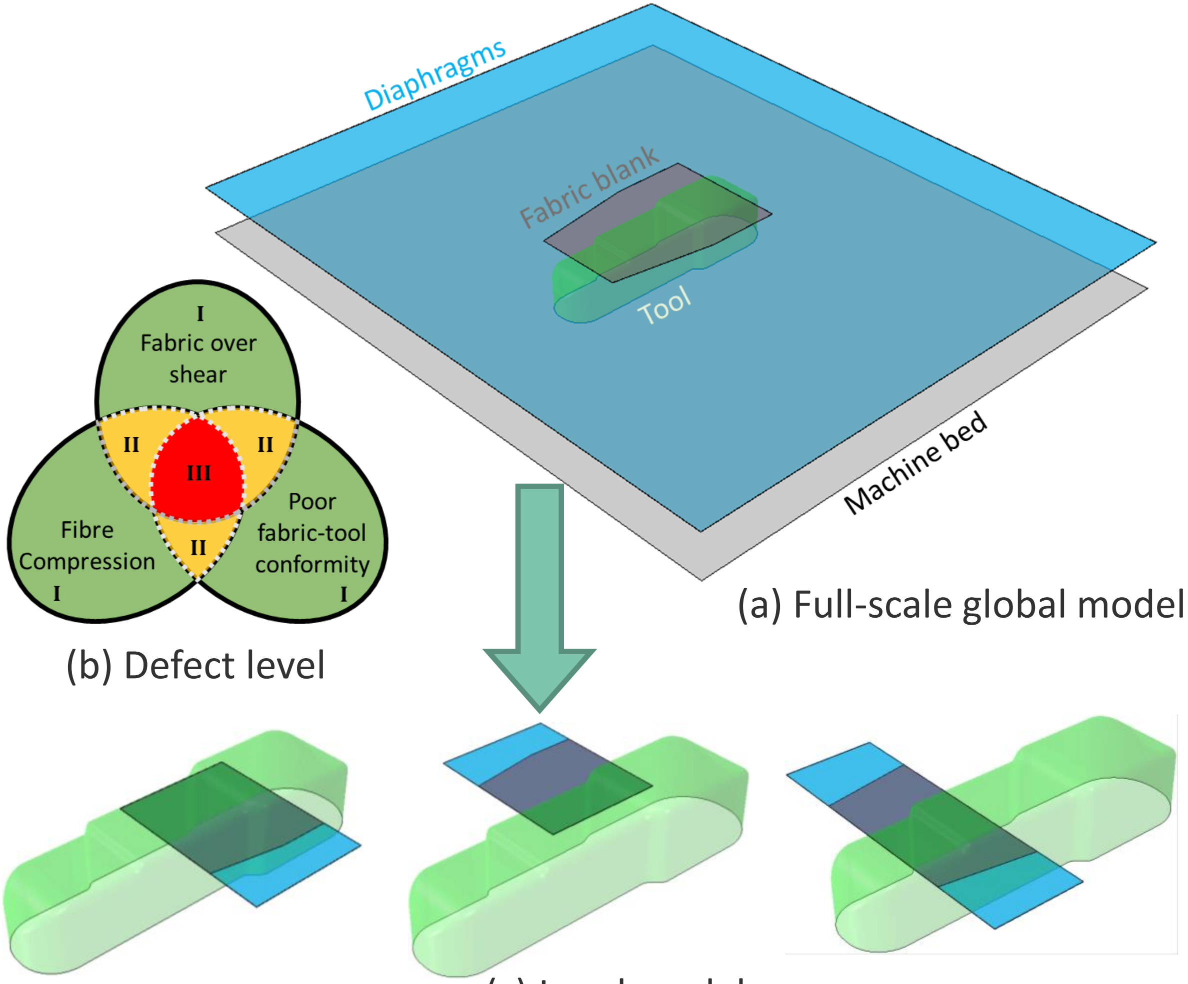
Global-to-Local FE Forming Model

Objective

- Rapid defects prediction for Double Diaphragm Forming (DDF) when forming large-scale parts with small defect-sensitive features.

Methodology

- Two-step global-to-local modelling
- Global modelling using membrane-only approach identify problem areas with potential defects.
- Local modelling using shell-based approach to predict the explicit shape of macroscale defects.



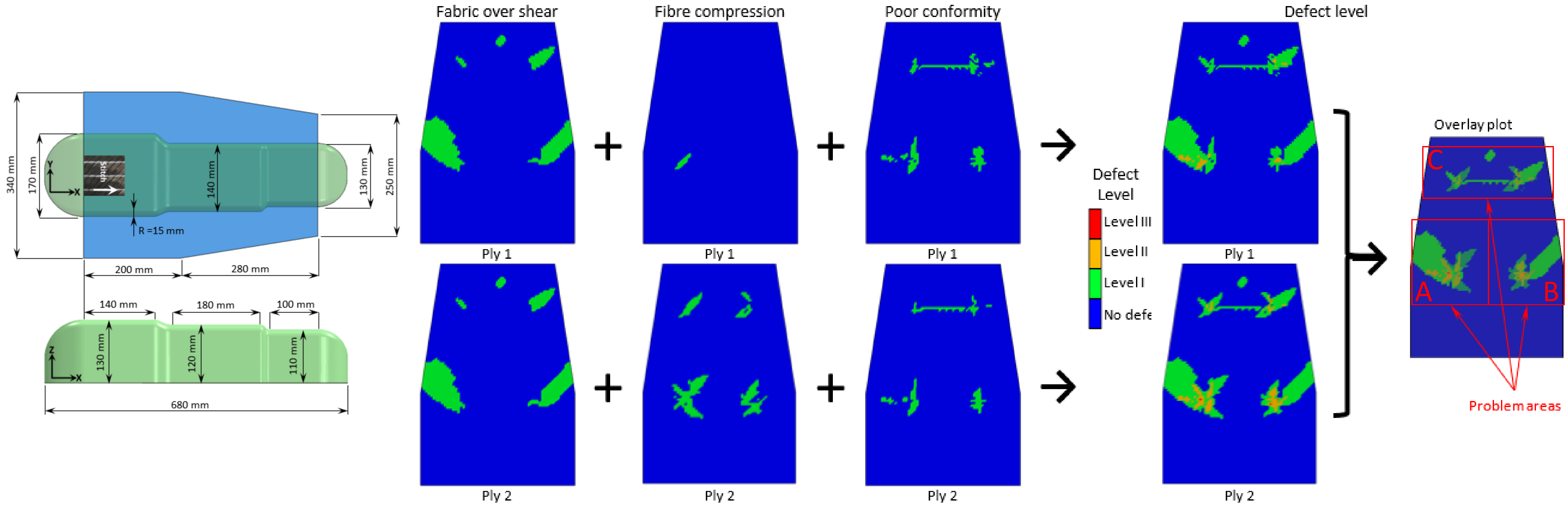
(a) Full-scale global model

(b) Defect level

(c) Local models

Global-to-Local FE Forming Model – Defect Criteria

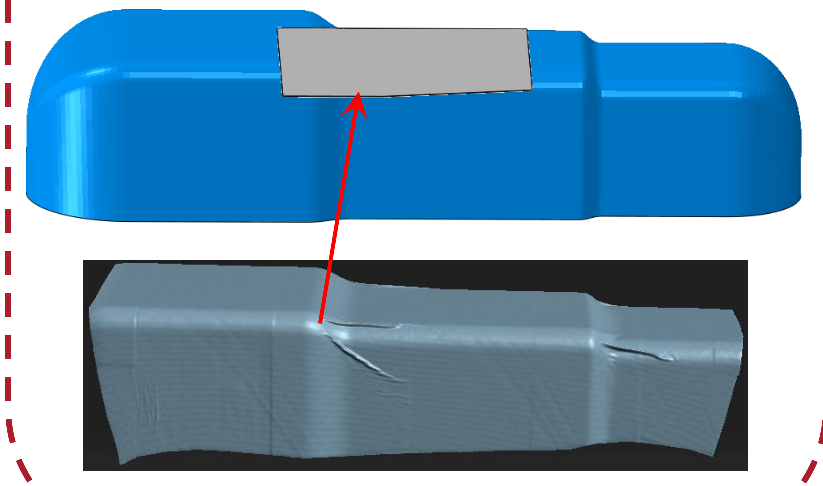
Global modelling to identify problem areas (Membrane-only approach)



Global-to-Local FE Forming Model

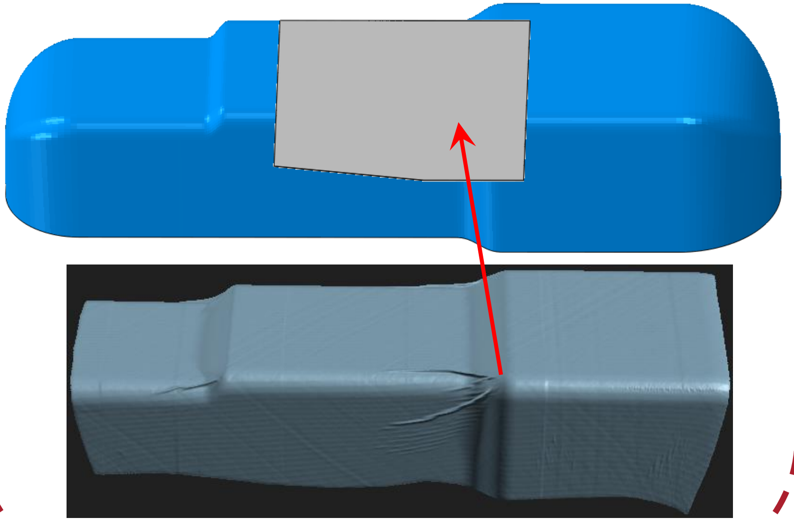
Wrinkles predicted by local modelling (Laminate shell approach)

Local model A



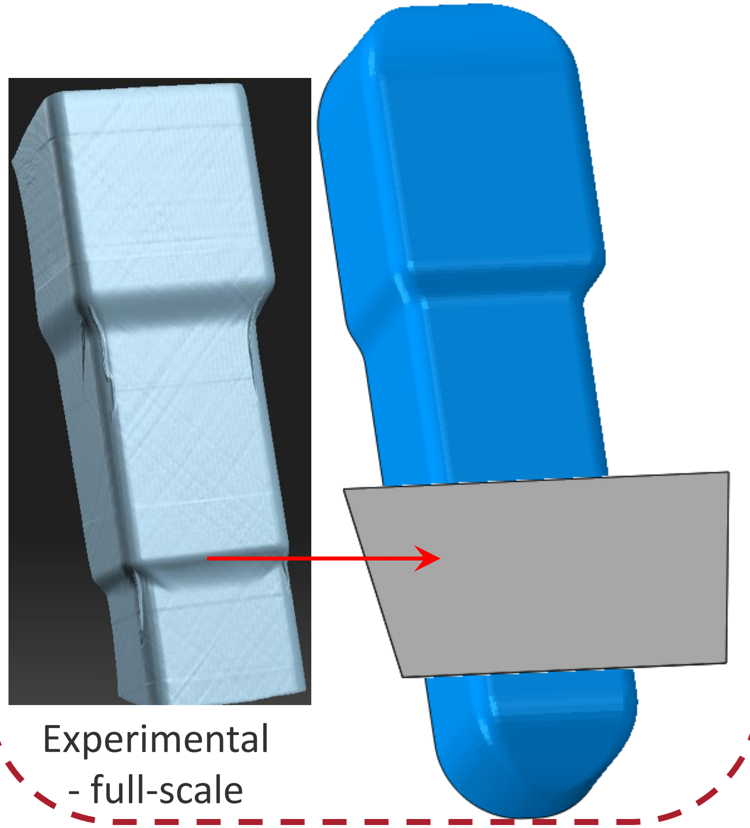
Experimental - full-scale

Local model B



Experimental - full-scale

Local model C

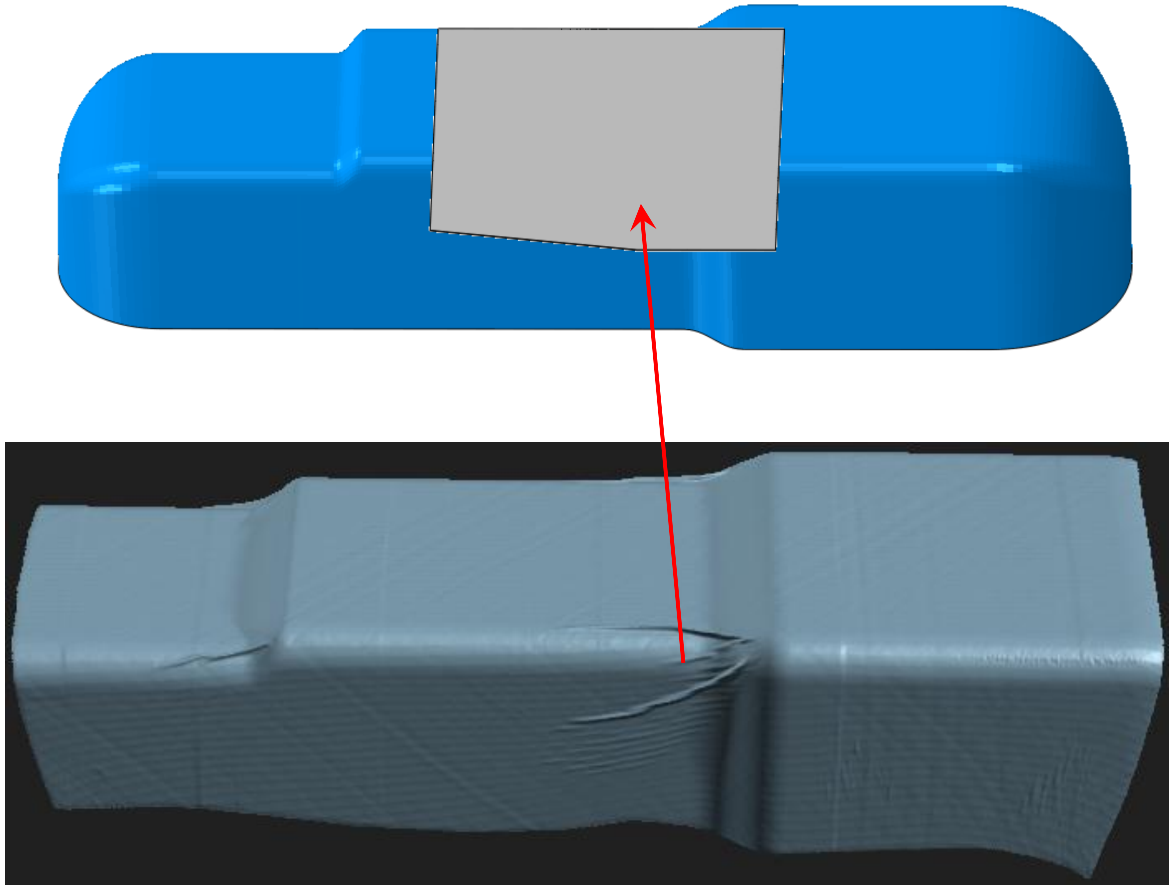


Experimental
- full-scale

Global-to-local FE forming model

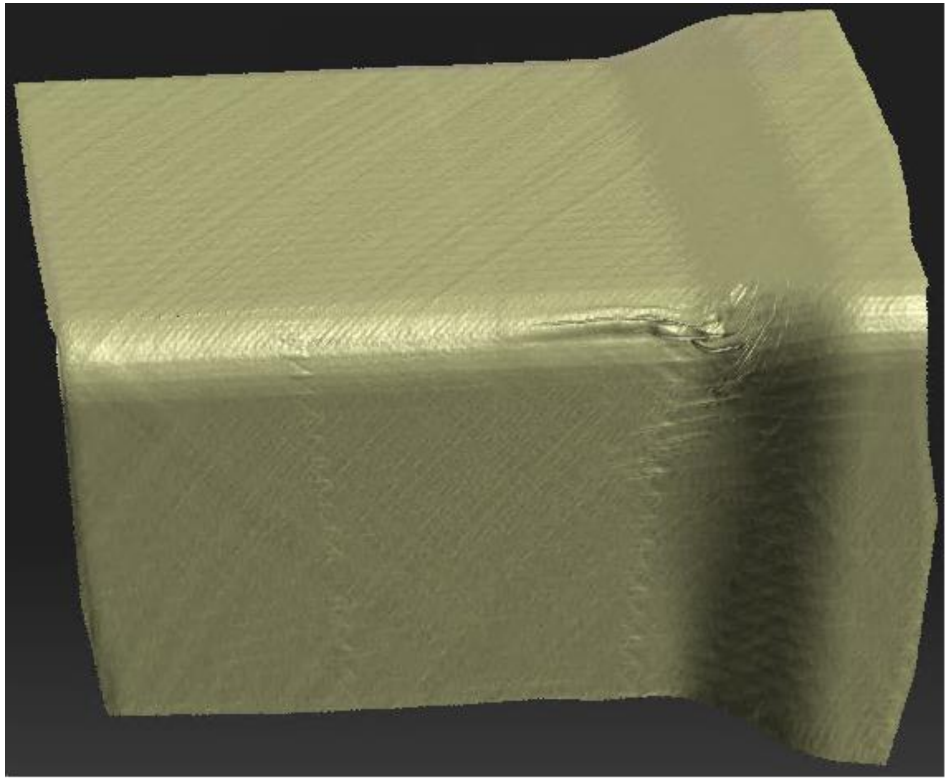
Wrinkles predicted by local modelling (Laminate shell approach)

Local model B



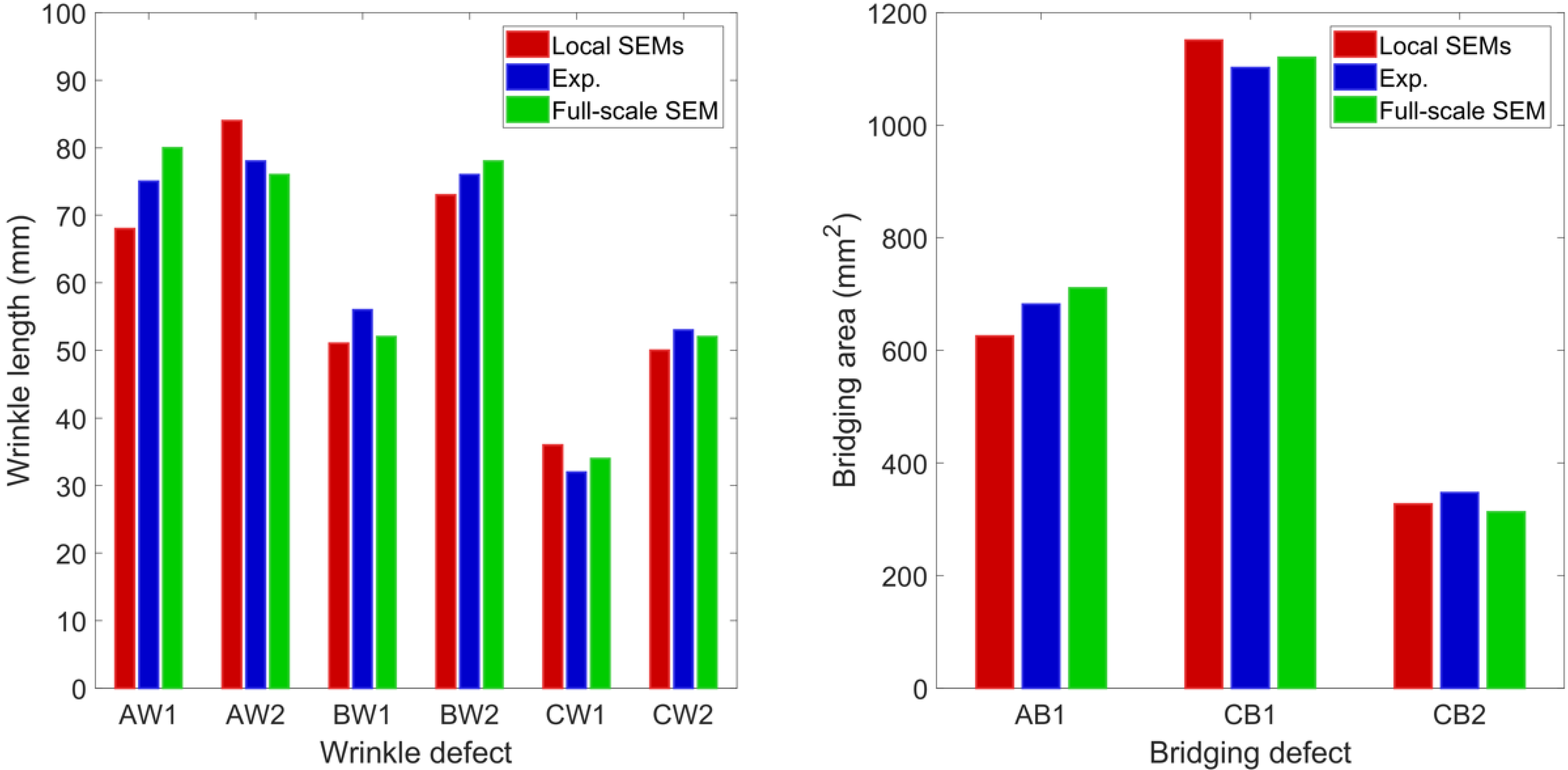
Experimental - full-scale

Local experiment B



Global-to-local model validation

(SEM – Shell Element Model)



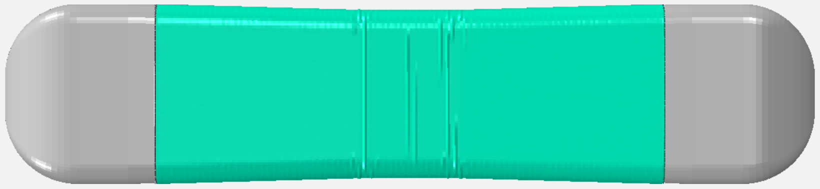
Global to local modelling for forming-related defect detection in aerospace parts

Work Package 1:	Automation of sub-modelling	(WP1.1,1.2,1.3,1.4,1.5,1.6	100% Completed)	6.00/8	**Completed**

Demonstrate global-to-local sub-modelling to validate approach

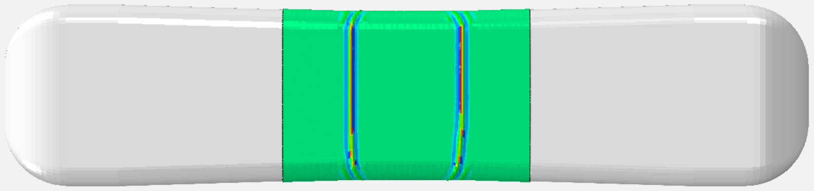
Step 1: Global simulation (Membrane model)

Blank length: 400 mm
Tool length: 640 mm



Step 2: Local simulation (Shell model)

Identified defect region: 120 mm x 160 mm
Dimension for local model: x + 60 %, y + 60 %
Tool length: 640 mm



- **Step 1**: Global modelling using a membrane model for fabric material to identify local regions for local simulations and to provide boundary conditions for local regions
- **Step 2**: Local modelling using a shell model for fabric material

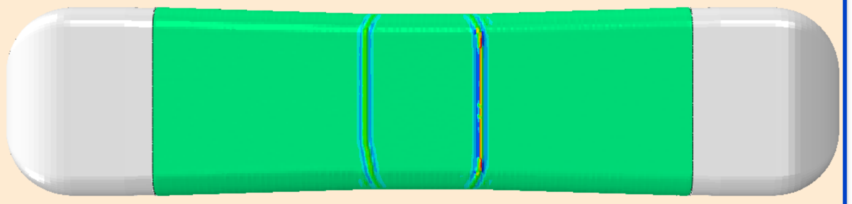
- **Result indicates that the global-to-local simulation is able to offer a consistent wrinkle prediction with the reference case**

Model information

- Layup sequence: **[-45/45//90/0]**
- Fabric-fabric friction coefficient: **0.35**
- Fabric-diaphragm friction coefficient: **0.40**

Reference case: Shell model

Blank length: 400 mm
Tool length: 640 mm

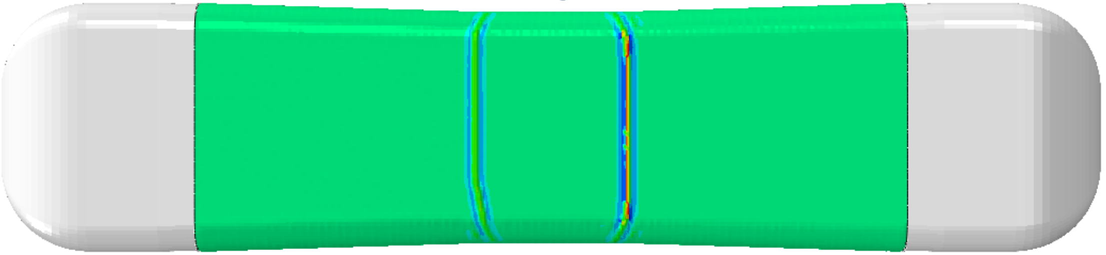


Global to local modelling for forming-related defect detection in aerospace parts

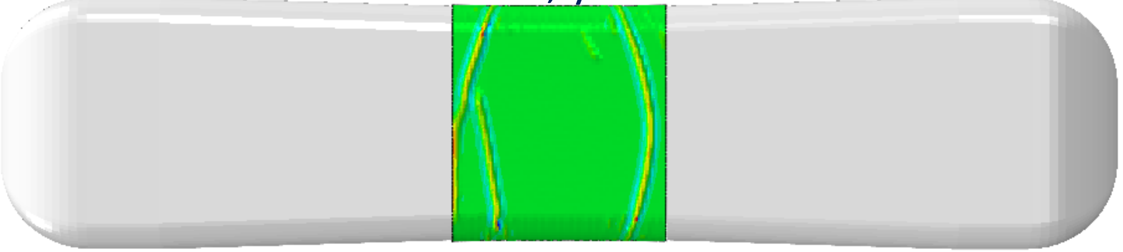
Work Package 1:	Automation of sub-modelling	(WP1.1,1.2,1.3,1.4,1.5	100% Completed)	**Completed**

Sensitivity analysis to identify critical area of sub-region for local modelling

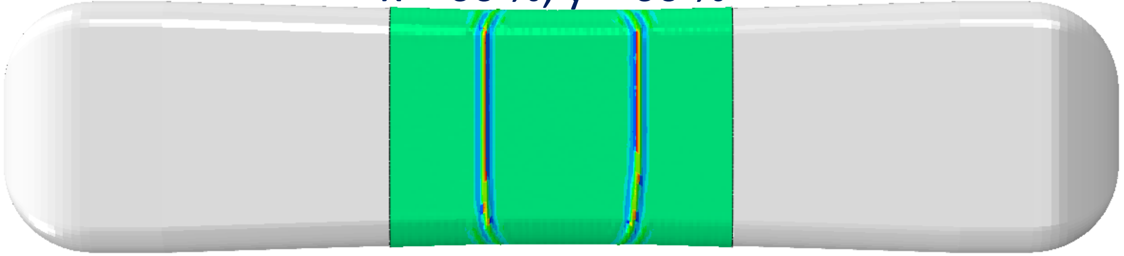
Shell, global



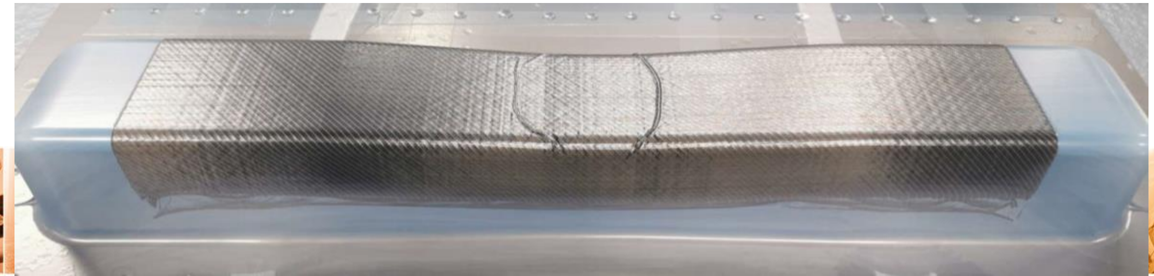
x + 0 %, y + 0 %



x + 60 %, y + 60 %

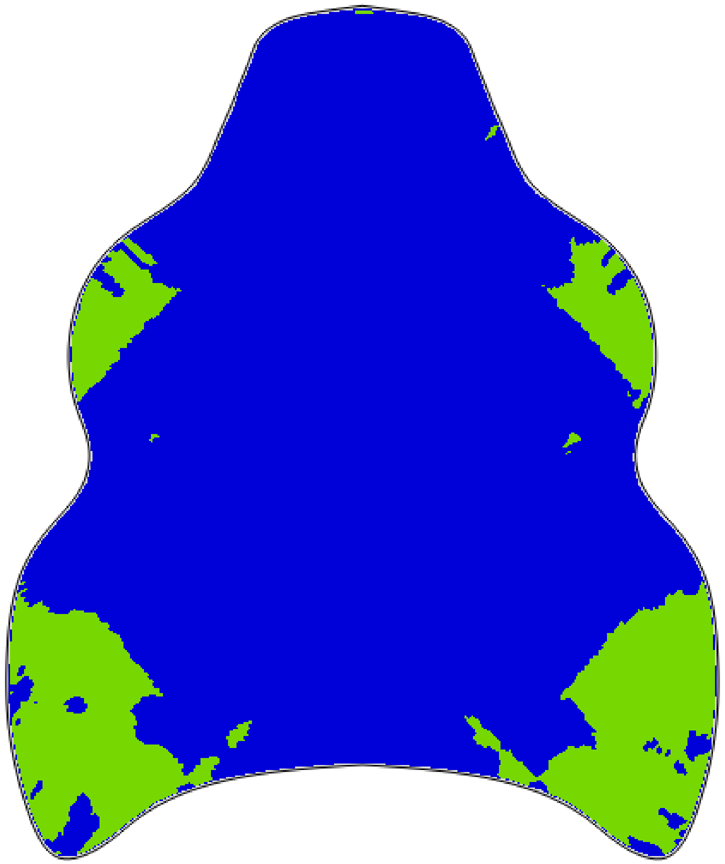


Experiment

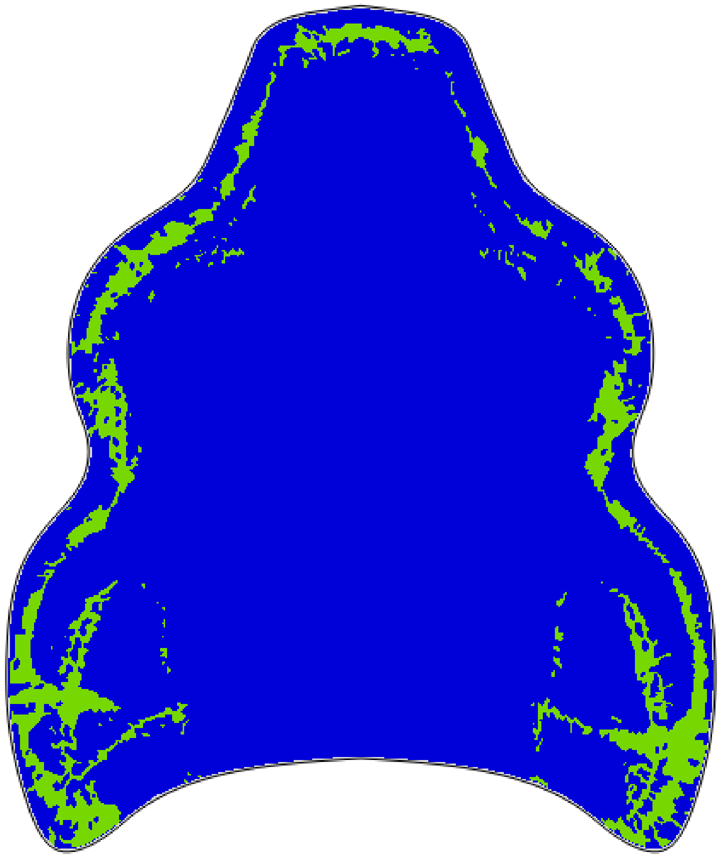


Step 1: Global Simulation – membrane elements

Fabric over shear



Nodal deviation



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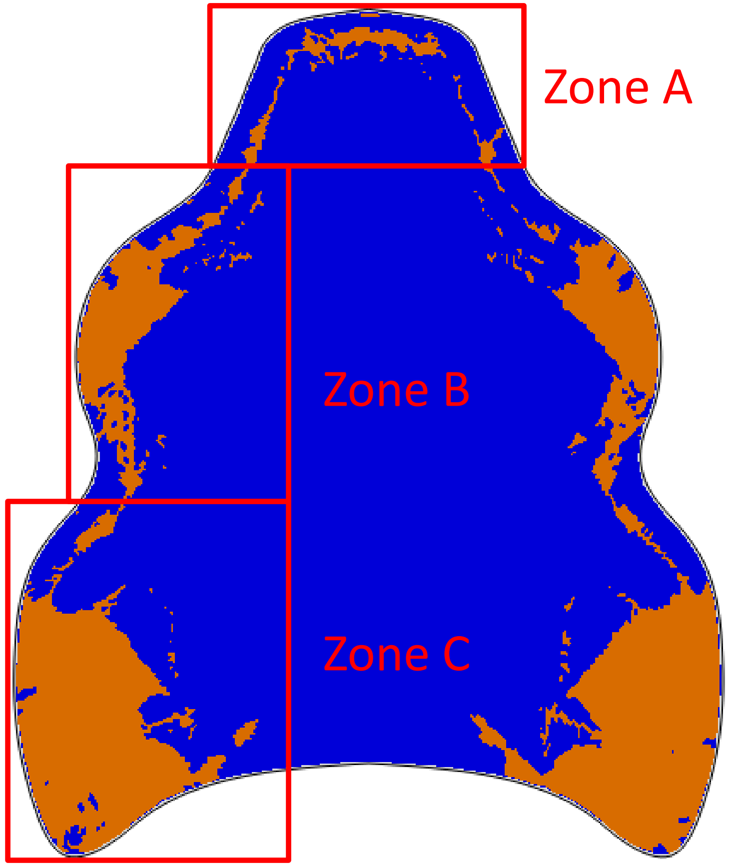
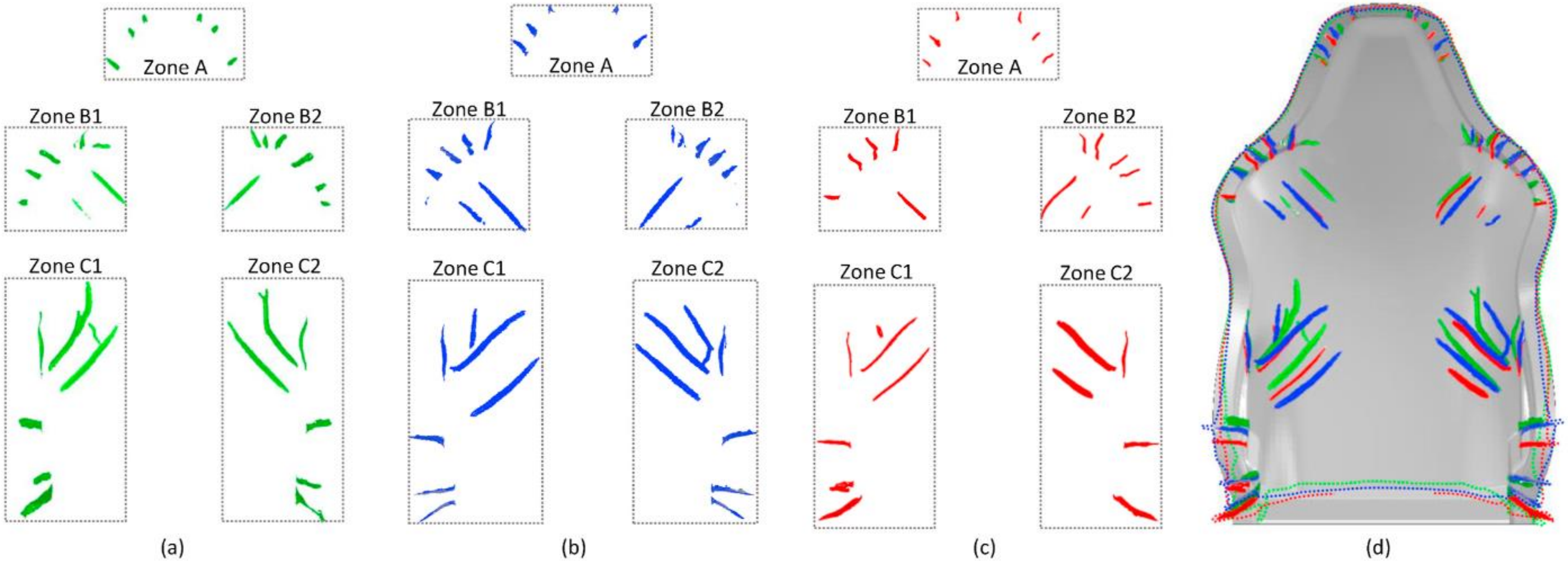
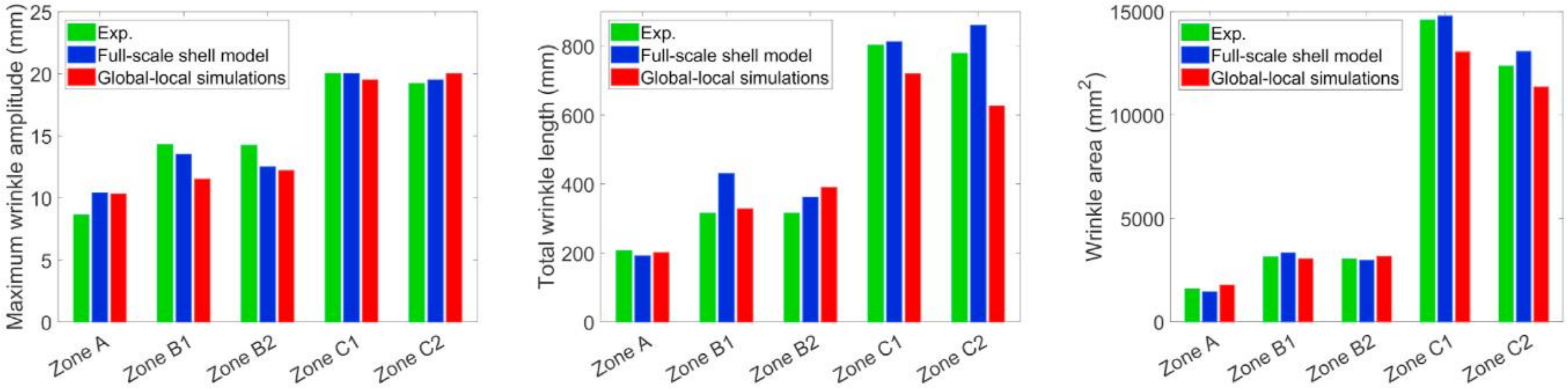




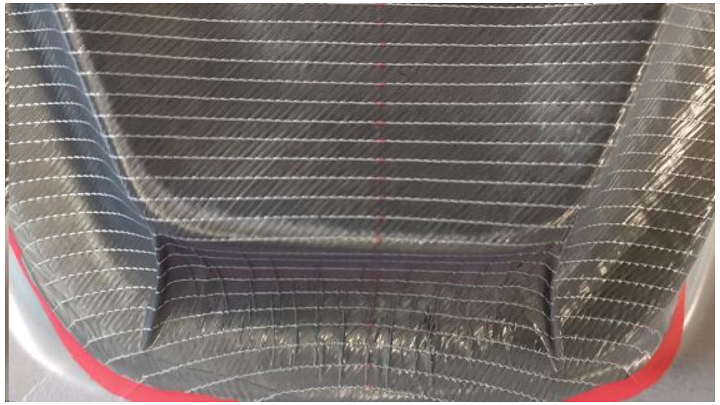


A global-to-local sub modelling approach to investigate the effect of lubrication during double diaphragm forming of multi-ply biaxial non-crimp fabric preforms',
F Yu, S Chen, G D Lawrence, N A Warrior, L T Harper, Composites Part B: Engineering

Step 2: Local Simulations – Shell elements

Comparison between simulations and experimental results

Zone A



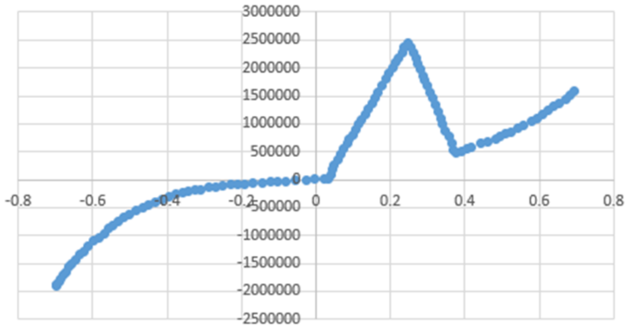
Zone B

Zone C

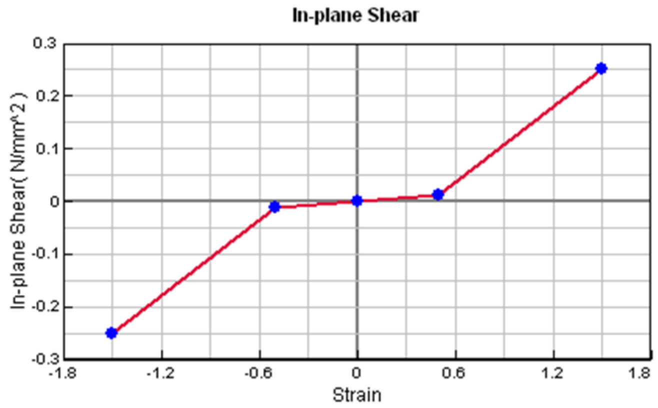
Benchmarking against commercial software

Work Package 2:	Benchmarking against COTS solvers	**Completed**

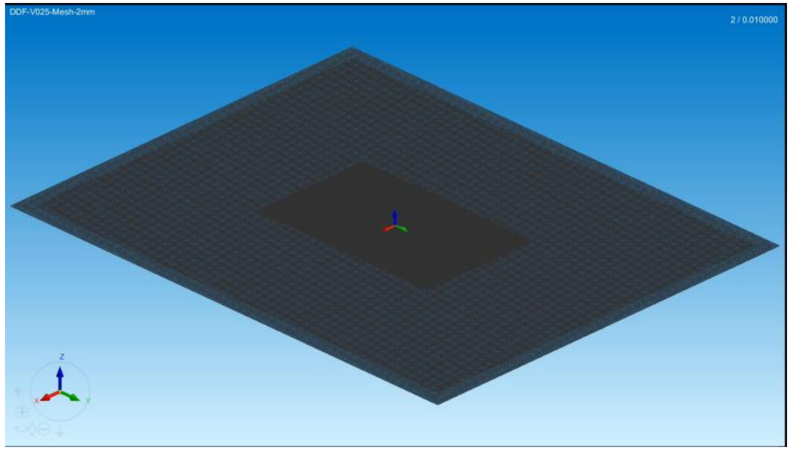
PAM-Form: Cannot simulate behaviour (No wrinkles) – 33 hours runtime



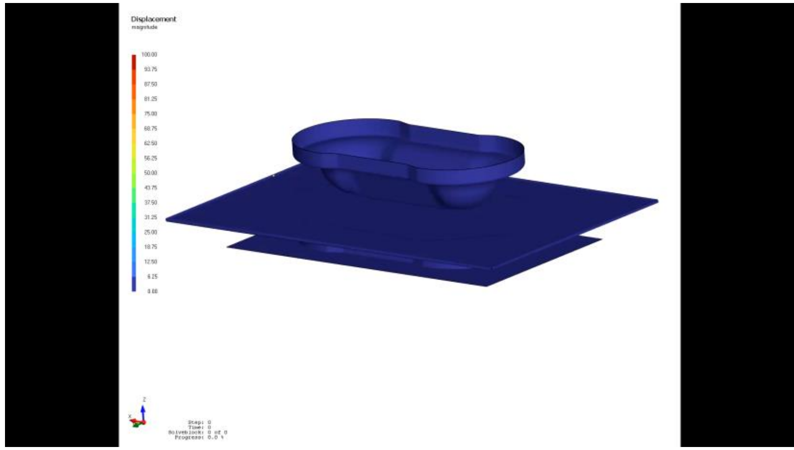
FCIM359 NCF (Actual Data)



Carbon Fabric (ESI Library)



Simulation with 2mm Mesh

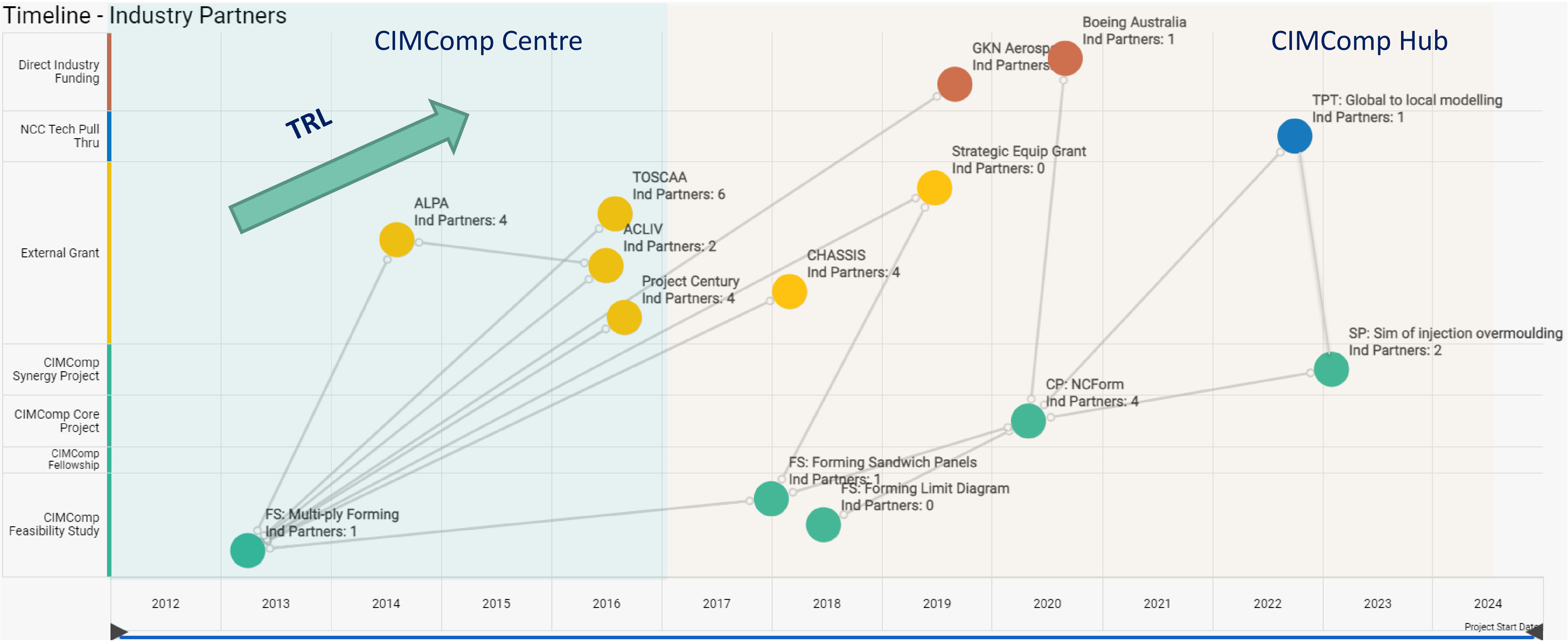


AniForm

Needs bespoke material card written by company.

Alternatively use 2 fabric plies with a stiff (fibre) and less stiff (stitch) direction with no separating contact between them (ongoing work)

Impact Timeline - Forming



Lessons Learnt and Future Opportunities

Current status:

- Established UoN NCF forming method superior over COTS software (speed + accuracy) and global to local method is more suitable for large-scale components
- Prepared training for NCC staff to be able to use the method
- Is the method parameterisable?

[important step towards greater user-friendliness and commercialisation]

Possible improvement:

- It is often assumed from applicants that NCC will have big industrial demonstrators available
- In most cases they are IP sensitive and cannot be shared

Next steps:

- Automation to identify local models
- Graphical User Interface for Python script
- Joint paper in preparation
- Possible opportunity to use the method at NCC for the IUK Airbus-led project CoSInC

- Hub Synergy Project – Injection overmoulding
  - Continued collaboration between UoN/UoB/NCC

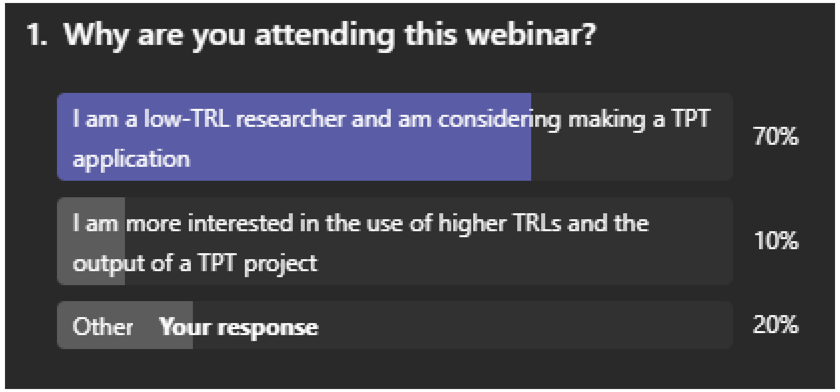
TPT: Summary and Conclusions

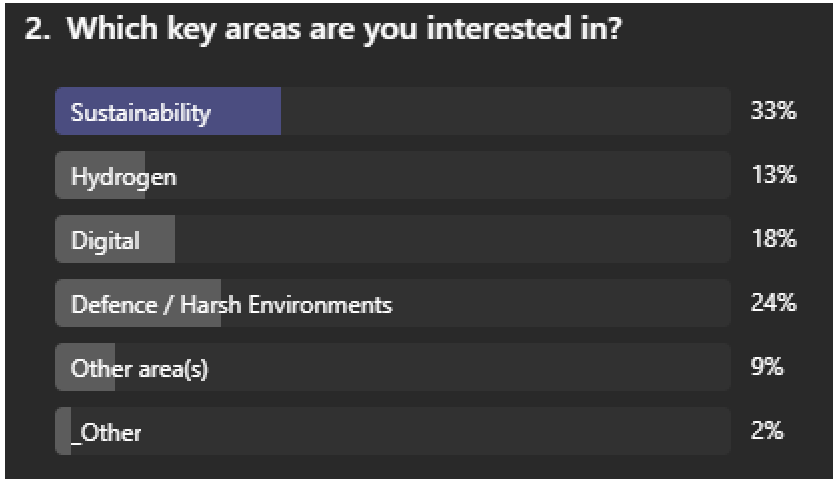
Matt Scott NCC Chief Engineer for Capability

13 September 2022

Poll Results

- What topic areas would you currently consider for a TPT proposal?
- If you're thinking of something beyond the Technology Challenge Themes (the Big Three) – what are you thinking?






3. If you're thinking of something beyond Sustainability, Hydrogen, Digital and Defence, what are you thinking?
Manufacturing efficiency
Design Optimisation
battery composites
Advanced materials
TPT programmes
Cross sector
intensive materials
materials for healthcare
example
structural performance
materials
automotive cars
materials / concepts
use cases
automotive
structural
indirectly enhance
carbon intensive
destructive evaluation
specific problems

So what?

- TPT stimulates the transition of suitably mature technologies from academia to industry

- This gives researchers the opportunity to show the IMPACT of their research (…REF)

- Prior work has shown that TPT gives promising technology the opportunity to progress

- Expressions of Interest open in 14 days – 13th October 2022

Thank you – questions?

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