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Aerospace Composite Technology Roadmapping

An ATI industrial consultation in collaboration with:

COMPOSITES LEADERSHIP FORUM

Composites UK Trade Association

Dr Marcello Grassi - Leading Edge Strategy Consulting
Dr Faye Smith - Avalon Consulting

Aerospace Technology Institute

- The Aerospace Technology Institute (ATI) is the objective convenor and voice of the UK's aerospace technology community
- We define the UK's national aerospace technology strategy
- We work closely with Government and industry to direct joint Government and industry funding of £3.9bn into aerospace R&T projects that align with the strategy
- We lead international technology engagement in aerospace for the UK
- We are a non for profit company, owned by UK Government and UK industry

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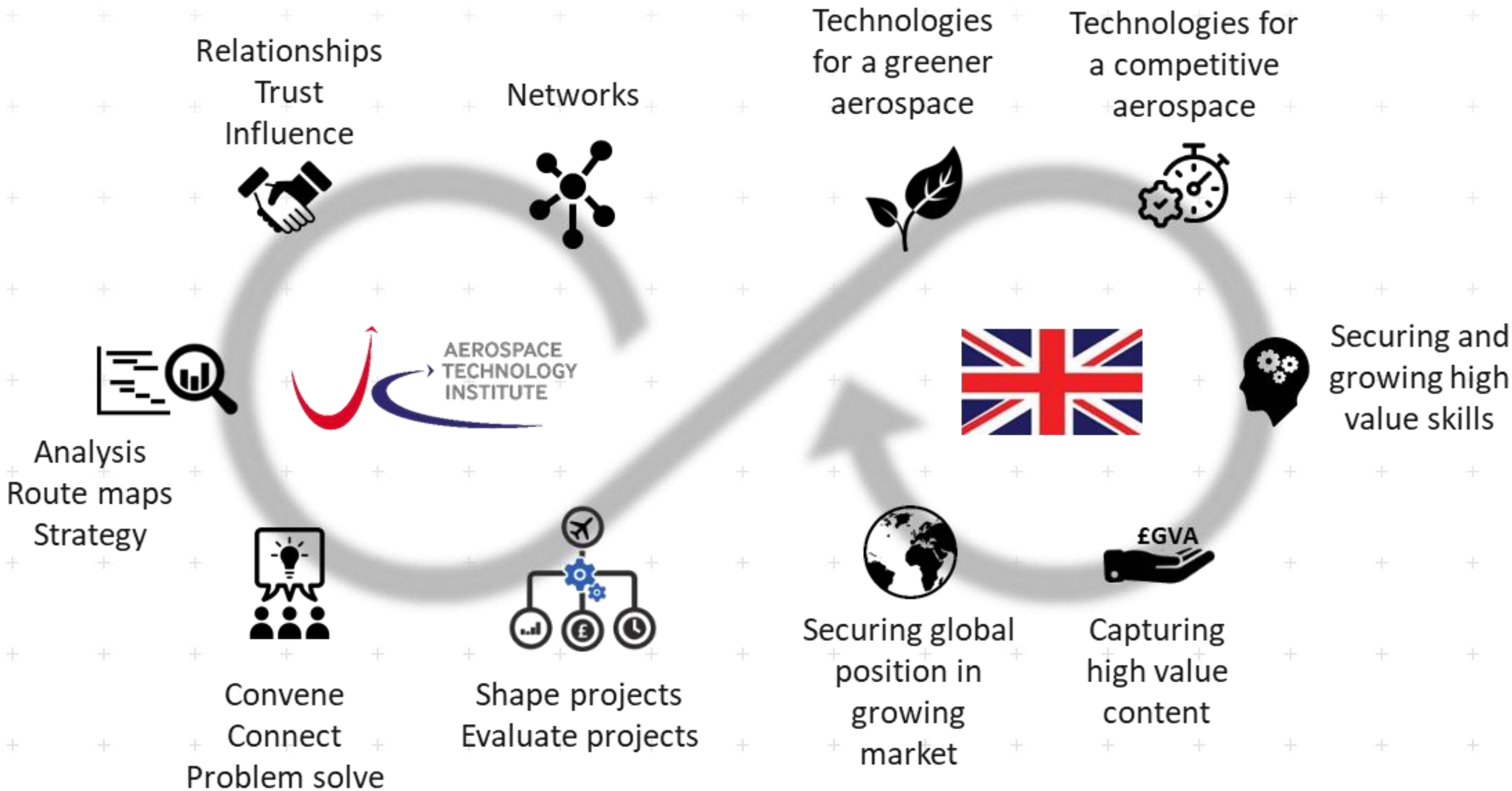
Working toward the economic mission

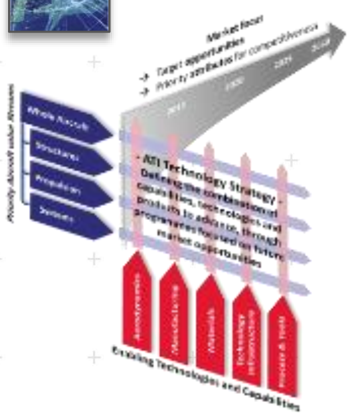


The Technology Strategy

July 2015

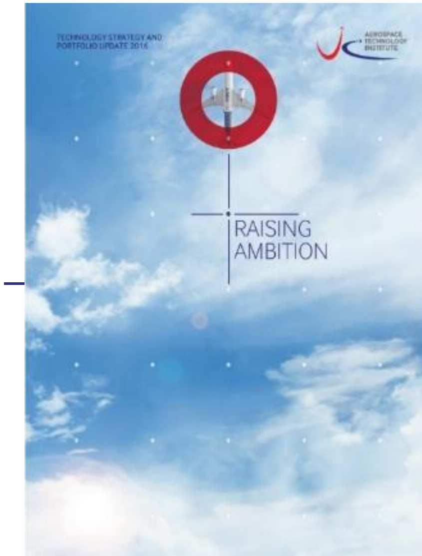
- 1st published strategy
- Institute embedded in strategic leadership of programme

ATI Live Portfolio



July 2016

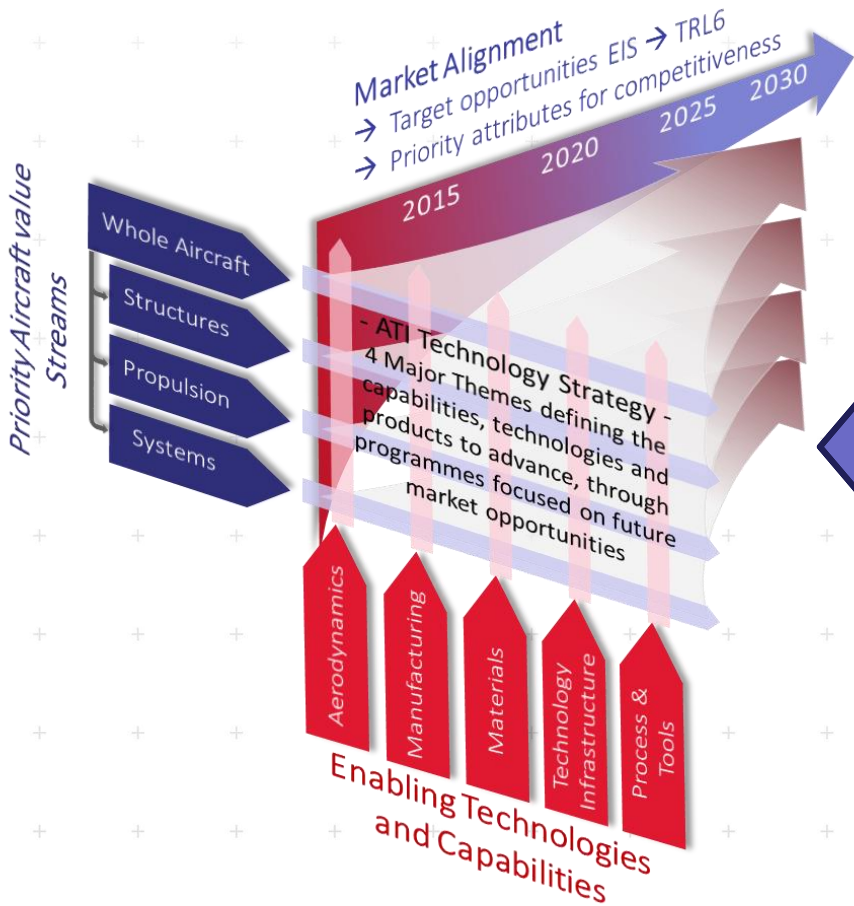
- Technology strategy and Portfolio Update



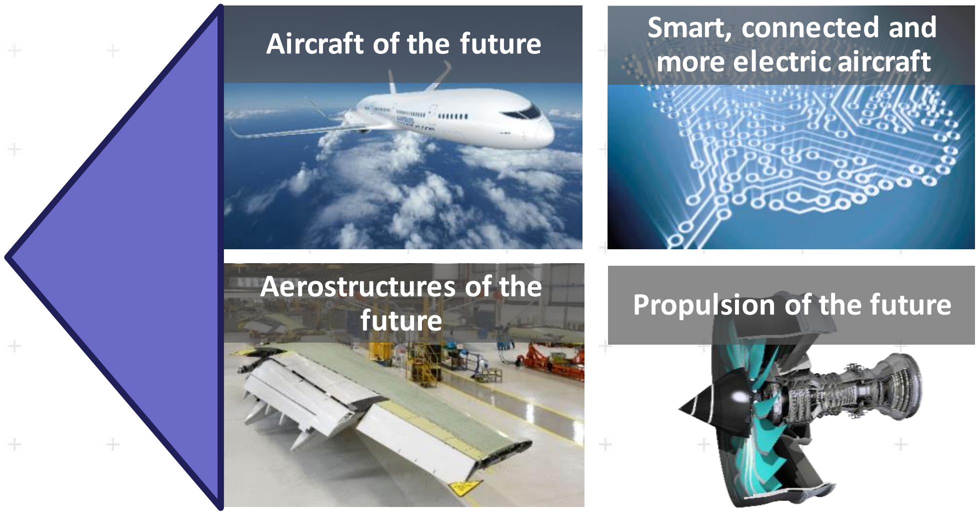
2017, 2018

- ATI INSIGHT papers

Raising Ambition



Four major technology themes



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UK Composites Strategy

Current UK status/ Opportunity	Action	Types of Parts Produced	Increased Productivity, Products and Services
UK is world class in low volume (autoclave/ prepreg), high performance composite part production. To grow market share need to develop higher volume & productivity materials & production technologies.	**DELIVER** Accelerate organic growth in established sectors already using composites.	Low Volume, High Performance	Nacelles, Wide Body wings; Land Systems, Military Aircraft, UAVs; Motorsport
		Higher Volume, High Performance	Engine Blades, Brackets, Engine Casing; Weapons; Spoolable Pipes
UK has limited high volume, low cost materials & production capability. Need to develop supply chain.	**DEVELOP** Technologies and supply chains to capture immediate market opportunities.	Mid Volume, Structural	Medium Volume, Luxury Vehicles, Bus; Lineside furniture, Gantries, Vehicles/ Modul; Functional Panels, Tunnel Linings; Cabin Modules, Leisure Craft; Single Aisle Wing: spars, skins, ribs; Wind Blades, Nacelles, Marine Turbines
		High Volume, Low Cost, Semi structural	Interiors; Components, High Volume; Interiors; Fittings, Pipes, Systems
UK has limited large structures production capability. Longer term opportunity once lower cost supply chain capability developed.	**DIVERSIFY** Enable UK industry to take advantage of increased use of composites in other sectors.	Large, Low Volume, Structural	Naval Vessels; Platform Systems, Trackbed; Custom Bridges; Work Boats, Super Yachts; Modules, Protection

UK Growth to 2030

- AEROSPACE £3,590m
- DEFENCE £1,150m
- AUTOMOTIVE £3,490
- RAIL £160m
- CONSTRUCT'N £1,520m
- MARINE £370m
- OIL & GAS £1,100m
- RENEWABLES £1,100m

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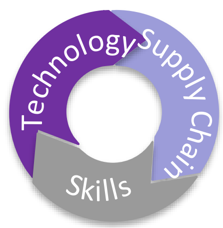
CLF: UK Strategy Delivery

ATI roadmapping

Composites Leadership Forum
Leadership & Strategy Delivery

Industry Groups
- Aerospace
- Automotive
- Construction
- + more, driven by industry

Working Groups
- Technology: Research, Collab'n
- Workforce Development
- Sustainability
- Regulations, Codes & Standards



Composites UK: Supply Chain
- Matrix & Formulation
- Fibres & Precursor
- Sizing/ Surface/ Additives
- Intermediates
- Part Production
- Integration/ Assembly
- Equipment Producers
- Recycling/ Environment

DELIVER
Accelerate organic growth in established sectors already using composites.

DEVELOP
Technologies and supply chains to capture immediate market opportunities.

DIVERSIFY
Enable UK industry to take advantage of opportunity in other sectors.

AEROSPACE	£3,590m
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RENEWABLES	£1,100m

Strategy & Analysis
- Strategy & roadmapping
- Cross-sector analysis, planning

Composites Sector Development
Coordination, Knowledge, Communication, Supply Chain Development

OUTPUT
- Industry Sector and Common Capability Requirements converted to Plan to Deliver
- Knowledge of Sector. Knowledge within Sector. Barrier Removal. Increased Supply Chain Capability & Workforce
- Increased Productivity, Targeted Products and Services
- Growth by £10.2bn to £12.5bn by 2030

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Sector wide consultation

Composites UK Trade Association

AIRBUS

BAE SYSTEMS

BOMBARDIER

GE

GKN

LEONARDO

MEGGITT

Rolls-Royce

SAFRAN

SPIRIT AEROSYSTEMS

UTC Aerospace Systems

Stakeholders

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Department for Business, Energy & Industrial Strategy

Department for International Trade

Innovate UK

COMPOSITES LEADERSHIP FORUM

CATAPULT High Value Manufacturing

CIMComp EPSRC Future Composites Manufacturing Research Hub

Aerospace Composites Roadmapping Process

STEP 1

GATHER DATA

- ATI Strategy
- Current Roadmap Templates
- CIMComp – existing OEM/ TIER 1 data
- SoA Review
- R&D funded programmes

STEP 2

ROADMAP TEMPLATES

- Aircraft Value Streams
- Market Forecasts and EIS
- Products
- Enablers: Technology & Capabilities
- Barriers
- R&D
- Exploitation Timeline (SEP Model)

STEP 3

OUTPUT REQUIREMENT

- Document Structure
- Prioritisation Process
- Data Capture Process
- Analysis Process
- Visualisation Process

STEP 4

INDUSTRIAL CONSULTATION

- Airbus
- BAE Systems
- Bombardier Aerospace
- Dowty Propellors
- GE Aviation
- GKN Aerospace
- Leonardo
- Meggitt
- Rolls- Royce
- Safran Landing gear
- Safran Nacelles
- Spirit Aero Systems
- UTC Aero Systems

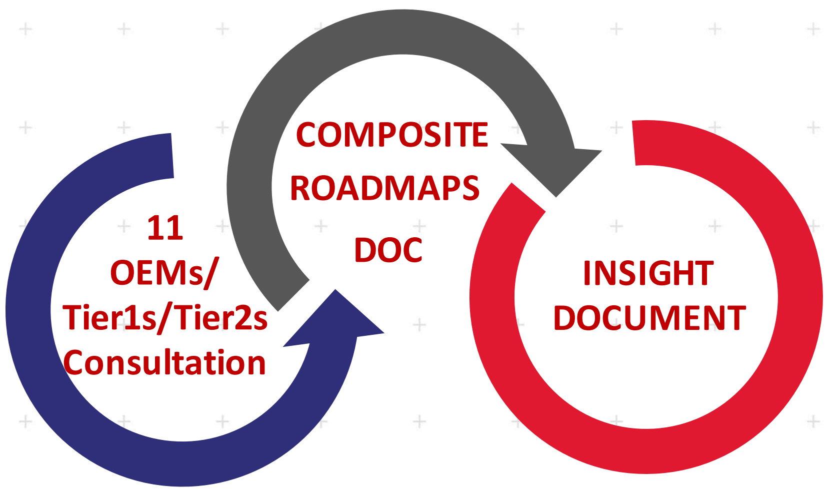
STEP 5

ROADMAP CONSOLIDATION & ANALYSIS

STEP 6

DELIVERY & COMMS

- Deliverables
- Conferences
- Presentation Material
- Link to CLF Aerospace Group

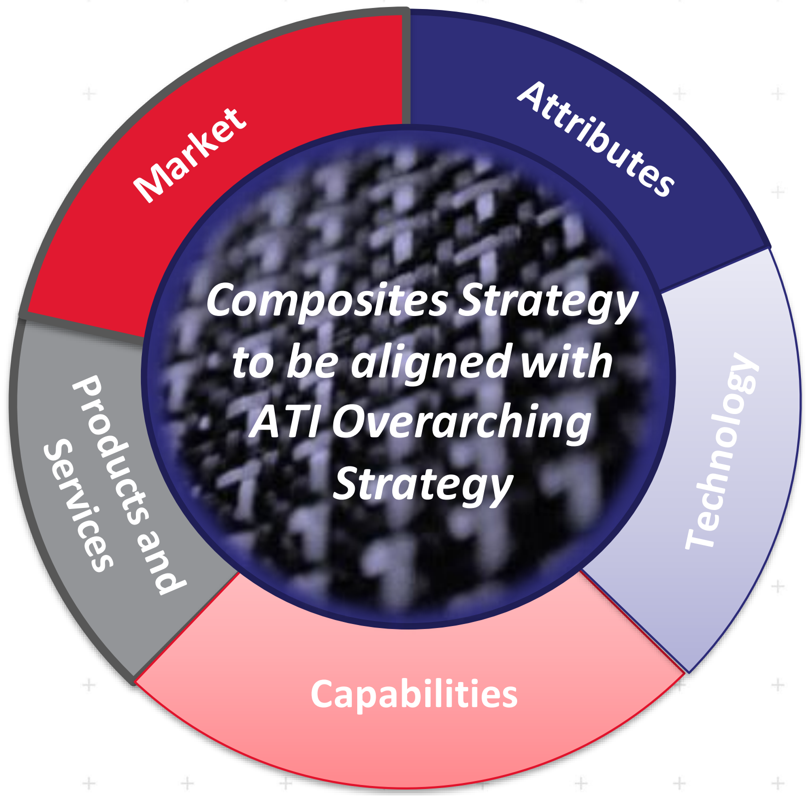


INSIGHT

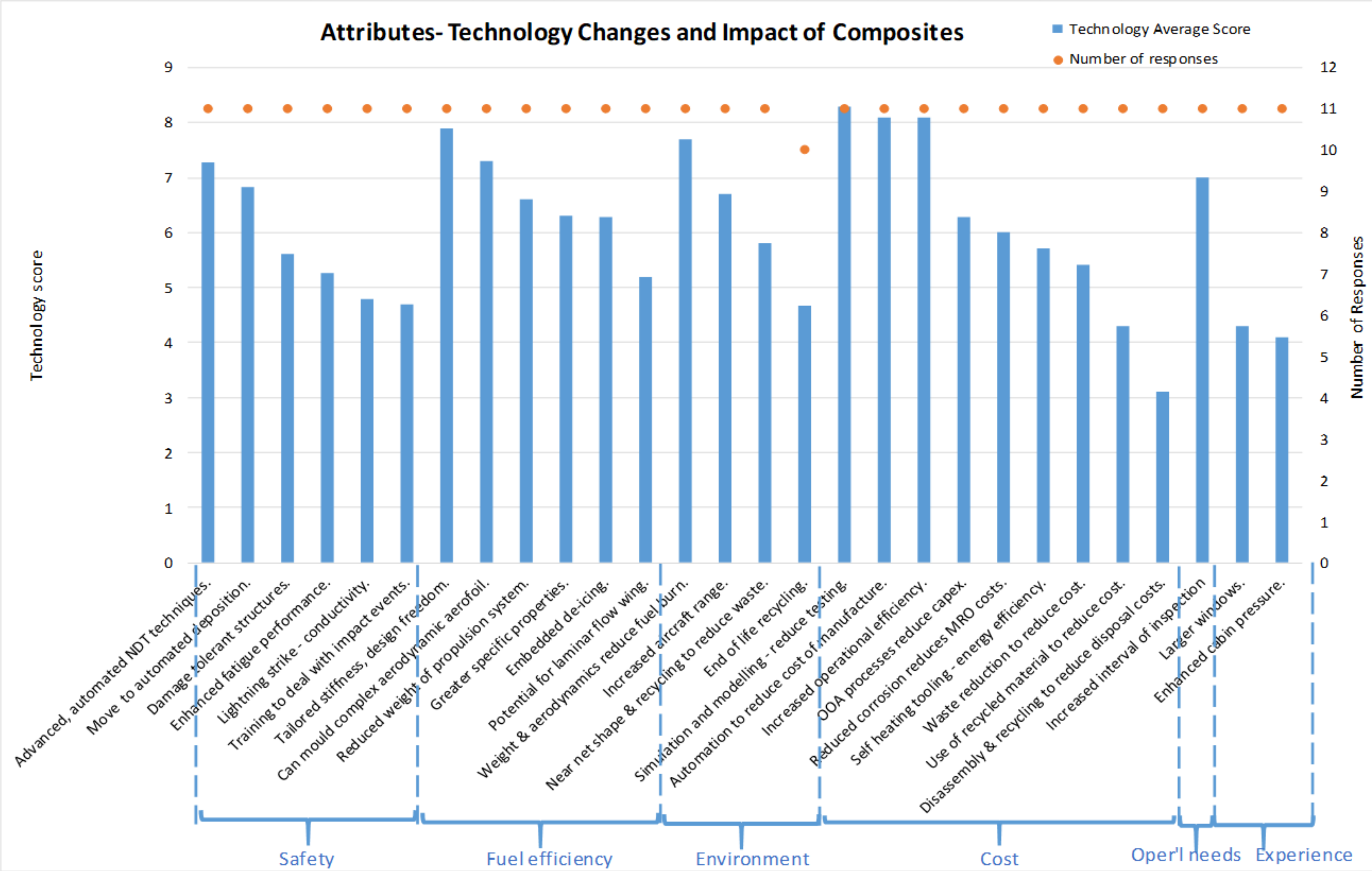
Introduction

09 COMPOSITE MATERIAL APPLICATIONS IN AEROSPACE

Methodology



Attributes – Impact Analysis



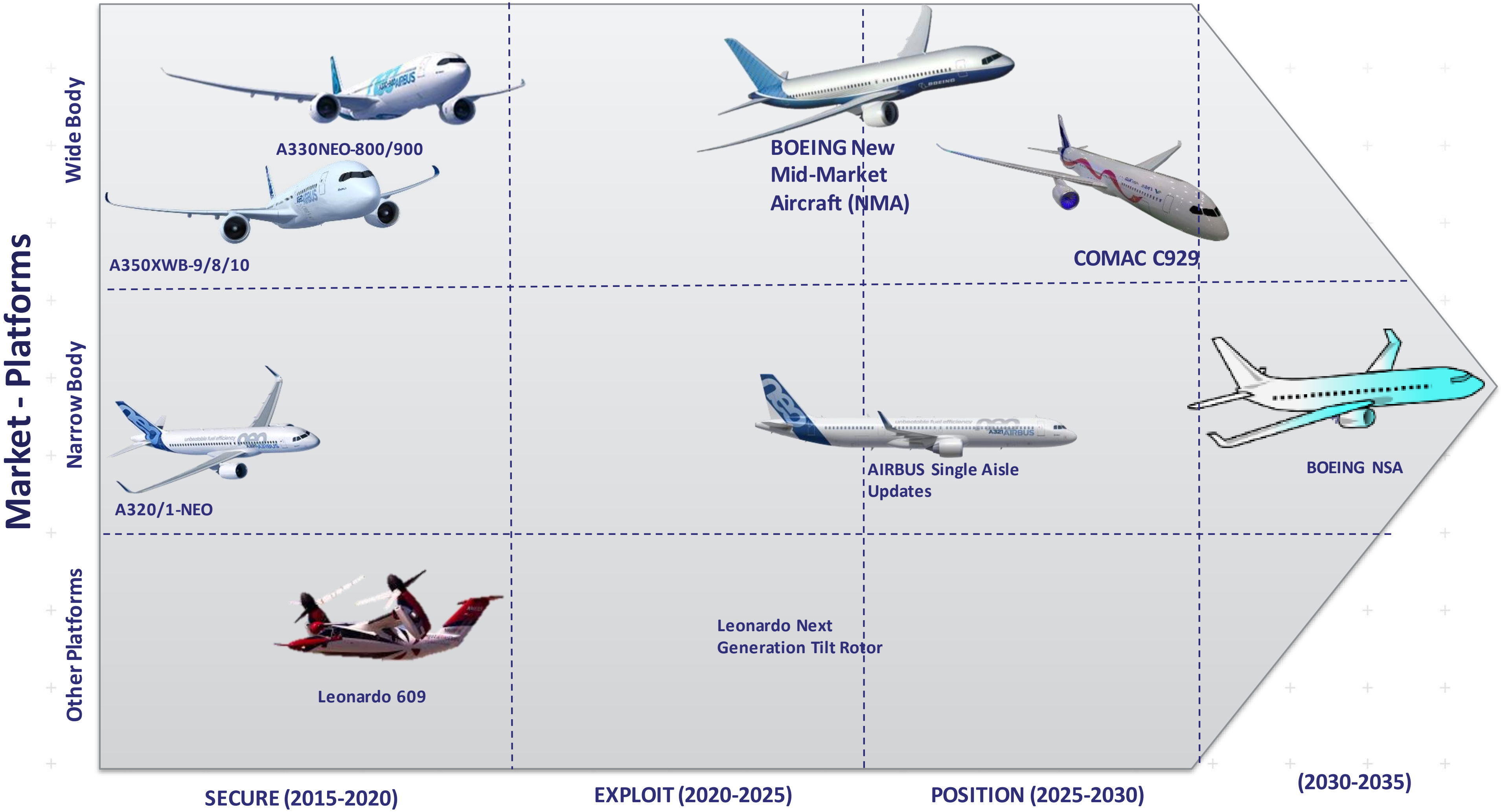
Market – Available Platforms

Opportunity key: Priority Platform for UK Composites | Announced: Public | Speculation: New architecture | Update

TIME ENTRY INTO SERVICE	2015 - 2020	2020 - 2025	2025 - 2030	2030 - 2035
WIDE BODY	A350-9/8/10; A330 NEO; B787-10	B777X; Updates - engine, systems, aerostructure	NMA; C929	Updates to engine, systems, aerostructure
NARROW BODY	A320/1 NEO; B737 MAX; C-Series	C919; Updates & derivatives – engine, systems, aero structure		New Single Aisle
REGIONAL JET/ TURBOPROP	E2, MRJ 70/90, ATR 42/72	Turbo-prop update	New turbo-prop; RJ updates	
BUSINESS JET	New large BJs; Updates (G7000, G8000)		China/Korea BJ	Supersonic
ROTARY WING	B505, A225e, AW 109x + 139x. AW169, AW609; SKYe SH09	NextGen CTR & other compound; X4	Updates/derivatives	

ATI market analysis and platform opportunity roadmap

Market – Platform Priorities for UK Composites

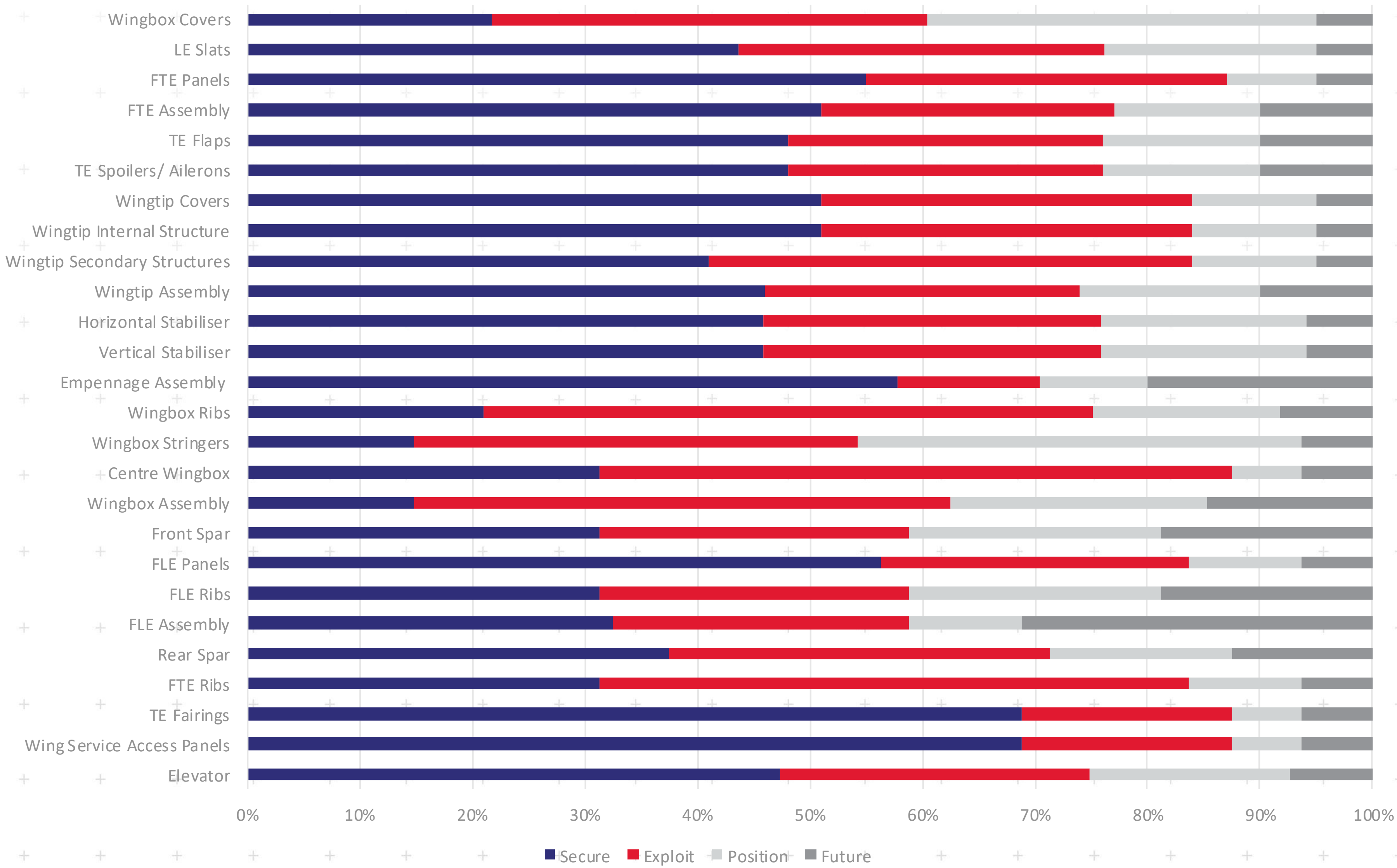


Market – Priority Platforms Opportunity Value Analysis

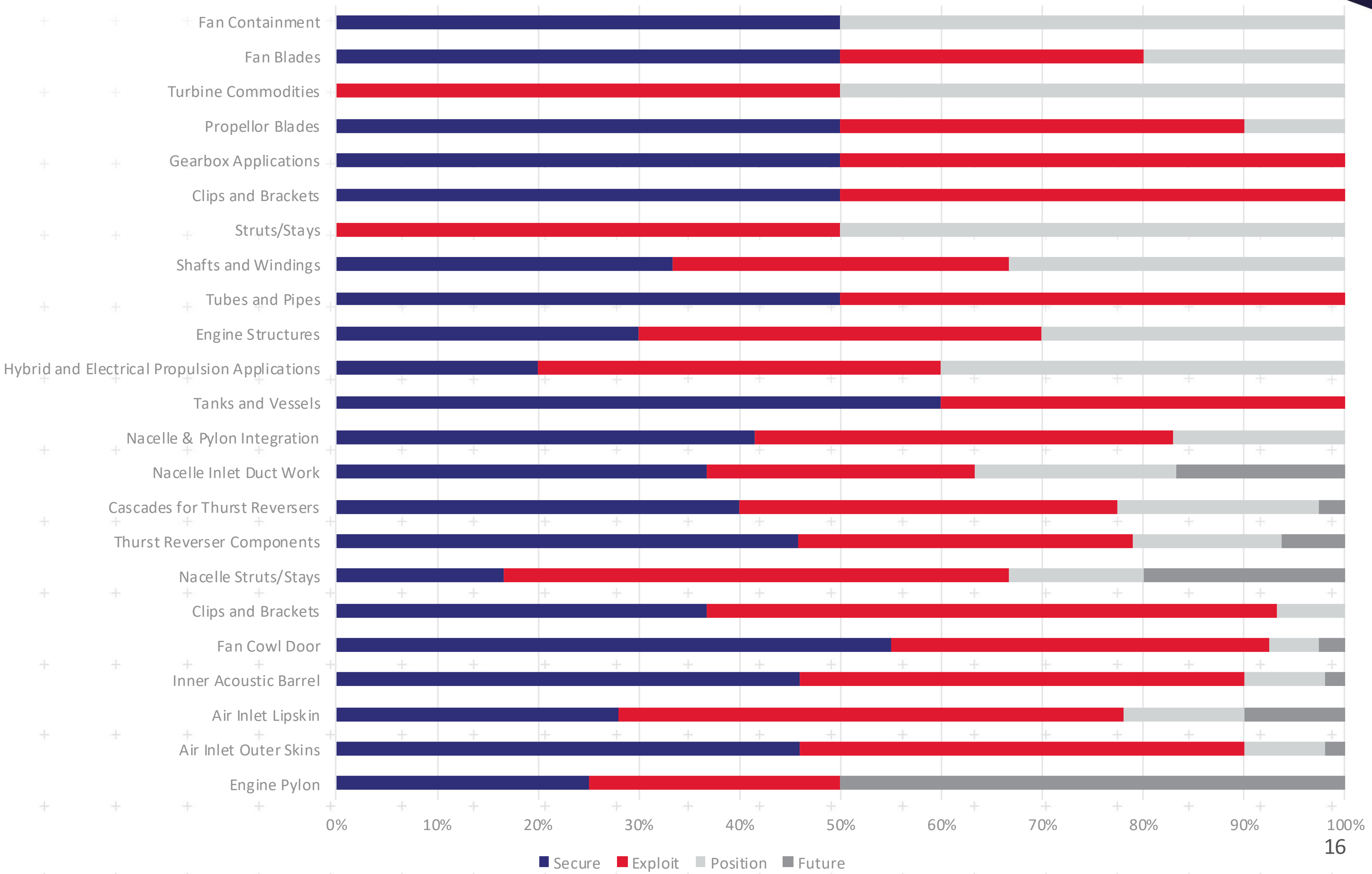
Overall Aircraft Revenue Value (2017-2035) - £1.4 Trillion

Product Area	Components	2017-19	2020-24	2025-29	2030-35
Aerostructures	Wing box covers, ribs, centre wing box, front and rear spars, FLE details, LE slats, flaps, ailerons, spoilers, winglets, fuselage, empennage	£10.2B	£20.2B	£17.1B	£40.1B
Nacelle & Pylon	Fan cowl door, thrust reverser, air inlet lipskin, inner acoustic barrel, cascades	£1B	£2B	£1.7B	£4B
Engine	Casing, fan blades, HP blades, OGVs, tailcone	£2.3B	£4.5B	£3.8B	£9B
Landing Gear	Wheels and brake systems	£2.6B	£5.2B	£4.4B	£10.3B

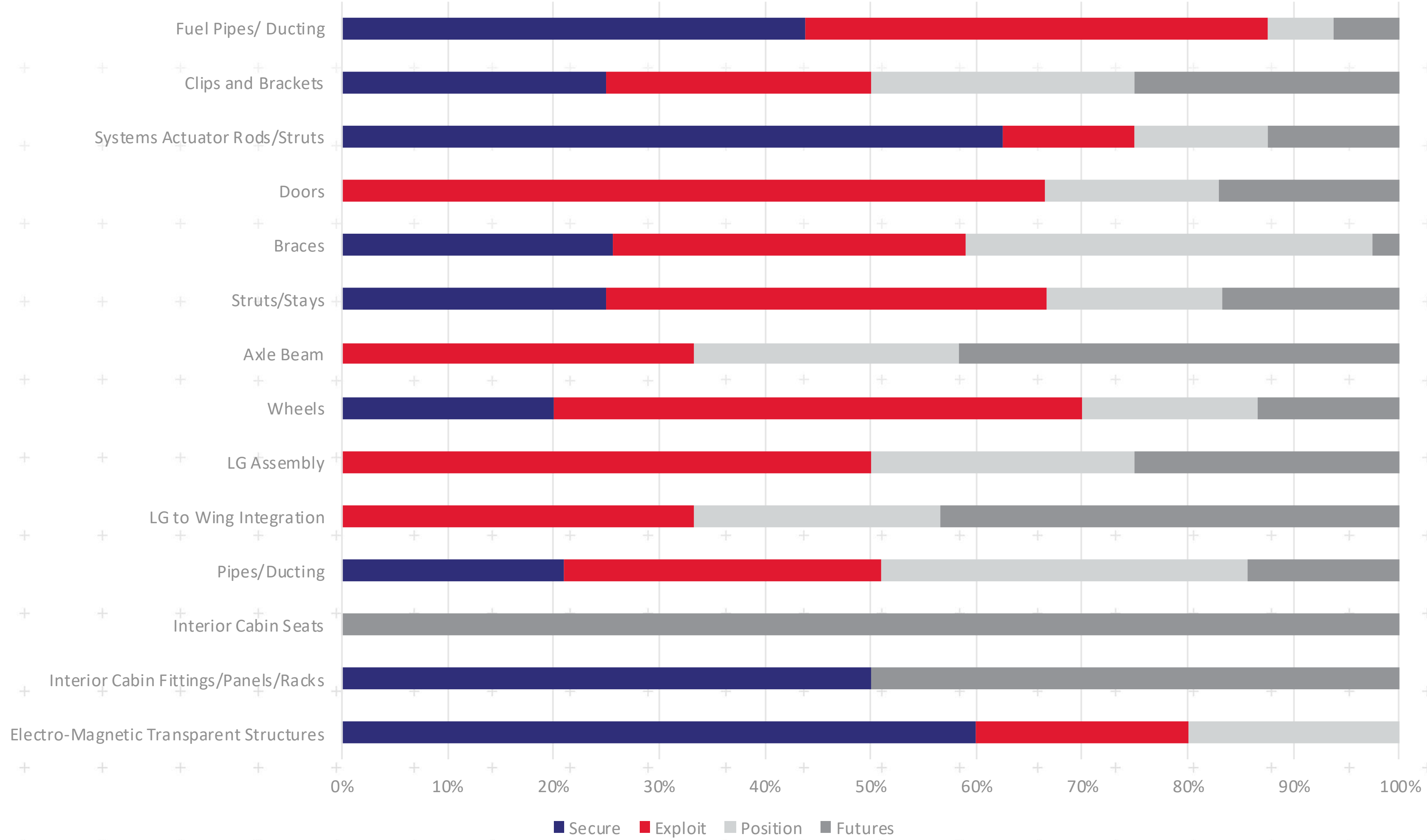
Products – Structures Priorities



Products – Propulsion Priorities



Products – Systems Priorities

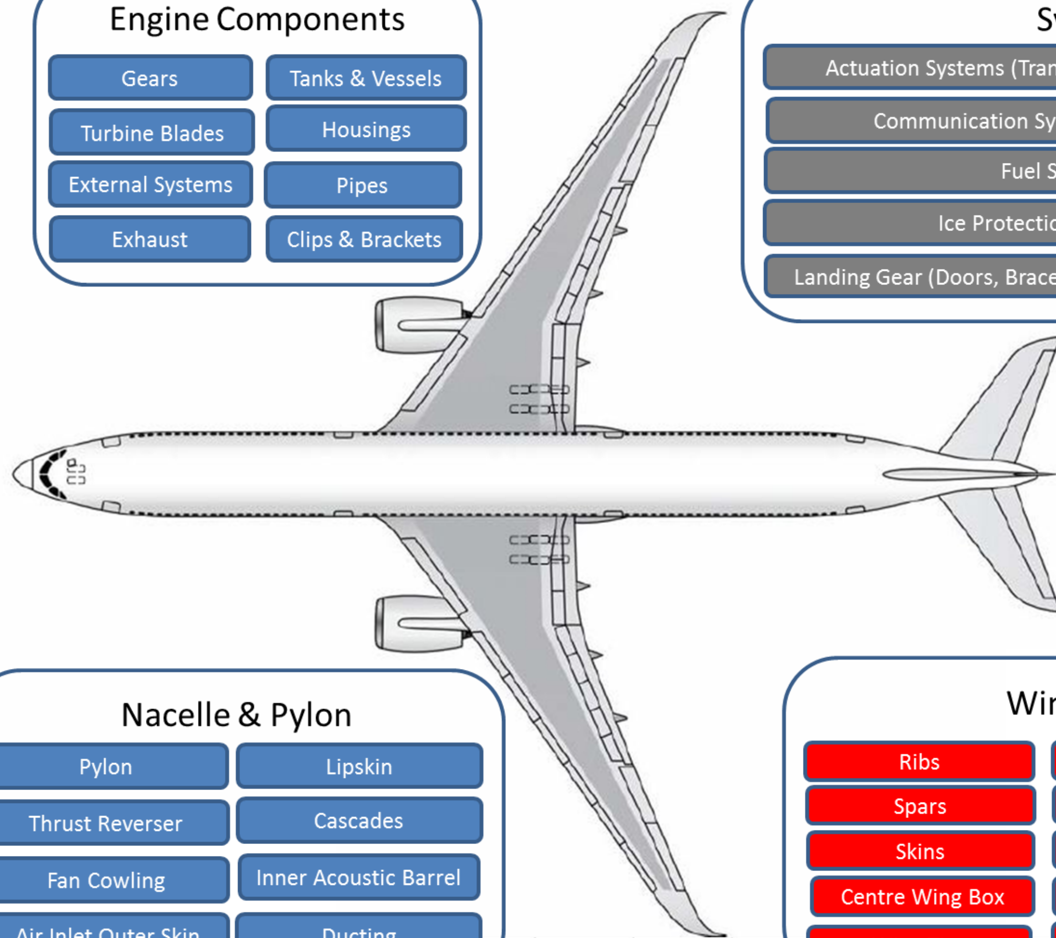


Products – Key Opportunities

Fan/ Propeller/ Rotor System
- Fan Blades
- Propeller Blades
- Rotor Blades
- Fan Casing

Engine Components
- Gears
- Tanks & Vessels
- Turbine Blades
- Housings
- External Systems
- Pipes
- Exhaust
- Clips & Brackets

Systems
- Actuation Systems (Transmissions, Shafts, Torque Tubes)
- Communication Systems (Radomes, Antennas)
- Fuel Systems (Pipes)
- Ice Protection Systems (Surfaces)
- Landing Gear (Doors, Braces, Struts, Brakes, Axel Beams, Skids)



Fuselage/ Structure
- Skin Panels
- Stringers
- Bulkheads
- Floor
- Panels
- Doors
- Ducting
- Interiors
- Cowling
- Tail boom
- Shrouding
- Frames

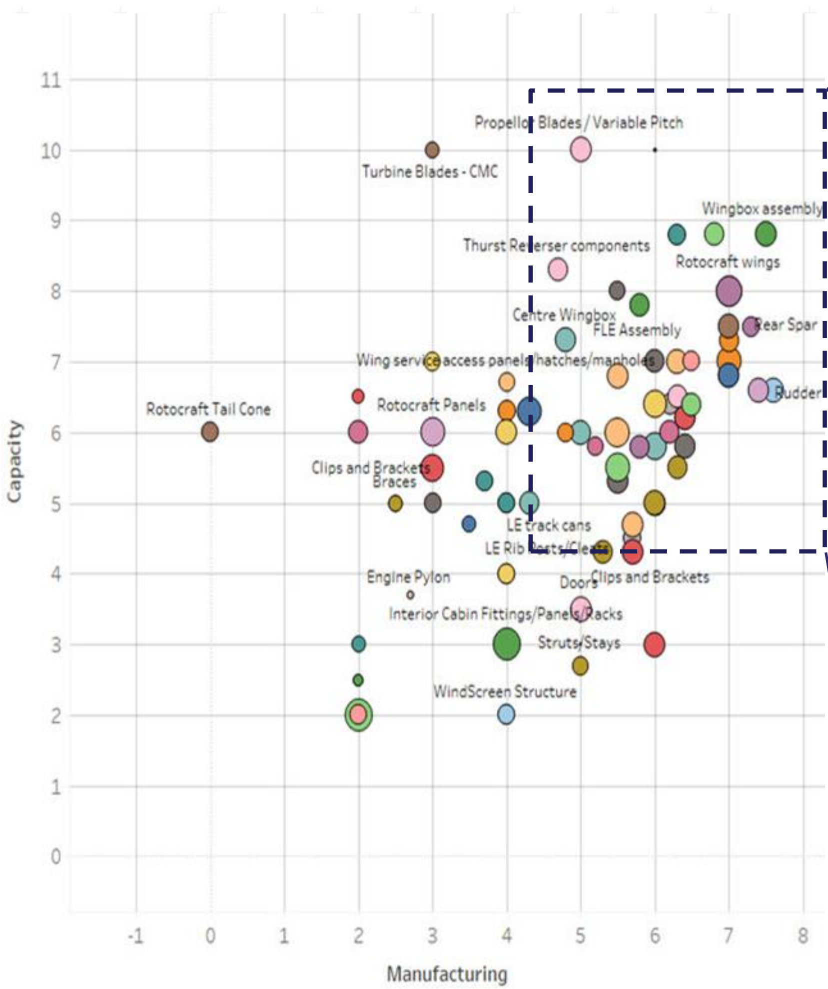
Empennage
- Horizontal Tail Plane
- Vertical Tail Plane
- Rudder
- Elevator

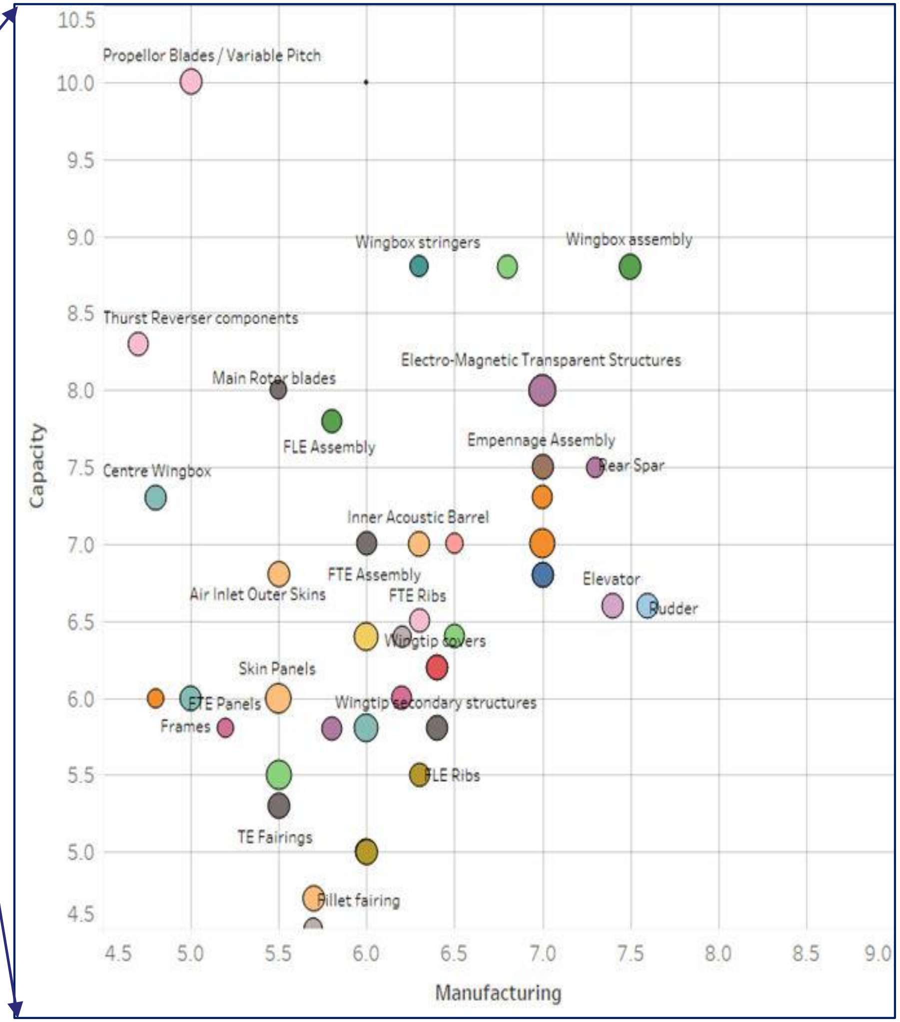
Nacelle & Pylon
- Pylon
- Lipskin
- Thrust Reverser
- Cascades
- Fan Cowling
- Inner Acoustic Barrel
- Air Inlet Outer Skin
- Ducting

Wing
- Ribs
- Moveables
- Spars
- Stringers
- Skins
- Fairings
- Centre Wing Box
- Fixed Trailing Edge
- Wing Tips
- Fixed Leading Edge

- Structures
- Propulsion
- Systems

Products – Competency Analysis





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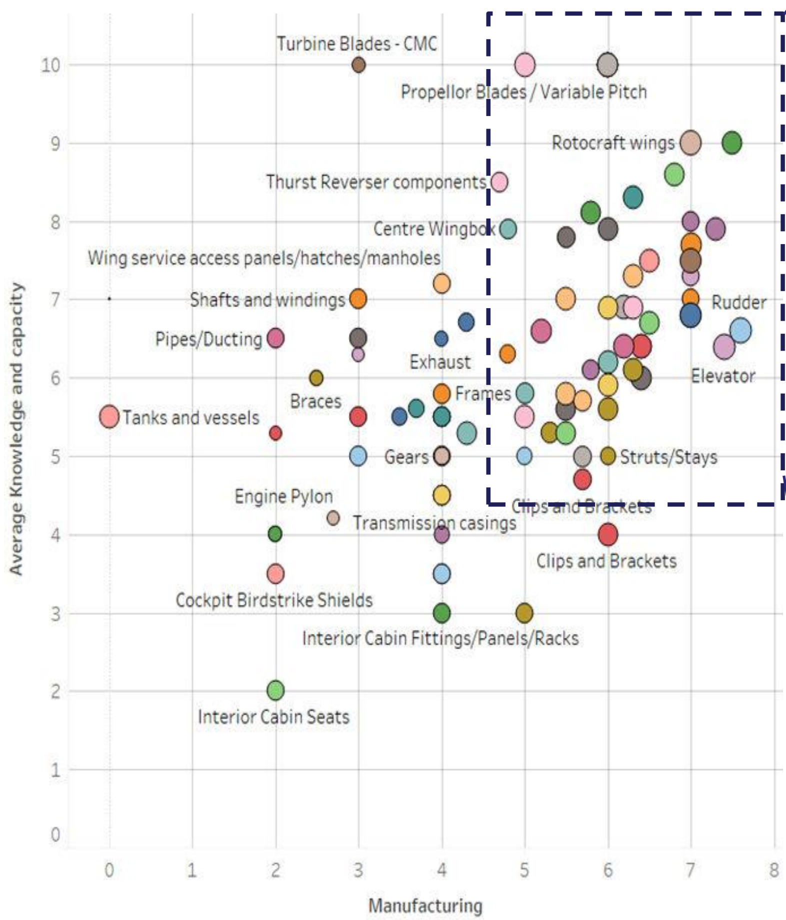

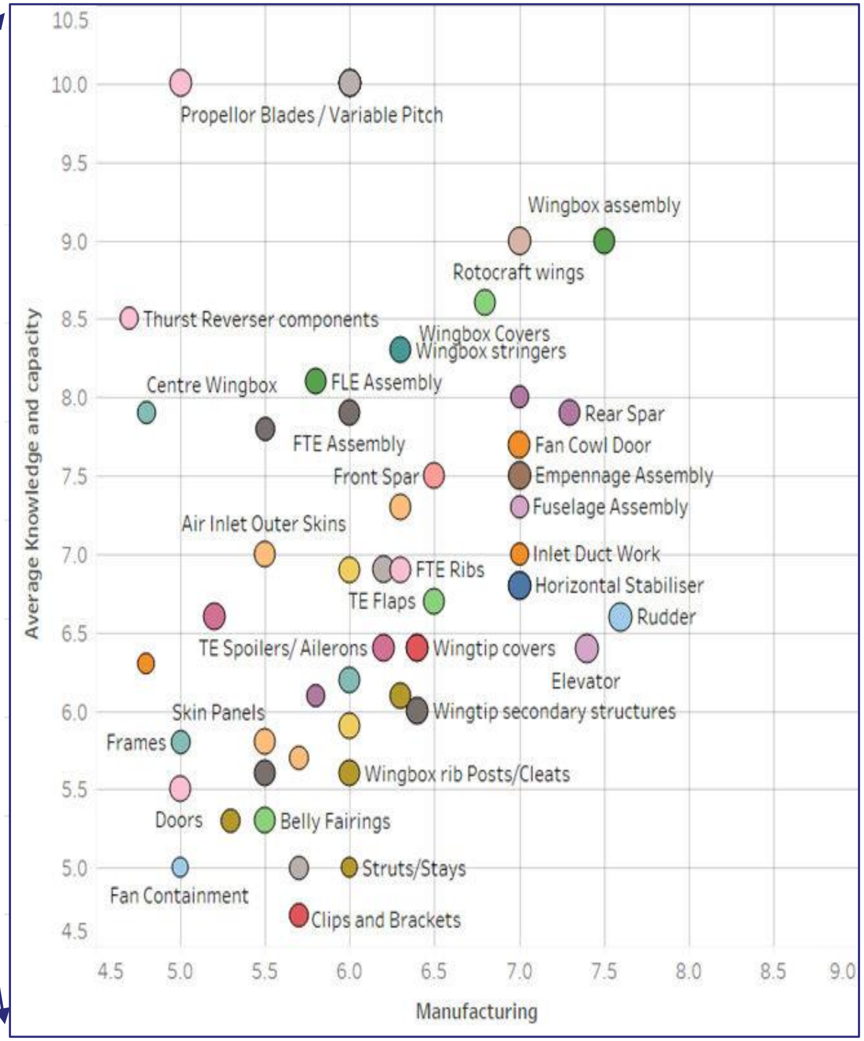

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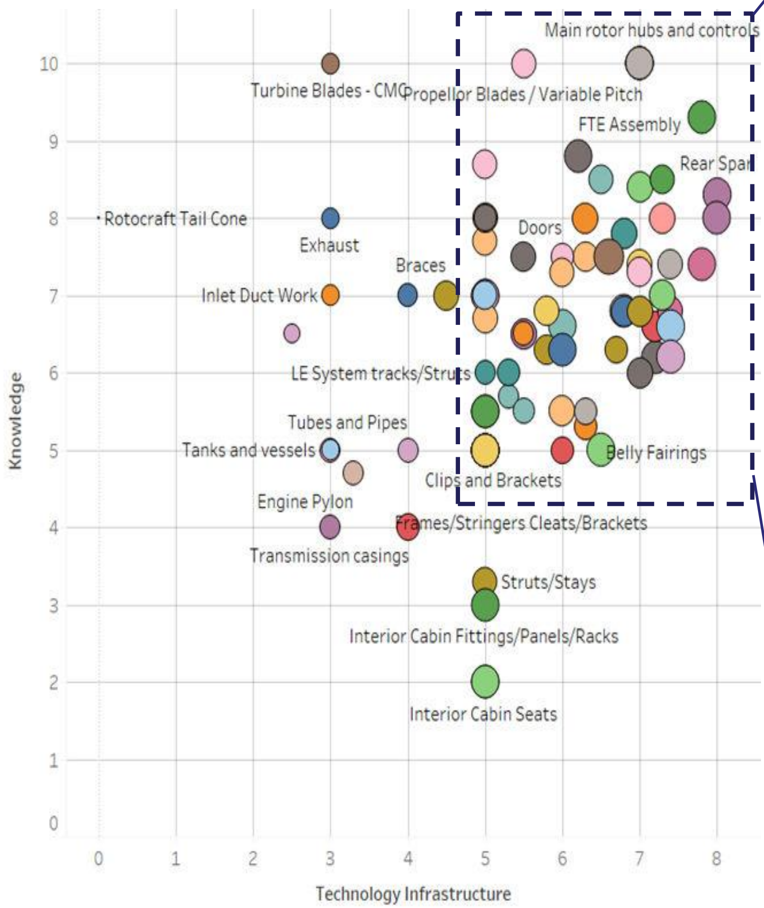

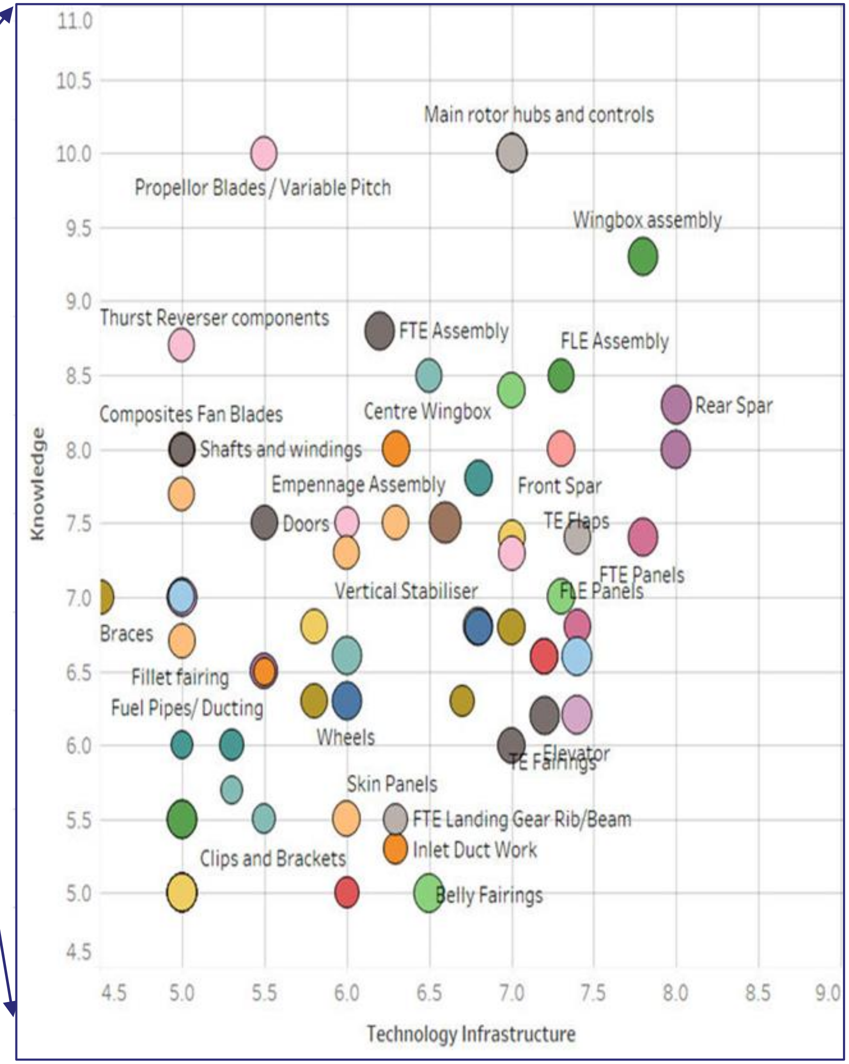

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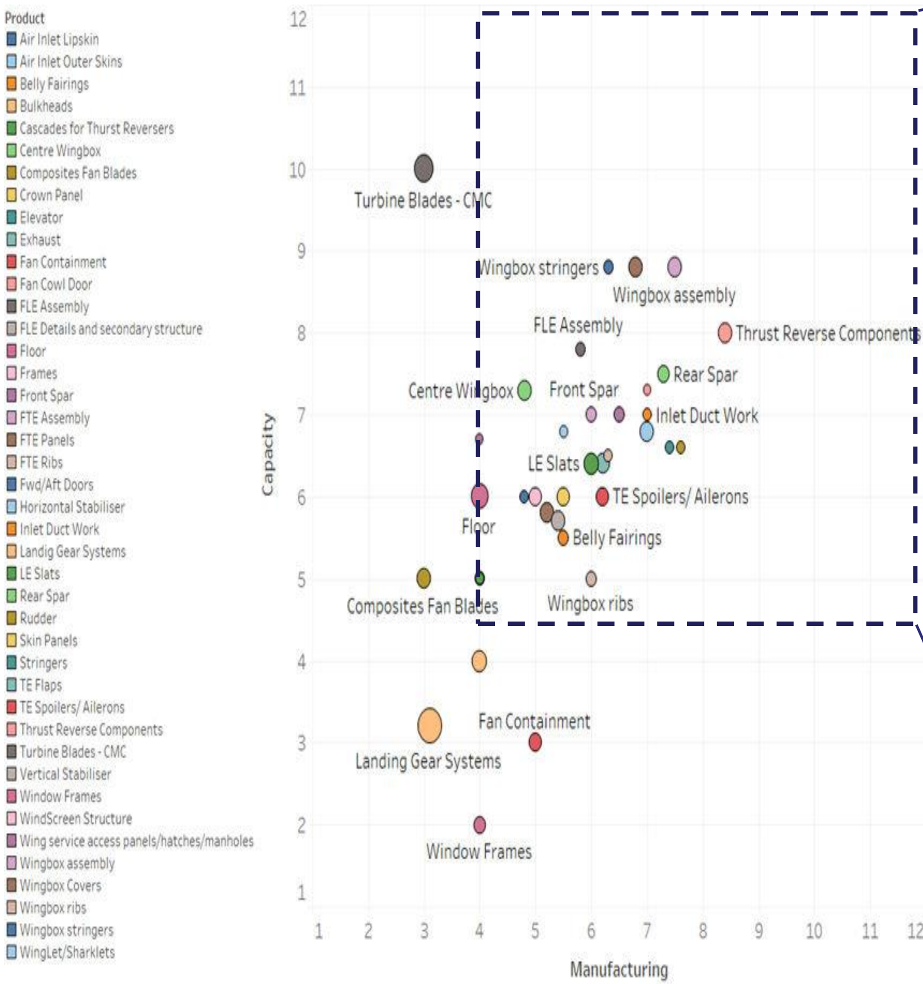

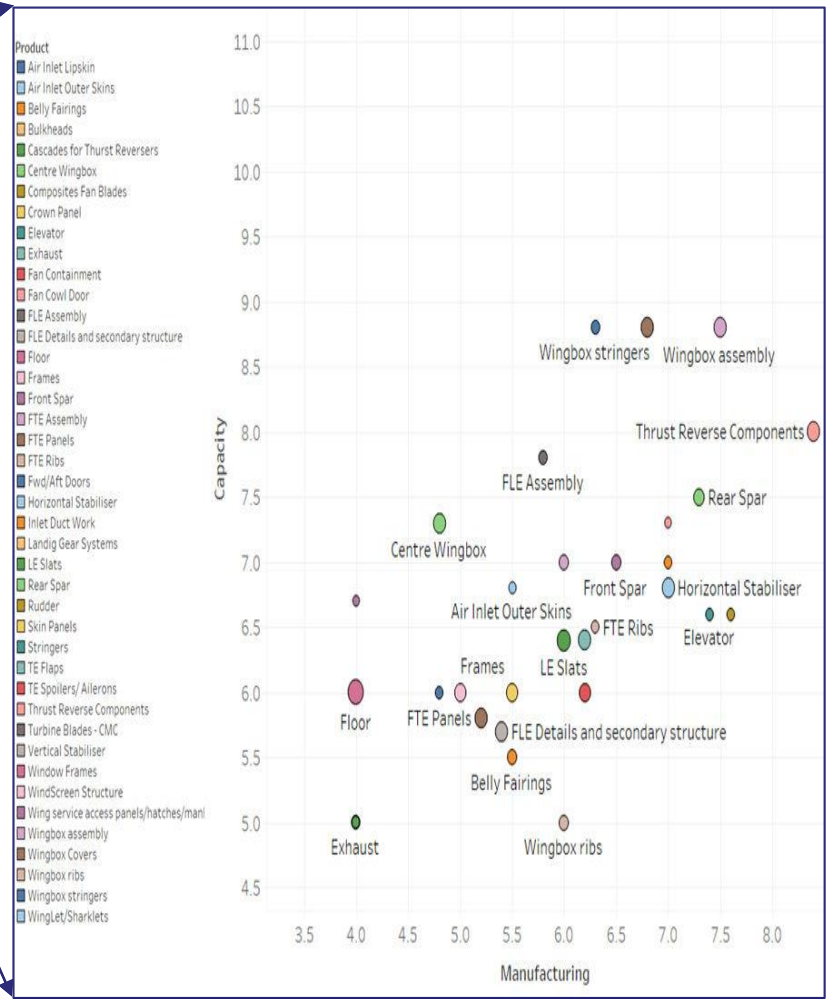

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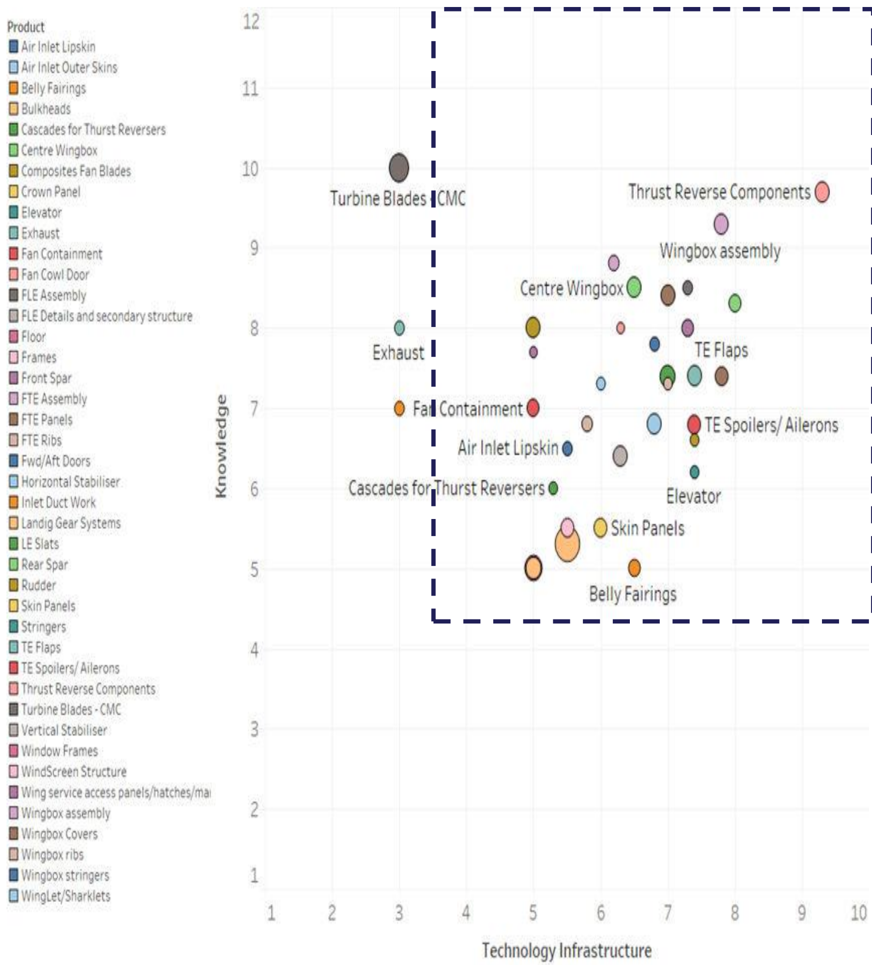

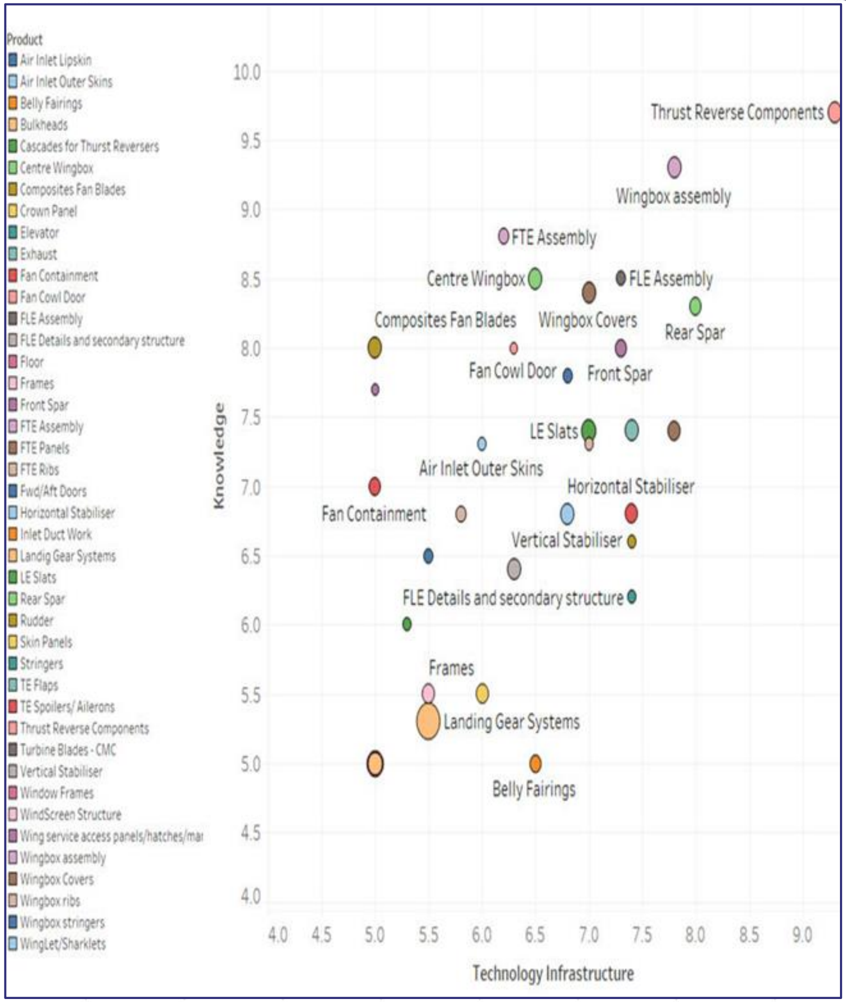

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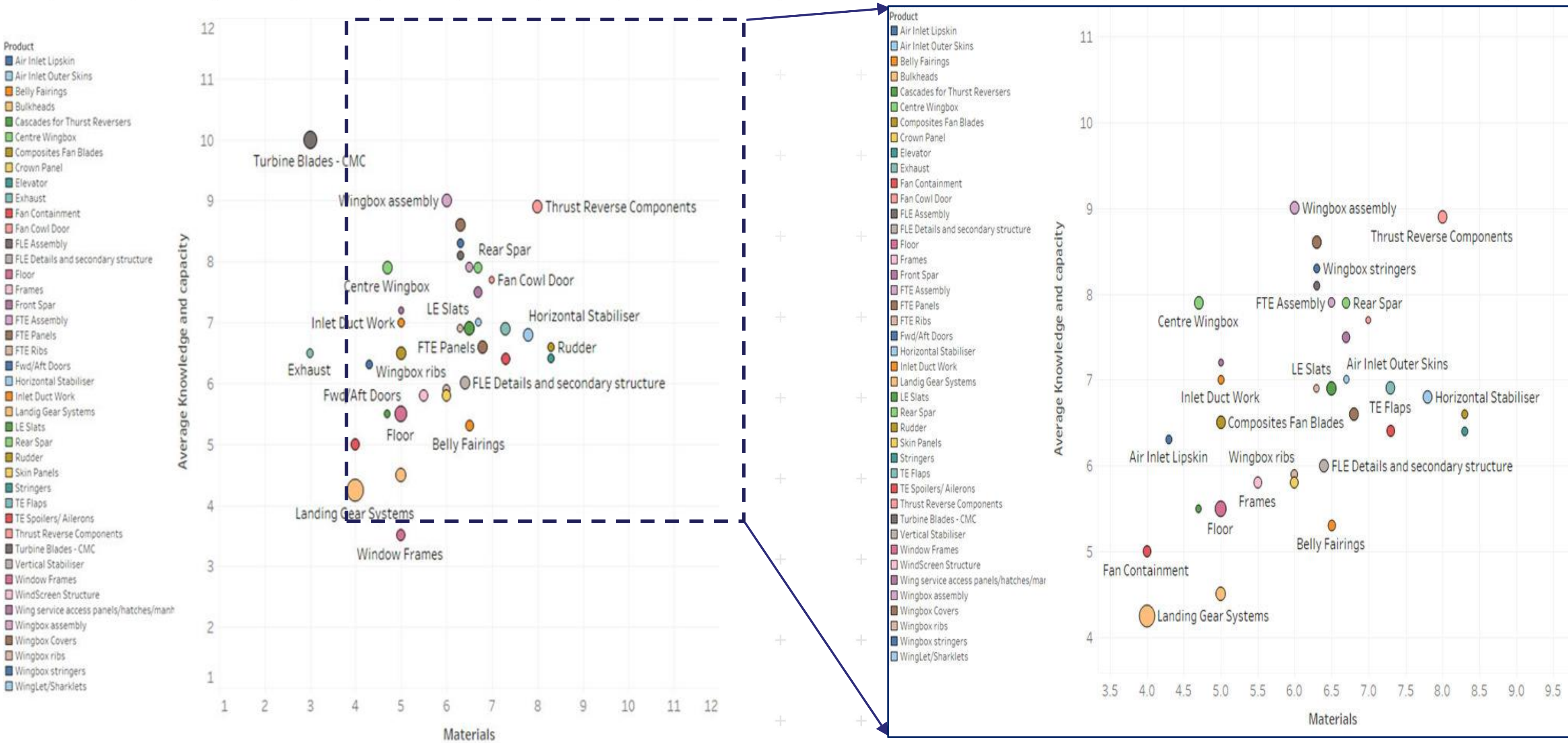
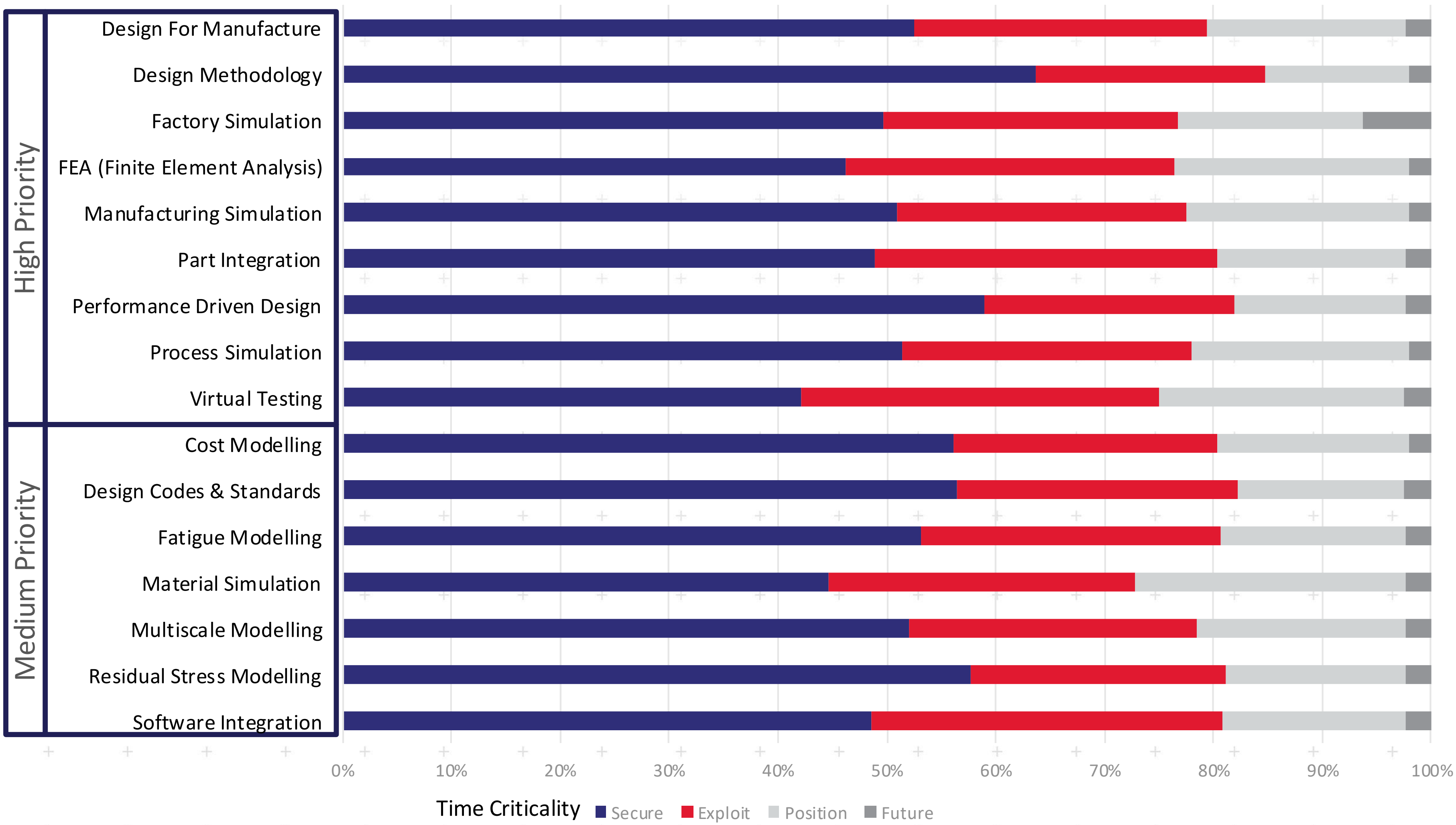


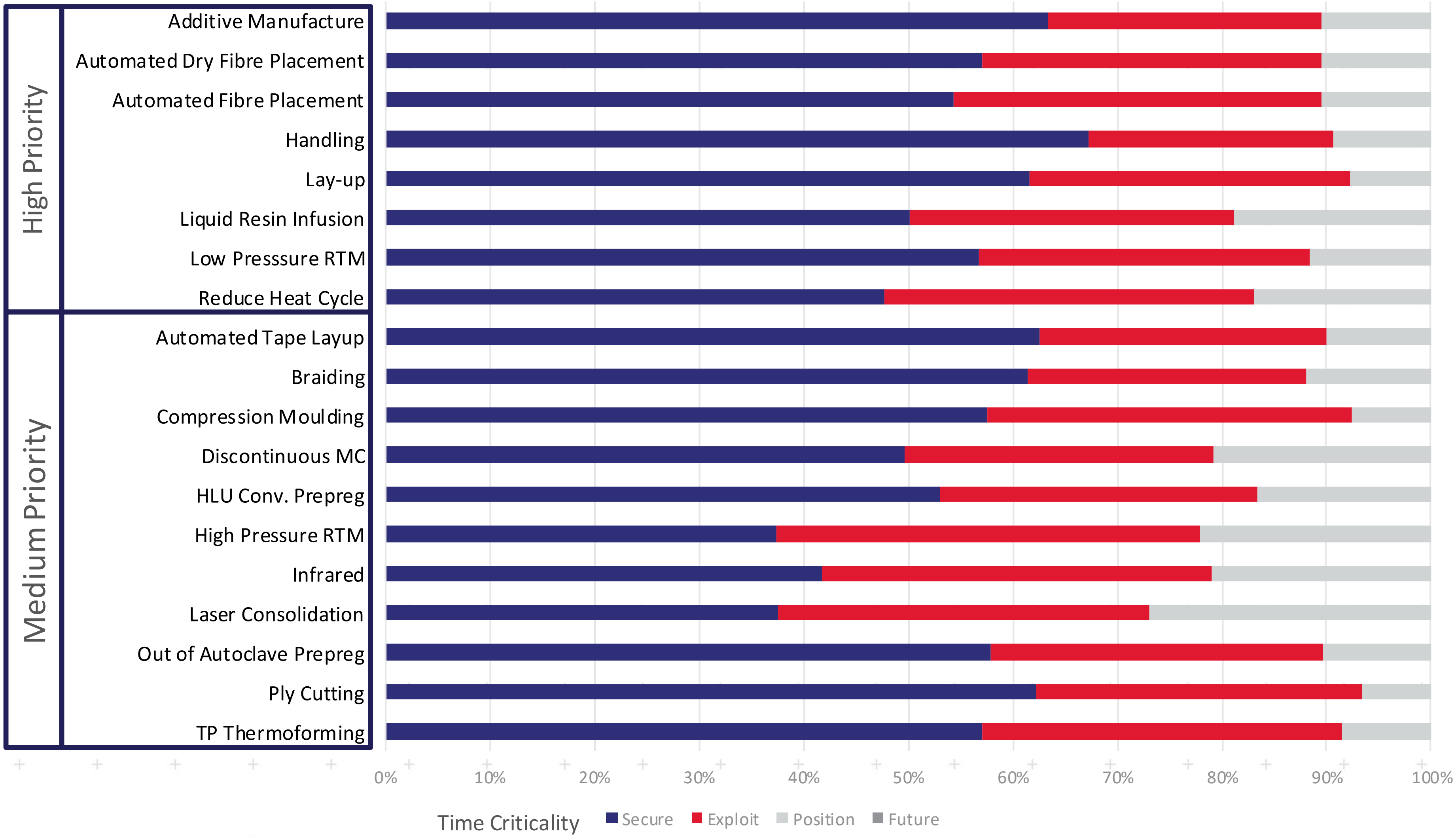
Technology - Priorities

Highest % R&D				
	Design & Analysis	Processes	Materials	Technology Enablers
Secure (0-5yrs)	• Design methodology • Performance driver design • Residual stress modelling • Design for dis/assembly • Design codes and standards • Cost modelling • Life cycle analysis • Fatigue modelling • Design for manufacture • Multiscale modelling	• Additive manufacturing • Handling • Automated tape laying • Ply cutting • Layup • Braiding • Stamping • Out of autoclave prepreg • Compression moulding • Thermoplastic thermoforming	• Tougheners • 3D woven • Binders/tackifiers • Glass fibre • Other fibres • Graphene • Thermoset polymers • Thermoplastic polymers • Carbon fibre • Carbon nanotubes	• Energy efficiency • Environmental impact • Machining • Recycling • Hollow parts • NDT • Testing • Coating/painting • Foam • Mechanical fastening
Exploit (0-10yrs)	• Virtual testing • Software integration • Part integration • Legislation/regulations • Finite element analysis • Material simulation • Fatigue modelling • Factory simulation • Design for manufacture • Process simulation	• RTI • Embroidery • Infrared heating • Spray • Laser • High pressure RTM • Reduce heat cycle • Automated fibre placement • Compression moulding • Injection moulding	• Kevlar fibre • Stitching • Tufting • Non crimp fabrics • Hybrid fibres • Woven • Discontinuous • Non-woven • Carbon fibre • Z-pin	• Welding • Structural health monitoring • Processing equipment • Cycle time reduction • Robots • Jig-less assembly • Fire resistance • Mechanical fastening • Human robot integration • Thermal conductivity
Position (0-15yrs)	• Material simulation • Virtual testing • Legislation/regulation • Finite element analysis • Manufacturing simulation • Process simulation • Multiscale modelling • Life cycle analysis • Design for manufacture • Cost modelling	• Laser heating • Microwave • Spray • Infrared heating • Diaphragm forming • Pultrusion • High pressure RTM • Embroidery • Filament winding • Injection moulding	• Bio fibres • Polymer fibres • Bio resins • Kevlar fibre • Recycled carbon fibre • Ceramic matric • Other fibres • New fibres • Hybrid fibres • Carbon nanotubes	• Morphing • Structural health monitoring • Recycling • Water efficiency • Human robot integration • Adhesive bonding • Welding • Structural power • Jig-less assembly • Factory automation

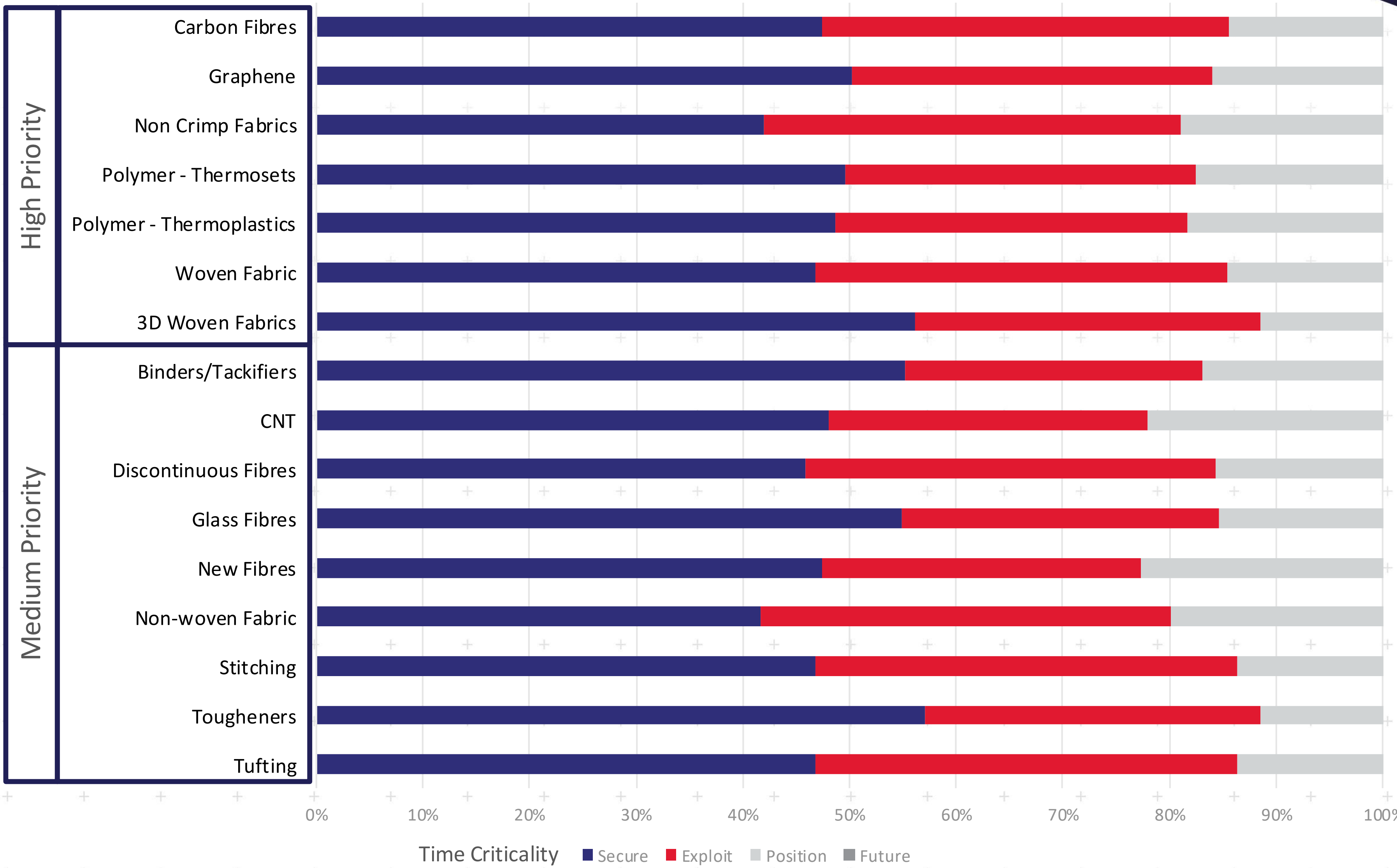
Technology – Design & Analysis



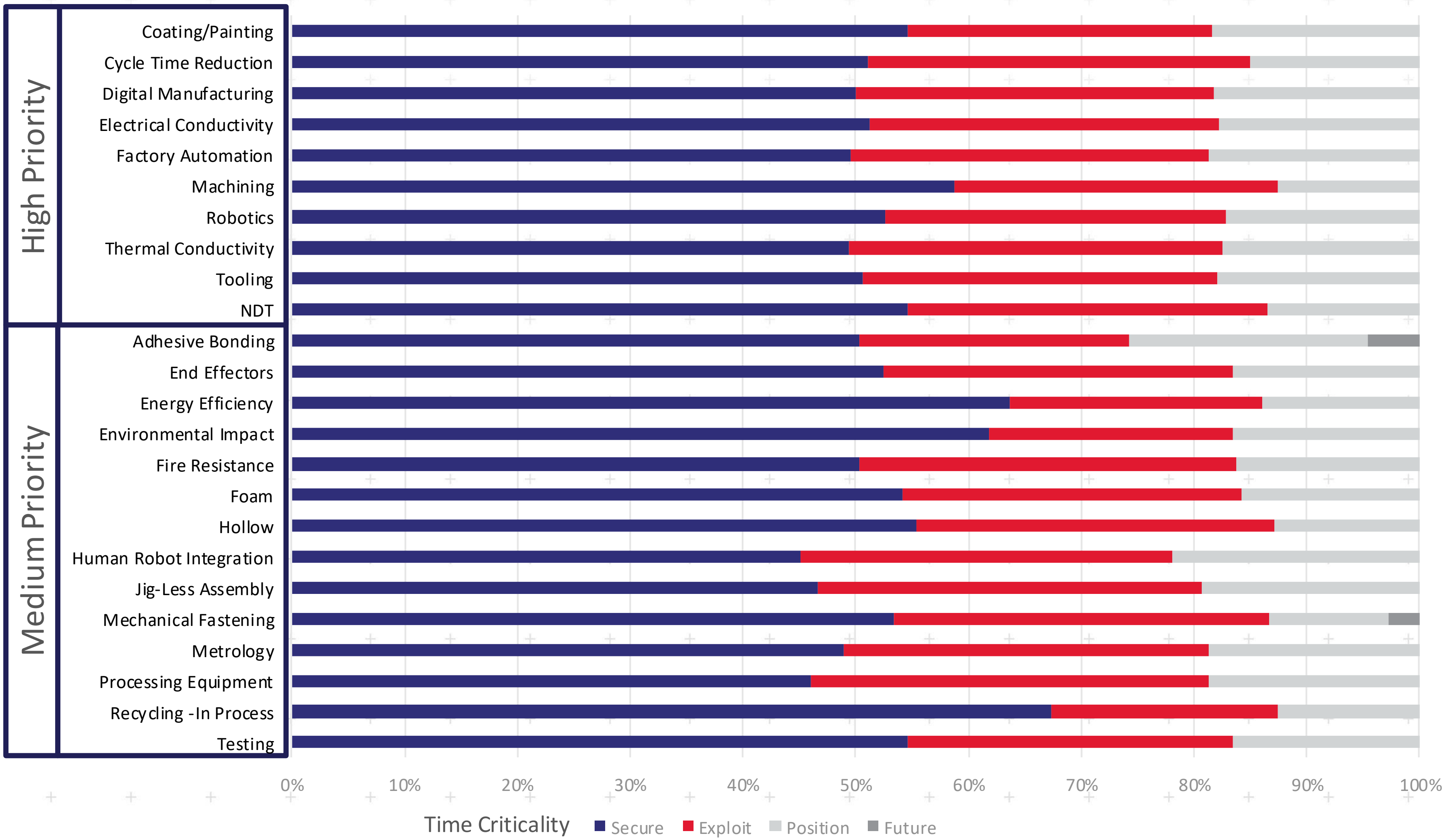
Technology - Processes



Technology - Materials



Technology - Enablers



Technology – Challenges

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ATI Theme	Key Challenge	Secure	Exploit	Position
Key Market Needs	Aircraft of the Future	Novel wing architectures integration with increased composite content	New air vehicle architectures with more electric systems with lightweight composite structures	New architectures for large all electric aircraft with lightweight composite structures
Key Market Needs	Aerostructures of the Future	Simplified architectures to achieve composite rate enablement and reduce manufacturing costs	More efficient wing and fuselage structures with advanced design and integration of composite materials	Advanced composite structures with morphing capability
Key Market Needs	Propulsion of the Future	Lightweight composite fan and rotor/propeller systems including containment elements	Ultra-High Bypass Ratio Engines with larger diameter composite fan systems	Ceramic Matrix Composites for turbine blades and other components
Key Market Needs	Smart, Connected & More Electric Aircraft	Multifunctional, multi-material systems and components to enabler weight reduction and achieve performance improvements	More electric aircraft systems with composite elements	All electric aircraft systems with composite structures and elements
Design & Analysis	Improved design for manufacture	Residual stress modelling and design for assembly/disassembly	Use of process and cost modelling to inform design know-how	Multi-scale (material through to factory) modelling to ensure design optimises manufacture
Design & Analysis	Enhanced simulation and analysis tools and techniques to reduce testing pyramid	Improved codes, standards, simulation validation and enhanced testing capabilities	Integrated design, test and simulation toolsets integration	Virtual aircraft for structures, manufacturing and assembly
Design & Analysis	Continued improvements in performance and design	Use of simulation to inform material and product design and performance	Part integration and design methodology	Fully optimised configurations and deployment
Processes	Cost effective, higher volume composite processing technologies	Low cost tooling, out of autoclave process, wet or dry fibre/tape pay and preform infusion	Novel heating/curing systems, material/preform handling	A range of cost effective processing techniques for high volume, high performance structures
Processes	More efficient part and assemblies manufacturing systems	Technologies to reduce cycle times. Near net shape production and in-process NDT to reduce waste	Development of production kit to optimise energy consumption, reduce wastage for manufacturing processes	Processes to reduce power and resource consumption
Processes	Cost effective automated manufacture, assembly and inspection of composite parts	Smart handling systems, in process NDT, advanced robotics	Reconfigurable and intelligent automation systems	Composite factory 4.0 – rapid reconfiguration, mixed product, automation and digital manufacturing

Technology – Challenges

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Materials		Lower cost through reduced materials cost with properties that also reduce processing cost	Quick cure thermoset resins, thermoplastics, optimised dry fibre materials, binders and preforms	Lower cost carbon fibres and intermediates for higher production rates	New innovative, low cost continuous and discontinuous reinforcing fibres
Materials		High performance materials	Enhanced functionality (graphene, carbon nanotubes)	Through thickness performance improvement (3D woven, z-pin, stitching)	New higher performance fibres and resins
Materials		Low environmental impact fibre and matrix production	Materials with reduced cycle time	Low environmental impact thermoplastic and thermoset resins and fibres	Recycled carbon fibre. Bio fibres and resins. Aspire to closed loop recycling
Materials		High temperature capability	Use of additives/coatings for higher temperature performance	Development of new higher temperature PMCs, CMCs, MMCs	Application of optimised multi-material systems
Technology Enablers		Multifunctional composite components and structures	Improved surface treatments and coatings. Increases electrical and thermal conductivity	Integrated structural health monitoring	Integration of morphing capability within primary structures
Technology Enablers		Lightweight multi-material structure production capability	Novel joining, core technologies and tooling. Finishing techniques. Robotics/automation	End effectors for in-process inspection, quality verification jig-less assembly. Human/robot integration	Fully automated, multi-material structures production system
Technology Enablers		Increased interval of inspection through improved monitoring	In-line monitoring and process control/modification. In service monitoring	Improved in-service Structural Health Monitoring (SHM) and big data analytics	Fully integrated, smart, self-monitoring structures. Data management and AI decision making algorithms

Technology – ATI Project Examples

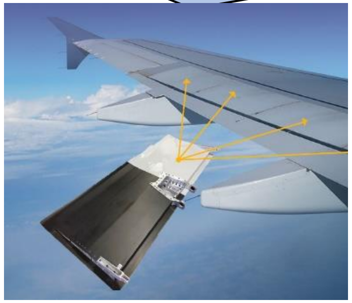
Number of Composite R&D projects 2014-2017	187
Funding	£252.46m
Total project costs	£463.63m

Case Study – Wing Integrated Leading Edge and Trailing Edge (WILETE)

- ATI supported project developing leading and trailing edge components and assembly technologies, supporting high-volume and low-cost composite wing manufacture, assembly and equipping.
- WILETE included a number of critical wing technology streams for Airbus including integration of LE and TE structures with the wing box structure, and integration of electrical systems including ice protection and flight controls.
- The project was supported by a selection of strategic and associate partners from respected research and industrial fields.
- The overall success and outcome of the project enabled Spirit AeroSystems to bring work back into the UK and win a spoiler contract with Airbus.

Case Study – CTI Composite Fan Technology (SAMULET 2)

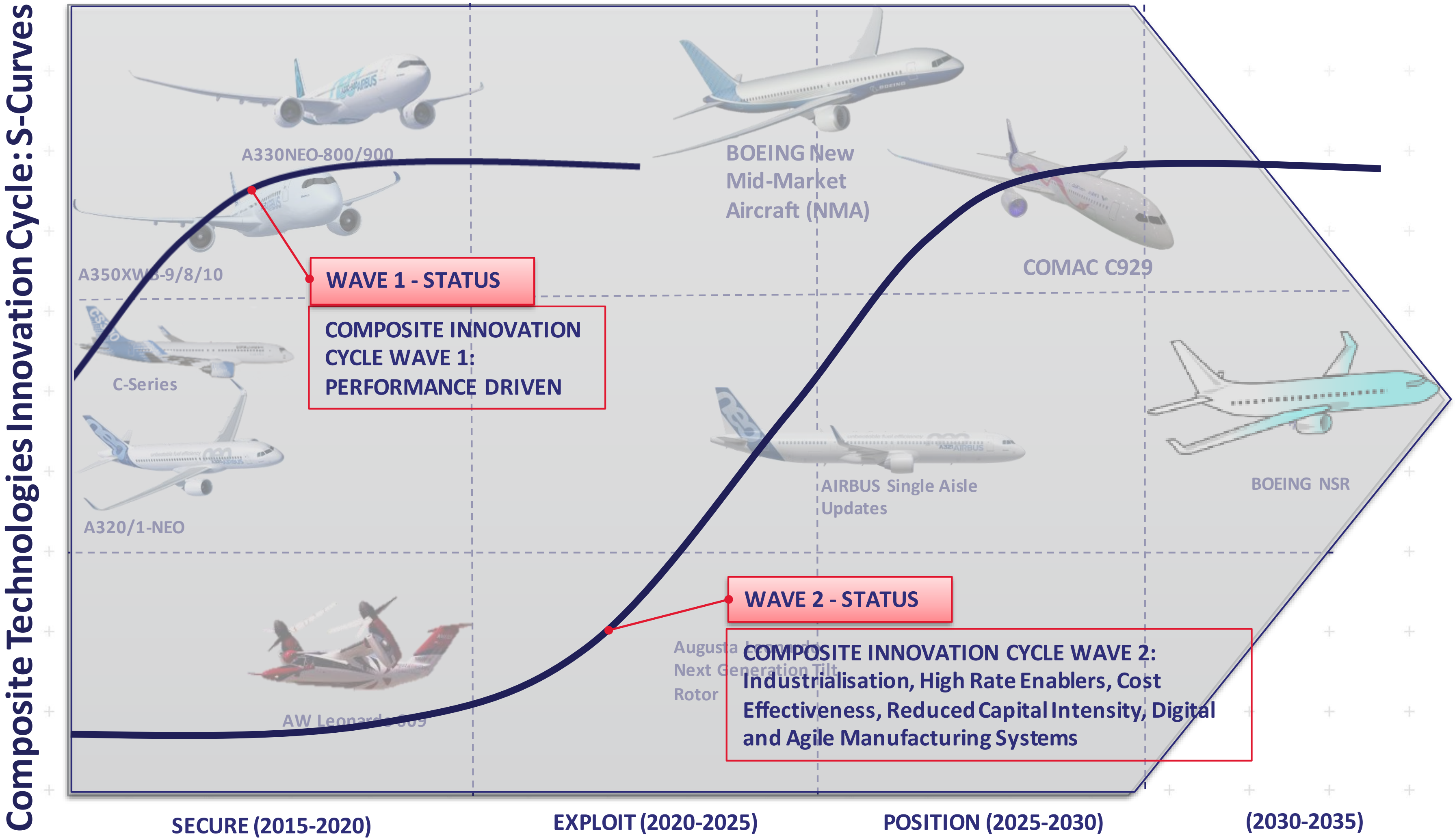
- The Rolls-Royce CTI (carbon/titanium) blades are a key feature of the Advance engine design, which will offer 20% less fuel burn and CO2 emissions than the first generation of Trent aero-engines.
- The blades and composite engine casings for the CTI fan system could reduce weight by up to 1,500lb per aircraft – equivalent to seven more passengers.
- Rolls-Royce has worked collaboratively to develop both composite fan blade and containment casing engineering and manufacturing technology for engine, including work with the National Composites Centre (NCC) and the Manufacturing Technology Centre (MTC) to develop an automated method for manufacturing a composite fan system.
- Advances made have given Rolls-Royce the confidence to invest in a new pre-production facility in Bristol.



Case Study – NCC Capital Equipment (AutoProStruct, HiStruct, NTProStruct)

- The National Composites Centre (NCC) is delivering a suite of ATI projects to implement state-of-the-art equipment for the aerospace industry and wider composites sector to position the NCC as a global centre of competence in large-scale and automated composite manufacture.
- Focussed around the next generation of composite structures for wing, aero-engine and propeller products, this investment will establish new capabilities for automated deposition, preforming, verification, high temperature resin moulding, large scale resin infusion and out-of-autoclave curing technologies, amongst others.
- All of this supports the digital transition of the UK composites industry, identifying and demonstrating high-value applications of I4.0 and embedded engineering knowledge within the sector.

Technology - Innovation



Technology - Disruption

Four technologies were considered potentially disruptive (received more than one vote):

- Additive manufacturing (5 votes).
  The discussion around additive manufacturing related to several different uses of the technology in relation to composite development as outlined in Table below.
- Graphene (3 votes).
  Relates to the requirement for improved functionality, particularly electrical conductivity.
- Welding (2 votes).
  Relates to the need to investigate thermoplastics for higher production rate and the need to join to create multi-material structures.
- Polymers – Thermoset (2 votes).
  Relates to the need to speed up production rates through faster curing polymers.

<table>
<tr><th colspan="4">Discussion on How Additive Manufacturing Is Used in Composite Part Production</th></tr>
<tr><td colspan="2">Part production:</td><td>Tooling/Core materials</td><td>Functionality/Complexity</td></tr>
<tr><td colspan="2">Is composite processing an additive manufacturing process?
Pro:
• Processes such as fibre placement allow selective placement of material to build up a shape, exactly as with AM.
Con:
• Part not always self-supporting during processing.
• May require post-processing (but so do some metals!)</td><td rowspan="3">Rather than being used to make the composite part itself, reference has been made to using additive manufacturing to create mould tools (some wash out) and also to create cores (e.g. honeycomb with very specific shapes).</td><td rowspan="3">Additive manufacturing can be used in combination with composite part lay-up/manufacture to bring added complexity or functionality to structure:
• Multi materials.
• Electrical conductivity paths.</td></tr>
<tr><td>Thermoset composites</td><td>Thermoplastic composites</td></tr>
<tr><td>Not cured during the process of laying down material therefore definitely requires significant post-processing to become a product.</td><td>Can be cured during the process of laying up therefore does not always require post processing to become a product (but may to achieve required properties).</td></tr>
</table>

Technology – Disruption Examples

Additive Manufacturing

Case Study – Additive manufacturing start-up companies

Continuous fibre-reinforced 3D printed composites development has been investigated in the USA since 2012. A number of US based start-up companies have been funded by a combination of private equity and VC funds. Amongst the most disruptive startup companies in this space it worth noting: Mark Forged, Arevo, Orbital Composites, Continuous Composites. Each of these start-ups is developing proprietary technologies for the deposition heads with different peculiar characteristics, e.g.

- multi-axis printing using continuous fibre,
- z-direction tow deposition and along contours via a robotic arm.
- Printing in three dimensions with continuous fibre including aramid, glass (GF) and carbon fibre (CF), copper, nichrome wire and fibre optics.
- UV-cure thermoset resins to enable high-speed printing and printing unsupported into space.
- Laser TP curing during deposition process
- TP resins such as PA6, PA66, PEEK , PEAK, PPS
- In-situ thermoplastic and thermoset resin injection within the deposition head
- Continuous Tow size flexibility from 6K to 24K tows
- Parallel deposition and associated software
- Faster rates than AFP/ATL via parallel processing
- Mould less, out of autoclave composite manufacturing processes

Some of these companies have already started to forge alliances with R&T centres in Europe, Orbital Centre is actively collaborating with Composite Technology centre (CTC) in Stade Germany. ATI has an important role to play here in capturing this "disruptive technology space" for the UK companies and facilitating collaborative R&D on this topic between start-up companies in UK and OEMs/Tier 1s.

Graphene

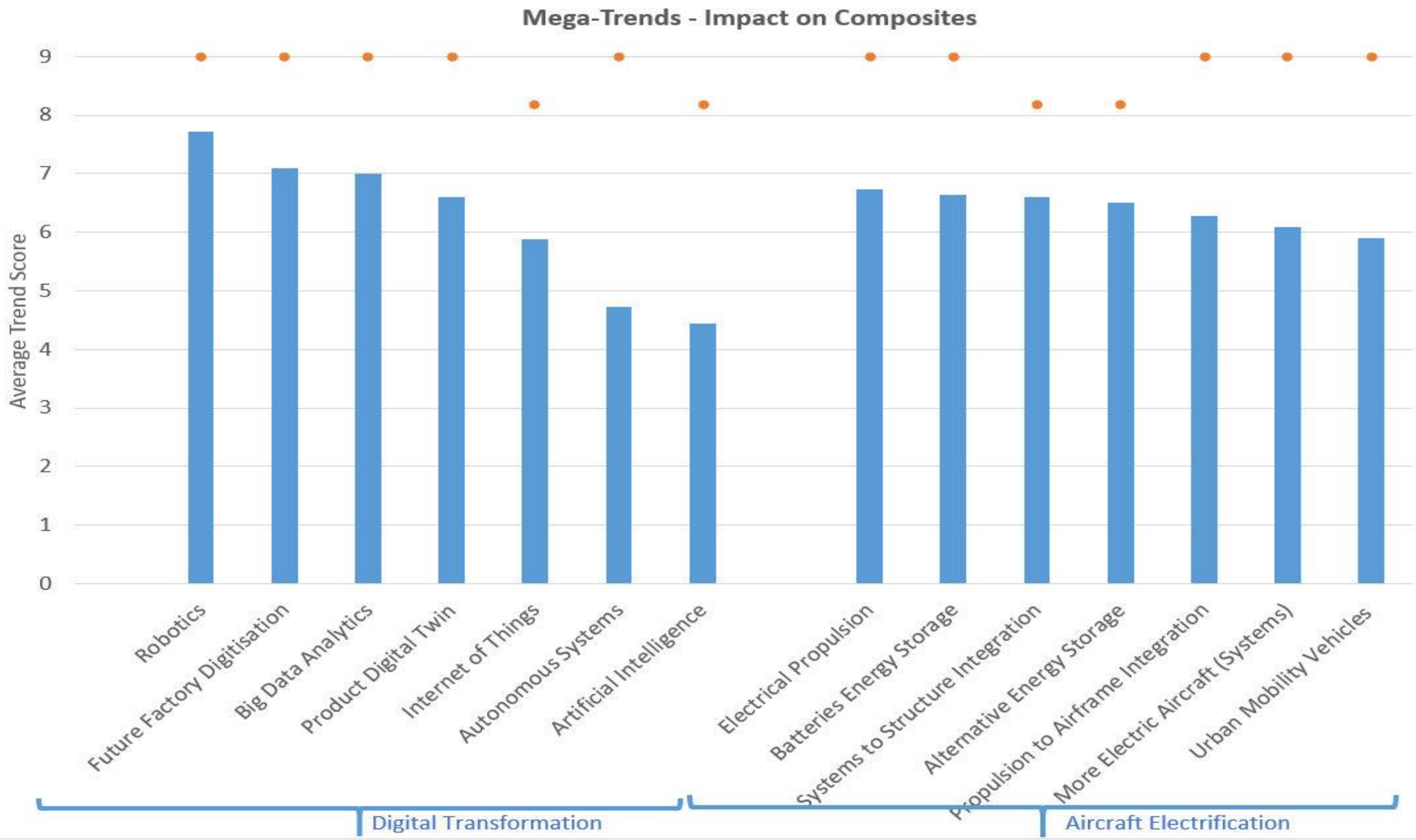
Case Study – NATEP Project Graphene enhanced composite structures

The NATEP-supported GraCELS Project, a collaborative research project involving Haydale Composite Solutions, Airbus UK, BAE Systems, Cobham Technical Services and SHD Composites. The highly innovative project developed a graphene-modified material which was used to manufacture an aileron inspired by a design from Airbus for their Eco-Flyer aircraft. The aileron was designed and preliminary sized by Airbus and optimized by Stanford University Composites Design Team.

Haydale Composite Solutions developed a graphene enhanced electrically-conductive carbon fibre-reinforced composite materials with improved resistance to damage from a severe lightning-strike event. The mechanical properties of the modified material have also been evaluated and it has been shown that the properties are maintained or improved by the addition of specific graphene particulates.

Thanks to NATEP funded project, that the electrically-conductive carbon fibre prepregs created in the GraCELS project will also be suitable for applications where metallised coatings or meshes are currently incorporated into CFRP such as electronic enclosures requiring EMC or RF shielding; masts and large turbine blades in the renewables energy sector and in applications where static discharge may be a critical factor in materials selection amongst others.

Technology- Mega Trends



Technology megatrend onto composites related to factory digitisation, robotics, big data analytics, digital twin. All aircraft electrification megatrends also will impact composites

Technology - Barriers

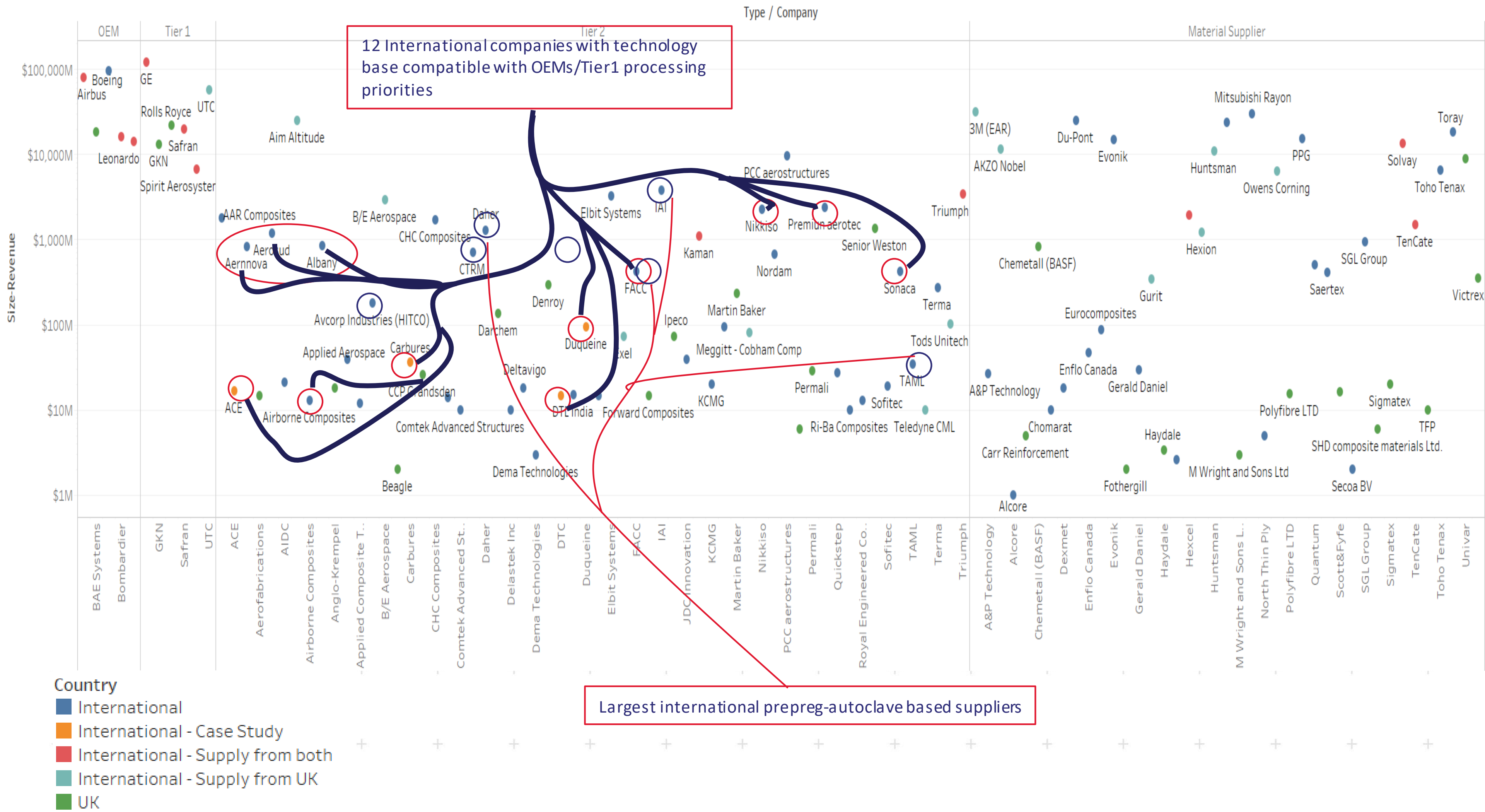
Cost	• Non-recurring costs • Recurring costs • R&D investment • Access to capital	**Intellectual Property**	• Concerns over ownership • Prevent forming of mutually beneficial collaborations
Capability	• Skills • Resources • Supply Chain readiness • Technology infrastructure	**Materials Systems**	• Cost and complexity moving to new systems • Last for multiple product cycles
R&T	• Design, modelling and simulation • Materials • Processes • Automation	**Competing Materials**	• Improvements in metallic performance • Emerging materials and processes - AM and graphene
Materials Data	• Appropriate and available data • Learnings from previous applications	**Platform Development**	• Increasing periods between new aircraft platforms • Maintaining capability and expertise

Supply Chain Analysis

Supply chain requirements include:

- **Improved Tier 2 Capability and Capacity** – Lack of larger Tier 2s, smaller ones need to develop capability other than prepreg/autoclave production. Need to be involved in ATI funded collaborative R&D.
- **Increased Interaction Between OEMs and Innovative SMEs** – ATI and Composites UK to facilitate interaction between innovative composites SMEs and OEMs and ATI to invest in collaborative programmes supporting the NATEP programme exploitation beyond TRL4.
- **UK-based Tooling Supply Development** – there are many UK-based tooling suppliers, but they need support to develop capability and capacity to deliver to future aerospace requirements.
- **Improved Engagement with Materials R&D** – good UK-based representation from materials companies, but many are international and do R&D elsewhere. ATI and DIT work to bring R&D to the UK.

Supply Chain Analysis



Summary of the findings (1/5): Whole Aircraft Attributes and Market Platform Priorities

- Safety, fuel efficiency, environment, cost, operational needs and flexibility of the **whole aircraft attributes** will be impacted by composites technology introduction
- **Whole Aircraft attributes** impacted by: Advanced automation techniques to deposit and non-destructively inspect composite materials , more complex aerodynamic air foils with tailored stiffness, light weight structures and propulsion systems and materials/systems integration, reduced corrosion, increased operational efficiency, process automation, out-of-autoclave manufacturing processes, enhanced modelling and simulation techniques to reduce composite aircraft reliance on the physical pyramid of testing.
- Within the **wide body market** industrial focus on **A350XWB** variants and **A330 Neo** in the secure timeframes, **Boeing NMA** aircraft as well as the **Comac C929** programme within Exploit-Position timeframes.
- Within the **narrow body market segment**, secure timeframes focus on **A320/1 Neo and Bombardier C-Series** platform, whilst **Airbus single Aisle updates and New Short Range (NSR)** developments both for Airbus and Boeing, dominated the medium to long term horizon.
- Within **the rotorcraft market** the short term focus platform was the **Leonardo 609**, the long-term development horizon was focused on the **next generation tilt rotor platform**.
- **Aerostructures market opportunities** within the 2017- 2035 timeframe were found to be around **£87bn**, with more than 50% of the value associated with Wing products and assemblies. Nacelle, Pylon, Engine and Landing Gear provided significant market opportunities to the tune of **£51bn** within the same timeframe.
- Using the **ATI market addressable size model** and based on the identified priorities within the narrow and wide body platforms, the composites components and assemblies addressable market size was confirmed to be **above £3bn by 2030** and could represent **more than £6bn opportunity for the UK by 2035.**

Summary of the findings (2/5): Composite Product Priorities

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- Within the **aerostructures value streams**, a number the key high priorities composite technologies applications areas were related to **wing box covers, front and rear spars, wing box, fixed leading edge and fixed trailing edge assemblies, wing tips sub-components and assemblies, aerodynamic surfaces**.
- New opportunity areas identified from the competency analysis were related to **LE slats, centre wing-box, wing box covers, horizontal and vertical stabilisers and associated control surfaces**.
- In the rotatory wing **main rotor blades and composite wing assemblies for tilt rotor aircraft** were also identified as key product areas.
- Within the **engine value stream** key high priorities composite technologies applications areas were related to **propeller blades, tubes and pipes, gears; with the "Position" timeframe dominated by turbine blades (CMC) and exhaust components**. New highly strategic opportunity areas identified from the competency analysis were related to **composite fan blades and fan containment casings.**
- Within the **nacelle value stream** key high priorities composite applications areas were related to **fan cowl door, Inner Acoustic Barrel, Air inlet lip-skin, air inlet outer skin, inlet duct work**. New opportunity areas identified from the competency analysis were related to **cascades, thrust reverse components, struts and stays, tubes and pipes.**
- Within the **systems value stream** high priority composite applications areas were related to **braces, interior panels cabin fittings, panels, racks, fuel pipes, ducting, strut and stays** with high opportunity areas within the "Exploit - Position" timeframe focusing on **wheels and axle beams**.
- Notably in terms of potential **addressable market size revenue** over the 2017-2035 timeframe some major components that stood out were: **turbine blades, fan blades and containment cases, wingbox main components and assembly, LE slats, TE control surfaces, centre wingbox, thrust reverser components, floor**.

Summary of the findings (3/5): Composite Technologies Roadmaps

- Most significant technological mega trends were related to **digital transformation:** robotics, future factory digitisation and big data analytics, **factory 4.0 technologies**.
- Second most important technology megatrends were related to **aircraft electrification** with opportunities for composites related to **energy storage, propulsion to airframe integration, urban mobility vehicles**.
- **Design and Analysis** technology challenges were related to design for manufacturing, improved simulation and analysis tools, including multi-scale modelling, design for manufacturing, testing and also part integration.
- **Composite Processing Technology challenges** were related to cost effective production at higher volumes, moving away from prepreg/autoclave to automated dry or wet placement and dry fibre preform infusion. Increasing environmental and cost efficiency of these processes will be delivered through technologies to reduce wastage, optimisation of processing kit to reduce power consumption and reconfigurable, intelligent handling and automation systems.
- **Composite materials technology challenges** were found related to reduction in process cost (e.g. reduced cycle time), as are lower cost fibres, resins and intermediates. Performance improvement include increased functionality (electrical, thermal etc.), and improved properties such as through thickness performance and higher temperature resistance (PMCs, CMCs and MMCs). Environmental concerns are to be addressed through development of bio-based materials and closed loop recycling.
- **Technology enablers** challenges included tooling, material multifunctionality, such as electrical and thermal conductivity, coatings, structural health monitoring and morphing capability; production of multi-material structures using joining, robotics, factory automation and jig-less assembly; improved quality assurance to increase the interval of inspection through in-line process monitoring/NDT, data management and machine learning.

Summary of the findings (4/5): Composite Technologies Roadmaps

- **Composite disruptive technologies** such as **additive manufacturing and graphene** were identified by industry and should be considered by ATI for future R&D investment and collaborations. In the case of composite additive manufacturing, the start-up company scene is currently one hundred percent geographically based in the USA.
- The **innovation and R&D funding analysis** identified the need for larger more focused research programmes around design for manufacturing, materials handling and deposition technologies, tooling technologies and low-cost, high speed production of intermediates such as non-crimp fabrics.
- The overall **R&D gross industrial cumulative expenditure** in composites was anticipated to be at **£268M** by 2020 secure timescales, at **£551** by 2025 exploit timescales, and totalling more than **£824M** by the position timeframes in 2030.
- The **composites technology infrastructure analysis** highlighted the need to support the scale up of technologies in the higher TRL/MRL space, beyond the current Catapult capabilities of TRL6.
- The **HVM catapult infrastructure**, especially with the latest round of funding from ATI was considered to be adequate however, the continuous focus on building expansion across the centres and the reactive approach to project delivery was a concern to industry.
- The **most significant barriers** to greater adoption of composites in the sector were related to financial barriers such as non-recurring costs (entry), recurring costs (materials), R&D investment and access to capital equipment.
- **Composite technology international competition**, the US was considered ahead of UK in fibre and graphene development, additive manufacturing and overall size of the composites industry especially in the tier 1 and Tier 2 space. Germany ahead of the game in terms of automation, processing machinery, thermoplastics, factory 4.0 technologies and overall investment in composites development; the Netherlands ahead of UK in thermoplastics primary structural applications.

Summary of the findings (5/5): Supply Chain findings

- The **supply chain analysis** within the industrial consultation highlighted the need for more **capable Tier 2 UK supplier base** to be able to engage with and pull through technologies for higher volume. The UK compares poorly in this respect to other aerospace intensive nations such as USA, Canada, Germany, France and Japan in which a lot more international part suppliers were identified as Tier 2s.
- The UK has some medium sized Tier 2 suppliers (10M$≤Revenue Size≤100M$), but many of these are still focused largely on autoclave, hand layup processes which it is incompatible with future direction of composites technologies.
- Examples are provided of companies that have developed a composite technology and capability base which is compatible with future OEMs/Tier 1s technological direction and as a result have grown on the back of commercial supplier contracts into Airbus A350XWB, A320 Neo platforms..
- The **UK lacks the larger Tier 2 companies** (100M$≤Revenue Size≤1B$). The UK is missing out on this addressable market size and examples of companies are provided that would appear to be good targets for foreign direct investment with support from the Department for International Trade.
- The UK composites supply chain includes many **innovative SMEs** who report difficulty in engaging with Aerospace OEMs. There is therefore, a role for ATI to invest in collaborative programmes supporting the NATEP programme exploitation beyond the TRL4 and enabling further dialogue and collaborations between OEMs/Tier 1s and SMEs.
- The long list of **UK-based tooling suppliers** does not at first glance align with the many comments received during interview about a lack of UK tooling capacity. However, it is believed that it is the size of the UK-based tooling suppliers that is one of the issues – many are quite innovative, but they need support to grow in order to be able to bid for the larger contracts that OEMs and Tier 1s need to fill.
- UK has strong **materials related aspect to the composites supply chain**, even though most of the companies are foreign owned. This strength is particularly true in the intermediates field. However, the depletion of the UK's chemical industry has led to many of these companies doing base materials R&D outside of the UK which makes it difficult for these companies to engage collaboratively in R&D in the UK. Aerospace OEMs and Tier 1s are no longer happy subcontracting materials supply, they want these companies to actively participate in collaborative R&D in the UK. Materials innovation taking place outside of the UK also makes it more likely that materials will be imported in, rather than developed and produced in the UK.
- ATI needs to work with the Department for International Trade and Aerospace OEMs and Tier 1s to influence international materials suppliers with a UK base to invest **more UK-based R&D.**

Concluding Remarks

- The wide adoption of composites technologies onto future aerospace platforms will largely depend of the ability of the technologies identified as important for development to be scalable, enable higher production rates, reduce the composite manufacturing system production costs and capital intensity.
- The industrial consultation highlighted the need for industry to focus on a **new innovation wave cycle for composites technologies**.
- Previous composite technologies S-Curve innovation cycle started off at the beginning of this millennium focused on the heavy use of CFRP technologies for primary structures to drive higher performances, increase aircraft range
- The industrial consultation feedback highlighted the importance of riding a new **S-curve innovation cycle** for composites technologies in which the main technological focus should be for **composites scalable, flexible, cost-effective, digitally connected manufacturing systems**, compatible with high rate aircraft programmes **without compromising on performance benefits**. It was industry view that this vision for future composite technological innovations will require a significant concerted effort between industry, academia and UK government support.
- Through the development of these roadmaps, it is hoped that this will generate **collaborative industrial research projects** aligned to these roadmaps to stimulate growth in the sector and position the UK aerospace composites industry to take advantage of emerging high value global aerospace opportunities.
- It is also anticipated that these collaborations will encourage the composites industry to become better **interlinked,** spanning from material research and formulation all the way through to product manufacture and part integration to deliver across the complete value chain.
- ATI will continue to work with Composites UK and the CLF to realise these opportunities and provide a joined-up approach to maximise value to UK organisations.

Acknowledgements

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