National Composites Network

Technology Roadmap for

Composites in the Aerospace Industry

June 2006

ncn
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Materials
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1. EXECUTIVE SUMMARY

A team of experts adopted accepted procedures to form a roadmap for Composites for the Aerospace Industry. The following actions and recommendations were forthcoming from the Workshop:

The vision is to achieve:

- Leadership in design and development of aerospace composites, by:
  - Establishing clusters of excellence in composites
  - Training more good engineers with composite skills, and offering clearer career progression and structure to encourage engineers to stay technical
  - Funding demonstrator activities
  - Establish high profile applications to increase awareness of composites

- Continued growth in aerospace composites manufacturing through both control of manufacturing in low cost areas of the world and investment in design of parts and processes for high value composites through automated production to increase quality and reduce costs in the UK

- Improved manufacturing situation through control of manufacturing in low cost areas of the world, and we require investment in design of parts and processes for high value composites through automated production to increase quality and reduce costs in the UK

- **Technology gaps need addressing:**

- Cost reduction considerations and improvements through the whole product life cycle are key to increased composites usage

- New materials for ‘out of autoclave’ processing and for preforms are needed through effective partnerships between materials manufacturers and composite end users

- Specific aspects of understanding of current and future materials performance such as impact tolerance and failure mechanisms need to be addressed

- Creating effective partnerships for technology development. This could be achieved for the UK through clustering between academic experts and industry, as is the case in some countries. A database of capabilities should also be established

- More effort applied to manufacturing and process research, topics that are currently less well resourced by academia. A reward structure to help this could be established.

- Improved understanding of variability within manufacturing structures

- In addition the workshop identified a number of specific areas where technology was weak

Skills:

- Better perception and recognition of engineering skills. Courses offered and industry requirements are not matched. A full survey of what is on offer and industries’ requirement should be carried out and effort put into correcting the situation

- Generally composites should be ‘sold’ better. Awareness of composites needs to be highlighted through improved links with school and college course content
- HEIs should be encouraged to cover composites in more courses

The Workshop was the first phase of the roadmap. Other opinions will be added and it will be updated on a regular basis.

2. CONTRIBUTORS

The following people attended a meeting at TWI, Granta Park, Cambridge on Wednesday 28th June 2006 to formulate the first phase of NCN's Roadmap in Composites for the Aerospace Industry:

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3. METHODOLOGY

The methodology used for this roadmap is summarised in Appendix 8.1, following the procedures typically used for other roadmaps that have been produced.

Experts, in groups of around five, are asked to provide their thoughts and opinions for the four main stages of the roadmapping process:

- Where are we now?
- Where do we want to be?
- What is stopping us getting there?
- What needs to be done to overcome the barriers?

For each stage, large hexagon *Post-its* are used to gather each input. These are then clustered under common topics as a spokesman from each group presents their findings. This draws comments from the rest of the participants and generally arrives at a consensus of opinion.

Using adhesive stickers, priorities are given to what are considered the most important issues for the second stage of the roadmapping process, enabling a key priority list to be established for subsequent steps.

The final outcome is a list of priority items that need action in order to enable the industry to progress in a more dynamic and competitive manner.

As with other roadmaps, once this first edition is produced, comments are sought from others in the field, so that ownership comes from the entire community.

4. CURRENT SITUATION

A number of recent publications are relevant to the future trends in composites, and some are directly related to the aerospace composites industry.. By way of introduction, these were summarised in Appendix 8.2.

With a group of experts from such a wide cross-section of interests in Composites for the Aerospace Industry (industrialists, academics, users and suppliers), the first stage of the roadmapping process, “Where are we now?”, raised the points reproduced in Appendix 8.3 and tabulated in Figure 1.

The clustered topics covered, addressed issues regarding markets, skills, finance, technology and general industry items, in response to prompts such as:

- What are the current trends?
- What are the main drivers?
- What is the competition up to?
- Who are present leaders in the field?
- What is the UK really good at? – what are our niche areas?
- What are the gaps in technology?
- Do we have the right skills?
- Is capital investment sufficient?

Figure 1: Current situation	
Trends and drivers	~ Multinational manufacture – driven by risk share ~ There is a changing attitude of MOD procurement ~ Movement of work to the Far East which is driven by cost and offset requirements ~ Reduced time to market and reduced development costs ~ Environmental aspects - health and safety in manufacture and serviceability (e.g. chromates) ~ Increased air travel ~ Paperless manufacture, CAD/CAM manufacture in a digital environment ~ Reduce costs ~ Environmental – in service ~ Increased use of composites, especially in critical areas e.g. primary structure ~ Performance – lower emission s ~ Improved performance – survivability ~ Military applications - less flexibility in cost and timescales ~ Improved aerodynamic shapes – cost ppm ~ End of life recyclability ~ Reduce initial cost ~ Reduce through life cost ~ Technology leadership is a driver ~ Trends to larger structures ~ Automated processes ~ Demand for carbon fibre exceeds supply ~ Niche applications and specialist parts ~ Badge engineering ~ Integrated complex structures ~ Standardised materials – same prepreg / materials
Customer	~ MOD, primes (OEMs), airlines ~ Tier 1 contractors ~ Aircraft assemblers: Airbus, Boeing, Raytheon, Lockheed, Bombardier ~ Engine assemblers ~ External to UK defence ~ Certification agencies ~ Space applications
Competition	~ Third world and low cost economies ~ Government assistance with infrastructure investment (outside UK) ~ Investment in R&D clusters worldwide ~ Well funded technology demonstrators (outside UK) ~ A more bold strategy – aggressively embracing composites – investment ~ Investment in automated processes (c.f. USA) ~ Vertical integration by manufacturing companies (Japanese fibre producers) ~ Clustering of technology companies around large manufacturers (CFK Hamburg) ~ Download responsibility to Tier 1 suppliers – risk and revenue sharing ~ Metals: lighter weight alloys, high speed machining more efficient design ~ Leaders in structures: GE, Airbus, Boeing, Aircelle ~ More extensive use of composites ~ Academic / industrial partnerships ~ Manufacturing technology investment (Japan) ~ Leaders: Boeing, Bombardier, Airbus, GKN, Spirit Aerosystems, Lockheed, MBDA, BAE Systems ~ Leaders in materials: Japan ~ Forming cohesive supply chains ~ New process technologies ~ Massive investment in large structures
Strengths	~ Systems integration ~ Large complex loaded structure design

	~ Composite tooling ~ Structures design ~ Low TRL (low readiness level) innovation ~ Military products (missile / aircraft weapons) ~ UK is pragmatic and adaptable ~ Nanotechnologies ! ~ Materials innovation ~ Commercial aircraft secondary structures ~ Airbus wings ~ Systems integration (defence) ~ Early investment in technology development
Technology gaps	~ Damage tolerance ~ Damage resistance ~ Failure mechanisms ~ Quality fibre production in the UK ~ Lower cost – out of autoclave – materials and processes for higher volume ~ Scalability for large parts and high volume ~ Curing technologies ~ Cost effective performing ~ Low cost processing, high deposition rate ~ Automation ~ Bonding / repair fastening and general joining technologies ~ Lack of understanding of failure mechanisms ~ Capability to make complex structures ~ 'Black metal' mentality ~ non-destructive examination ~ higher performance low cost material durability and degradation
Skills	~ skills shortage in materials and process structures design ~ shortage of materials and process engineers ~ shortage of design / stress engineers for composite structures ~ shortage of people with large scale processing experience, including digital environment ~ need investment in developing capability infrastructures ~ insufficient numbers
Funding	~ lack of technology demonstrators ~ lack of investment for long-term vision ~ lack of funding infrastructure (buildings), machinery and equipment (short term vision) ~ good funding programme – no follow-up ~ lack of investment in market opportunities ~ R&D budgets in companies reducing – increased requirement for government funding ~ Capital investment insufficient if we want to be manufacturer of parts

The current status for Composites for the Aerospace Industry was identified and is summarised in the following chart:

Current key strengths and weaknesses in Composites for the Aerospace Industry

Strengths	UK is pragmatic and adaptable UK strong in certain markets: Military products (missile / aircraft weapons) Airbus wings

Commercial aircraft secondary structures

UK good at:
- Large complex loaded structure design
- Composite tooling
- Structures design
- Low readiness level innovation
- Materials innovation
- Systems integration (defence)
- Early investment in technology development

Increased use of composites, especially in critical areas e.g. primary structure

There are some good funding programmes, but there is no follow-up

Weaknesses

Movement of work to the Far East which is driven by cost and offset requirements

Outside the UK there is government assistance with infrastructure investment and well funded technology demonstrators - this is a definite weakness.

UK does not have a bold strategy that aggressively embraces composites

There is little focus on industry / academic partnerships

Supply chain not cohesive

No massive investment in large structures in the UK (need another Concorde)

R&D budgets in companies is reducing, so there is an increased requirement for government funding

There is a lack of:
- technology demonstrators
- investment for long-term vision
- funding for infrastructure, machinery and equipment
- investment in market opportunities

There is a skills shortage
- materials and process structures design
- materials scientists
- design / stress engineers for composite structures
- too few with large scale processing experience

and generally there are insufficient numbers

5. FUTURE DIRECTION

For the second stage of the roadmapping procedure, "Where do we want to be?", the technique was the same. During the first stage, looking at the current situation, some of the visions and aspirations of the participants were emerging.

To stimulate further thought, the following questions were posed:

- What is our vision for the future?
- What should we be doing to maximise benefit for the UK?
- Are we doing something now that we should put more effort into?
- Are we doing something currently that we should drop?
- What is going to make a real impact on our activities?
- What new areas should we be working in?
- Are there opportunities for creating spin-out companies?

The ideas from the participants are shown in Appendix 8.3, and are reproduced in the following diagram (Figure 2), with dots (●) indicating the level of priority judged by the team.

Figure 2: Future Direction (● indicates priority level)	
Vision	~ Leaders in design and development of aerospace composites ●●●●●●●●● (1) ~ Manufacturing: 1. control of manufacturing in low cost areas of the world; 2. highly automated manufacture in UK ●●●●● (7) ~ Invest in high value composite design and manufacture capability (not necessarily production) ●●●●● (8) ~ Increased level of modelling and simulation from nano to macro scale ●●●● (9) ~ Adequate production facilities in the UK ●●●● ~ Controllable shaped structures – curing ●● ~ Supply of all Airbus wings in carbon fibre ●● ~ Integrated structures and systems ●● ~ Better damage tolerance than aluminium materials ●● ~ Low heat processing and no pressure curing ● ~ Epoxy improved materials processing ● ~ Affordable low volume high performance polymer manufacture ● ~ Probabalistic design (risk) ● ~ Sustainable competitive supply chain ● ~ High strain structures – design of completely bonded structures ~ Complex 3D performs – advanced textiles ~ Better out of plane properties for epoxies ~ Improved manufacturing engineering guide lines / tools / advice / software tools ~ Need UK leadership ~ More holistic approach e.g. motorsports ~ Control the supply chain to give a thriving business – design through to manufacture ~ Centre of materials science development
Skills	~ Better perception and recognition of engineering skills ●●●●●●●● (3) ~ Improved joining technologies – fully bonded aircraft ●●●● (13) ~ Specialist training tailored to meet company needs ●●● ~ Must train more engineers ~ Must pay engineers more
Benefits	~ Invest in large technology demonstrators ●●●● (10) ~ Invest in raw materials manufacturing made in UK ●●●● (11) ~ Improved supply chain ●●●

	~ Trained workforce ● ~ UK needs to be at the centre of design process for major programmes ● ~ Carbon fibre manufacture in the UK ~ Sell and market UK's composite capabilities
Technology – more effort	~ New materials (resin, nano, etc); out of autoclave processing, preforms ●●●●●●●● **(2)** ~ Creating effective partnerships – technology development ●●●●●● **(4)** ~ More effort into manufacturing and process research ●●●●● **(5)** ~ Improved understanding of variability within manufacturing structures ●●●●● (6) ~ Make an impact: digital definition – design through to manufacture ●●●● (12) ~ Automated manufacture: tape layering, tow placement, performing / RTM ●●●●● (14) add later automation comment with 1 blob ~ More effort into real world failure mechanisms for composite structures ●●● ~ Challenge design rules for composites ●●● ~ Material failure process modelling ●●● ~ More effort into design tools ●● ~ Develop infusion performing technologies ●● ~ Structure modelling ●● ~ 3D performs ●● ~ Smart tooling ●● ~ Health monitoring, WKH prognostics ●● ~ Automation of components – layering / assembly ● ~ High processing rates – automation ● ~ New polymer / fibre developments and surface treatment technologies (interface technologies ● ~ More work on composite tooling and smart materials ● ~ Automated manufacture: tape layering, tow placement, performing / RTM ● ~ Joining and improved bonding structures ~ Easier processing of polymers – thermoplastics and thermosets ~ New core materials ~ Integration of sensing technologies into components ~ Improved lightning strike protection ~ Hairy fibres for improved through thickness ~ Design for manufacture ~ More applied academic research ~ More lobbying of government, local and European as well
Drop	~ Testing ~ Irrelevant out of date academic research ~ More judicious funding for nanotechnology ~ Less emphasis on university general materials evaluation research – be more selective; more processing
Funding	~ Funding gap remains

The main priorities raised are shown in the following diagram:

Main priorities for future direction for Composites in the Aerospace Industry

Vision

Leaders in design and development of aerospace composites (1)

Manufacturing:

1. control of manufacturing in low cost areas of the world
2. highly automated manufacture in UK (7)

	Invest in high value composite design and manufacture capability (not necessarily production) (8)
	Increased level of modelling and simulation from nano to macro scale (9)
Skills	Better perception and financial recognition of engineering skills (3)
	Improved joining technologies – fully bonded aircraft (13)
Benefits	Invest in large technology demonstrators (10)
	Invest in raw materials manufacturing made in UK (11)
Technology	New materials (resin, nano, etc); out of autoclave processing, preforms (2)
	Creating effective partnerships – technology development (4)
	More effort into manufacturing and process research (5)
	Improved understanding of variability within manufacturing structures (6)
	Make an impact: digital definition – design through to manufacture (12)
	Automation; tape laying; tow placement; (14)

For the next phase of the roadmapping procedure, looking at the barriers to achieving the vision and what needs to be done to overcome the barriers, these top priorities were discussed by the groups.

6. BARRIERS TO PROGRESS AND POSSIBLE SOLUTIONS

Having arrived at a consensus of the future direction for Composites in the Aerospace Industry, the next stage was to determine *"What is stopping us getting there?"* and deciding *"What needs to be done to overcome the barriers?"*.

Typical questions asked were:

- Do we have the skilled people we need?
- What are the gaps in our technology?
- Is funding likely to be adequate?
- Do we have the necessary infrastructure?
- What is inhibiting manufacture?
- Are patents inhibiting progress?

Actions needed to overcome the barriers (shown in blue) are also included in the following table (Figure 3), and are taken from the priorities shown in Appendix 8.3. The priorities are those indicated by participants in the Workshop.

Figure 3: Barriers and Possible Solutions

Vision	**(1) Leaders in design and development of aerospace composites**
Barriers	• There are gaps in that there are no demonstrable, repeatable processes because industry is too conservative • There is no product concept demonstrator such as Concorde ' • Skills shortage • Funding is inadequate. Assistance is needed with building and infrastructure as happens in France • The infrastructure is developing slowly e.g. AUK and GKN centres but is too little too late • A gap is a tiered supply chain with a robust risk management culture • There are no trainers • Lack of skilled people: we are missing designers, manufacturing engineers, CAD/CAM knowledge. What is not missing is shop floor skilled people because processes are being automated.
Next steps	• Establish clusters of excellence in composites for TRL 3-6 (industrial) • Train more good engineers with composite skills • Clearer career progression / structure to encourage engineers to stay technical • Fund demonstrator activities • Establish high profile application to increase profile of composites • Pay engineers more money • Promote the exciting nature of working in the composites industry • Lobby HEIs to include composites in courses

Technology	**(2) New materials (resin, nano, etc); out of autoclave processing, preforms**
Barriers	• Industry is risk averse • There is an absence of risk sharing • Economic quantities of new materials and processes • Money is not targeted at most relevant areas e.g CARAD was targeted at aerospace engineering; • Timescales for approval and certification • Money for R&D – city is seen as the most important stakeholder for many engineering companies.
Next steps	• Effective partnerships between materials manufacturers and composite end users for mid to long term materials development • Lobby dti and other funding bodies for continuance end expansion of funding.

Skills	**(3) Better perception and recognition of engineering skills**
Barriers	• There is a mis-match of university courses with industries' needs • The industry need to promote their sector more effectively
Next steps	• Assess what is available and exactly what industry requires • industry can use incentives to attract and retain people into the industry such as burseries and formal training schemes. • More work at the teenage level when students are making choices about their career.

Technology	**(4) Creating effective partnerships – technology development**
Barriers	• Competition between academic establishments for funding by govenment initiatives, as in the Technology Programme • Industry wanting to reduce its own investment in research.
Next steps	• UK needs clustering in academic experts with industry, as is the case in some countries

	• Provide a database of capabilities

Technology	**(5) More effort into manufacturing and process research**
Barriers	• Not seen as academically challenging as 'blue sky' research • Such research is generally more expensive particularly as it becomes more targetted
Next steps	• Provide incentive through success rewards • Loby for priorities in dti tech programme, etc

Technology	**(6) Improved understanding of variability within manufacturing structures**
Barriers	• Barriers are time and money
Next steps	• Present information needs collating

Vision	**(7) Manufacturing: 1. control of manufacturing in low cost areas of the world; 2. highly automated manufacture in UK**
Barriers	• 'Offset' obligations drive set up of manufacturing in target countries • cannot automate currently qualified hand lay-up processes • high capital investment needed
Next steps	• Investment in design of parts and processes for automated production is needed to increase quality and reduce costs

Vision	**(8) Invest in high value composite design and manufacture capability (not necessarily production)**
Barriers	• Same as Priority (1)
Next steps	• Same as Priority (1)

Vision	**(9) Increased level of modelling and simulation from nano to macro scale**
Barriers	• Lack of applied research in the universities (compare Priority (5))
Next steps	• Draw together simulation modules to provide toolkit for composite simulation • Link simulation toolkit with certification bodies (industry standards for composites)

Other priority items were:

(10) Benefits: Invest in large technology demonstrators
(11) Benefits: Invest in fibre production in the UK
(12) Technology: Make an impact with digital definition – design through to manufacture
(13) Skills: Improved joining technologies – fully bonded aircraft
(14) Automated manufacture: tape laying, tow placement, preforming

7. ACTIONS / RECOMMENDATIONS

The following actions and recommendations were forthcoming from the Technology Roadmap in Composites for the Aerospace Industry:

The vision is to achieve:

- Leadership in design and development of aerospace composites, by:
    - Establishing clusters of excellence in composites
    - Training more good engineers with composite skills, and offering clearer career progression and structure to encourage engineers to stay technical
    - Funding demonstrator activities
    - Establish high profile application to increase awareness of composites

- Improve manufacturing situation through control of manufacturing in low cost areas of the world, and we require investment in design of parts and processes for high value composites through automated production to increase quality and reduce costs in the UK

- Continued growth in aerospace composites manufacturing through both control of manufacturing in low cost areas of the world and investment in design of parts and processes for high value composites through automated production to increase quality and reduce costs in the UK

Technology gaps need addressing:

- New materials for out of autoclave processing and for preforms are needed through effective partnerships between materials manufacturers and composite end users

- Creating effective partnerships for technology development. This could be achieved for the UK through clustering between academic experts and industry, as is the case in some countries. A database of capabilities should also be established

- More effort applied to manufacturing and process research, topics that are currently less well resourced by academia. A reward structure to help this could be established.

- Improved understanding of variability within manufacturing structures

- In addition the workshop identified a number of specific areas where technology was weak

Skills:

- Better perception and recognition of engineering skills. Courses offered and industry requirements are not matched. A full survey of what is on offer and industries' requirement should be carried out and effort put into correcting the situation

- Generally composites should be 'sold' better. Awareness of composites capabilities needs to be highlighted through improved education.

- HEIs should be encouraged to cover composites in more courses HEIs should work with industry to incentivise and encourage people into the industry.

8. APPENDICES

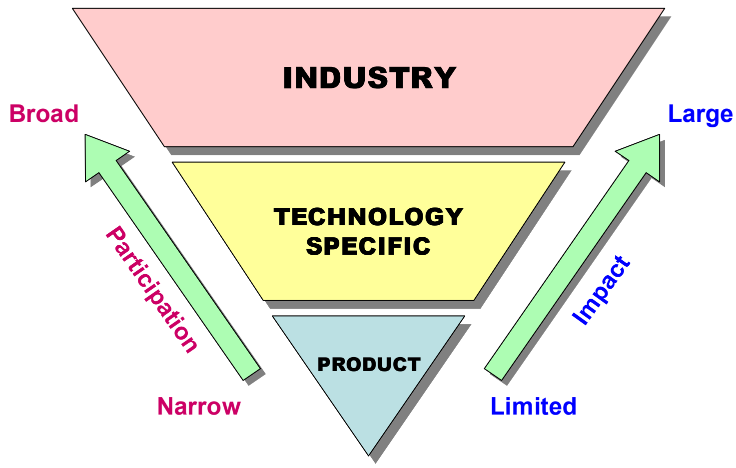
8.1 Methodology for Roadmapping

What is Roadmapping?

Based on a Foresight model, roadmapping is a high-level planning tool to help both project management and strategic planning in any technically-based establishment, whether in academia or industry.

Motorola first coined the word roadmapping in the seventies, but only recently has it been widely adopted by both individual companies and industry sectors as an essential part of their future growth. Figure (i) summarises the types of roadmaps that have already been produced. They can be for industries such as "glass" and "petroleum", or for specific technologies such as nanomaterials, biocatalysis, etc. Some roadmaps have been produced just for single product areas.

Figure (i): Types of roadmaps

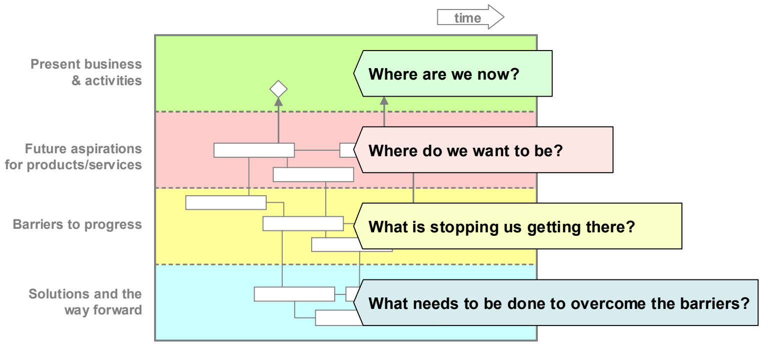


How are the Roadmaps produced?

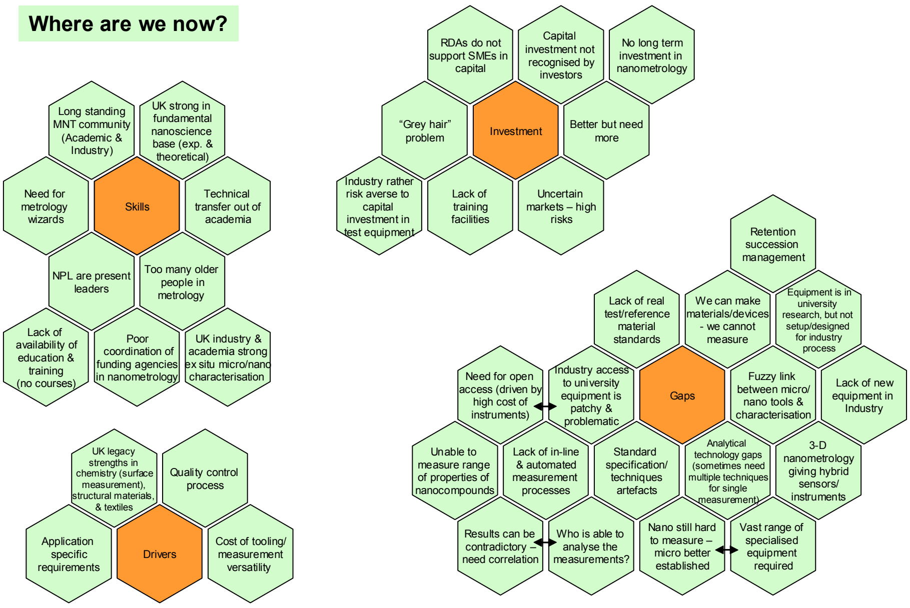
The process gathers together groups of commercial as well as technical experts, and takes them through the four stages that are shown in Figure (ii). The participants need to have sufficient information about the markets and the business to say where the topic under consideration is at the present time. The first step is to agree what the present situation is, and then to move on to provide a vision of where they see things going in the future - where they want to be during the next 20 years.

The third stage is to determine what the barriers to achieving the objectives and goals are. Finally decisions and proposals need to be made to enable the barriers to be overcome. These are arranged over a timescale, with short-term (0 to 3 years), medium-term (3 to 10 years), and long-term (> 10 years) goals.

Figure (ii): Stages in the Roadmapping exercise



Hexagon shaped *Post-its* (colour coded for each stage) are used to gather the participants' thoughts for each step. These are then grouped into topics, and a typical example is shown in Figure (iii). When a consensus is reached regarding the conclusions, "dot" stickers are added to indicate the main priority items.



Such roadmaps provide a collective opinion about the future strategy, with agreed objectives.

As soon as the roadmap has been completed, it can be sent out to other interested parties for their additions and comments.

Roadmaps are "live" documents and should be updated on a regular basis.

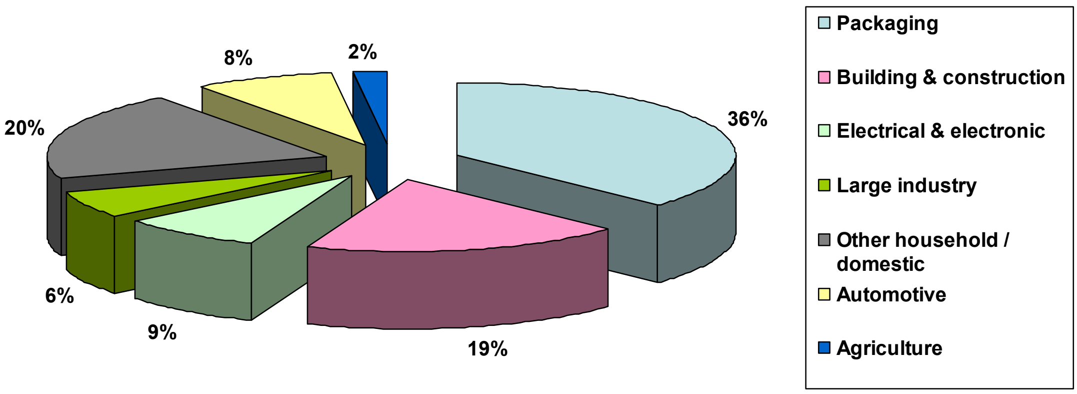
8.2 Background to Roadmapping in the Field of Composites for the Aerospace Sector

In connection with the National Composites Network's activities to roadmap composites for the aerospace sector, there are a number of roadmaps and strategy documents relating generally to composites. The following summaries highlight the main issues relating to composites for the aerospace industry.

General Roadmaps on Composites

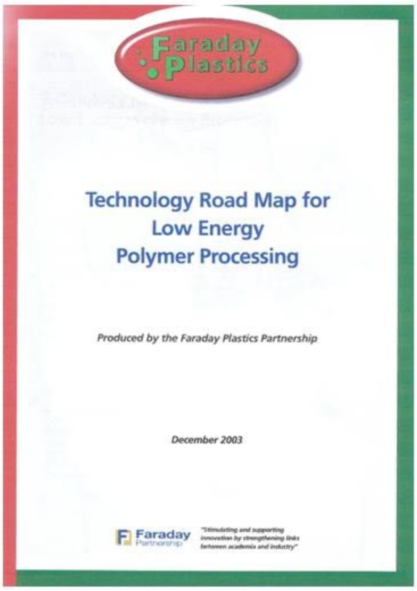
Figures from 2004 (http://europa.eu.int/comm/environment/waste/pdf/epec_report_05.pdf) indicate the main users of plastics by industry sector throughout Europe.

Plastics consumption by sector (PlasticsEurope 2004)



Technology Roadmap for Low Energy Polymer Processing by RAPRA

In December 2003, Faraday Plastics, one of the Faraday Partnerships, produced a roadmap on low energy polymer processing (http://www.faraday-plastics.com/techroadmap.htm). Nanotechnology, which is influencing many developments in composites, was not mentioned specifically.



Areas for research and development were identified and the main ones are listed below:

- Increased understanding of the energy balance in polymer processing
- Computer modelling of polymer processing
- Robust in-line melt temperature measurement
- Robust in-line energy measurement
- Supercritical fluid processing
- Single step processing
- Weight minimisation through micro-cellular foaming
- Fluid assisted processing.

Most of the above topics are now receiving attention, but a further 4 areas were identified as being worthy of R&D:

- Mixing technologies
- Process design for energy minimisation
- Intelligent processing additives
- In-line screw wear monitoring.

This particular roadmap resulted in over £3 million funding being obtained from the EU to progress certain aspects of the findings.

Thermoplastic Composites In Europe to 2025 by Coronet

Coronet, a European Research Infrastructures Network, produced in April 2004 a Foresight study into future research needs for thermoplastic composites (http://www.coronet.eu.com/DesktopDefault.aspx?tabindex=98&tabid=182).

A STEEP analysis identified Cost-effective Manufacturing as an important issue, with increases in productivity, lower part costs, reduced parts count, hybrids and advances in competing materials all falling into this category.

A trends analysis highlighted a number of key areas of research that will be needed to meet the expected trends in materials, processes and applications. In materials, these were:


coronet

April 2004

Thermoplastic Composites in Europe to 2025

Foresight Study into Future Research Needs

Thermoplastic Composites Infrastructure Cooperation Network - Coronet

Output from Task 3.2: Foresight Activity
Final Version After Validation

- Natural fibre composites, including wood fibres
- Polymeric fibres such as PET, PP and PE
- Nano-reinforced fibres
- Self-reinforced polymers
- Reactive thermoplastics
- New commodity materials (e.g. PA, ABS, PBT, PET, and TPU)
- High performance materials (e.g. fluoropolymers, LCPs and PEKK)
- Bio-derived matrices
- Thermoplastic nanocomposites.

Modelling techniques and long-term performance characterisation of these materials is also needed. For processing technologies, the following were regarded as important research needs:

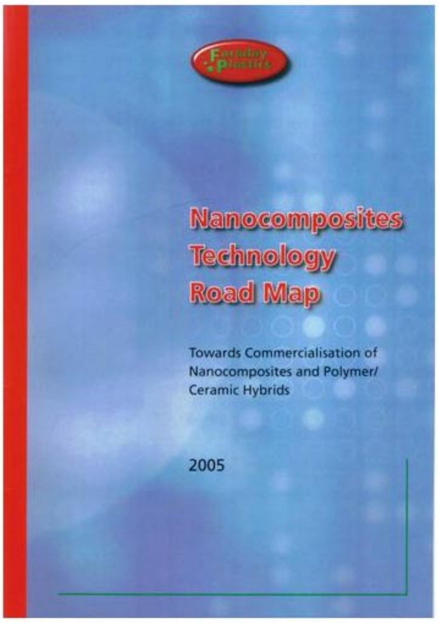
- Thermoplastic RTM
- New LFT injection processes
- Hybrid moulding processes (e.g. thermohydroforming) and structures
- Press and stamping processing routes
- Thermoplastic pultrusion and extrusion
- Diaphragm forming
- Filament winding
- Fibre placement and automated tape-laying.

Future needs in nanotechnology were identified below:

Materials	Research	Infrastructure
Self-reinforced polymers	Nano-reinforcement	Fibre spinning, continuous lamination lines, twin screw extruder
Nano-reinforced fibres	Self-reinforced polymers or other matrices, improved stiffness and temperature	Twin screw extruders, fibre-spinning
Nanocomposites	Enhanced fire properties; use with / without fibres, RTM with carbon nanotubes	Twin screw extruders, analytical equipment
Fire-testing	Fire retardance of nano-clays	Twin screw extruders, fire testing rigs

Towards Commercialisation of Nanocomposites And Hybrids, Faraday Plastics and Hybridnet

This roadmap (May 2004) focused on nanocomposites (http://www.faraday-plastics.com/techroadmap.htm). Processing was the first main point raised by the roadmap, stating that there is a lack of understanding of how polymers filled with nanoparticles or nano-clays behave under processing conditions.



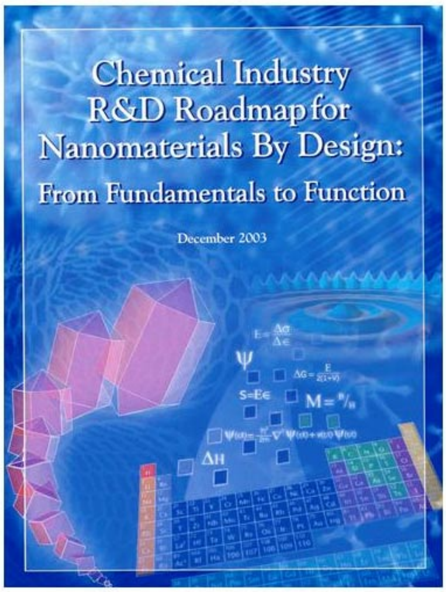
The report identified a real need to establish the processing behaviour for a range of nanocomposite materials especially when processed on traditional polymer processing equipment. Reproducibility is needed, and processing capabilities for nanocomposites should run parallel to product development and the development of reliable Quality Control techniques.

The full list of research needs for processing nanocomposites was:

- Development of processing technologies that will give reproducible products
- Develop in-line monitoring and control technologies
- Uniformity of exfoliation, dispersion and distribution on the nanoscale must be achievable
- Increased processing knowledge is required e.g. what factors affect material integrity, and how can these be controlled?
- Parallel manufacturing developments such as micromoulding need to be developed in-line with developments in nanocomposites technologies
- Presently there is a lack of knowledge of the processing characterisation of materials and how machinery design can be optimised
- Techniques must be developed that allow processing on traditional machinery
- Process induced structuring of nanomaterials must be more fully understood
- Processing technologies must be developed that are cost effective
- Quality control methods need to be developed.

Chemical Industry R&D Roadmap for Nanomaterials by Design

In the United States, the Chemical Industry Vision2020 Technology Partnership, in December 2003, produced their roadmap on nanomaterials. The 93 page report was called *Chemical Industry R&D Roadmap for Nanomaterials by Design: Fundamentals to Function*. It is well worth viewing at www.chemicalvision2020.org/pdfs/nano_roadmap.pdf.



It is very comprehensive; having taken a large number of people a great deal of time and effort to prepare. The emphasis is on getting nanotechnology based products to market as rapidly as possible.

The report begins by saying that Nanomaterials by Design will require concurrent development of:

- Nanoscale fundamentals and synthesis
- Methods of manufacturing
- Multi-probe measurement tools for the nanoscale
- Reliable models relating nanostructures to properties

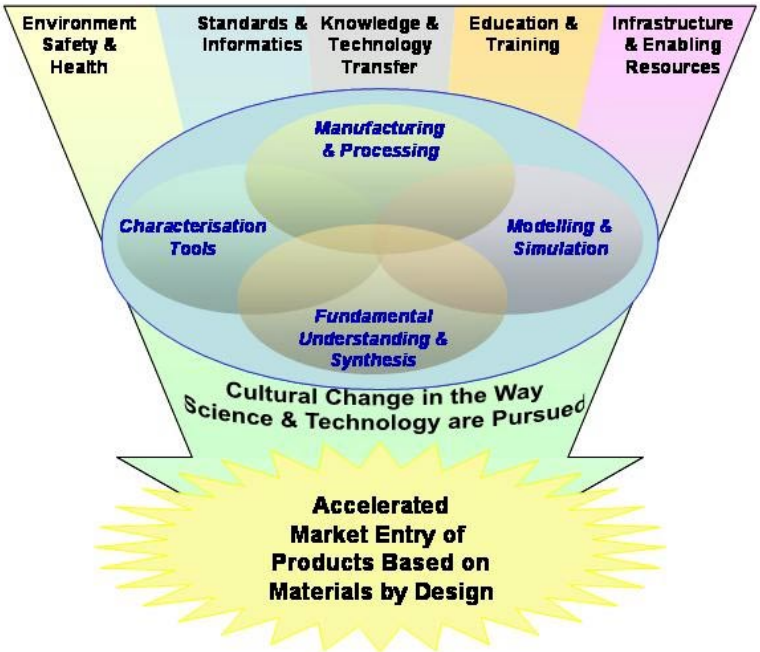
Additional supporting activities must address:

- Environmental impacts
- Safety and health
- Standards

- Technology transfer
- Infrastructure
- Education

Manufacturing and processing are seen as being particularly important to the US community achieving its objectives in nanotechnology. The following diagram summarises the essential elements of the research pathway to Nanomaterials by Design.

Essential elements of the research pathway to nanomaterials by design



Under Manufacturing and Processing, the following priority issues are highlighted, with timeframes and relative expenditure:

Priority	Task	Timeframe	Investment
Top	Unit operations and robust scale-up and scale-down methods	5 years	$$$$
Top	Manufacturing techniques for hierarchical assembly	20 years	$$$$
Top	Dispersion and surface modification processes that retain functionality	5 years	$$
High	Process monitoring and controls for consistency	20 years	$$$
High	Integrate engineered materials into devices while retaining nanoscale properties	20 years	$$$
Medium	Impurity removal from raw material precursors	5 years	$

Roadmaps for the Automotive Sector

In addition, there are a number of roadmaps that specifically cover the automotive industry, which have sections that could be relevant to the aerospace sector. Clearly they differ from aerospace practices in that mass production is a feature of the automotive sector, with recycling becoming an increasing issue.

Plastics in Automotive Markets – Vision and Technology Roadmap

The American Plastics Council has carried out a roadmap on the future of plastics in the automotive industry (www.plastics-car.com/roadmap/haveflash.htm). The web summary is set out as follows, some of which is relevant to Aerospace:

1. UNPRECIDENTED CHALLENGES

Today automakers are faced with formidable challenges:

- Consumers expect cars to perform better, have more features, and cost less
- Existing architectures are reaching their practical limit
- Globalisation and rapid manufacturing techniques are driving the industry to rapidly move innovative vehicles to market
- Design and assembly times must be compressed, and tooling and fabrication costs minimised
- Expectations for a clean environment and sustainable products are pushing automakers to be more responsible in the use of energy and materials

Automakers and designers have already embraced the versatility of plastics in such demanding applications as body parts, intake manifolds, safety devices, fuel systems and tanks, bumpers, structural applications and high performance racing cars.

While polymer use has increased dramatically, it has only just begun to use them to their full potential. The continuous drive to improve the bottom line will create even more opportunities for plastics in automotive applications.

2. A VISION FOR THE FUTURE OF AUTOMOBILES

The vision is that by 2020 the automotive industry will have established plastics as a material of choice in the design of all major automotive components and systems. To realise the vision, plastics producers and automakers will work to maximise the value of polymers throughout the supply chain and over the entire life cycle of the vehicle.

- Plastics will be the preferred material for enhancing component and system value
- Designing with plastics and composites will positively impact vehicle cost, environmental performance, and customer preferences
- Plastics will be the principal tool to produce safer, more affordable, stylish, durable, energy-efficient, and low emission vehicles in every market segment
- Rapid, cost-effective processing systems will provide automakers with the flexibility to respond to dynamic markets
- Polymer-based architectures will give automakers the freedom to create innovative vehicles that increase the value throughout the supply chain and for the driving public.

3. A STRATEGY FOR SUCCESS

To achieve the vision for the year 2020, a bold business strategy will be pursued, composed of 4 main elements:

- New applications for plastics – develop a portfolio of polymer-based tools that maximise the performance advantages of polymers and composites and allow the design and prototyping of new vehicle architectures
- Speed to market – shorten design and engineering cycles to fast-track polymer applications from concept to commercial product
- Enabling infrastructures – present automakers with a sound business case for plastics and built plastics
- Sustainable transportation – develop and use new plastics and composites to create sustainable vehicle.

4. TECHNICAL PRIORITIES

To achieve the strategic goals and vision a diverse portfolio of critical technologies will be pursued. Critical new technology development areas are:

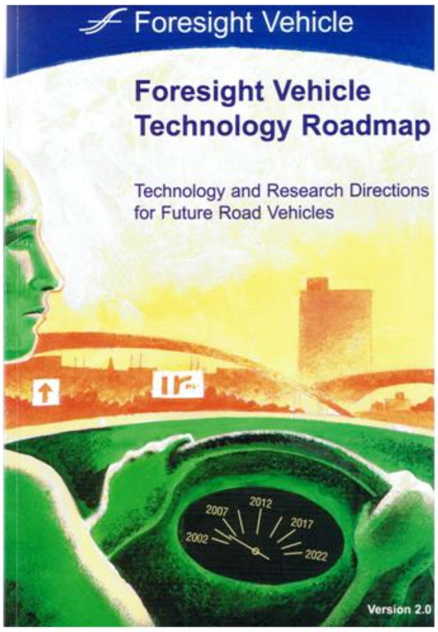
- Advanced material systems
- Predictive engineering
- Automotive design
- Advanced manufacturing technology
- Business, market, and education infrastructure
- Environmental performance.

5. PARTNERSHIPS BRING VALUE

Achieving the vision will require resources beyond the practical reach of any single company. A coordinated strategy is essential, involving all stakeholders.

6. THE PATH FORWARD

In application after application, plastics have replaced conventional materials because they provide the functionality that engineers demand, the styling that designers seek, and the value that customers expect. Automobiles are no exception.



Foresight Vehicle Technology Roadmap

As part of the UK Government's Foresight exercise, the Society of Motor Manufacturers and Traders Limited produced, in 2004, a Foresight Vehicle Technology Roadmap (www.foresightvehicle.org.uk).

Technology targets are shown in the following table:

	0-5 years	5-10 years	10-20 years
Safety	• Selection of joining systems to match material performance capabilities	• Design/production and validation of 'smart' crash structures	
Product configurability and flexibility	• Component integration • Easier separation of materials for recycling or re-use • Effect of modular structures (and joining) on crash structures/NVH /stiffness • Robust engineering solutions for rapid modular reconfiguration	• Automotive industry relevant materials information database with all needs covered – one source • Management of customer customisation and effect on design process/homologation and supply chain	
Economics	• Reduce cost of moulded composites • Component performance beyond single vehicle life • Development costs • Re-processing of metal mixtures to give pure metals for re-use • A higher, safer and more environmentally sound vehicle development	• Disassembly techniques • Develop viable alternative to traditional paint finish for body panels	
Environment	• Establish standards of environmental friendliness • Development of polymer separation techniques • ELV compliant composite materials • Reduce vehicle weight • Attachment strategies for dismantling • Wider understanding of materials in the industry • Overcoming energy saving vs. recycling perceptions	• New magnetic materials for hybrid/ fuel cell powertrain • Develop re-use mechanisms/ methodologies • Identify higher value markets for recovered materials • National systems for materials re-use and recycle	• Solve H_2 fuel infrastructure issues to enable widespread uptake and use • Hardwearing, low friction coatings to eliminate lubricants from powertrains

	• National system for re-use of components • Low cost CFRP panels and structures		
Manufacturing systems	• Joining hybrid structures • Surface quality thermoplastic composites • Develop low cost composite manufacturing process • Cost effective joining/dismantling of mixed material structures • Cheap, environmentally friendly system to join steel, aluminium and magnesium without corrosion issues • Awareness of and access to process models and life cycle analysis • Establish central register of production routes to advise on potential facility sharing • Single piece structure development costs	• Coatings which survive production • Reduce time to manufacture for novel technologies • Materials that do not require paint protection • Convergence of business and technology research models • Flat pack/modularity requires ability to make cheaper, structural, sealed joints post-paint process	• Die-less forming

Monet Roadmap – Where does the future lead?

Monet is a European Centre of Excellence in 'artificial intelligence into industry', based at the University of Wales in Aberystwyth. It produced a report in June 2002 entitled *Model Based Systems in Automotive Domains: Applications and Trends* (http://monet.aber.ac.uk:8080/monet/docs/tg_minutes_and_reports/automotive/a1_report.pdf).

The approach taken has been through questionnaires to experts in the field. It claims that model-based reasoning has proved to be a very powerful technology for automotive applications for tasks such as diagnosis, design, and simulation. The general idea is that qualitative models can support several activities which are critical to the life cycle of vehicles: from analysis of the original design through on-board monitoring, diagnosis and recovery, to diagnosis and repair in the workshop.

Roadmaps relating specifically to the aerospace sector

There are a great many references to aerospace and aircraft roadmaps on the Web, mostly emanating from the United States. There is strong emphasis on electronic components and very little specifically on new materials. Unlike the automotive industry the reports contain less information. A 'Google' search produces many references, and the following two references may be worth looking at.

Proposed Canadian Roadmap for Aerospace

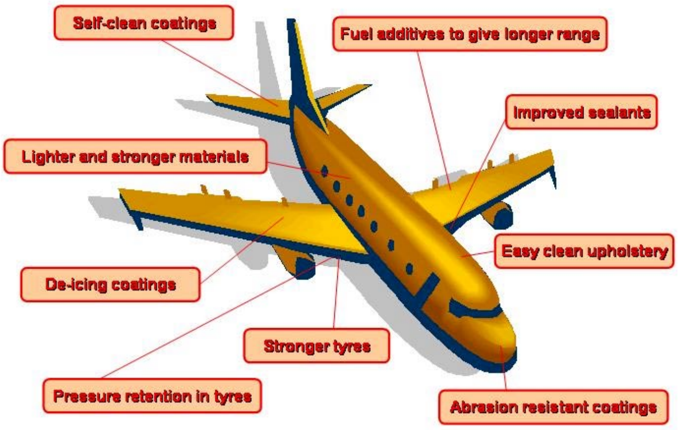
Together with the Canadian aerospace community (industries, universities and research laboratories), herewith, it is proposed (http://www.cls3.ca/mems/past/Appril2001/paststranegies_roadmap.htm) to develop a technology roadmap for development and manufacturing of micro-electro-mechanical (MEMS) devices and systems for aerospace applications in Canada. This work will (a) identify and define the scope, and (b) propose necessary requirements and pertinent short-term and long-term implementation strategies which would include priority areas, projects, tools and resources, and their effective coordination.

The Lean Aerospace Initiative

The Lean Aerospace Initiative (LAI) is a collaborative effort among major elements of the United States Air Force, leading companies within the aerospace defence industry, and the Massachusetts Institute of Technology. Lai was formed to identify and implement lean principles and practices throughout the military aerospace systems' acquisition, development, and production processes. Their roadmap may be found through http://lean.mit.edu/index.php?option=com_content&task=view&id=53&Itemid=63.

Nanotechnology Developments

The following diagram summarises the potential of developments in nanotechnology, which are already impacting on markets:



IMPACT OF NANOTECHNOLOGY

Nanotechnology is already having a considerable effect on the automotive industry, enabling lighter weight materials and additional properties leading to new products.

The diagram shows the possibilities, with respect to the marine sector.

Examples of use in automobiles are:

- *With 20% weight saving over conventional parts, the Toyota Camry's air intake cover and the Mitsubishi GDI models engine cover both has a nylon/nanocomposite material rather than a metal part. As well as light-weighting, this also makes use of the heat deflection properties of nanocomposite materials.*
- *The Chevrolet Impala uses 245 tonnes per annum of montmorillonite/polypropylene nanocomposite for its side body mouldings.*
- *The final lacquer on a number of Mercedes models is silica nanoparticle based and provides a durable anti-scratch surface. Other coatings developments in the field of nanotechnology are for textiles, where easy-clean coatings are now being used on Hugo Boss suits.*
- *Carbon nanotubes promise composites with 50-100 times the strength of steel and one sixth the weight! 60% of new cars in the US have plastic fuel lines incorporating carbon nanotubes to dissipate charges.*

The DTI's MNT Network, set up by the Government to coordinate the UK's activities in this rapidly developing area, has produced awareness packs which are designed to update specific sectors on the potential impact nanotechnology could have on their business. One has been produced for the marine sector with help from Marinetech South. The packs contain slides describing the opportunities, with notes on each slide, and case studies. Examples of some of the slides are shown below:

Antifouling coatings

EU AMBIO project

Fouled ship hulls burn 40% more fuel

- alternatives to tributyl tin (TBT) are urgently needed
- nanostructuring of a surface coating controls properties such as surface energy, charge, conductivity, porosity, roughness, wettability, friction, physical and chemical reactivity, and compatibility with biological organisms
- the new types of coating will not release any harmful chemicals into the environment

Classical biofouling of a ship hull by barnacles (Image: International Paints Ltd).

Swimming spores of *Ulva* (Image: A Callow).

MNT Network
Collaborating for the future

Advanced composites

Portsmouth University – "smart" gel coat:

- combines polymer, nanoclay and photocatalytically active nanoparticles with varying densities, surface treatments, particle sizes and surface areas
- selectively self-cleans, anti-fouls, destroys bacteria and resists abrasion, depending on ambient conditions
- is environmentally friendly
- is blister and fouling resistant
- can be used in marine paints and gel coats
- offers 100% performance improvements
- offers improved mechanical properties

Blistered gel coat.

MNT Network
Collaborating for the future

High-performance composites

Composites using carbon nanotubes offer:

- enhanced mechanical properties
- potential long-term applications
- high-performance masts
- lighter, stronger, more durable hulls

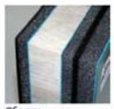
Carbon composite foams (Cfoam):

- use nanoscale carbon buckyballs
- are 1000 times as strong as Styrofoam
- make larger composite vessels possible through increased strength and fire resistance

UK Aerospace and Marine Composites and Research Centre:

- composites for the aerospace and marine sectors

Multiwalled carbon nanotube.



Cfoam.

Composite mast.

MNT Network
Collaborating for the future

Textiles

Hydrophobic fabrics:

- dirt-deflecting and stain-resistant
- environmentally sound
- resistant to friction
- flexible and soft
- "nanowhiskers" increase surface tension so that liquid cannot soak through
- improved sail performance and durability
- dirt-repellent interior and exterior fabrics for boats

MNT Network
Collaborating for the future

Self-cleaning, hydrophobic and scratch-resistant coatings

Scratch-resistant coatings:

- wearing surfaces (e.g. flooring and worktops)
- window and plastic glazing

Hydrophobic and self-cleaning coatings:

- coated marine antenna systems show rain attenuations of only 10% compared with 50% losses for uncoated systems
- self-cleaning glass

MNT Network
Collaborating for the future

Fuel additives

Envirox diesel fuel additives:

- are produced by Oxford-based company Oxonica
- are reported to:
  - promote longer and more complete combustion
  - significantly improve fuel economy in excess of 5%, verified in large-scale trials
  - reduce emissions
  - reduce carbon deposits
- can be added to bulk fuel storage or automatically dosed into a fuel line
- offer low application rates (5ppm)
- are classified as non-hazardous

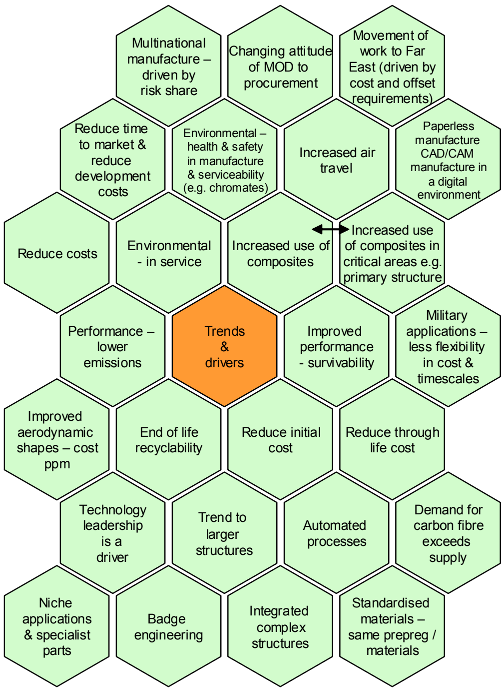
Oxonica are seeking partners to conduct large-scale marine application trials.

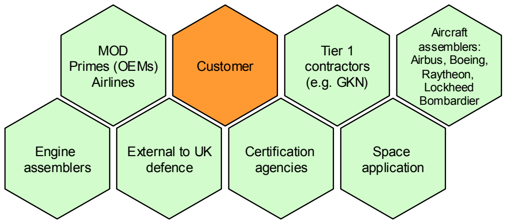
Images: Oxonica plc.

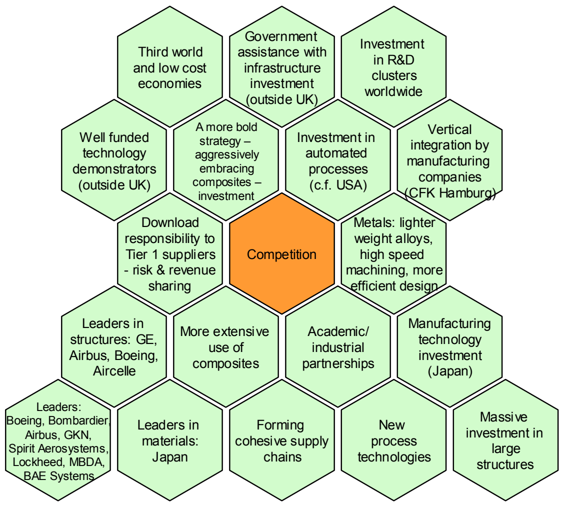
MNT Network
Collaborating for the future

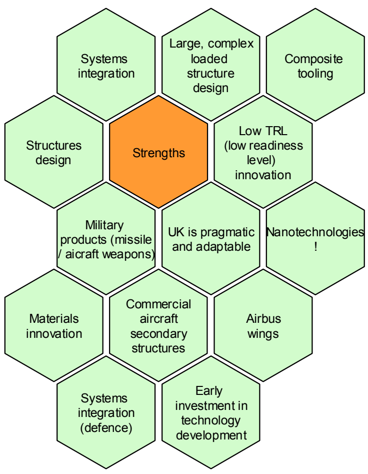
8.3 Results of the Brainstorming with Hexagons

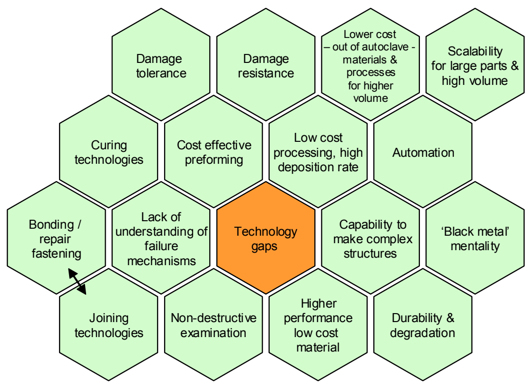
Where are we now?

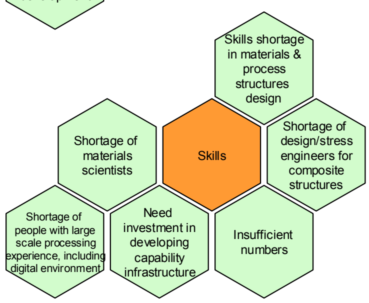


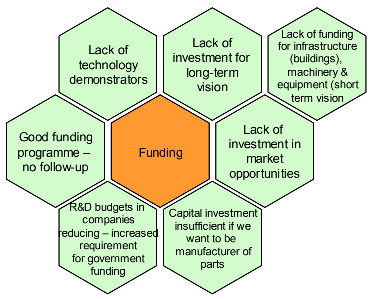




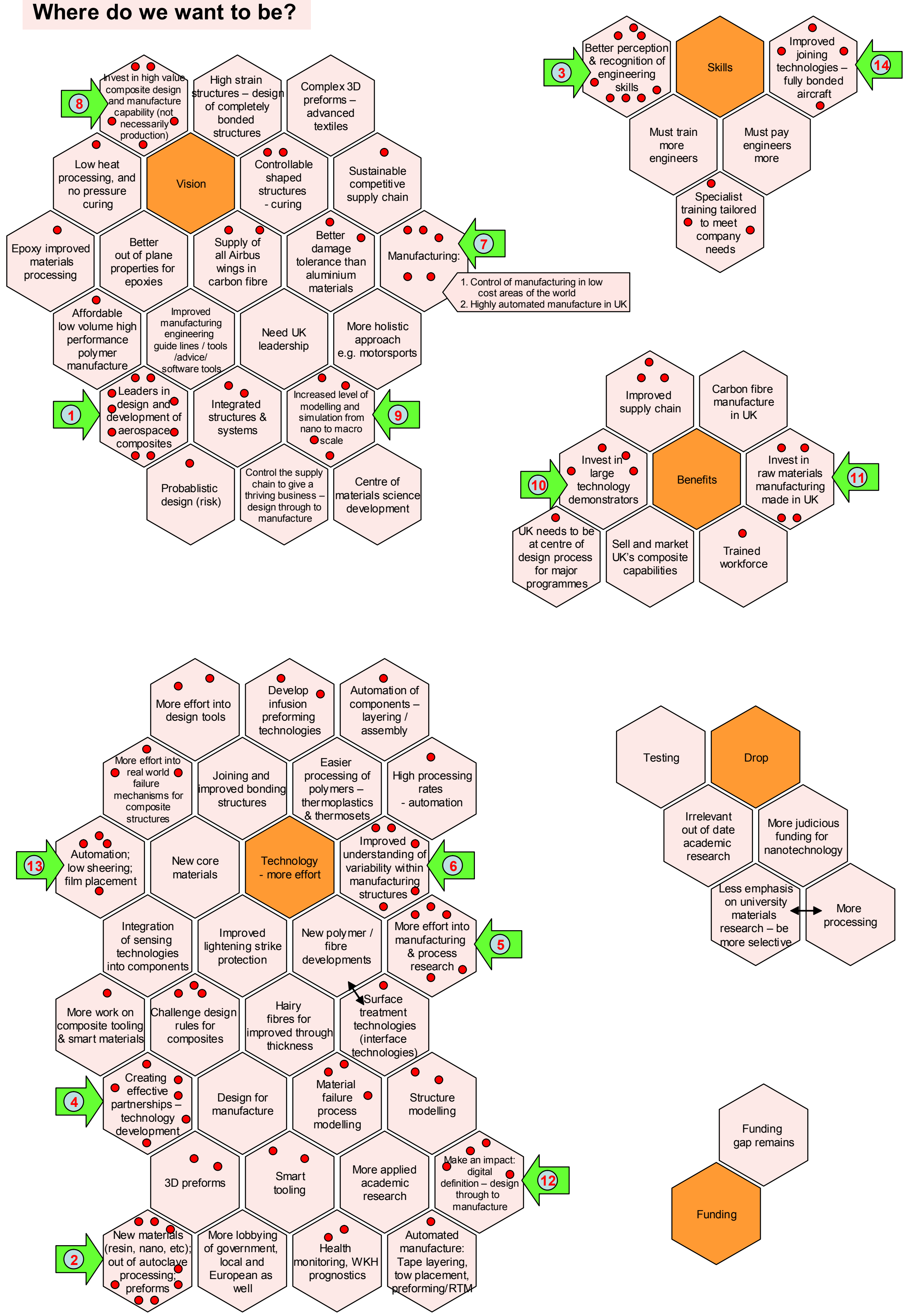




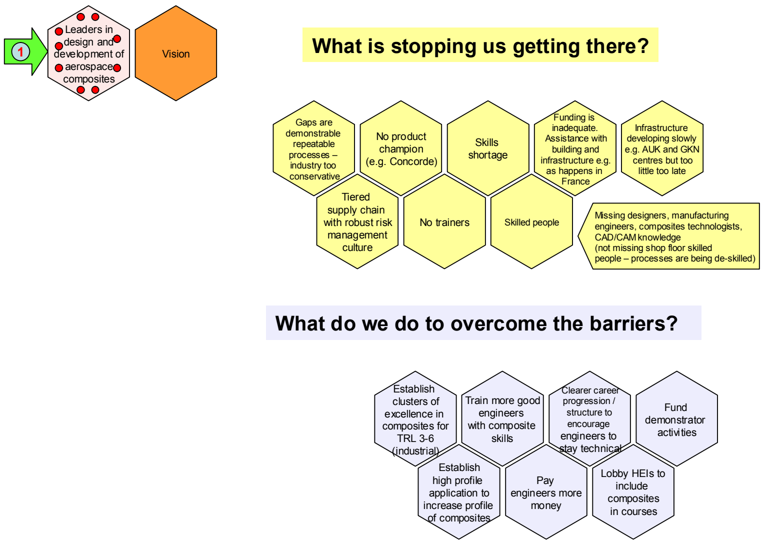


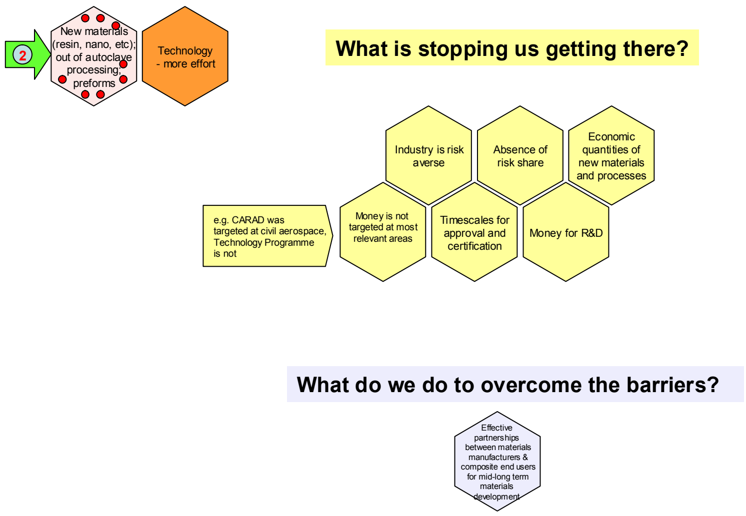


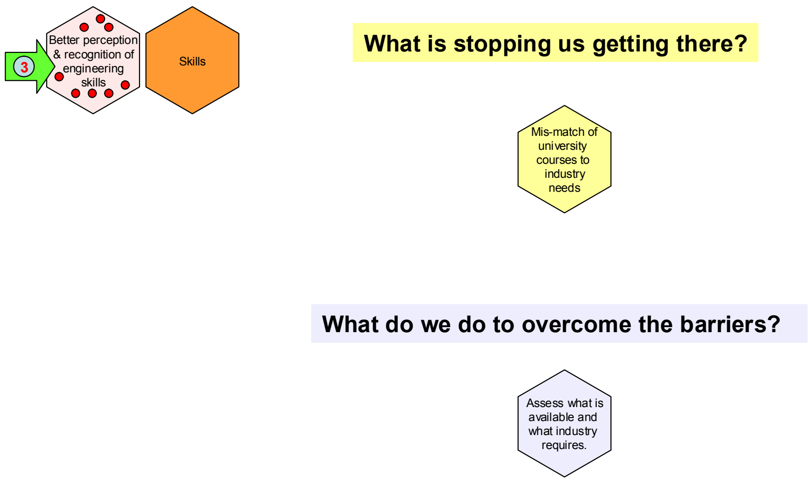
Where do we want to be?

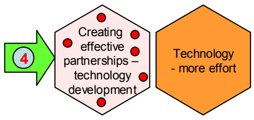


Priorities – barriers and actions:



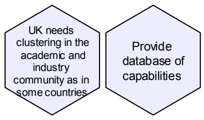


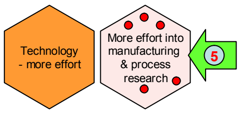




What is stopping us getting there?

What do we do to overcome the barriers?





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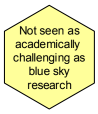

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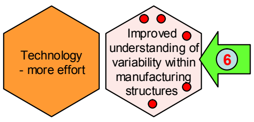

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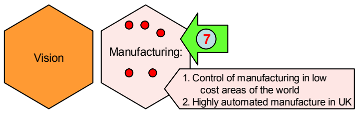

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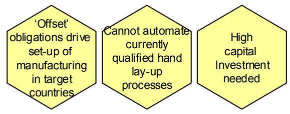

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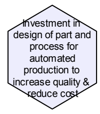

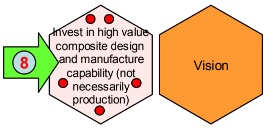

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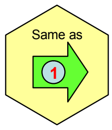

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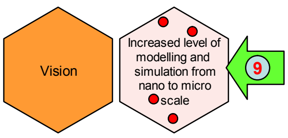

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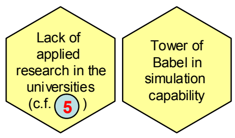

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