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The Use of composites in aerospace:  
Past, present and future challenges.

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# Contents

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- ▶ Introduction to composites.
- ▶ Use of composites in aerospace.
- ▶ Current challenges and opportunities.
- ▶ Future challenges and opportunities.
- ▶ Summary.



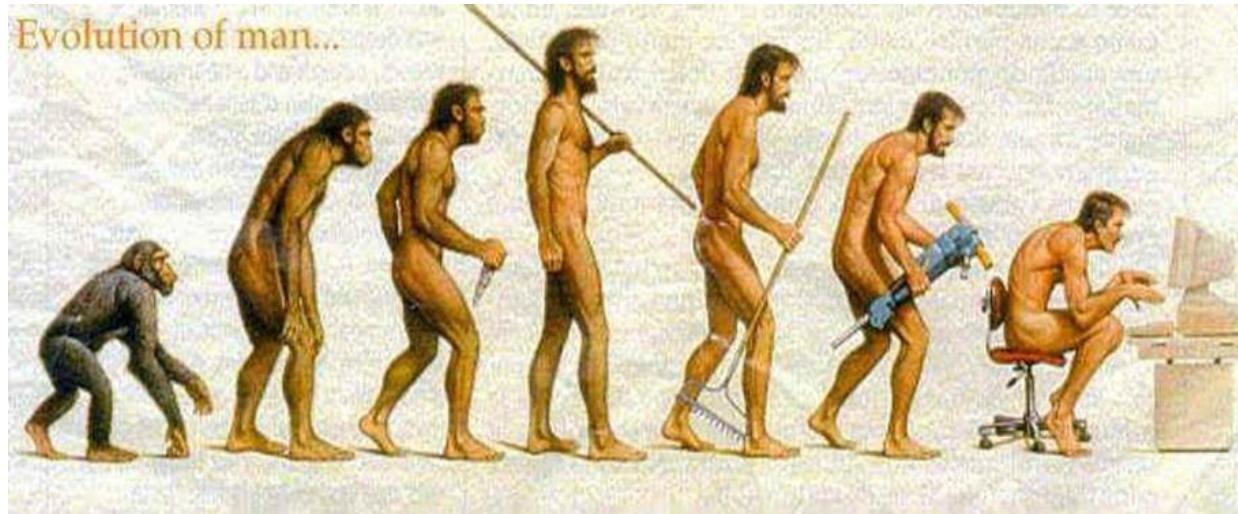
# Introduction to Composites

# Material Evolution

- ▶ Evolution is driven by economics, logistics and the expectations of society.
- ▶ Evolution is facilitated by developments in materials, processing methods and design tools (understanding of materials).



# Material evolution



**Stone age**

**Bronze age**

**Iron age**

**Steel age**

**Plastics age**

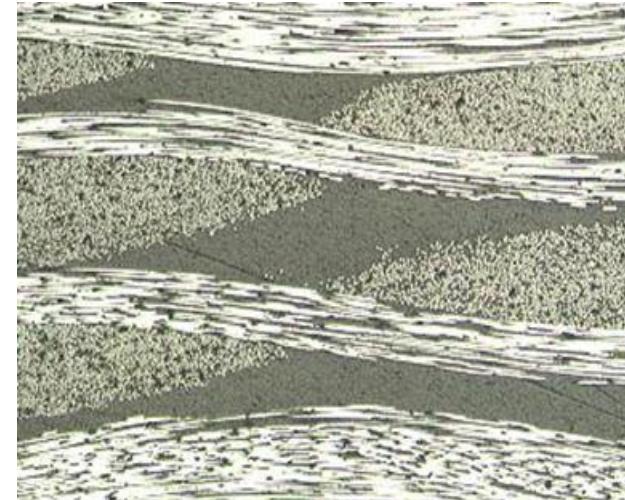
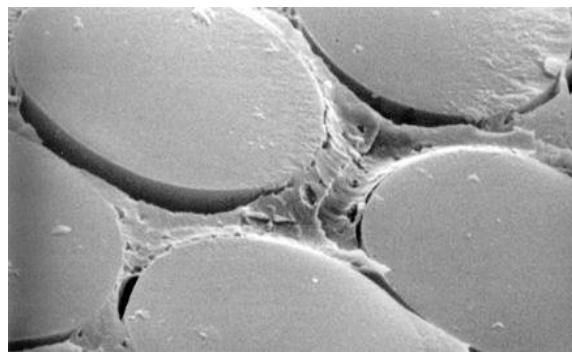
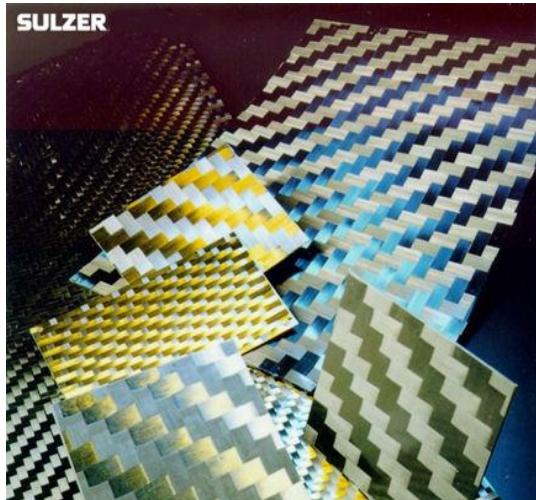
**Silicon Age**

**Designer materials age**

Material Ages  
of Man

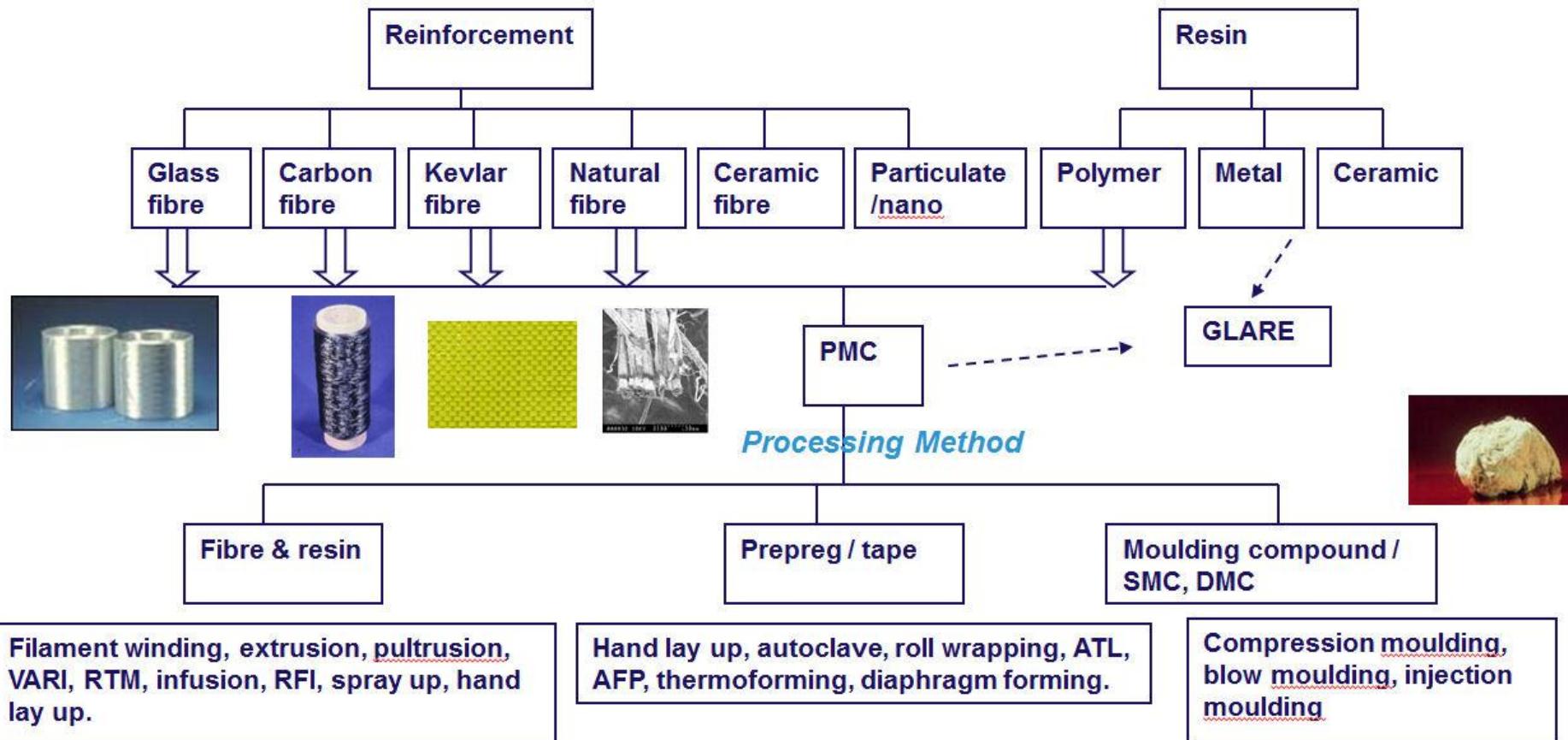
# What Are Composites?

- ▶ A composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own.
- ▶ Typically reinforcing fibres in a matrix.
- ▶ The ultimate 'designer material'!

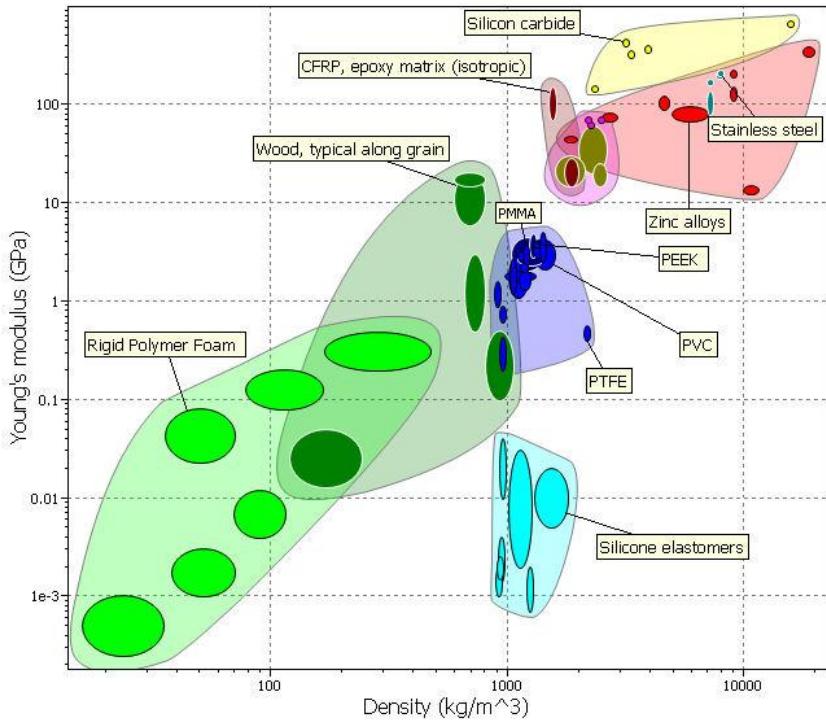




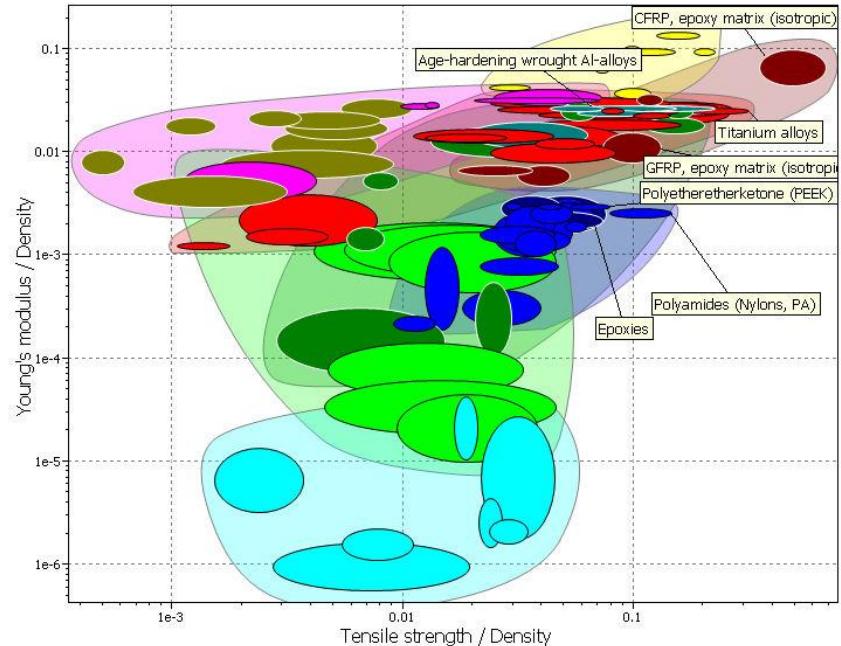
# A wealth of design options



# Composite properties



For a given stiffness, composites have low density.



Composites have excellent specific strength and stiffness.

# Swot analysis

## Strengths

- ▶ Properties.
- ▶ High strength to weight ratio.
- ▶ Fatigue resistance.
- ▶ Corrosion resistant – reduced life cost.
- ▶ Tailor properties within a part.
- ▶ Complex shapes possible.
- ▶ Lower pressure tooling.
- ▶ Reduced part and fastener count.
- ▶ Reduced materials waste.



## Opportunities

- ▶ Innovative manufacturing (automation, ALM, OOA).
- ▶ New recycling technologies.
- ▶ Legislation.
- ▶ Smart/functional materials (self healing, heating, morphing, SHM).



## Weaknesses

- ▶ High cost.
- ▶ Damage tolerance.
- ▶ NDT requirements.
- ▶ Lack of design data and tools (improving).
- ▶ Uncertainties in failure prediction (improving).
- ▶ Need specialised repair techniques.



## Threats

- ▶ Titanium – FFC process.
- ▶ Innovation in metals (machining/ ALM/ super plastic forming).
- ▶ Recycling Issues.
- ▶ High profile failures.
- ▶ Material shortages.
- ▶ Legislation (REACH).
- ▶ Cost of oil.



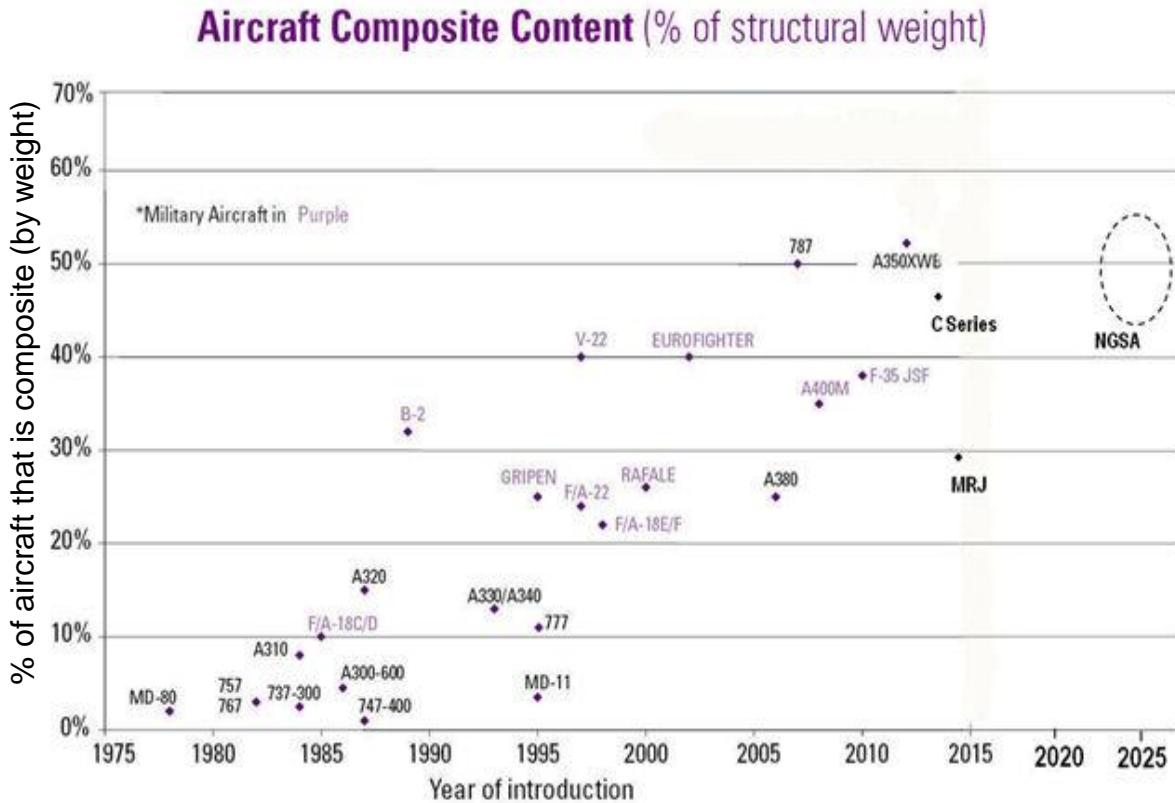


# Use of Composites in Aerospace Applications

# Aircraft Composite Content

Graph shows:

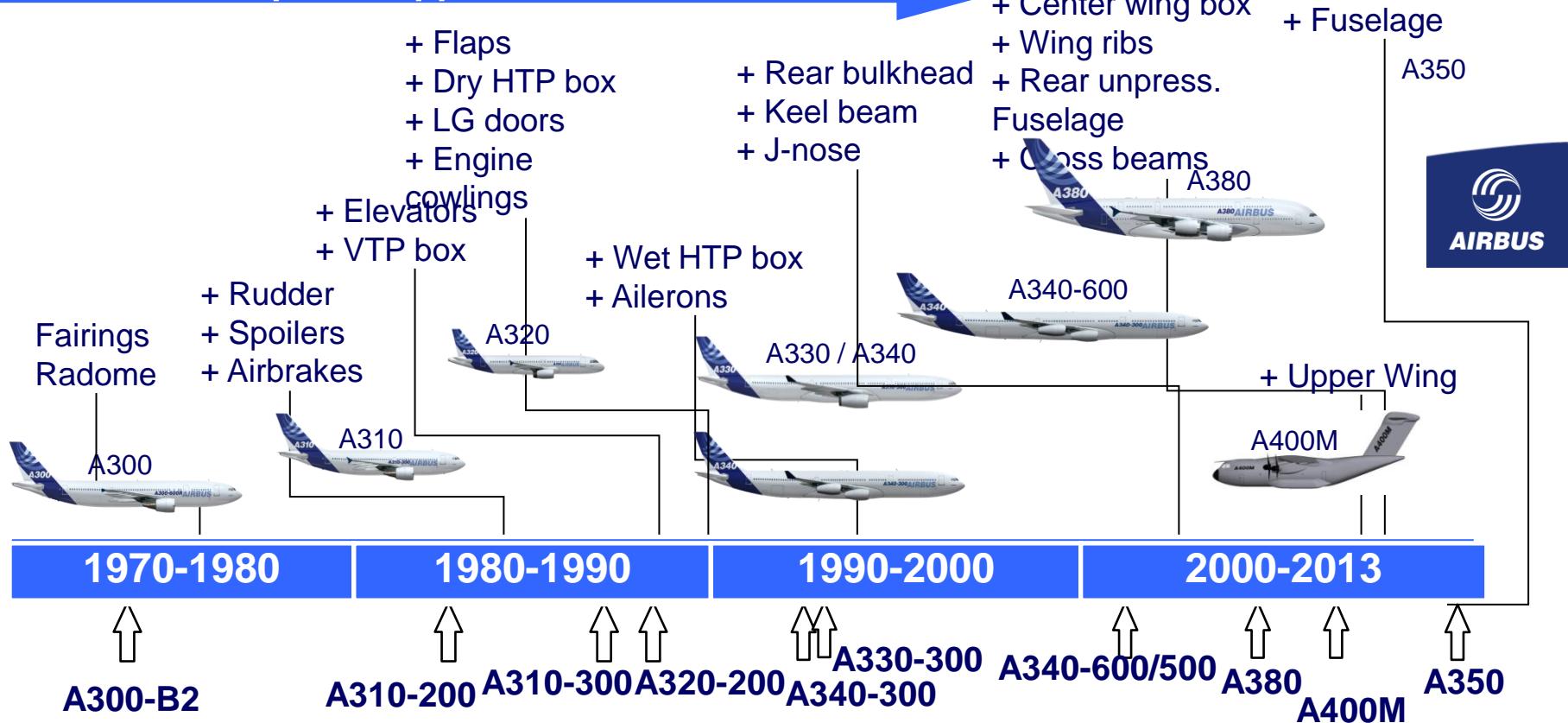
- ▶ Civil aircraft in black, military in purple.
- ▶ Historically military used more composite than civil.
- ▶ Since 2005, civil aircraft have dramatically increased the composite content.
- ▶ Airbus has relatively steadily increased its usage of composites over the years.
- ▶ Boeing has jumped from 12% composite by weight in the 777, to 50% composite by weight in the 787.
- ▶ Next generation single aisle – percentage composite and launch date still unknown.



Source: Teal Group, Boeing, Airbus, Composite Market Reports



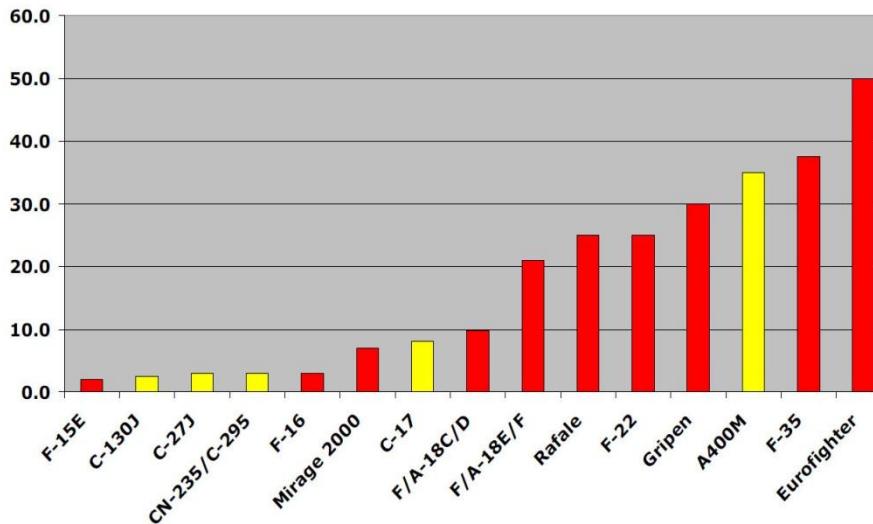
## Evolution composite application at Airbus



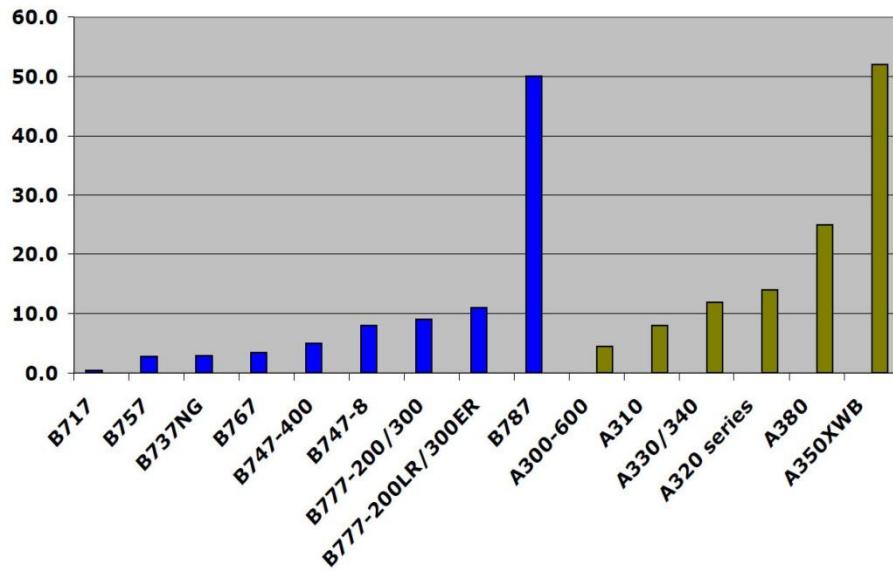
# Aircraft composite content



**Military aircraft % composite by weight**



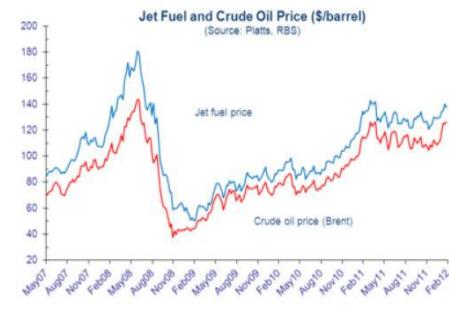
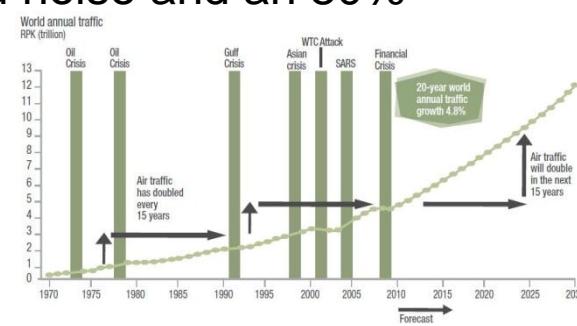
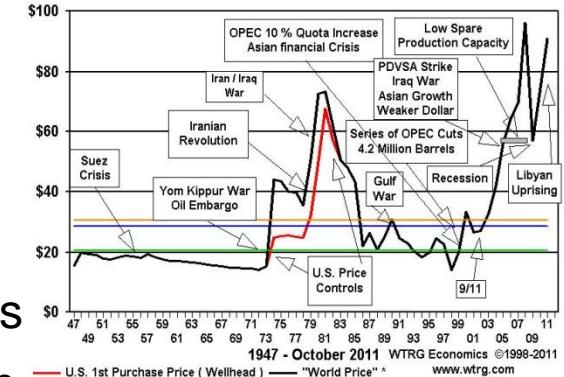
**Airliner % composite by weight**



# Explanation



- ▶ Development of composites for aerospace use was both costly and potentially risky, therefore initial development was performed by military who had relatively large development budgets and are not so risk averse as the civil side.
- ▶ On the civil side, composite development was restricted to non-structural applications.
- ▶ However, the drivers to produce light-weight structures were provided by:
  - Price of oil
  - Change in attitude towards environmental issues (e.g. the ACARE targets of 50% reduction in  $\text{CO}_2$ , a 50% reduction in perceived noise and an 80% Reduction in  $\text{NO}_x$  by 2020).
  - Predicted increase in airline traffic.



# Explanation

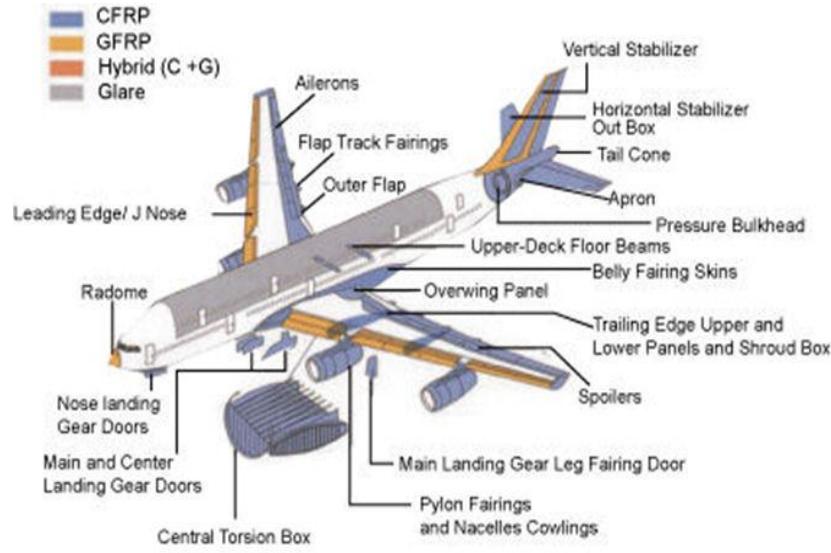
- ▶ Composites give the OEMs the opportunity to produce lightweight structures thereby reducing fuel bills and reducing emissions.
- ▶ The cost of development and introduction of these new structures is now offset by the gains.
- ▶ Hence the increase in the usage of composites in aerostructures.



787-8



- Carbon laminate
- Carbon sandwich
- Other composites
- Aluminum
- Titanium



Not Shown: CFRP  
Passenger Floor Panel  
and Struts



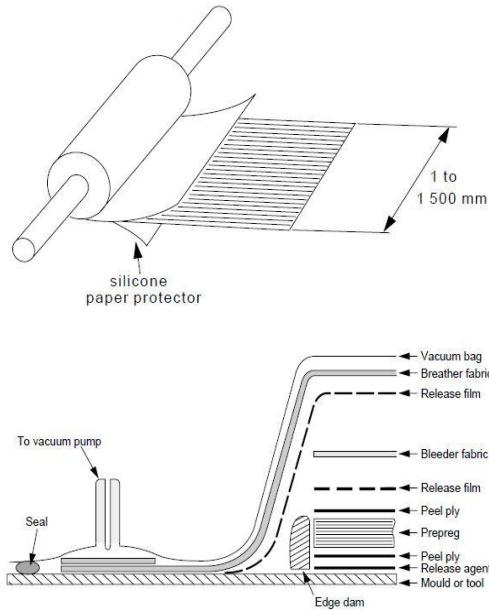
## Current Challenges and Opportunities:

1. Manufacturing
2. MRO
3. Functional composites
4. Reputational damage

# 1. Manufacturing

- ▶ Prepreg and autoclave cure has traditionally been the standard for aerospace - necessary to guarantee ultimate quality (high  $V_f$ ).
- ▶ Not appropriate for very large scale structures and preparation and cycle times are long.

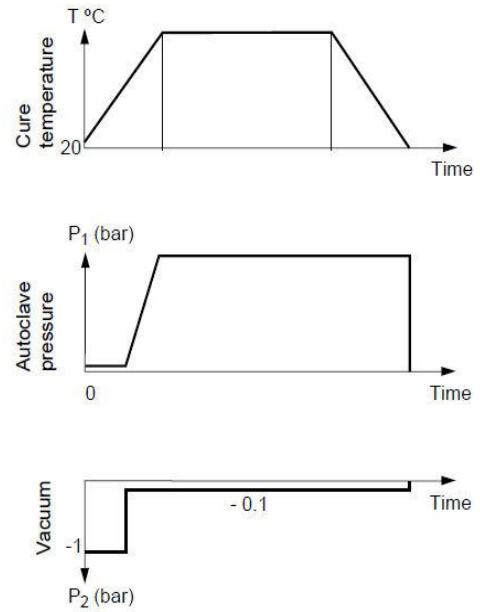
Lay-up process



Autoclave



Cure process





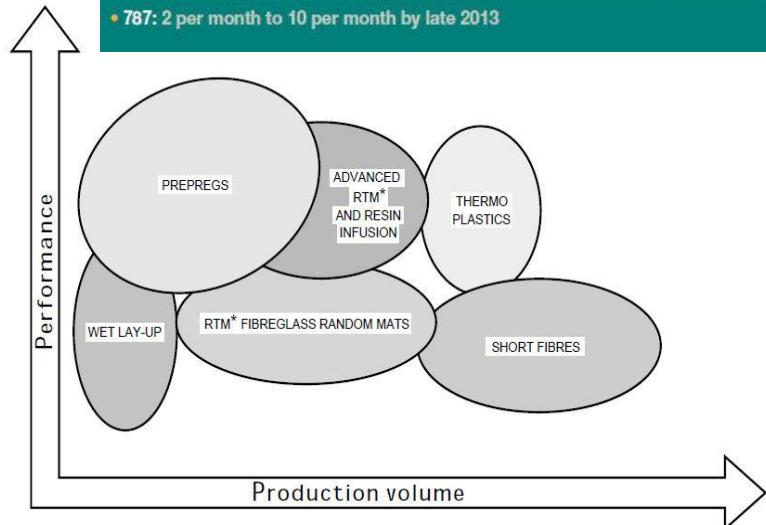
# Manufacturing

- ▶ With build rates rising to satisfy demand, the OEMs needed to find a way, without compromising quality, to:
  - Increase production rate.
  - Eliminate autoclave.
- ▶ This has produced two trends:
  - Automated production.  
e.g. Automated tape laying (ATL), automated fibre placement (AFP).
  - Out of autoclave processing.  
e.g. Infusion, SCRIMP, RFI, RTM.

## By the numbers

Boeing is boosting production rates for all its commercial jets

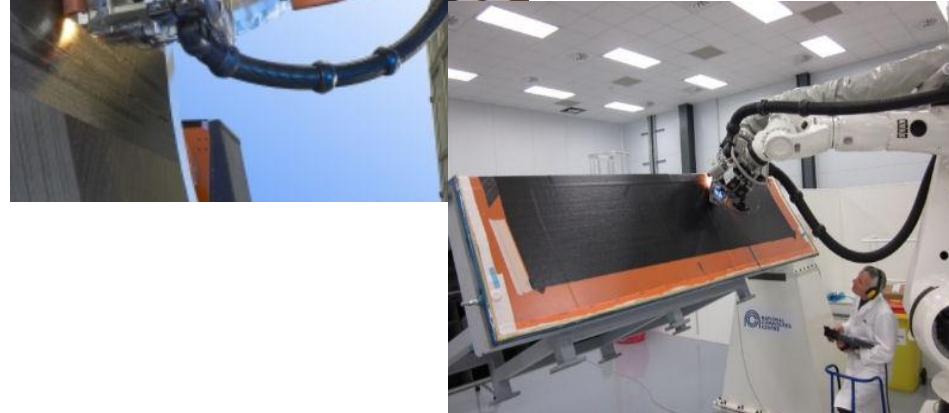
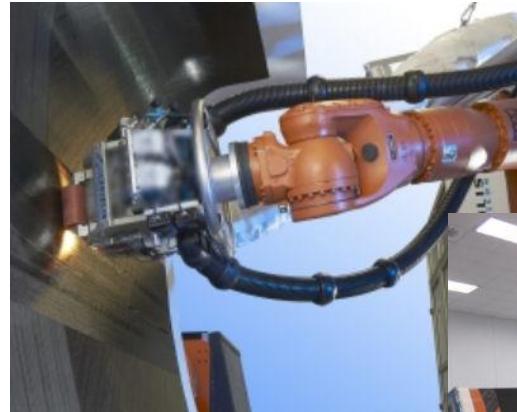
- **Next-Generation 737:** From 31.5 airplanes per month to 35 per month in early 2012 to 38 per month in second quarter of 2013 to 42 in 2014
- **747:** 1.5 per month to 2 per month in mid-2012
- **767:** 1.5 per month to 2 per month in mid-2011
- **777:** 7 per month to 8.3 in first quarter of 2013
- **787:** 2 per month to 10 per month by late 2013



# AFP/ATL



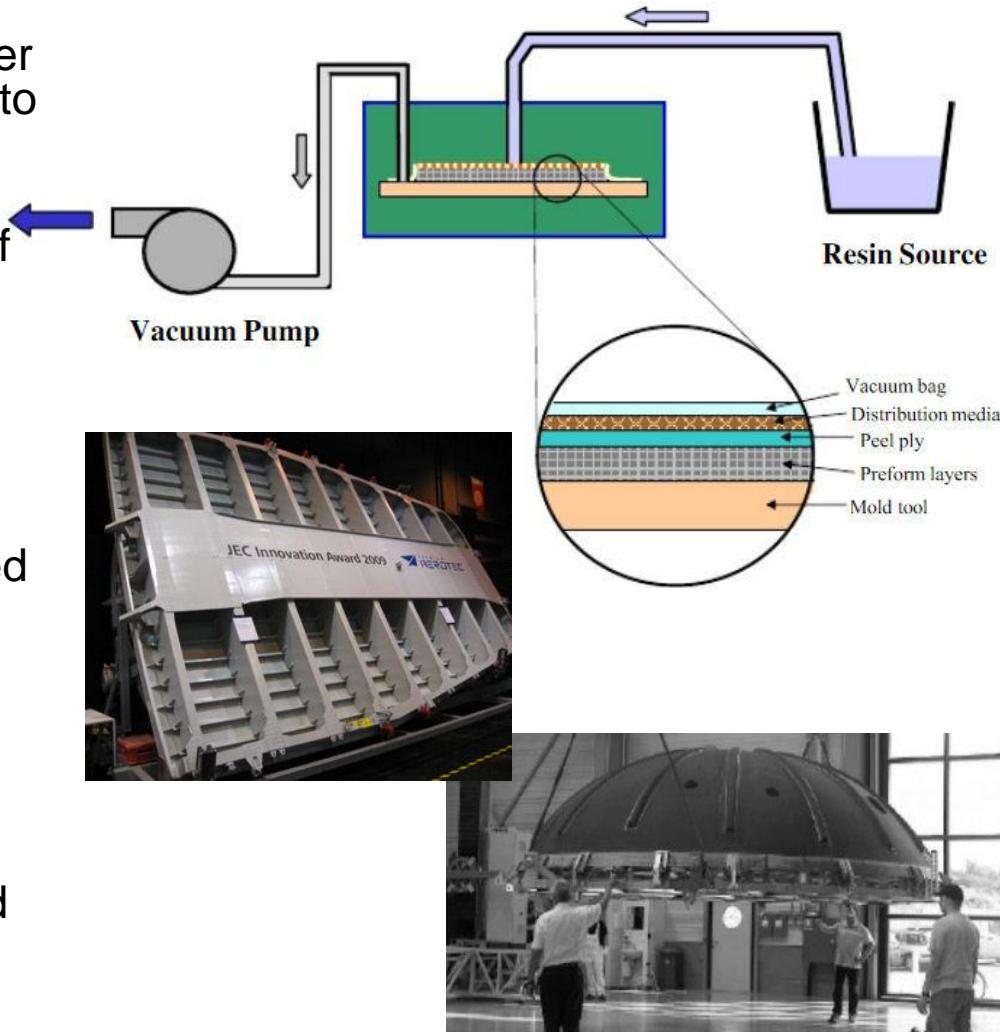
- ▶ AFP (automated fibre placement) and ATL (automated tape laying) provide rapid automated placement of strips of prepreg material onto a mould.
- ▶ AFP can be used with much more complex geometries because it lays narrow tows, which can be steered over sharply curved surfaces whereas wider tapes cannot be so placed without buckling some of the fibres and potentially weakening the laminate.
- ▶ Cure can either be done in or out of an autoclave as long as an appropriate material is used.
- ▶ Examples of usage are 787 nose and A350 fuselage panels.



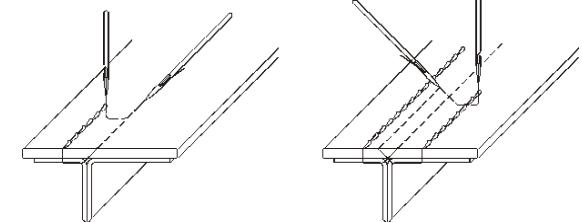
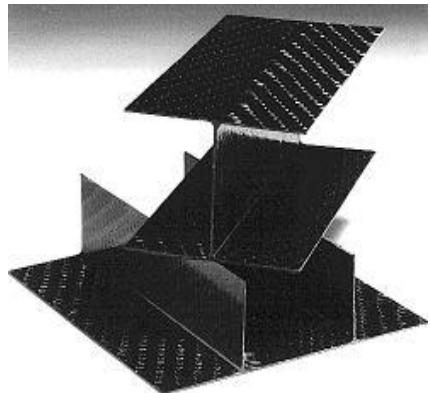
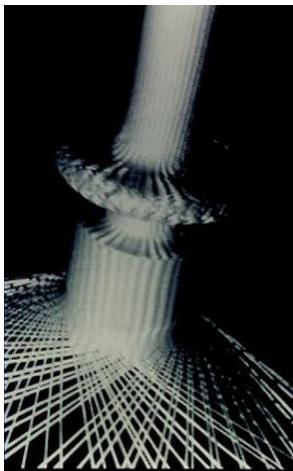
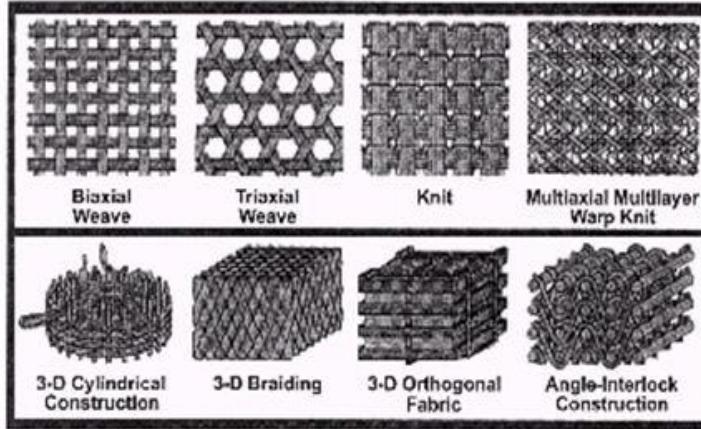
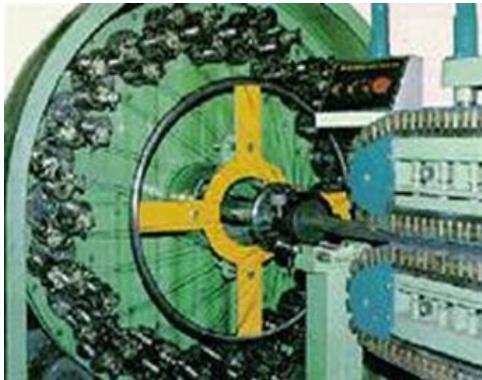
# Out of autoclave processing



- ▶ Process involves laying up of dry fabric and introduction of resin either in wet or film form using a vacuum to pull it through the fabric.
- ▶ There are many variations on the technique and therefore a wealth of names and acronyms – vacuum infusion, resin film infusion (RFI), vacuum assisted resin transfer moulding (VARTM), SCRIMP etc.
- ▶ This technique allows the use of technical textiles, which provides more design freedom and enhanced through thickness properties.
- ▶ However, the resin usually has to have a relatively low viscosity to allow it to flow through the fabric, which can mean compromising on toughness of the final part.
- ▶ Example – A380 rear bulkhead and A400M cargo door.



# Textiles



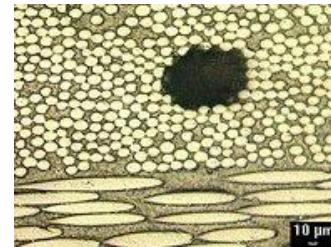
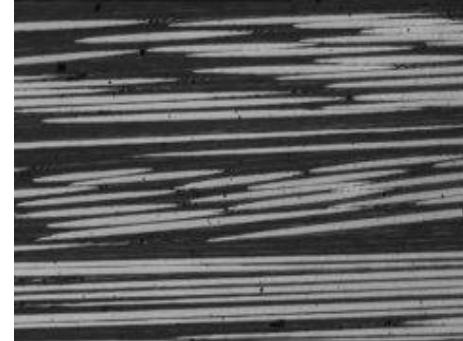


## 2. MRO - Maintenance

- ▶ Maintenance, repair and overhaul (MRO) requirements of composites are very different from those of metals.
- ▶ Shorter track record of use than metallic structures, many MRO companies therefore do not have much experience of maintaining composite structures.
- ▶ Parts are designed to cope with typical defects/damage (although given variations in microstructure in composites, even this can be difficult) but non-destructive testing is required to pick up damage/growth beyond these limits.
- ▶ Specific challenges with maintenance:
  - Specific defect types due to inhomogeneous nature of composites.
  - Defects are initiated during manufacturing  as well as in-service. 
  - Inspection regime usually involves use of several NDT techniques. 
  - New and developments in existing techniques offer improvements in current state of the art, but these need to be validated and certified.

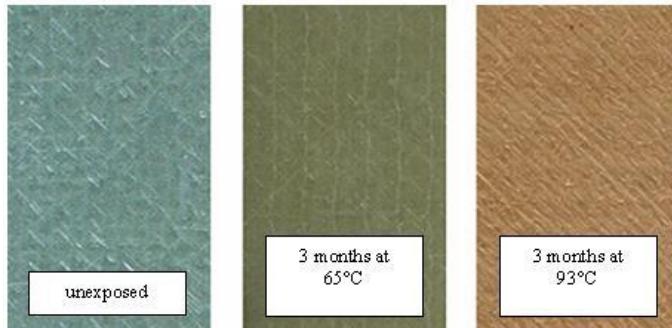
# Manufacturing Defect Types

- ▶ Fibre misalignment.
- ▶ Inappropriate fibre volume fraction.
- ▶ Overlap or gap between fibre bundles.
- ▶ Knots or missing roving.
- ▶ Inclusions and contamination.
- ▶ Uneven, insufficient or over curing.
- ▶ Non-uniform hardener content.
- ▶ Cure shrinkage (Delamination, broken & buckled fibres and matrix cracking).
- ▶ Excessive porosity or voids.
- ▶ Poor wet-out and/or dry spots.



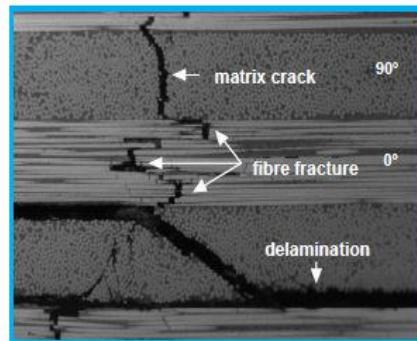
# In-Service Defect Types

- ▶ Impact damage
- ▶ Ballistic damage
- ▶ Moisture ingress
- ▶ Chemical attack.
- ▶ UV damage & weathering
- ▶ Erosion or abrasion
- ▶ Fatigue

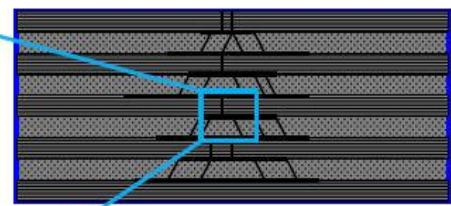


## What an impact damage *IS*

*Contains all damage types*

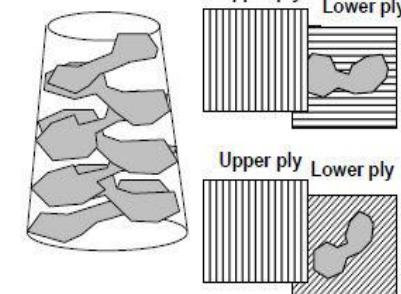
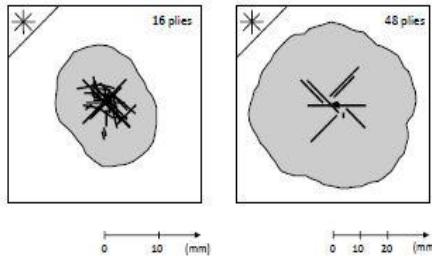


*Complex and affects all plies*



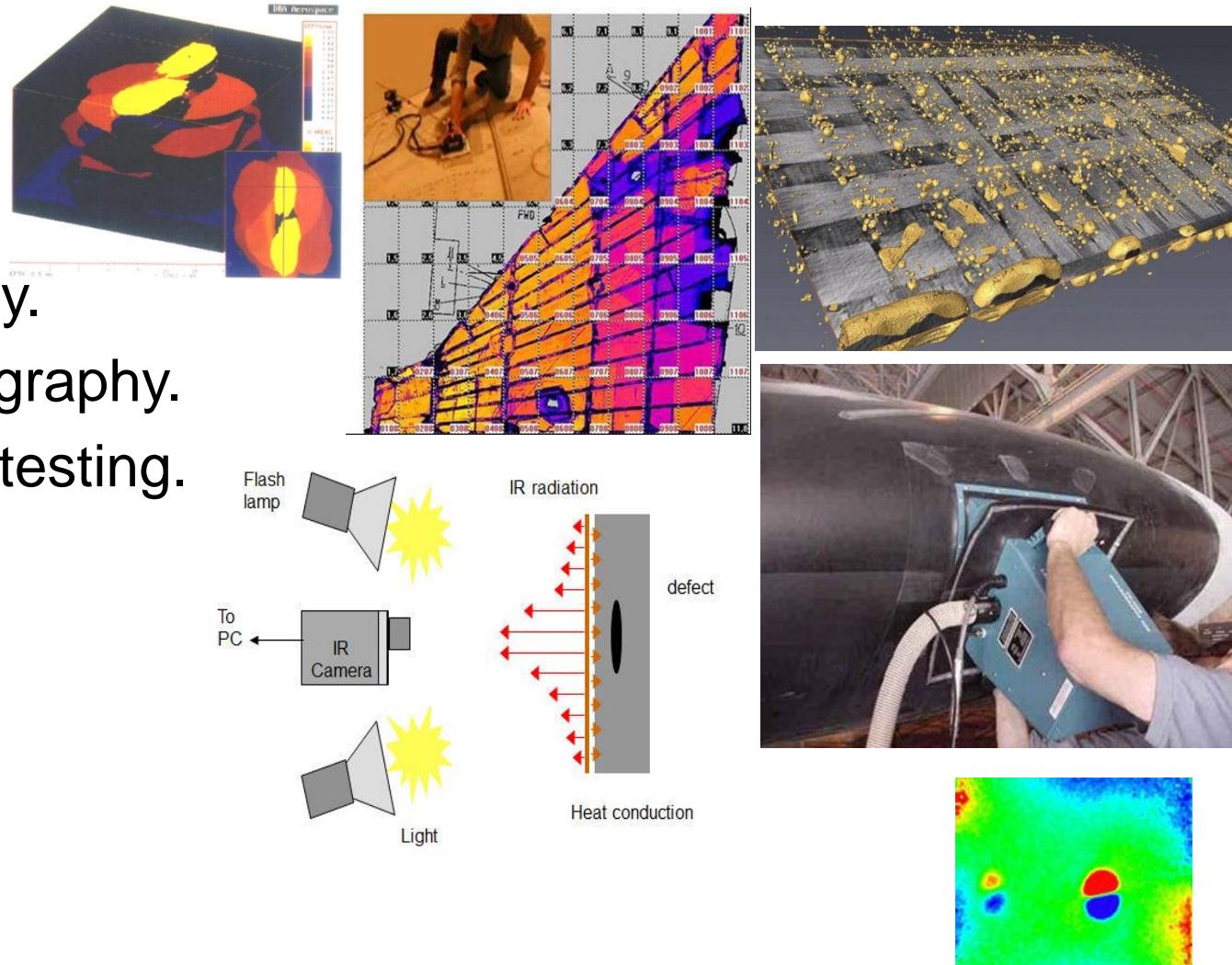
*Delaminations of irregular shape*

*Nonuniform in the plane*



# NDT Methods

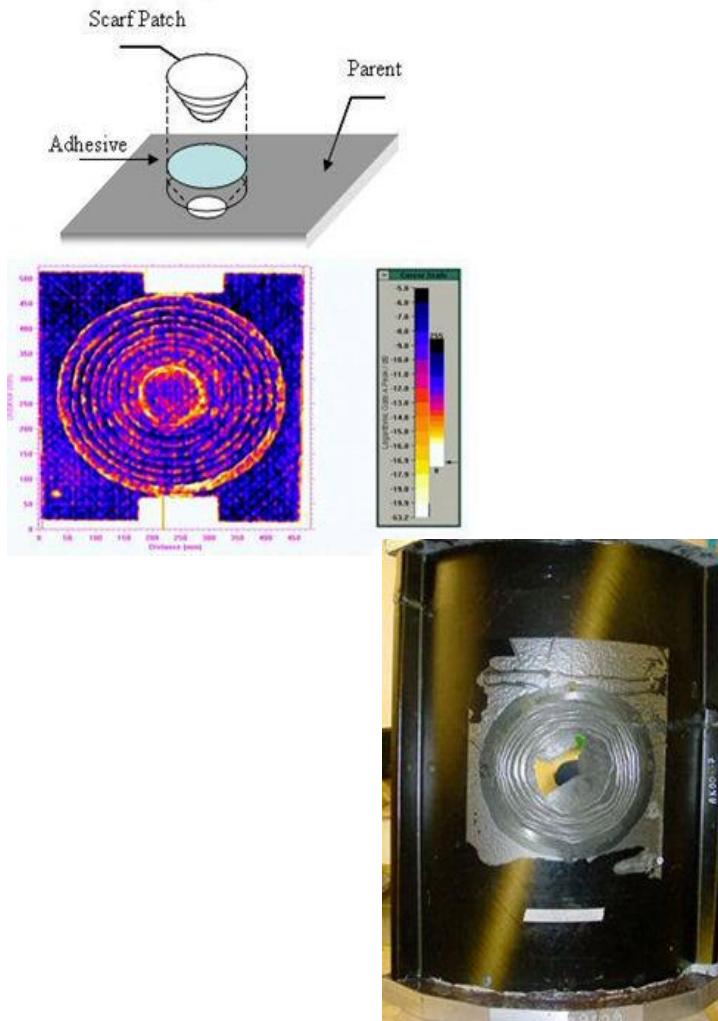
- ▶ Visual.
- ▶ Ultrasonics.
- ▶ Radiography.
- ▶ Thermography.
- ▶ Laser shearography.
- ▶ Coin and tap testing.
- ▶ Microwave.
- ▶ Acoustic.



# MRO - Repair



- ▶ Damage to composites or repair of damage to composites involves cutting of fibres, therefore strength and stiffness of a repaired composite will always be compromised.
- ▶ Repair of composites usually uses one of 2 techniques; bolting a patch (potentially metal) over the damaged area or scarf repair.
- ▶ A bolted patch increases weight.
- ▶ Scarf repair techniques require clean conditions, are time consuming and have traditionally utilised expensive, and difficult to store, pre-libs.
- ▶ In-field repair techniques based on dry fabric preforms and infusion are being investigated. Possible problems centre around the use of brittle resins for infusion and the likelihood of poor fatigue life and shock resistance.





### 3. Functional Composites

By virtue of the fact that composite materials consist of more than one material, and the material is formed at the same time as the part, it is possible to incorporate other materials or structures during processing to provide integrated functionality to the part.

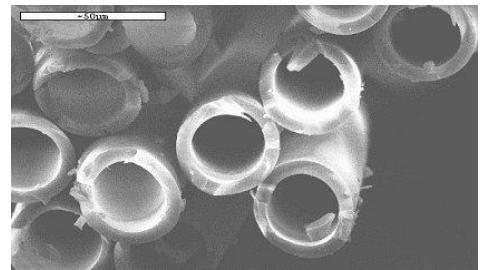
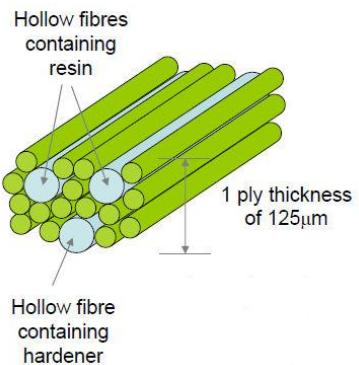
The following slides provide examples of research being done to provide additional functionality to composite structures in the areas of:

- ▶ Self-healing
- ▶ Sensing
- ▶ Morphing
- ▶ Lightning protection
- ▶ Energy storage

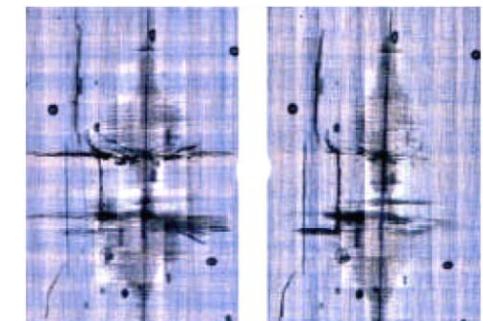
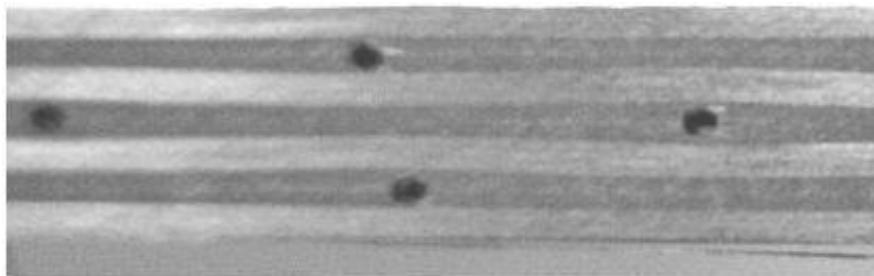
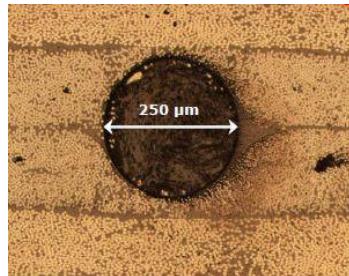
# Self-Healing Composites

## Examples:

- ▶ Hollow fibres. (I. Bond, et al. Bristol University)
- ▶ 'Lost wax' process. R. Trask et al. Bristol University.
- ▶ Sheffield Solid State Healing. S. Hayes et al. Sheffield University



Courtesy of Bristol University



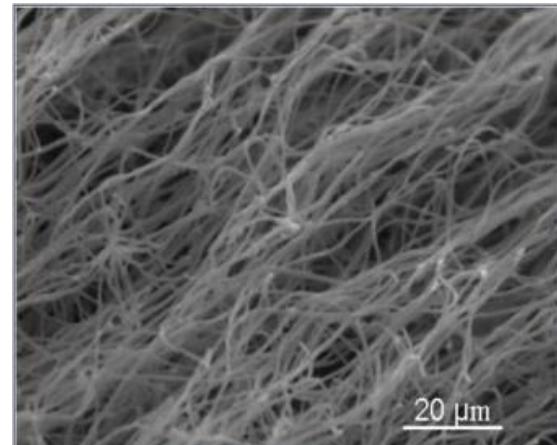
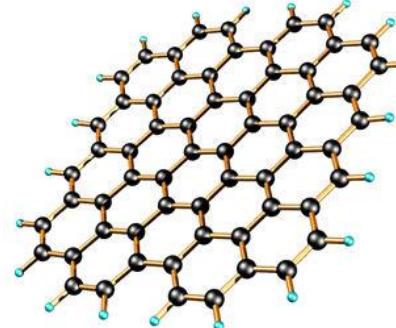
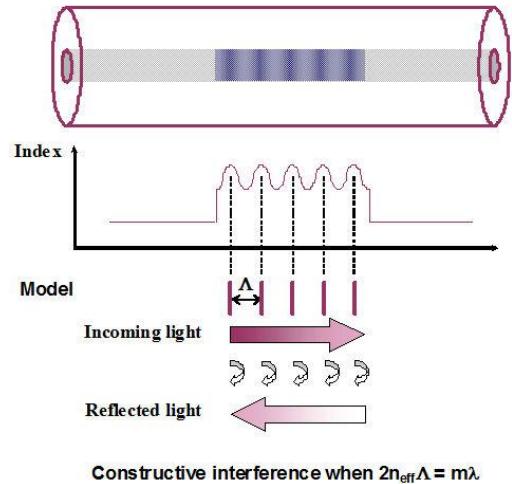
Courtesy of Sheffield University

# Sensing



In order to trigger self-healing, composites need to be able to detect damage, i.e. contain a health monitoring system. There are many approaches under development including:

- ▶ Fibre Optic/Bragg Gratings (e.g. Aston Uni, Birmingham Uni, Insensys, Ulster (woven structures)).
- ▶ Carbon nanotubes/graphene (Reading Uni, Imperial, Bristol Uni, Cambridge Uni etc.)
- ▶ Ferromagnetic microwires (Bristol Uni)
- ▶ Acoustic Emission (Airbus)

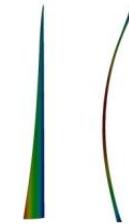
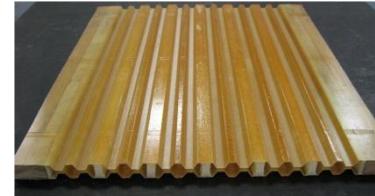


# Morphing

Structures that can change shape negate the need for motors and other weight adding mechanisms.

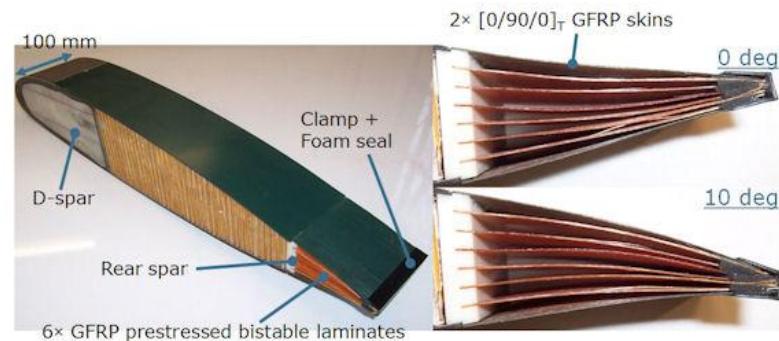
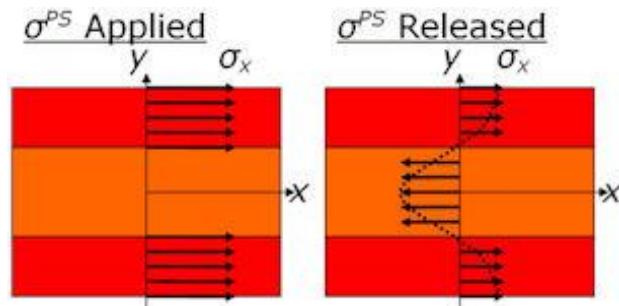
Examples from Bristol University:

- ▶ Tow-steered composites with variable stiffness to form bi-stable structures. A. Panesar and P. Weaver.
- ▶ Morphing corrugated structures, C.Thill et al.



Finite Element modelling  
assists in identifying the  
deformed shapes of the  
multi-stable states.

- ▶ Prestressed, bistable composites.  
Daynes, S., Weaver, P., Potter, K., and Hardick, M., U.K. Patent Application



# Lightning Protection

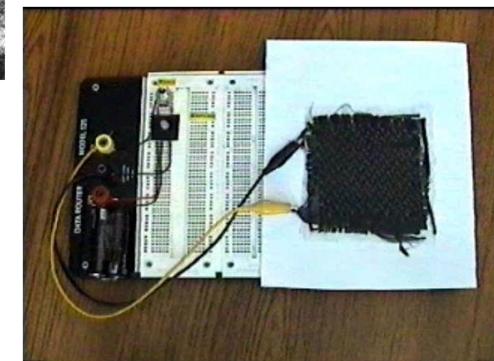
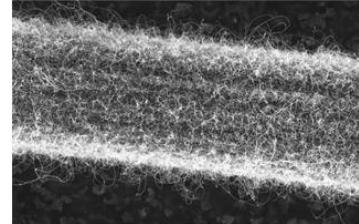
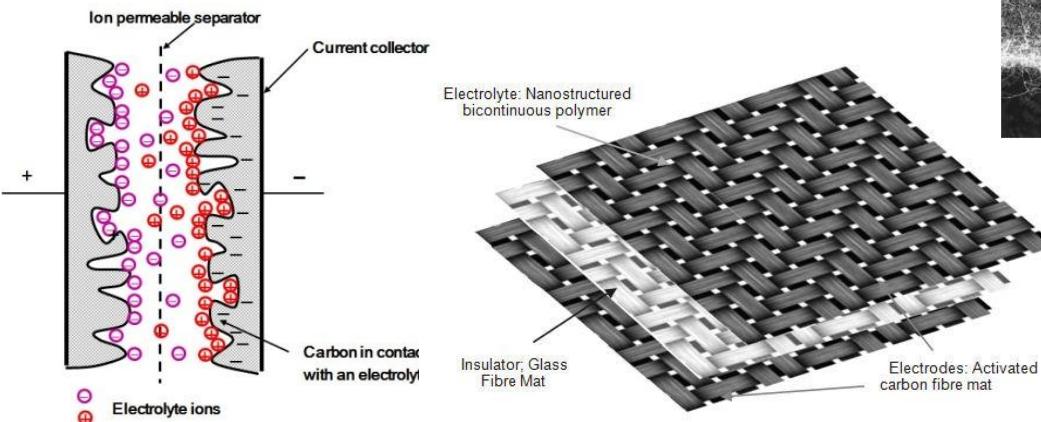


- ▶ Two types of effect caused by lightning strike:
  - Physical damage at attachment locations.
  - Indirect effects from induced voltage and current.
- ▶ Prevention methods in composite structures:
  - Cu foils & meshes in the outer plies.
  - Co-bonding Cu strips to the inside skins of panels.
  - Insulation caps on collars, nuts and fasteners.
  - Conductive paints (sprayed metal).
  - Al foil strips for shielding.
  - Nickel-coated carbon fibres.
- ▶ Examples of new innovations:
  - MAST Consortium (UK MoD programme) developed an integral woven SMA/carbon fibre preform. Improved damage tolerance AND lightning protection.
  - Bristol, M. Russ et al – CNT coatings for lightning protection.



# Energy Storage

- ▶ Giving a composite structure the added functionality of being able to store energy could allow further reductions in weight through elimination of heavy batteries.
- ▶ Work at Imperial College has produced a composite supercapacitor.
- ▶ Prototypes being developed for aircraft tertiary structures and automotive application.



Courtesy of Imperial College

## 4. Reputational damage

- ▶ It is a dangerous time for the reputation of composite structures. Increase in their use in aerostructures has been widely reported and is being closely monitored by the press.
- ▶ The Airbus A300 crash in Queens in Nov 2001 and the Team Phillips catamaran were classic examples of how confidence in composites can be damaged despite neither failure being due to deficiencies in the composite material itself.
- ▶ Delays in the production of the 787, which were primarily due to lessons being learnt by Boeing on outsourcing of part production, could be associated with problems in composites part production.
- ▶ It is a shame that the press is not congratulating the aerospace industry more for innovation and development of the use of new materials.
- ▶ The fact that the sector has very strict regulations and procedures has facilitated the safe implementation of these new structures and all industry sectors can learn from this.

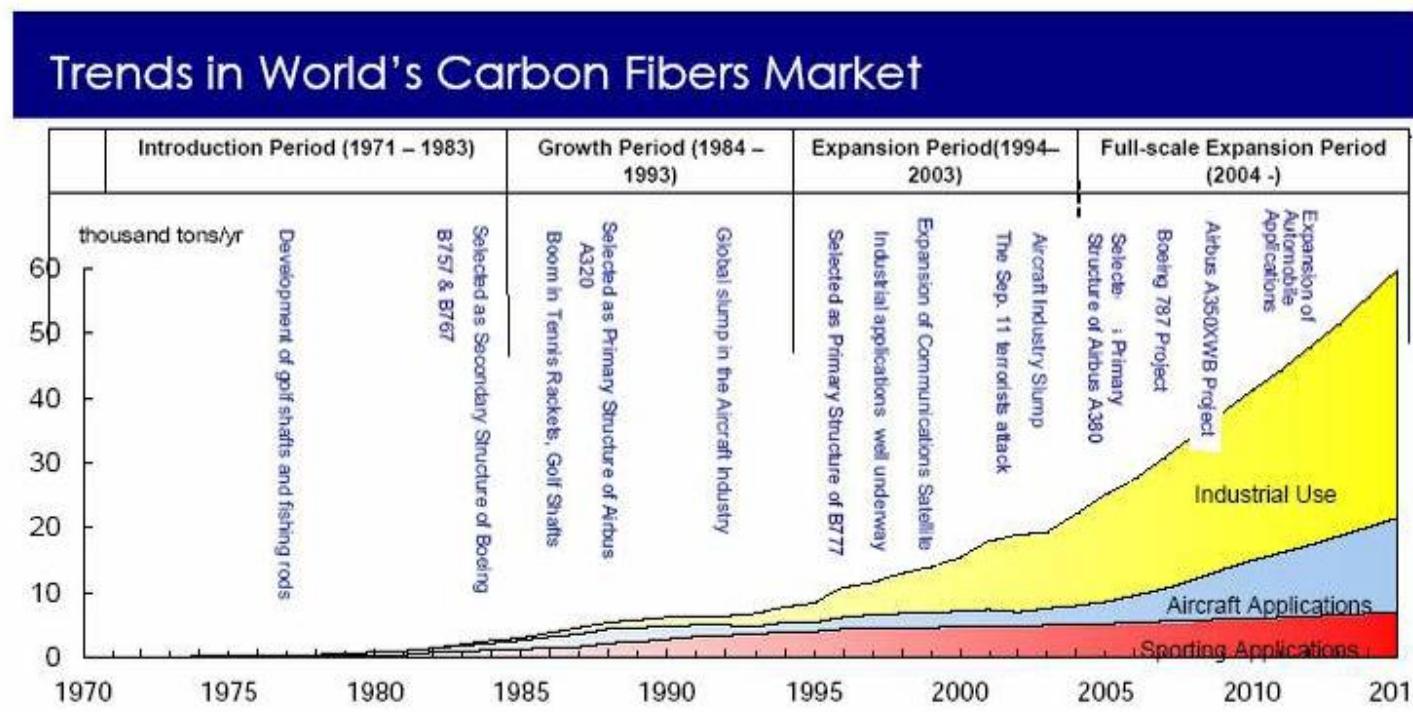


# Future Challenges and Opportunities

1. Carbon fibre availability
2. Recycling
3. Materials development

# 1. Carbon fibre availability

Global usage of carbon fibre is growing in many industry sectors and the growth rate is accelerating.





# Carbon fibre availability

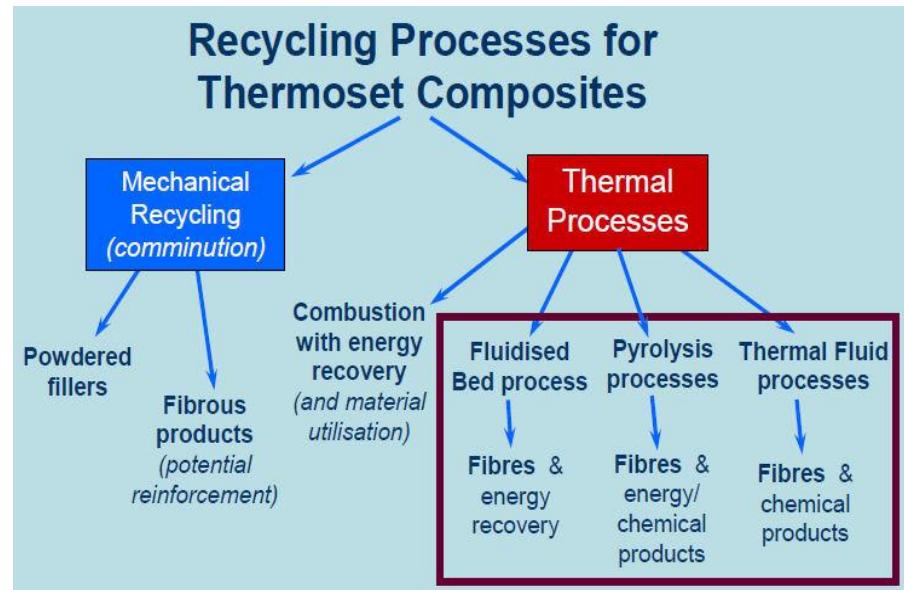
- ▶ Carbon fibre production globally in 2012 will be ~ 45,000 tonnes.
- ▶ The aerospace sector is not the only sector increasing use of carbon fibre. There are massive expansion in the wind and automotive sectors too.
- ▶ Although current producers are increasing production and new producers are coming online at a high rate, aerospace grade fibres are the most expensive to produce and need to be certified before use therefore increase production may be limited.
- ▶ Shortages in supply of suitable fibres will drive prices up and make metal again seem like a viable option for future designs.

Aircraft	Approx Predicted Build rate per year	Flyaway weight of CFC per a/c	Total flyaway weight
Boeing 777	80	10 tonnes	800
Boeing 787	112	35 tonnes	3920
Airbus A380	45	35 Tonnes	1575
Airbus A350	116	61.5	7377
Approx predicted <b>annual</b> demand from these 4 aircraft			13672 tonnes

With a fly/buy rate that is between 55 and 60%, carbon fibre demand for these 4 planes alone could be between 23 000 and 24 000 tonnes annually.

## 2. Recycling

- ▶ 3000 tonnes CFRP scrap produced annually, 6000 to 8000 commercial planes expected to reach end-of-life dismantlement by 2030.
- ▶ Neither landfill nor incineration disposal of CFRP scrap is optimal, and environmental regulations may eventually lead to a ban on both.
- ▶ Therefore work has been done to develop methods that can be used to recycle carbon fibres out of CFRP.
- ▶ This process has only recently been commercialised (Recycled Carbon Fibre in the UK and CFK-Valley Stade Recycling GmbH in Germany).
- ▶ There is currently no real market for the recycled product that is produced.



Work needs to be done to demonstrate the properties of the recyclate, create a market and give it a value.

### 3. Materials development

- ▶ The recent increase in the use of composites has involved the development of new/improved manufacturing methods.
- ▶ These manufacturing techniques are now allowing us to develop parts that are testing the limitations of the materials used.
- ▶ Future applications will require developments in material properties.

Example:

- ▶ The Boeing 787 has a CFRP fuselage.
- ▶ If Boeing wanted to scale this down to produce a new 737 with a composite fuselage, hail stones could potentially penetrate the fuselage.
- ▶ One possible solution – rather than increasing the thickness of the fuselage and increasing the weight of the plane, look to use a tougher composite material.



# Summary



# Summary

- ▶ Environmental regulations have meant that the cost of introduction of lightweight composite structures is now often offset by the gains and has led to a significant increase in the use of aerospace composite structures.
- ▶ Current challenges include:
  - ▶ Development of rapid rate manufacturing processes.
  - ▶ Coping with MRO requirements very different to metallic structures.
  - ▶ Avoiding reputational damage while composites are so high profile.
- ▶ Current opportunities include the ability of composite structures to include functionality such as morphing, energy storage, damage sensing, self repair etc.
- ▶ Future challenges include:
  - ▶ Supply of carbon fibre may struggle to match the increase in demand.
  - ▶ Developing applications for recycled carbon fibre.
  - ▶ Developing new materials to optimise output from new production methods.



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