Royal Aeronautical Society
TOULOUSE BRANCH

17th December 2014

"The Development of Composite Applications in Commercial Aircraft Engines"

David COOK, I.Eng, FRAeS
Independent Consultant, President RAeS Paris Branch

Please sign the Attendance Sheet
& include your email address *if changed from our records*

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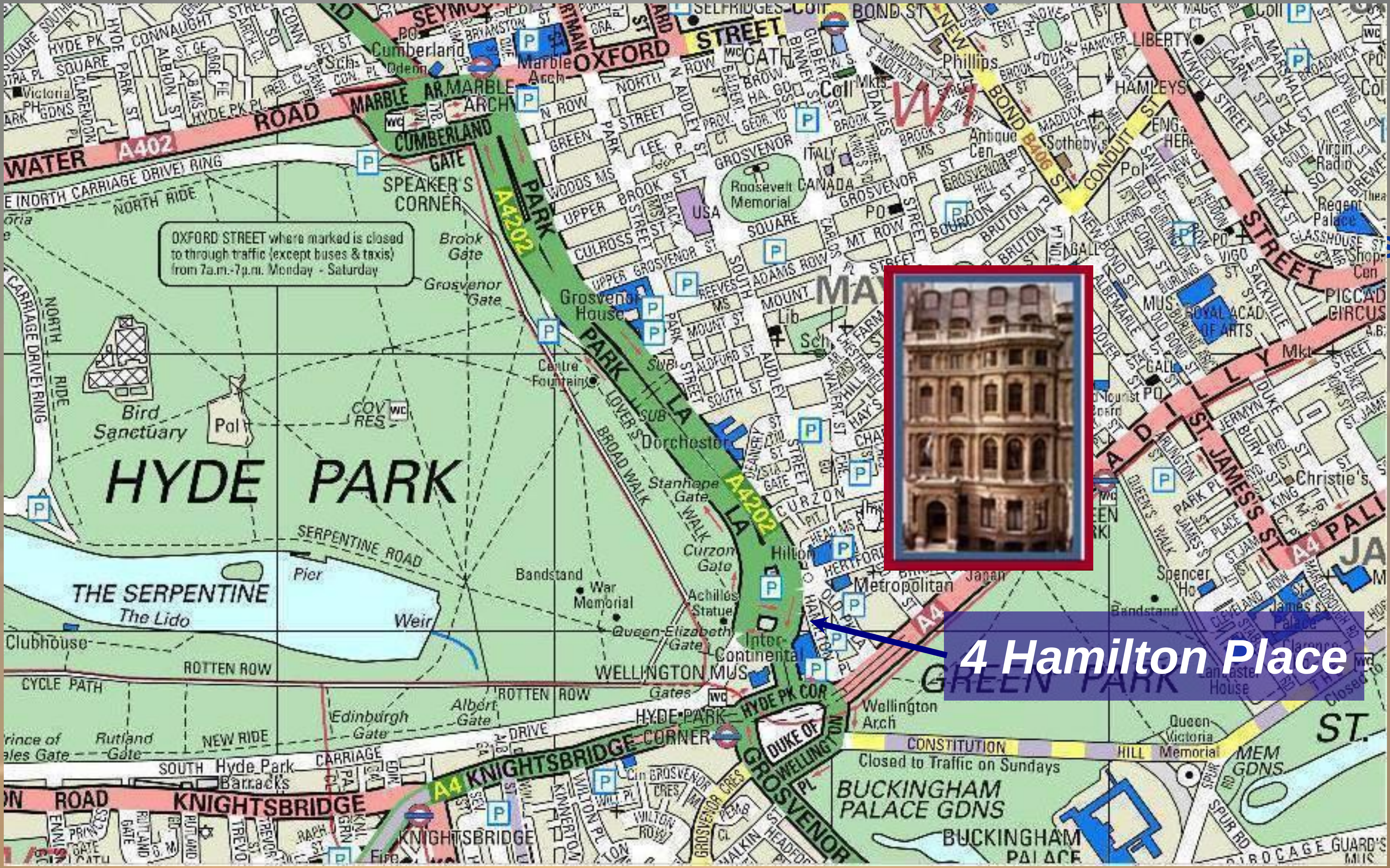

Royal Aeronautical Society
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AIRBUS Business Suite – free for members

Whole building covered by WiFi internet

Royal Aeronautical Society
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Now more 66 branches in 20 countries

Prime aim remains to share knowledge –

Toulouse Branch formed in 1991

Gordon Corps, Airbus Chief Test Pilot, as first Chairman

(application forms online)

Royal Aeronautical Society
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- **"Friend of the Branch"**
  - **Cost : €10 per annum**
  - **Support the Toulouse Branch programme**

- **Students have Free Membership to RAeS London**
  - **Magazine available electronically**
  - **Can pay £13 per year to receive paper copies of magazine**

- **RAeS Members' Subscriptions Tax Deductable**
  - ***Fabrice Coletto & Peter Potocki will explain***

David COOK

1976 - Graduated from N°1 School of Technical Training, RAF Halton,
Phantom FGR2 aircraft and Chinook helicopters

1982 - BAe Civil Aircraft Division, Hatfield Customer Support
BAe146 and BAe125 programmes.

1989 - Joined Snecma in France, Sales for CFM56 in Scandinavia
CFM Vice President International Sales, Nordic Europe and Middle East
Director, Business Development Aircelle – introduced to Composites

2004 – Independent Consultant

2014 – President RAeS Paris Branch

David COOK

“The Development of Composite Applications in Commercial Aircraft Engines”

The development of composite applications in commercial aircraft engines.

A presentation to the
Royal Aeronautical Society,
Toulouse Branch,
17th December 2014.

David Cook,
President, ASM Consulting

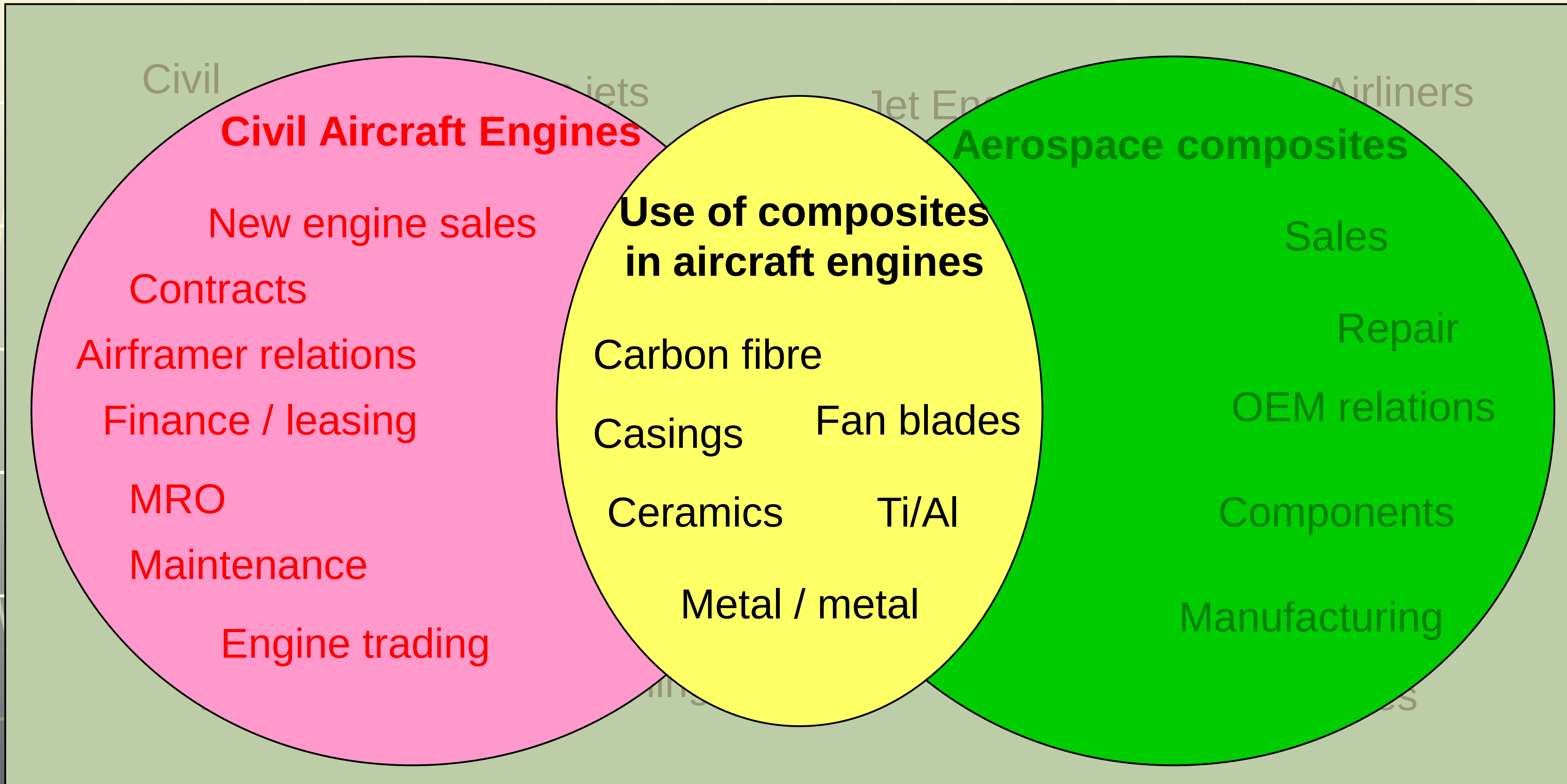
Advise, Support, Motivate.

David Cook: a lifetime of working with engines …

Aircraft maintenance technician,
Royal Air Force

Senior Sales Executive,
Safran Group

… with a particular interest in composite applications,



How to earn a living as a Consultant,

$$P = \frac{W}{T}$$

but

Knowledge is Power!

and

Time is Money!

$$K = \frac{W}{M}$$

hence

$$M = \frac{W}{K}$$

As knowledge (K) tends towards zero money (M) tends towards infinity !

Contents:

- A historical review of the use of composites in aerospace,
- The use of composites in commercial aircraft engines,
- MRO issues,
- The future of composites in aircraft engine design,
- Future aircraft concepts

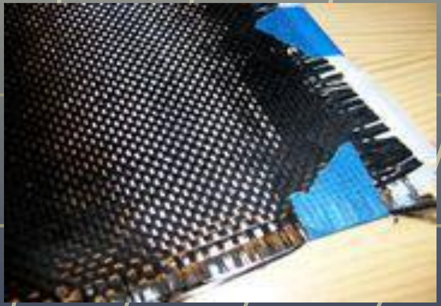
What is a ‘composite’?

Composite materials *(or* ***composites*** *for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure.*

Source: Wikipedia

Examples:

- Straw and mud bricks
- Re-enforced concrete



- Fibre glass
- Carbon fibre re-inforced plastics (CFRP)

The advantages and disadvantages of organic composites,

Advantages:

- Weight savings vs equivalent metal part,
- Ease of production?
- Corrosion resistance,
- Damage tolerance,
- Limited consequential damage,
- Repairability,

Disadvantages:

- Cost (per equivalent metal part),
- Temperature resistance,
- Electrical insulation,
- Inspectability,

Major aircraft components (1),

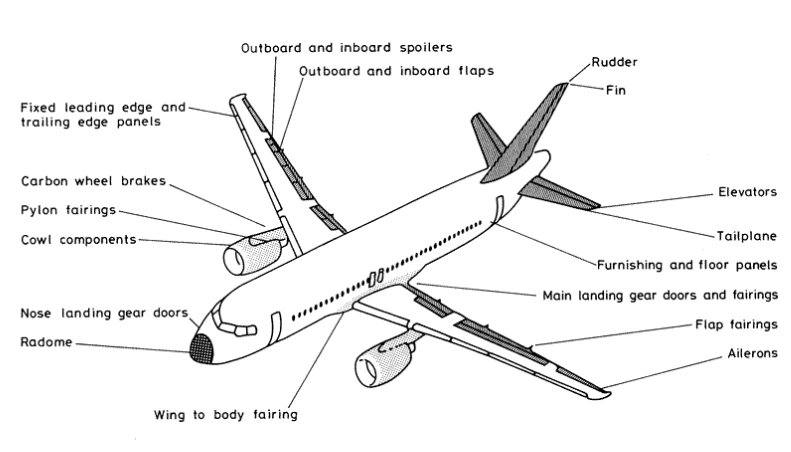
1948: Boeing B-36 used fuel cell support panels made from ‘reinforced plastics’

1953: Sud Aviation Vautour used ‘significant quantities’ of fibreglass and composite sandwich panels . . .

1974: Boeing F-15 speedbrake made entirely from carbon composite and tailplane from boron/epoxy composite

1975: Boeing tests a solid carbon composite laminate 737-200 stabilator. The programme was certified in August 1982

Major aircraft components (2),



Typical CFRP applications for aircraft flight control surfaces and other components

Composite applications on the A33O

Most commercial aircraft now using composites for non-critical structural components

Major aircraft structures,

Boeing F18: Carbon composite wing centre box, tail fins and elevators. EIS 1983

Beech Starship: first all carbon composite fuselage. EIS 1989

Beech Premier 1: first Business Jet with an all composite fuselage, certified in October 2005

Major aircraft structures – Boeing 787,

Boeing 787

Boeing 787 fuselage section manufactured by automated fibre placement

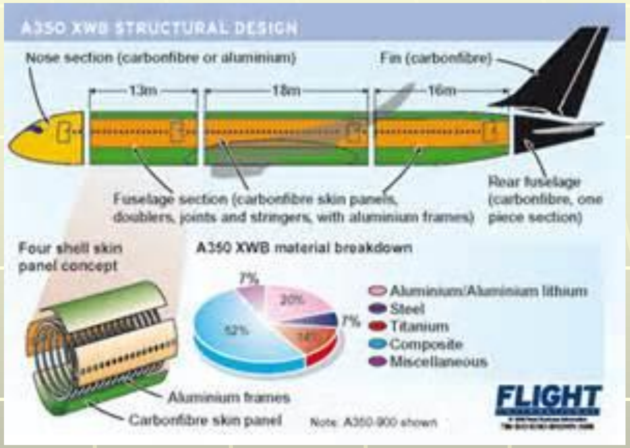
Boeing 787 rear fuselage ready for delivery

Boeing 787 fuselage skin with integrally moulded longerons and riveted frames

Boeing 787 – the first commercial airliner with composite wings and fuselage

Major aircraft structures - Airbus A350 XWB,

Airbus A350 XWB



Composite fuselage panel

Composite wing

Airbus A350 XWB – composite major structures but a slightly different strategy

The use of composites in aircraft engines …

Engine applications,

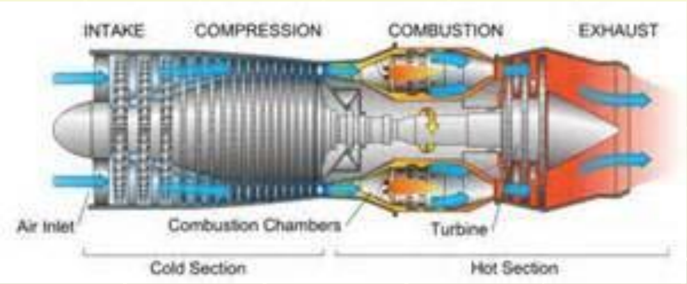
1948: Boeing B-36 used fuel cell support panels made from ‘reinforced plastics’

47 years of development

Early 197… of composite parts in nacelles and no… ngine components.

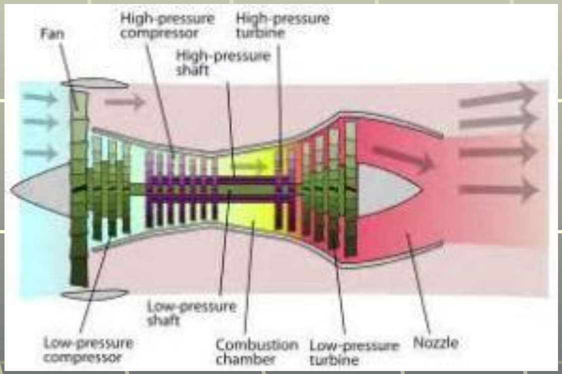
September 1995: GE90 enters service on Boeing 777 with first use of CFRP fan blades.

How an engine works 1.0.1:



A simple turbo-jet engine

Predominantly used in military applications

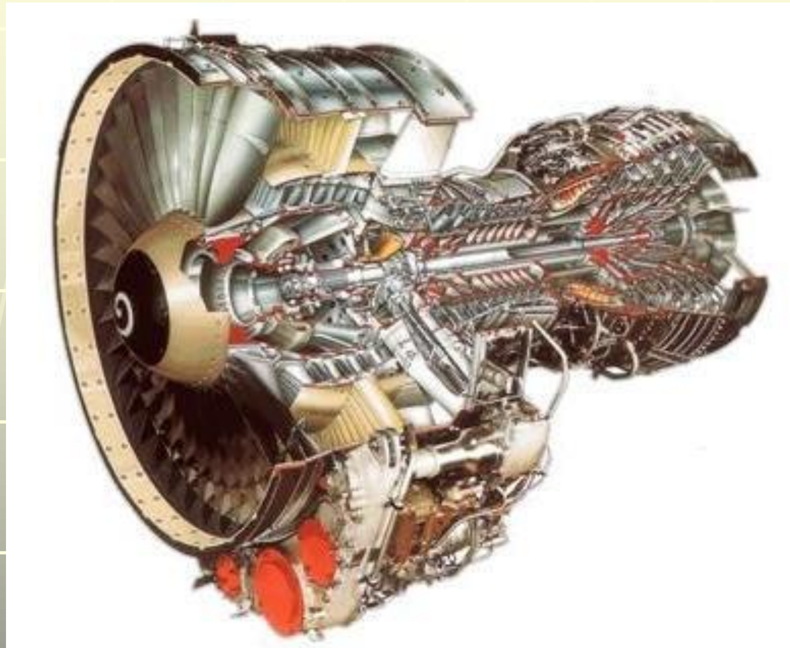


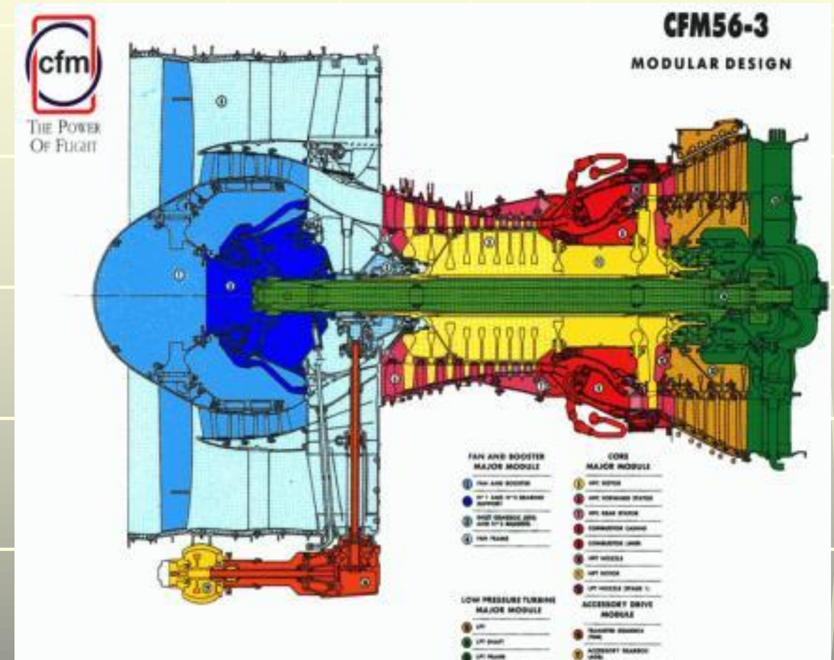
Turbo-fan engine

Predominantly used in civil applications

Different engine concepts for different performance requirements and aircraft applications

How an engine works 1.0.2:

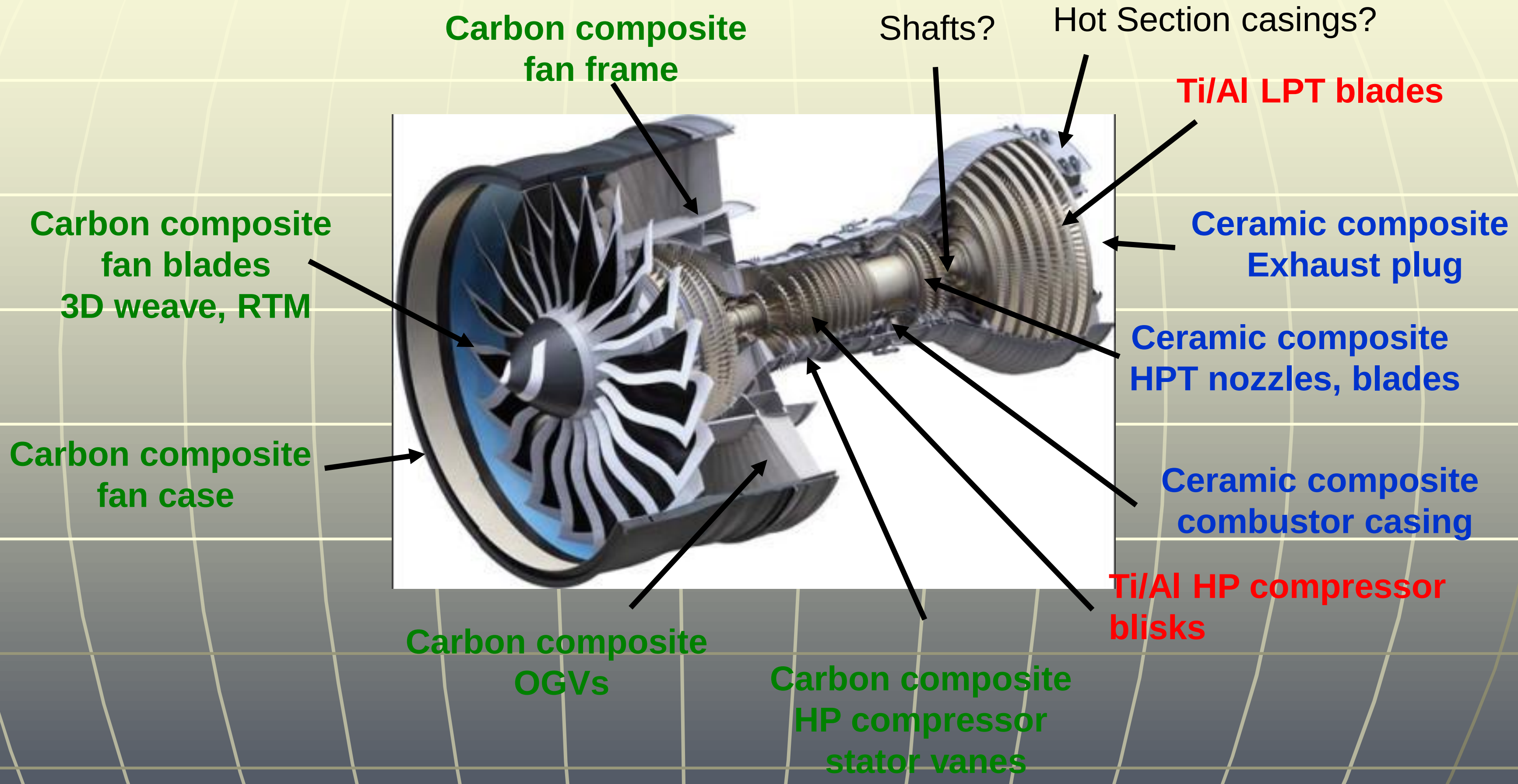




- Very high rotational speeds (15,000 rpm) and very high temperatures (1,700°c) ensure that many engine parts are safety critical,

- Engine design must resolve a number of engineering contradictions:
  - Fan and turbine speeds,
  - Compressor ratio and surge margin,
  - Combustion temperatures and NOx pollution,
  - Aircraft noise and engine weight,

Multiple applications for composites already identified,



Carbon composite outer bypass duct,

Snecma M88 engine for the Dassault Rafale aircraft

M88 composite outer bypass duct saves 4kg (20%) relative to titanium duct

Composite applications for engine components,

Components

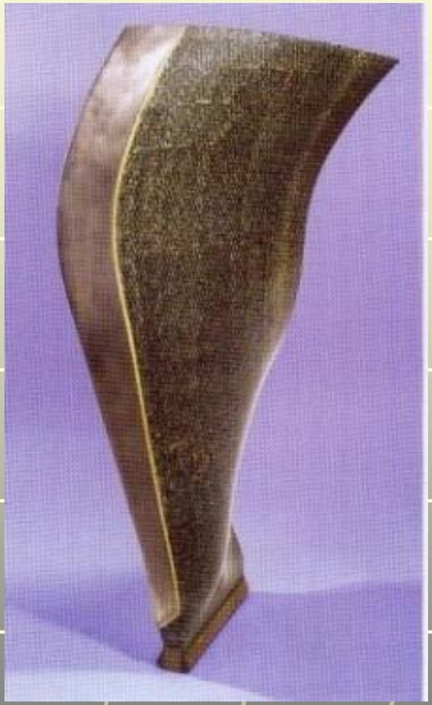
- Component manufacturers looking at composite materials for housings, casings, etc
- Potential 25% weight reduction ?
- Issues:
  - High pressure hydraulic systems (3,000 psi to 5,000 psi),
  - Long term porosity resistance,
  - All electric NGSA aircraft?

Composite filter housings
Source: Green Tweed

Carbon fibre FADEC housing for Rolls-Royce engine
Source: ASM

- Systems
  - Fibre glass and carbon composite low pressure pipes and ducting already in use,

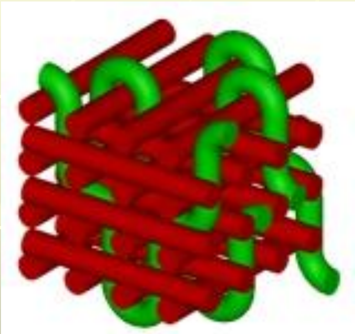
Applications for CFRP materials: CFM LEAP engine family,



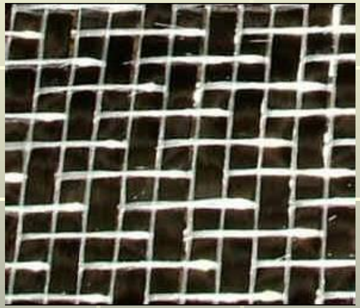
CFM LEAP fan blade
Photo: CFM

- Classic high BPR engine architecture,
  - Two shafts, direct drive fan,
  - 12:1 BPR, 45:1 OPR
- Incorporates key technology developments vs CFM56,
  - Composite ‘3D weave’ RTM fan blade and case,
  - Blisks,
  - New ceramic temperature-resistant coatings,
- Objectives: 16% improvement in fuel burn with reduced noise and emissions,
- EIS on A320neo and Comac C919 in 2016, EIS on 737max in 2017,

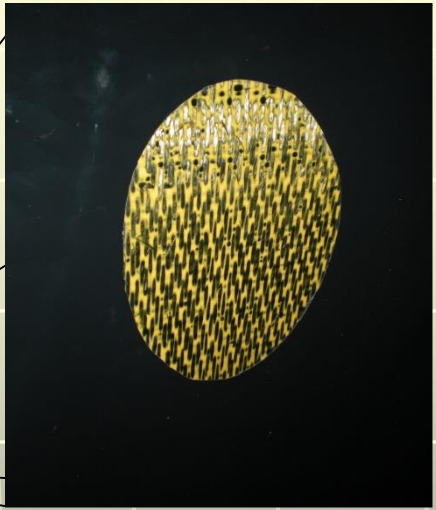
Demystifying the 3D weave …

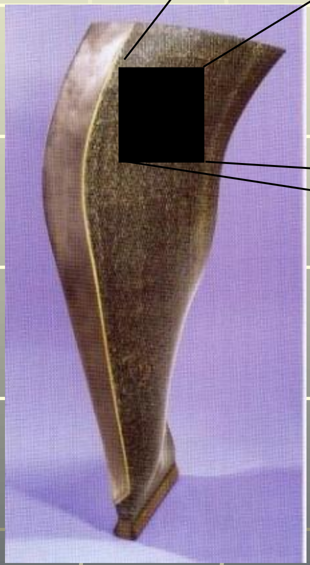


Complex weave pattern



CFM LEAP 3D weave fan case
Photo: ASM



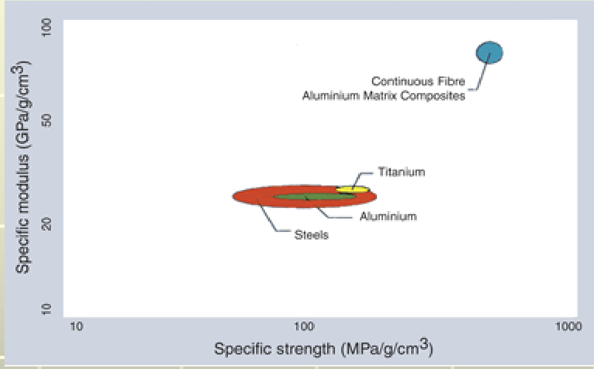


CFM LEAP 3D weave fan blade
Photos: ASM

3D weave fibre insert
Photo: ASM

Metal composites (1),

Most suitable for high temperature, high stress parts like compressor disks and LP turbine blades



Source: CMT

- Typical metal composites:
  - Titanium/Aluminides (Ti/Al)
  - Aluminium, magnesium or titanium re-inforced with boron, silicon or carbon fibres
- 60% weight reduction compared to conventional metal part
- Significant (200%?) increase in strength and stiffness

Silicon fibre re-inforced aluminium

Metal composites (2): some examples …

CFM LEAP Ti/Al compressor blisk
Photo: CFM

PW6000 compressor blisk
Photo: MTU

CFM LEAP
Al/Ti LP Turbine blade
Photo: CFM

Ceramics (1),

Most suitable for very high temperature, high stress parts like combustion chambers and HP turbine nozzles

Tough and shock resistant!

- Typical ceramic composites:
  - Silicon Carbide reinforced with silicon carbide fibres (SiC/SiC)
  - Silicon Carbide reinforced with aluminium filaments (SiC/Al)
- 50-70% weight reduction compared to equivalent metallic part
- Capable of withstanding +1,300°c without cooling
- No cooling system = less weight and complexity, increased reliability
  - full use of ceramics in LEAP engine could save 175 lbs per engine
- No cooling air = less NOx

Ceramics (2): some examples …

Prototype ceramic combustion chamber.
Photo: GE

Prototype ceramic HPT nozzle.
Photo: GE

LEAP ceramic HPT shrouds. Photo: CFM

Snecma prototype A340 ceramic exhaust nozzle.
Photo: ASM

Snecma prototype ceramic exhaust plug.
Photo: ASM

MRO issues

Composite fan blade maintenance,

CFM56-7B
61 ins fan diameter
24 blades
260 lbs fan weight

Traditional metal blades are resistant to damage and easily repairable

Large diameter, slow turning composite fan blades avoid damage and rarely need repairing

LEAP-X
71 ins fan diameter
18 blades
168 lbs fan weight

High speed 3D weave composite blades may not be so resistant to damage, will be difficult to repair (if at all) but may be replaced singly

GE90-115B
128 ins fan diameter
22 blades
1,019 lbs fan weight

Compressor blades repair - blisks,

Traditional

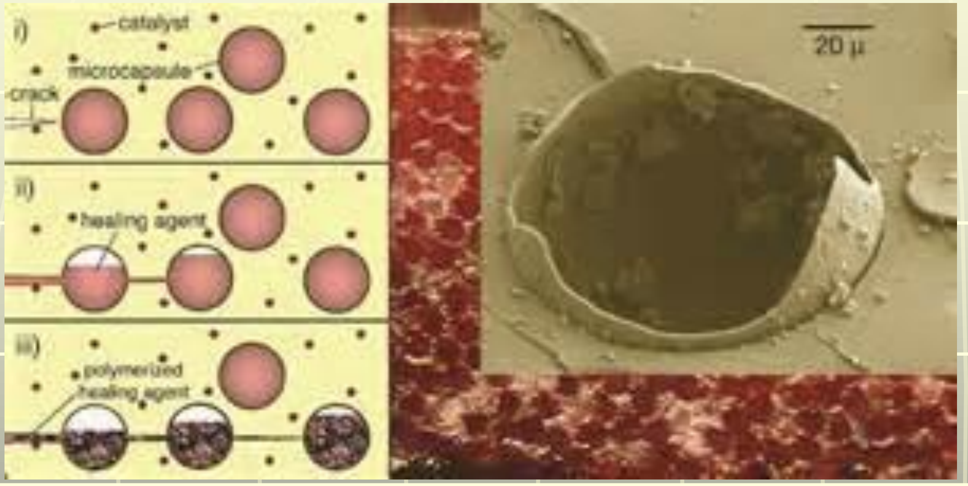
- Blades accessed by opening up Top Case,
- Blades are free on the disk:
  - Minor defects rectified by in-situ grinding,
  - Major defects rectified by individual blade replacement,

ASM photo of MTU display

Future

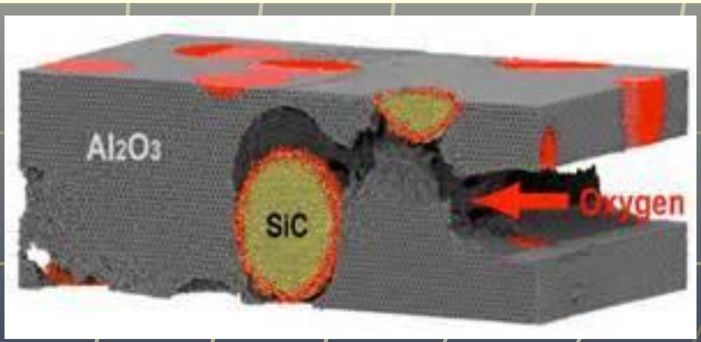
- Blades accessed by module breakdown,
- Blades are integral part of the blisk:
  - Minor defects rectified by repair on removed blisk,
  - Major defects rectified by blisk replacement,

Self-healing composites,



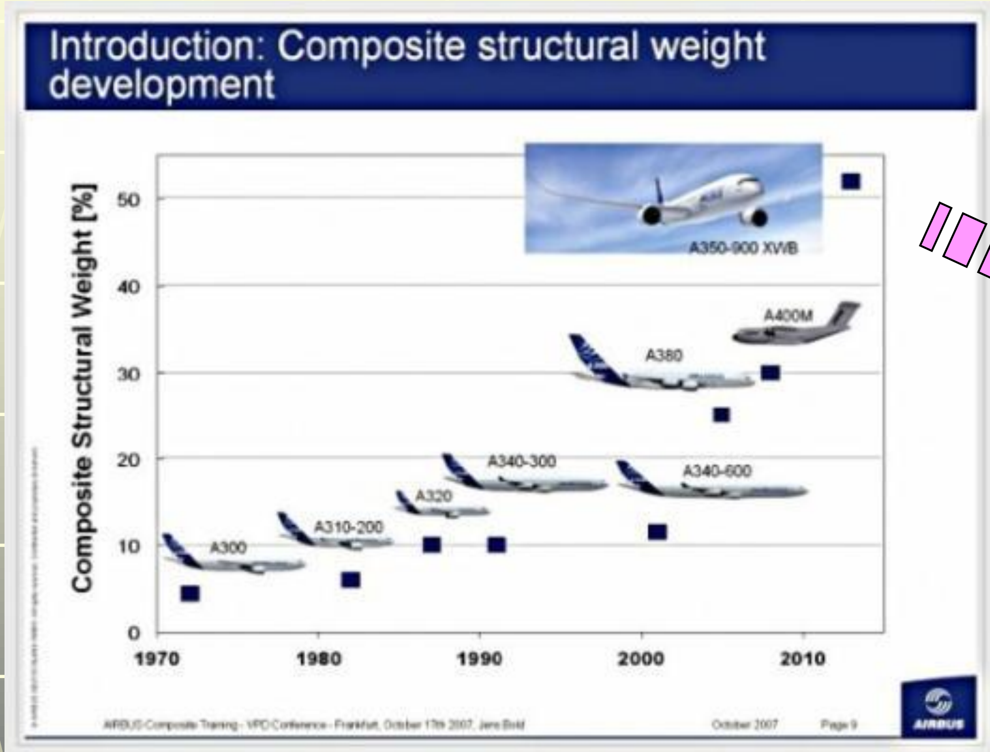
Carbon fibre composites can recover 75% of their original strength using self-healing repair techniques,

Ceramics can 'self-heal' when the penetration of oxygen into a crack provokes oxidisation of a glassy 'fuse' which stops crack progression,



The future of composites in aircraft engine design

Future composite applications,



CFRP use expected to FALL in future generations of civil aircraft

Modern aircraft use high percentages of composites – but will this situation last?

Reasons for composites likely fall from favour,

- Cost:
  - Carbon fiber and resins are products derived from oil – and we expect the price of oil to rise,
  - Increasing costs of production,

- Revenge of the metals:
  - If 53% of A350 is CFRP then 47% is still metal!
  - Metals have reacted to CFRP popularity by getting cheaper – esp Titanium,
  - New alloys (Al/Li, Al/Mg) are lighter than CFRP – and cheaper,
  - Metals are cheaper to manufacture into complex shapes,
    - Additive Manufacturing,

- Aircraft manufacturers commercial strategy is changing:
  - Order books are full,
  - Only way to make more money is to improve margins,
  - Manufacturers paying less for weight advantage,

Proportion of composites used in aircraft structures will fall as oil prices rise and alternatives emerge

Composite manufacture: a costly and complex process?

Many complex CFRP structures are laid-up by hand

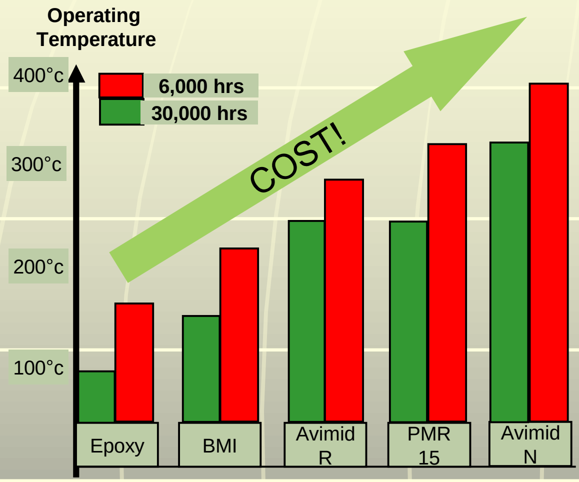
‘Clean Room’ facilities often required to meet aerospace quality requirements

Automation only suitable for large, regular shapes

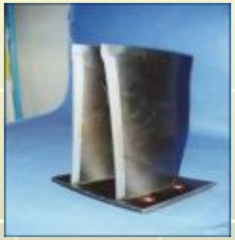
Autoclave curing is expensive, time-consuming, and risky

The manufacture of composite parts for the aerospace industry is labour intensive, expensive, and time-consuming

Challenges facing the increased use of CFRP in engines,



Source: Cytec



Prototype HP compressor stators
Source: Snecma

Increased operating temperatures,

A prototype composite fan frame

Increasingly complex structures,

High volume, cost effective production with acceptable quality and repeatability.

Use of composites remain a high-cost option for improving engine efficiency

But composite demand for engines is expected to remain high …

- Carbon composites used in aircraft engines was1.49 million lbs in 2007,
- This represented a market value at the time of $400-450m,
- Demand for carbon composites to be used in aircraft engines is expected to exceed nearly 3 million lbs by 2016,
- Value of carbon composites consumed by engines during this 10 year period is expected to be around $7-8 bn,

Source: ‘Aviation Outlook Report 2008

Challenges facing the increased use of carbon composites,

- Design:
  - Ensuring optimum ply lay-up for high stress components,
  - Ensuring optimum mold design for complex shapes,

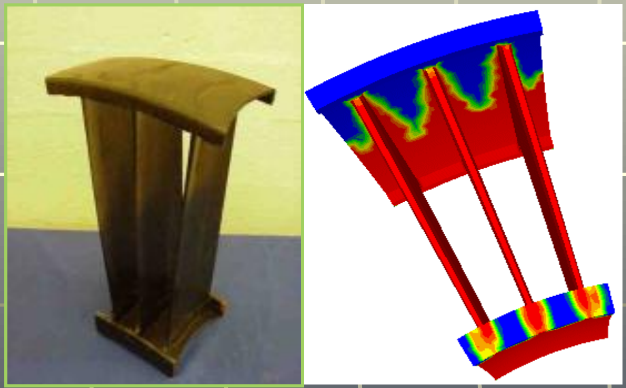
- Materials:
  - New resins and fibers for greater temperatures / greater strength / greater fatigue resistance,
  - Develop materials which lend themselves to industrial manufacturing processes,

- Manufacturing:
  - Ability to transform increasingly sophisticated CAD designs into workable production programmes,
  - Develop more cost-effective industrial manufacturing processes,

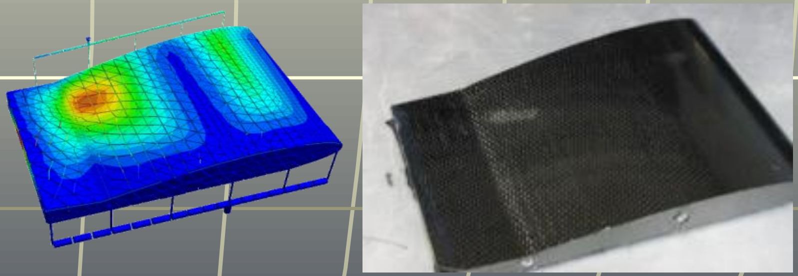
Design challenges:

- Design
  - Increasingly sophisticated CAD programmes to determine ply layup in 3D aero, highly stressed engine components,
  - Sophisticated flow simulation software to ensure correct moulding of complex parts,

Ply orientation simulation for aerofoil
Source: Snecma



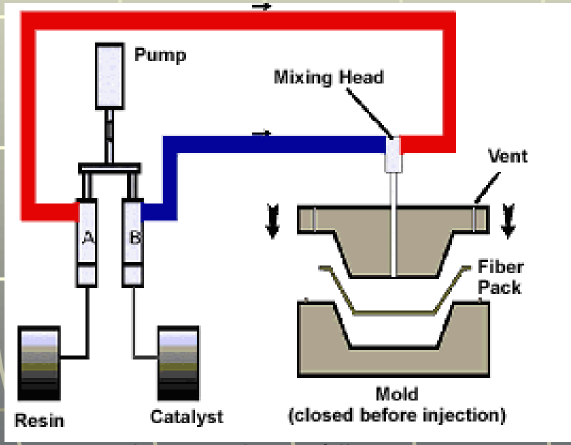
Simulation of resin flow in a complex RTM mold
Source: Snecma



Prediction of dry spots in an RTM molded aerofoil using ‘Polyworx’ software.
Source: Polyworx

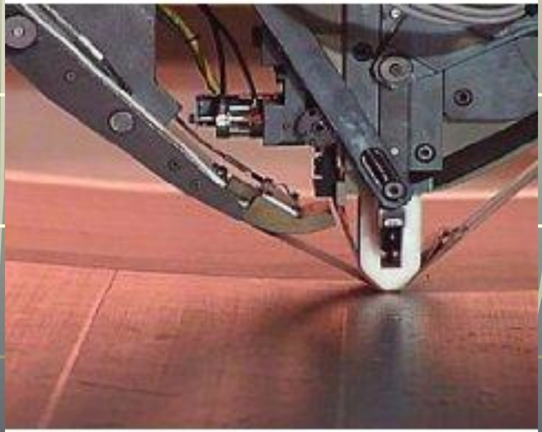
Materials challenges:

- Develop materials which lend themselves to industrial manufacturing processes:
  - Chopped fibre filler for complex RTM molding,
  - ‘non-stick’ resins which facilitate tape layup,



Resin Transfer Molding process

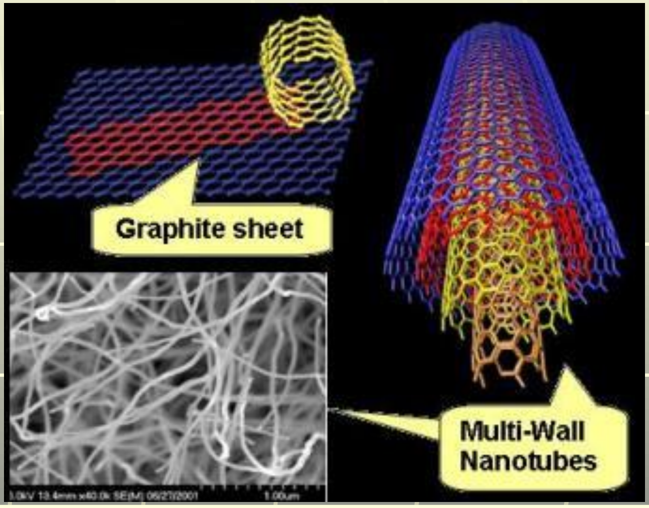
Source: JHM Technologies



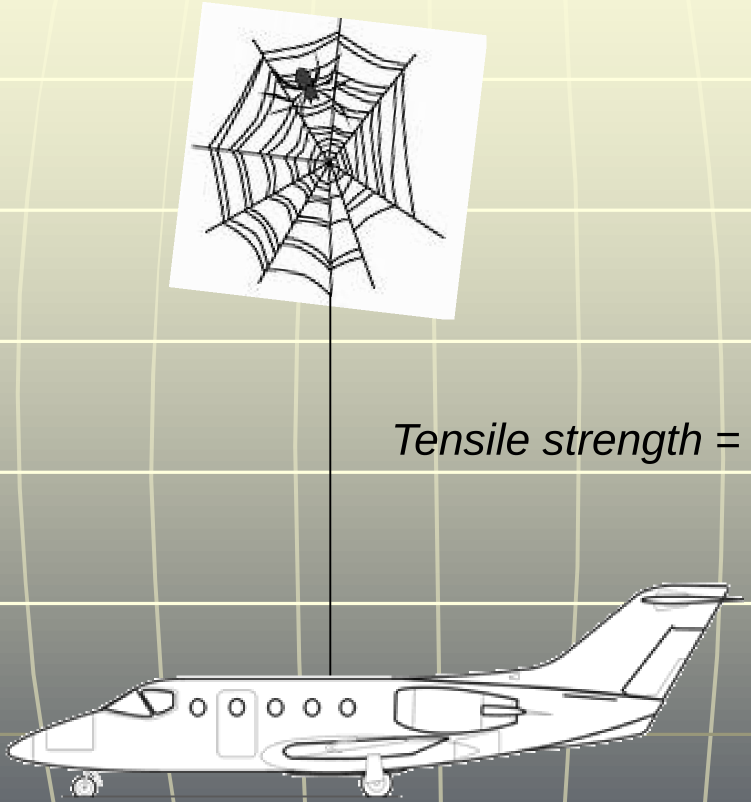
Tape lay-up by machine

Carbon Nanotubes (CNT): the wonder material for the future?

- First discovered in 1991,
- Cylindrical carbon molecules with a l/d ratio greater than 1,000,000,
- Exhibit extra-ordinary mechanical properties such as strength, stiffness, conductivity, flame resistance, wear resistance, …..
- Experiments with CNTs as bulk filler in resin matrix,
- Potential engine applications:
  - structures,
  - thermal barrier coatings,
  - high temperature sensors,
- Issues:
  - Ability to bond with matrix and transfer stress,
  - Uniform distribution and alignment of filaments within the matrix,
  - Cost currently prohibitive - $1,000 / gm,



Nanotube strength capability:



Tensile strength = 63 gigapascals !

Manufacturing,

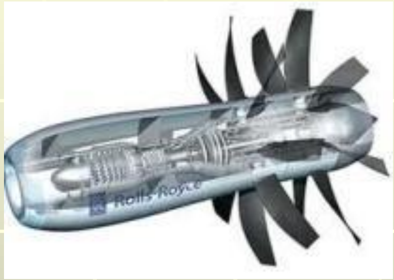
- Manufacturing
  - Ability to transform increasingly sophisticated CAD designs into workable production programmes,
  - Develop cheaper manufacturing processes:
    - ‘Quickstep’ hot oil curing eliminates autoclave,
  - Achieve high volume production to meet production ramp-up with very high levels of quality,



Future engine concepts

Open Rotor Concepts – geared or ungeared?

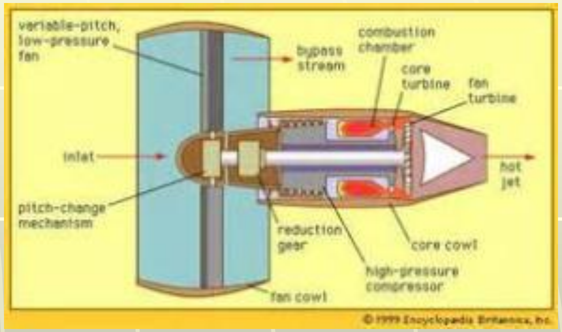
- Two concepts currently being developed:
  - Rolls-Royce geared counter-rotating rotor system,
  - Snecma direct-drive counter-rotating rotor system,
- Similar objectives:
  - 25 to 30% reduction in fuel burn relative to today's technology engines,
  - similar reductions in CO_2 levels,
- Expected EIS – 2025 to 2030?
- Challenges:
  - Noise,
  - Complexity,
- But the 'Open Rotor' already exists! Antonov 70 first flew in 1994,



Open Rotor - an expensive 'knee jerk' reaction to high fuel prices?

Ultra High Bypass ratio engines,

- Ultra-high Bypass ratio (UHBPR) engines use a more conventional architecture,
    - Simple layout,
    - Next-generation materials,
    - Large diameter fan driven by gearbox,
    - Reverser pitch change mechanism in the fan,
- BPR of < 25:1 will achieve significant fuel burn reductions,
- Rolls-Royce have already unveiled their geared ‘Ultra-Fan’ concept for EIS 2030,
- GE have recently unveiled a ‘hybrid’ concept,
    - UHBPR engine,
    - Electric motor on LP shaft,
    - HP core is run at idle, or even shut down, in cruise,



UHBPR geared fan engines – a much more credible option for high thrust engine development (IMHO)

More electric – or all electric – aeroplanes?

- Boeing 787 is the first aircraft with a ‘no bleed’ powerplant
  - Electrically driven Air Conditioning systems takes 35% less power from engines than conventional system
  - Electrically driven hydraulic pumps with one engine-driven pump as back-up
  - 2,000 lbs weight saving
  - 3% fuel burn improvement
  - 1,400 Kva generation capability
- Fly-by-wire’ flight controls,
- Electric brakes and engine controls,

Elimination of high pressure air bleeds from engines produces significant efficiency improvements

Towards the 'All Electric' aircraft?

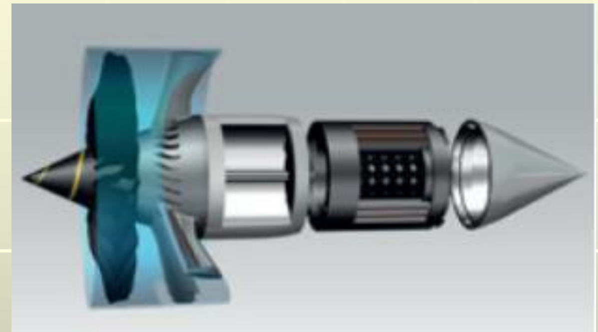
Airbus 'E-Fan' currently under flight test

Electroflight racer concept currently being developed in UK

Airbus and Boeing studying various concepts

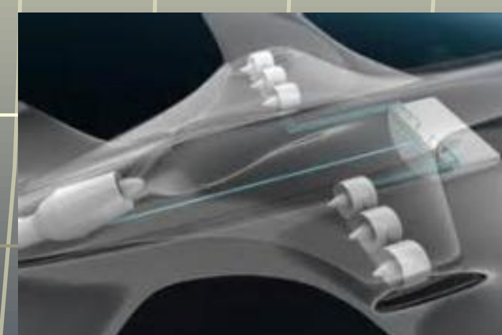
A number of concepts are being studied but energy storage considerations are critical to commercial success

The Airbus ‘e-concept’ aircraft



Electrically driven fans integrated into the structure of the aircraft

Distributed propulsion system uses a gas turbine as a source of electrical power to drive propulsion fans and all the other aircraft systems



‘Hybrid’ is the new buzzword in the aerospace industry!

Conclusions:

- Carbon fibre composites have an established place in aerospace design bringing a significant number of advantages and some inconveniences,

- While carbon fibre usage in aircraft structures may diminish in the future it will remain a key feature of engine design,

- New composite materials will continue to be developed to respond to the aircraft engine's unique design and operational requirements,

- Continued attention will need to be paid to MRO and manufacturing processes to keep production and maintenance costs low,

- New aircraft propulsion concepts will continue to ensure that materials development will be at the forefront of engine research,

Thank you for your attention.

asmcontact@aol.com

+33 6 1135 4330


ROYAL AERONAUTICAL SOCIETY
1866

RAeS Toulouse Branch Lectures 2014 - 2015

Tuesday 16th September 2014 18h30
"What Neuroscience Can Tell us about Human Error in Aviation"
Professor Frédéric DEHAIS,
Institut Supérieur de l'Aéronautique et de l'Espace (ISAE)
ISEA/SUPAERO 10 avenue Édouard Belin, 31055 Toulouse

Wednesday 15st October 2014 18h00
"Training for Resilience"
Captain David OWENS
Senior Director Flight Crew Training Policy, Airbus, Toulouse
Symposium room, Building B01, Airbus Campus 1, Blagnac

Tuesday 18th November 2014 18h30
"Experiences Flying Vintage Aircraft – Spitfire to Me Bf109"
Air Marshal Cliff SPINK, CB, CBE, FCMI, FRAeS, Retired
President of the Battle of Britain Memorial Flight Association.
Symposium room, Building B01, Airbus Campus 1, Blagnac

Wednesday 17th December 2014 18h00
"Use of Composite Materials in Aircraft Engines"
David COOK, I.Eng, FRAeS
Independent Consultant, President RAeS Paris Branch
Symposium room, Building B01, Airbus Campus 1, Blagnac

Tuesday 20th January 2015 18h00
23rd Annual Gordon Corps Lecture
"Safety Priorities in Helicopter Flight Test" *(provisional title)*
Andrew WARNER
Chief Test Pilot, Airbus Helicopters
Symposium room, Building B01, Airbus Campus 1, Blagnac

Tuesday 17th February 2015 18h00
Rolls-Royce Mini-Lecture Competition *
20minute lectures by students from Toulouse aeronautical universities
"Lecture from Rolls-Royce"
Speaker from Rolls-Royce
Symposium room, Building B01, Airbus Campus 1, Blagnac

**** Note: The competition is open to students under 25 years old.***

RAeS Toulouse Branch Lectures 2014 - 2015

Tuesday 17th March 2015 18h00
"Subject & speaker to be advised"
Symposium room, Building B01, Airbus Campus 1, Blagnac

Tuesday 14th April 2015 18h00
"Understanding GPS without the Mathematics"
David ALLERTON, BSc, PhD, PGCE, CEng, FIEE, FRAeS
Emeritus Professor of Computer Systems Engineering, Sheffield.
Symposium room, Building B01, Airbus Campus 1, Blagnac

Tuesday 12th May 2015 18h00
"Small Space Satellites" – *lecture to be confirmed closer to date*
Professor Sir Martin Sweeting FRS, FREng, FIET, FRAeS
Executive Chairman, Surrey Satellite Technology Ltd, UK
Symposium room, Building B01, Airbus Campus 1, Blagnac
The lecture will be preceded by the Branch AGM

Tuesday 16th June 2015 18h00
8th Annual ADS RAeS Toulouse Branch Lecture
Speaker and subject to be confirmed
Affiliation
Symposium room, Building B01, Airbus Campus 1, Blagnac
The lecture will be preceded by the Branch AGM

Friday 26th June 2015
Annual Dinner
Speaker to be confirmed
Château de Larroque, 32200 Gimont
www.ChateauLarroque.fr

1. *In order to make sure the Airbus Symposium room seating capacity is not exceeded ALL participants INCLUDING AIRBUS EMPLOYEES must REGISTER online for RAeS Toulouse Branch lectures at: http://goo.gl/WbiKtV, as soon as possible but by latest 18:00 two working days before the lecture and select if you require a temporary Airbus security pass. Attendees who require an Airbus pass must bring a photo ID eg a passport, to be exchanged by Airbus Security for a temporary pass whilst at Airbus.*
2. *Members who wish to join the speaker for dinner afterwards at le Ribouldingue, 1 blvd Firmin Pons, Blagnac please contact Dinner@RAeS-Toulouse.org or 06 03 85 28 82, preferably 24 hours before the lecture.*
3. *Maps showing the location of Airbus Campus 1 are is our website www.RAeS-Toulouse.org*

Forthcoming Programme

For posters / any changes / updates

www.RAeS-Toulouse.org

and links to

www.Academie-Air-Espace.com

AAAf-MP@sfr.fr

Frohes Fest und ein gutes Neues Jahr

Merry Christmas and Happy New Year

Bonnes Fêtes / Meilleurs Voeux

Feliz Navidad & Feliz Aňo Nuevo

God Jul och Gott Nytt År