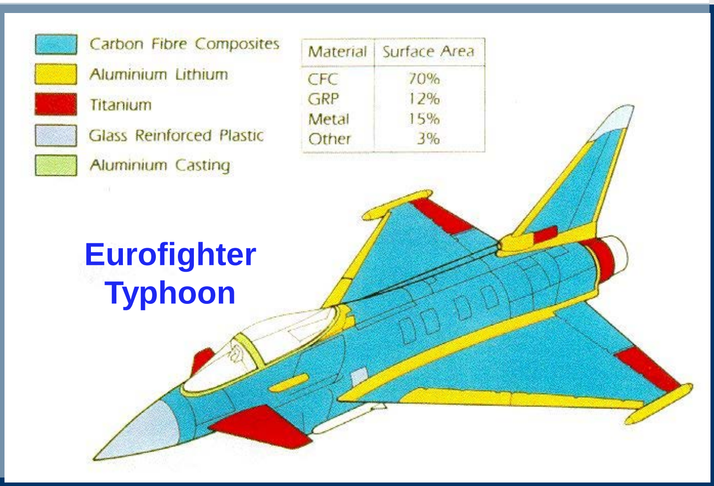
Lecture Note #1

IIT Kharagpur

1st Semester, 2019

Short Course

Design of Aircraft Components using Composite Materials



Indian Institute of Technology-Kharagpur
Department of Aerospace Engineering
Professor Changduk Kong

Lecture Syllabus

【Course Title】

Design of Aircraft Components using Composite Materials

【Instructor】

Family Name: KONG

Given Name: Changduk

Nationality: Republic of Korea

Academic Titles: Professor(Emeritus)/Visiting Professor/Invited Professor /Invited Professor /Director/CTO/President

Currently Work in: Chosun University/IIT Kharagpur/Korea Aerospace University/ Beihang University/AMRC(UK)- Korea/EGT /Korea Society for Naval Science & Technology

Email Address: cdgong@chosun.ac.kr / cdgong@kau.ac.kr

Lecture Syllabus

【Teaching Language】

English

【Credits/Credit Hours】

3/42

【Students】

4 years undergraduate students, post graduate students

【Size of Class】

Less than 40

【Prerequisites & Requirements】

Strength of Materials, aerospace structure, composite materials

【Methods of Instruction】

Lecture and design practice (Theory and Tutorial)

【Performance Evaluation】

Performance will be graded according to both the exam results and evaluation by homework and quizzes; exam 70% / attendance 10% / homework and quizzes 20/% of the total result 100%

【About the Instructor】

Prof. Changduk Kong graduated with a BSc in Aerospace Engineering from the Korea Aerospace University (national) and a PhD in Aerospace Engineering from the Osaka Prefecture University, Japan. He worked as Head of the Aero-Propulsion Division of ADD (Agency for Defense Development (1978-1994). He served as Professor at Department of Aerospace Engineering of Chosun University (1994-2016), and was appointed as Dean of the School of Aerospace and Naval Architecture Engineering (1999 and 2005-2006), and Dean of the Facility Management Office at Chosun University (2011-2012).

Prof. Kong has contributed greatly to the development of Aerospace Engineering in Korea, primarily through his roles as Director of KIAST(Korea Institute of Aviation Safety Technology) (2015-2018), Director of AMRC(UK)-Korea (2015-2019) President of KSNST(Korean Society for Naval Science and Technology) (2017-2020), President of SASE(The Society for Aerospace System Engineering) (2013-2016), President of ICRC (International Collaboration Research Centre in Natural Composites, Chosun University (2012-2014), President of KSAS(The Korean Society for Aeronautical and Space

Lecture Syllabus

Sciences (2010), President of KSPE(The Korean Society of Propulsion Engineers (2007-2008), Chair of Cycle Innovation-IGTI-ASME (2009-2011), President of RIME(Research Institute of Mechanical Engineering-Chosun University (2006-2008), and First Lieutenant of ROKAF (Republic of Korea Air Forces (1974-1978).

He was Visiting Professor at Imperial College London (2001-2002), and he is Invited as Invited Professor at Korea Aerospace University (2016-2018), Invited Professor at Summer School of Beihang University (2017-2018) and Vising Professor at IIT-Kharagpur (2017, 2019-20121).

He is the Editorial Board Members of IJTJ(International Journal of Turbo & Jet Engines), IJCM(International Journal of Composite Materials), CJS(Chinese Journal of Aeronautics) and AEAT(Aircraft Engineering and Aerospace Technology), and Editor-in-Chief of JKSAS(Journal of Korean Society for Aeronautical and Space Science) and JKSPE(Journal of Korean Society of Propulsion Engineers) (2006-2010).

He received the Korean National Decoration in Science for his scientific achievement and contribution to Korean aerospace development, Academic Achievement Awards from KSAS, SASE and KSPE and the 2015 KAI-KSAS Prize.

Prof. Kong has authored and co-authored more than 611 papers including 61 SCI journal papers, and has received numerous lecture invitations from companies, research institutes and universities and delivered eight keynotes and invited lectures at international conferences. He has organized 25 national conferences, forums and workshops and was co-organizer on four international conferences.

Lecture Syllabus

【Course Description】

Recently, advanced aerospace vehicles tend to reduce the weight as well as improve the economic efficiency using the advanced composite materials and the simplification of manufacturing process. Therefore in order to understanding more the composite materials structures this lecture introduces firstly kinds and behaviors of matrixes and reinforcements, manufacturing methods, test methods and inspection methods, and teaches design procedure and method of aerospace vehicle structure, laminates analysis method and application examples, and finally provides a design capability through some design examples of typical aircraft composite component structures and a case study on design of regional aircraft fuselage floor beam.

【Syllabus】

42days (6 weeks) course (basically 2days per a week, 4 hours per a day)

Lecture Syllabus

< Module 1 (4 hours)>

Subject : Introduction of composite Materials

Contents : Definition of composite materials, kinds of composite materials, kinds and behaviors of matrixes/reinforcements/interface, terminologies related to composite materials. Mechanical behaviors of composite materials, selection of composite materials, laminate laying-up, structure design and analysis, and manufacturing method

< Module 2 (8 hours)>

Subject : Fundamentals of composite materials structural mechanics

Contents : Macro-Mechanics, laminate stress-strain relation, rule of mixture, Failure Criteria of composite materials, Laminate Strength Analysis, residual stress, notch stress, methods of design data measuring, behaviors of fatigue/impact/water absorption/ corrosion, and repair methods

< Module 3 (4 hours)>

Subject : Composite materials laminate analysis and design

Contents : Analytical laminate analysis method, experimental analysis method, laminate design example, thin wall section design

Lecture Syllabus

<Module 4 (2 hours >

Subject : Mid term exam and evaluation

< Module 5 (6 hours)>

Subject : Design of composite materials structure

Contents :

- **Design procedures, definition and methods (structure concept, shape, cross section, manufacturing, fatigue life, stiffening, joints, material type, selection criteria, manufacturing process), Design review and analysis (strength, stiffness, stability, secondary load, thickness wise stress, hole and notch, bolt joint, bonding joint, sandwich, fatigue, impact, design limit, cost, weight, manufacturing process and cost, trade-off)**

< Module 6 (8 hours)>

Subject : Design examples of several typical aircraft composite components

Contents :

- **Composite laminate design with given loads: comparison of QI design method and PS design**

Lecture Syllabus

- Comparison of laminate analysis methods of strength and stiffness such as laminate analysis method, netting rule, Hart-Smith 10% rule, Carpet plot method of cross ply, angle ply and quasi-isotropic laminates
- Composite panel buckling calculation examples loaded by uniaxial compression loading and in-plane shear loading, and comparison with Al alloy panel buckling
- Thin wall section designs :
  1) C type channel structure loaded by axial load, shear load, bending moment and torsional moment
  2) Thin wall box beam structure loaded by axial load, shear load, bending moment and torsional moment

Lecture Syllabus

< Module 7 (4 hours)>

Subject : Case study of composite materials structure design

Contents : Design of regional aircraft fuselage floor beam;

- **Design of new composite floor beam for reduced weight, minimum cost and reduced number of parts from given original metal floor beam using composite materials, the proposed design process by define, scheme, check, refine and trade-off with consideration of structure, material and manufacture concurrently.**

< Module 8 (4 hours)>

Subject : Case study of composite materials structure design

Contents : Design of Wing Spar of Light Airplane;

- **Design of new wing spar to reduce weight, cost and number of parts from given original metal spar using composite materials using the proposed design process by define, scheme, check, refine and trade-off with consideration of structure, material and manufacture concurrently**

<Module 9 (2 hours)>

Subject : Final term exam and evaluation

Lecture Syllabus

【Textbooks and References】

1. C. Kong, 'Lecture notes- Aerospace Composite Structures', Beihang University, 2018
2. M.C.Y. Niu, 'Composite airframe structures', Hon Kong Comilit Press Ltd., 1996
3. R. F. Gibson, 'Principles of Composite Material Mechanics', McGraw-Hill Inc., 1994
4. E. J. Jeon et al., 'Advanced Composite materials', Gyohaksa Ltd., 1995
5. M. H. Datoo, 'Mechanics of Fibrous Composites', Elsevier Applied Science, 1991

【Textbooks and References】

1. C.D. Kong et al., 2005, Structural investigation of composite wind turbine blade considering various load cases and fatigue life, Energy, Vol. 30, pp. 2101-2114
2. C.D. Kong et al., 2006, Investigation of fatigue life for a medium scale composite wind turbine blade, International Journal of Fatigue, Vol. 28, pp. 1382-1388
3. C.D Kong et al., 2016, Design and manufacturing of automobile hood using natural composite structure, Composites Part B, Vol. 91, pp. 18-26
3. 4. C.D. Kong et al., 2013, Development of a high-efficiency and long-life 500W class H-Darrieus type vertical axis wind turbine(VAWT) system using skin-spar-foam sandwich composite structure, Science and Engineering of Composite Materials, Vol. 20, pp. 383-394

Lecture Syllabus

5. C.D. Kong et al., 2013, Study on design of high efficiency and light weight composite propeller blade for a regional turboprop aircraft, International Journal of Turbo & Jet-Engines, Vol. 30, pp. 33-42
6. C.D. Kong et al., 2008, A study on conceptual structural design of wing for a small scale WIG craft using carbon/epoxy and foam sandwich composite structure, Advanced Composite Materials, Vol. 17, pp. 343-358
7. C.D. Kong et al., 2008, Preliminary design for the fuselage of a small scale WIG craft using composite materials, Science and Engineering of Composite Materials, Vol. 15, pp. 189-206

INTRODUCTION

Composite aircrafts
Faster, lighter, smarter

Greener, Quieter, Safer,…

Indian Institute of Technology-Kharagpur
Department of Aerospace Engineering
Professor Changduk Kong

Outline

- **Background**
  - What are composites?
  - Why use them?
  - What forms do they take?
- **Near future R&D in Aerospace composites**
- **Status of Aerospace Composites in Korea**

What are composites?

- **Composites combine the properties of two or more materials (constituents). Any two materials (metals, ceramics, polymers, elastomers, glasses) could be combined to make a composite.**

- **They might be mixed in many geometries (particulate, chopped-fibre, woven, unidirectional fibrous and laminate composites) to create a system with a property profile not offered by any monolithic material.**
  - In mechanical design it is often to improve the stiffness-to-weight ratio or strength-to-weight ratio or improve toughness
  - In thermo-mechanical design, it is to reduce thermal expansion, or to maximise heat transfer, or to minimise thermal distortion.

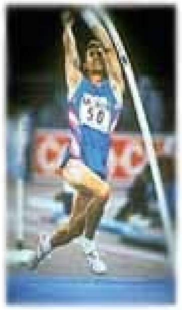
What are the benefits?

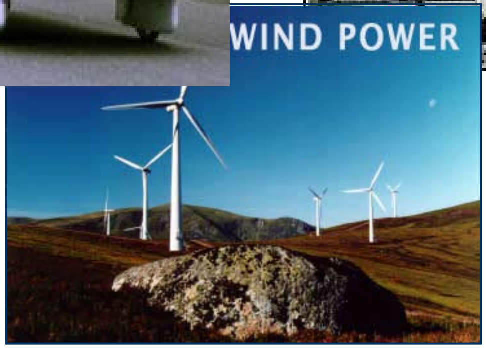
- **Weight saving compared to aluminium alloys**
- **High strength and stiffness**

  (3 to 6x higher than Al-Zn-Mg alloy)
- **Tailored directional mechanical properties- complex shapes and contours easily accomplished**
- **Reduced part count over metallic equivalent**
  - ✓ Lockheed Tristar Tail Fin number of fasteners 40,371 → 6911 when composite
- **Reduced machining**
- **Non-corroding in aggressive environments**
- **Excellent fatigue resistance**
- **Potential for embedded functionality (damage sensing etc)**

Applications

- **Composites are used extensively in**
  - ✓ **Aerospace**
  - ✓ **Automotive**
  - ✓ **Marine**
  - ✓ **Sports**
  - ✓ **Civil infrastructure**



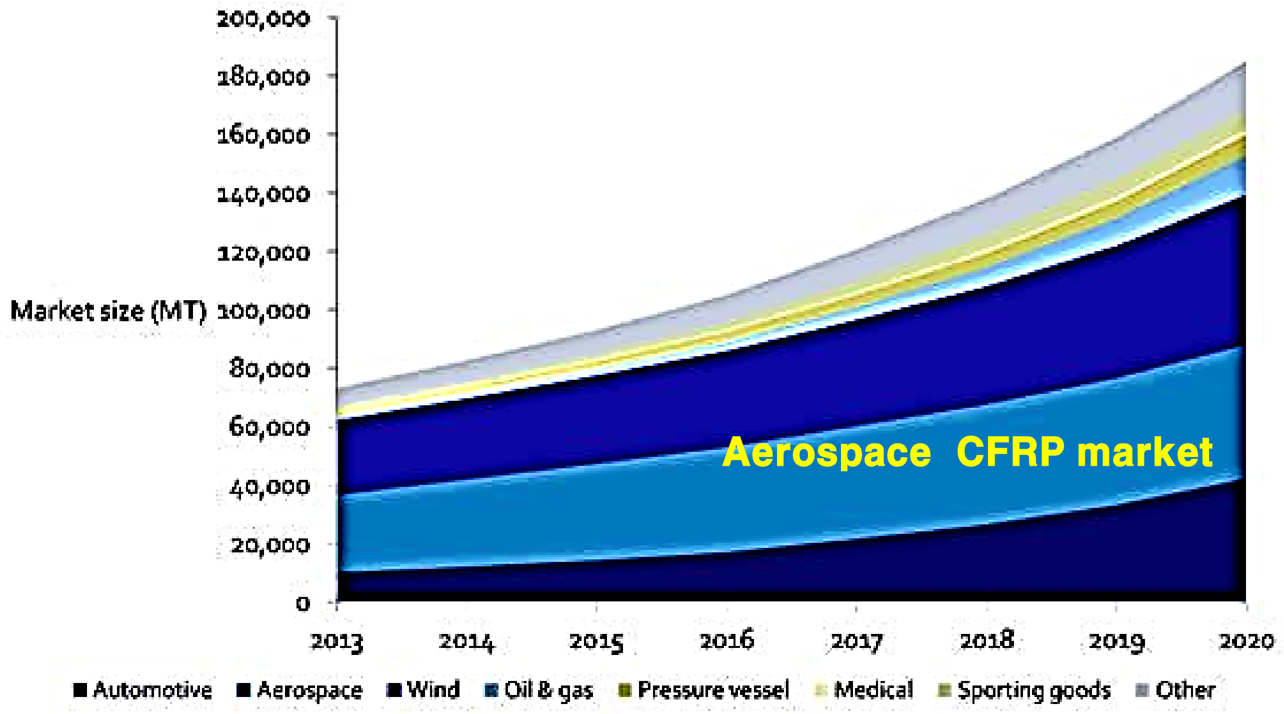


Carbon Fiber Industrial Status

✓ World Market of CFRP

- Aerospace CFRP market will grow to 47,000 MT in 2020

CFRP Market will Grow to 183,000 MT in 2020



CFRP Market will Grow to $35 Billion in 2020

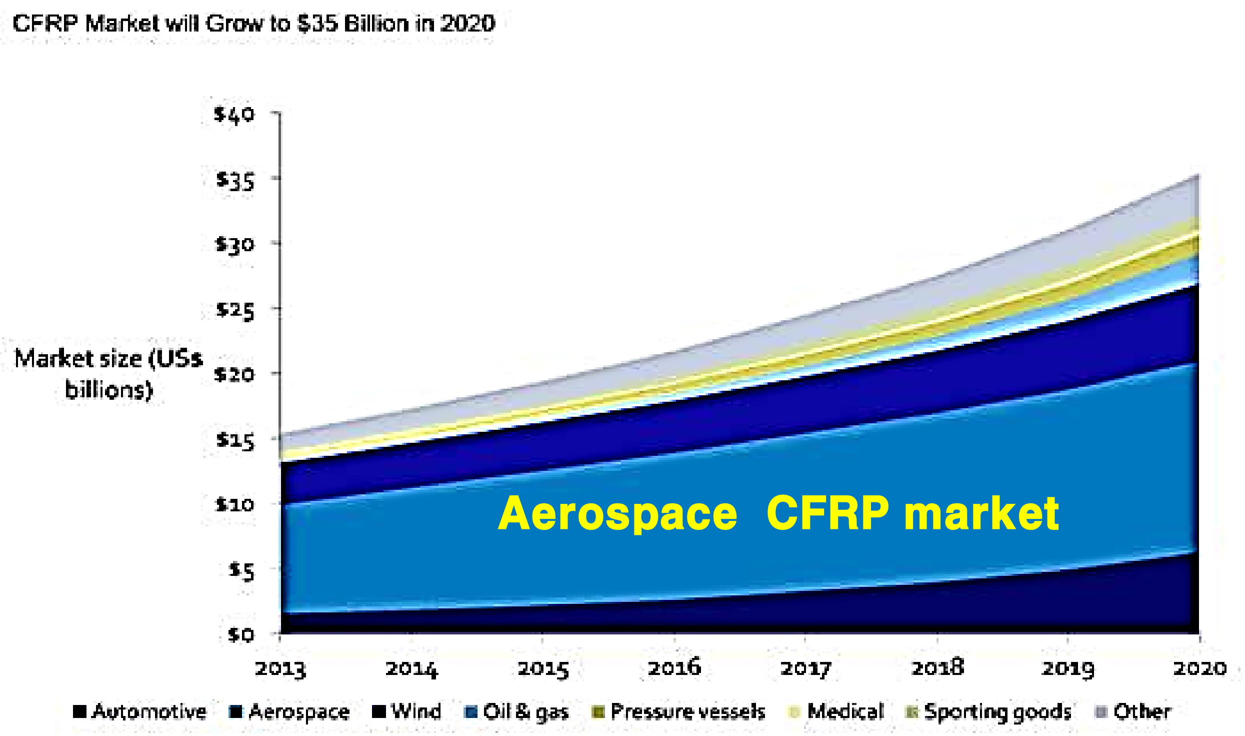
❖MT : metric ton= 1000kg

Carbon Fiber Industrial Status

✓ *World Market of CFRP*

- Aerospace CFRP market will grow to USD 15 Billion in 2020

* **AAGR: Average Annual Growth Rate → 15%!**



Source: Lux Research, Inc.
www.luxresearchinc.com

Applications

- Suffolk bridge reinforced with carbon fibre strips (3 mm thick)
- M6 motorway columns reinforced with Kevlar fibre/epoxy layers (7mm thick)

Applications

San Marino, 25 April 2004

- **F1 Ferrari with a carbon fibre chassis weighs less than 600kg with oil, water and driver!**
- **4.495 m long, 1.79m wide and 0.959m high**

Applications

Typical Composite Failure Sequence

1. Resin cracks
2. Interface failure
3. Fibre pull-out
4. Fibre fracture

Applications

Carbon fibre super yacht, *Cheyenne 2004*, built to smash the RTW speed sailing record, 58d 9hr 32' (Steve Fossett, USA, 5 April 2004)

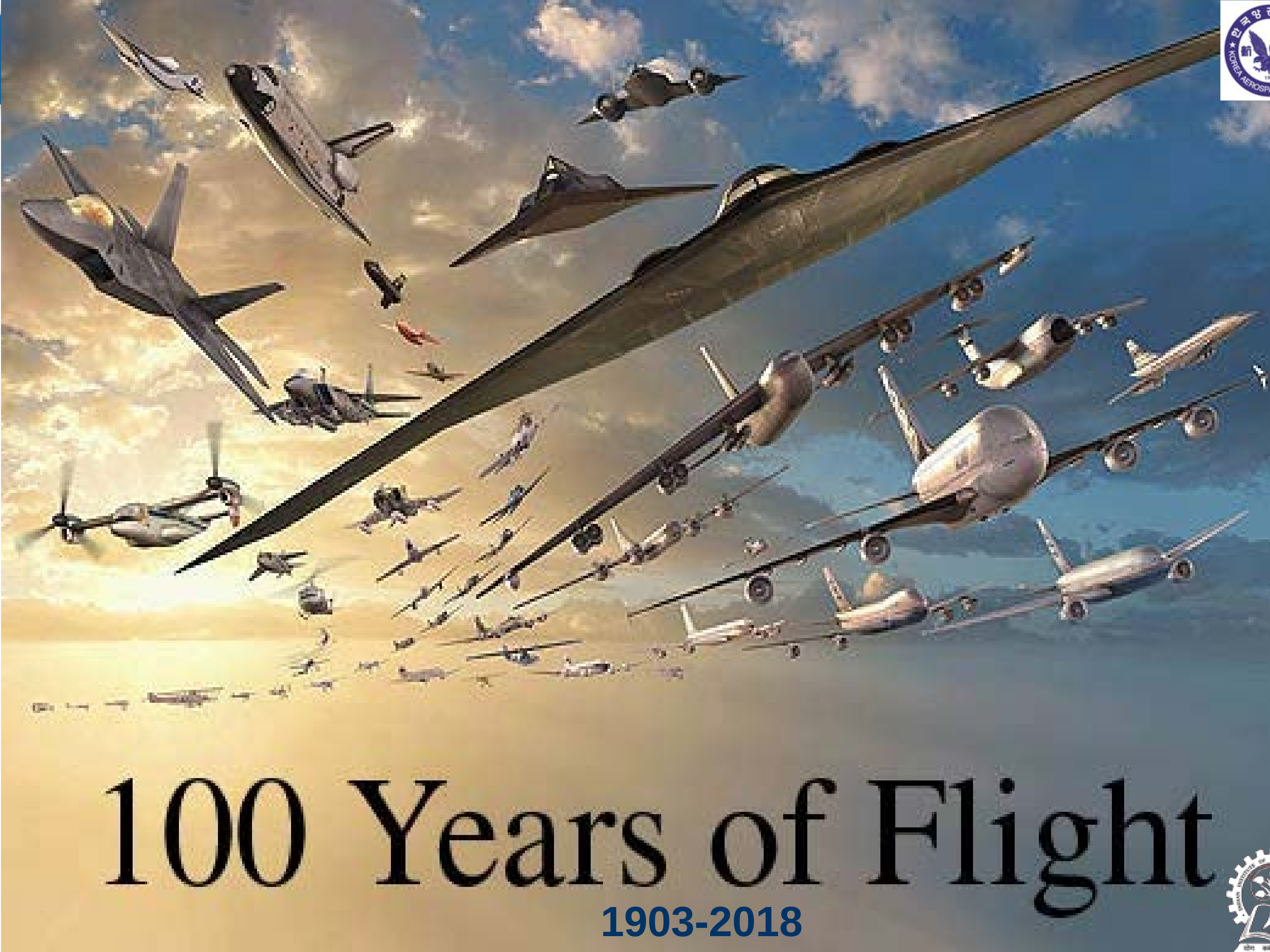
Virgin Atlantic Global Flyer

- Built by Scaled Composites (Mojave, USA)
- 1st test flight on 5 March 2004, 1hr 30'
- It can carry >4x its own weight in fuel. TOW is 22,000lbs
- The plane flew up to 52,000ft and travelled at speeds of 290mph
- Non-stop RTW flight in February 2005 <80hrs

Williams FJ44-3 turbofan engine

Steve Fossett

❖Unfortunately millionaire, adventurer, sailor and aviator Steve died in 2007 due to plane crash!



1903-2018

Earlier Planes

- In the pioneering days of flight, a/c structures were composite, being fabricated largely of wood (natural composite), wire and fabric
- Aluminium alloys took over in 1930s and have dominated the industry to the present time.

Boeing wing 1922

Air Traffic

1930's DC3

Aluminium Aeroplane

War Technology

Merlin Engine

1940's

Pressured Cabin – Boeing 307

TWA

Constellation

Jetliner - 102

Comet

Tu-104

1960's

707, Swept Wing, Jets

747 Pan-Am

DC-10

A300

1970's

A380 - ($250m)

787 ($120m)

2004

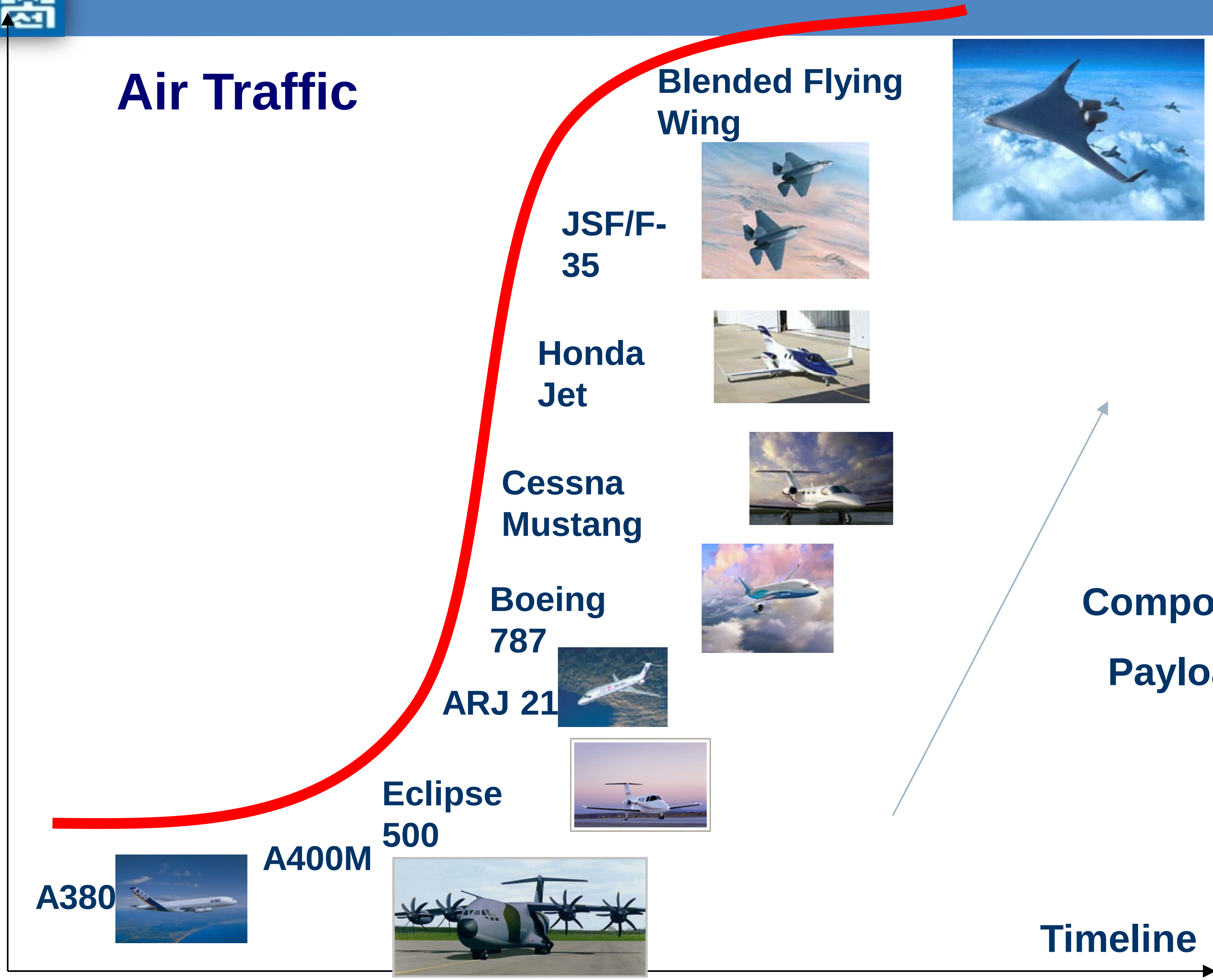
Composites

Flying Wing

Timeline

Courtesy of Prof Andrew Walker

Air Traffic



Blended Flying Wing
JSF/F-35
Honda Jet
Cessna Mustang
Boeing 787
ARJ 21
Eclipse 500
A400M
A380
Composites
Payloads
Timeline

Civil Aerospace

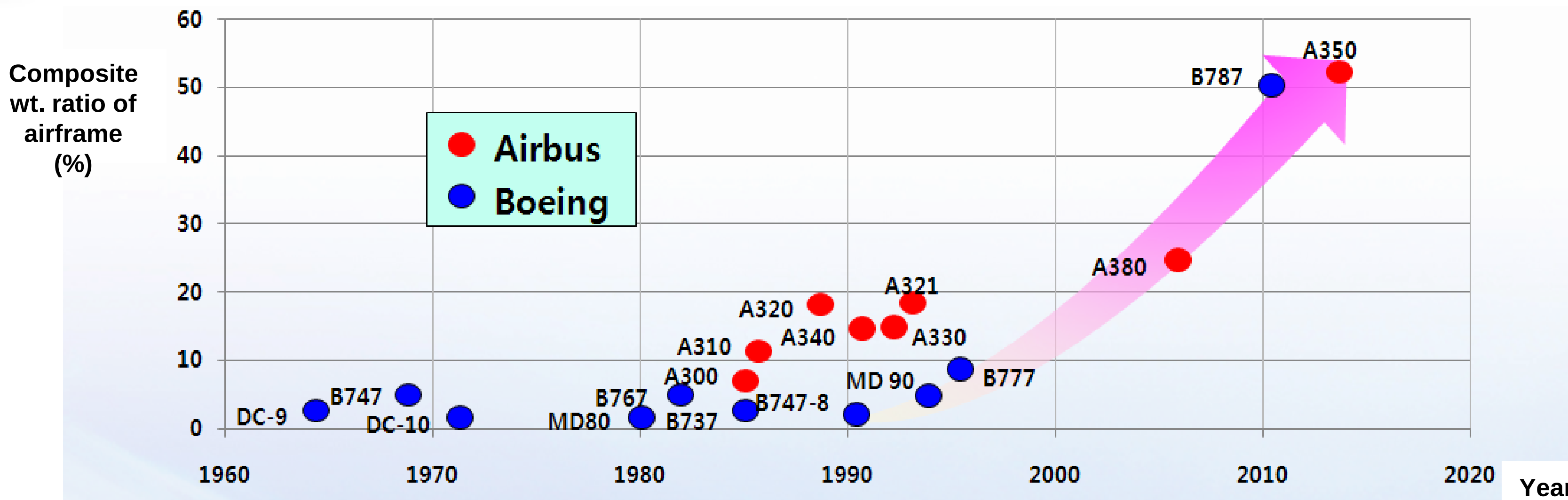
- **Increasing use of composites**
- **All secondary structure and tail structure mainly composite already – Airbus and to lesser extent Boeing**
    - ✓ leading / trailing edges, flaps spoilers, fairings, access panels, engine nacelles
- **Recent Airbuses also have composite horizontal / vertical stabilisers, fuselage keel beams and wing leading edges**
- **Airbus, 550-seat A380 super jumbo, also has a lot of composite primary structure**

Airbus A340 - 18% CFRP

Ultra-long-range aircraft

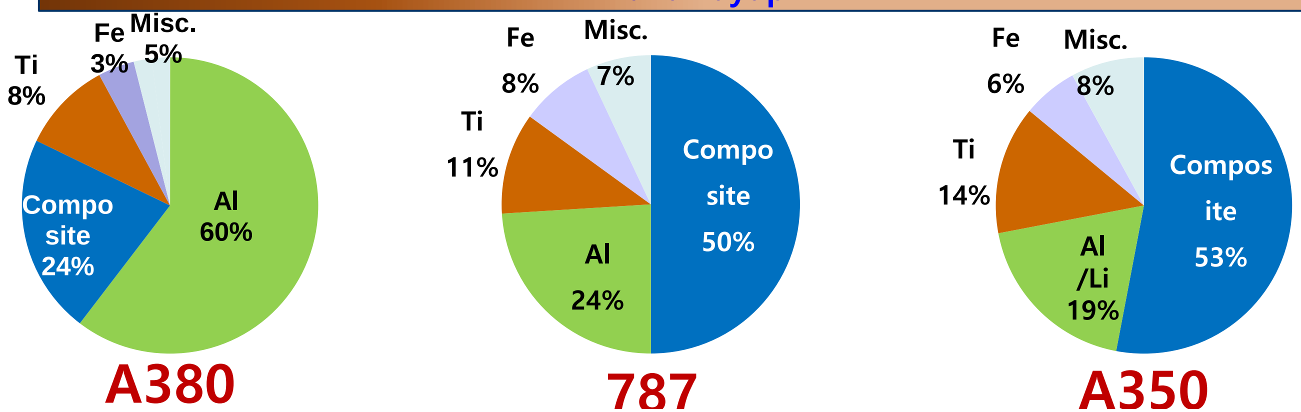
Composite keel beams and wing leading edges

Application of Composites to Civil Aircrafts

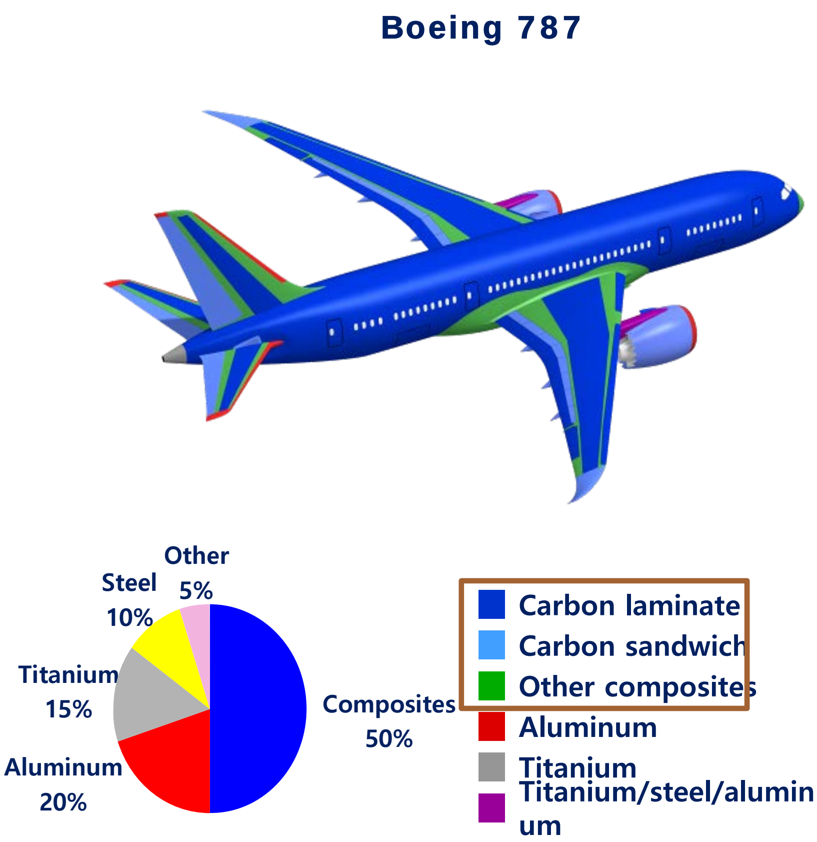


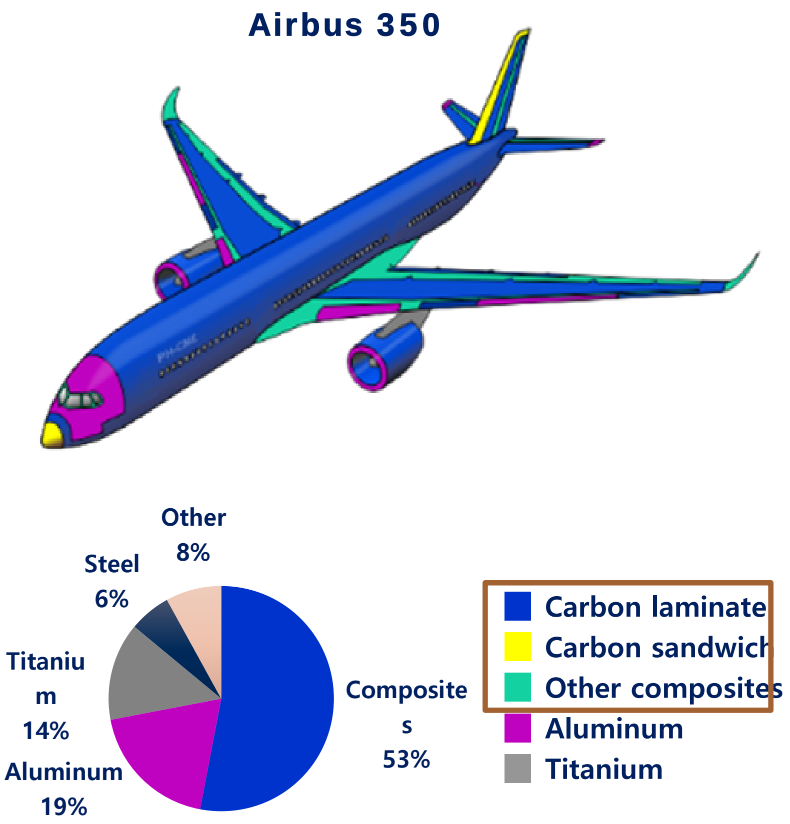
Composite manufacturing Technology

- AFP/Co-cure Technology
- ATL/Co-bond Technology
- Hand Layup



Application of Composites to Civil Aircrafts

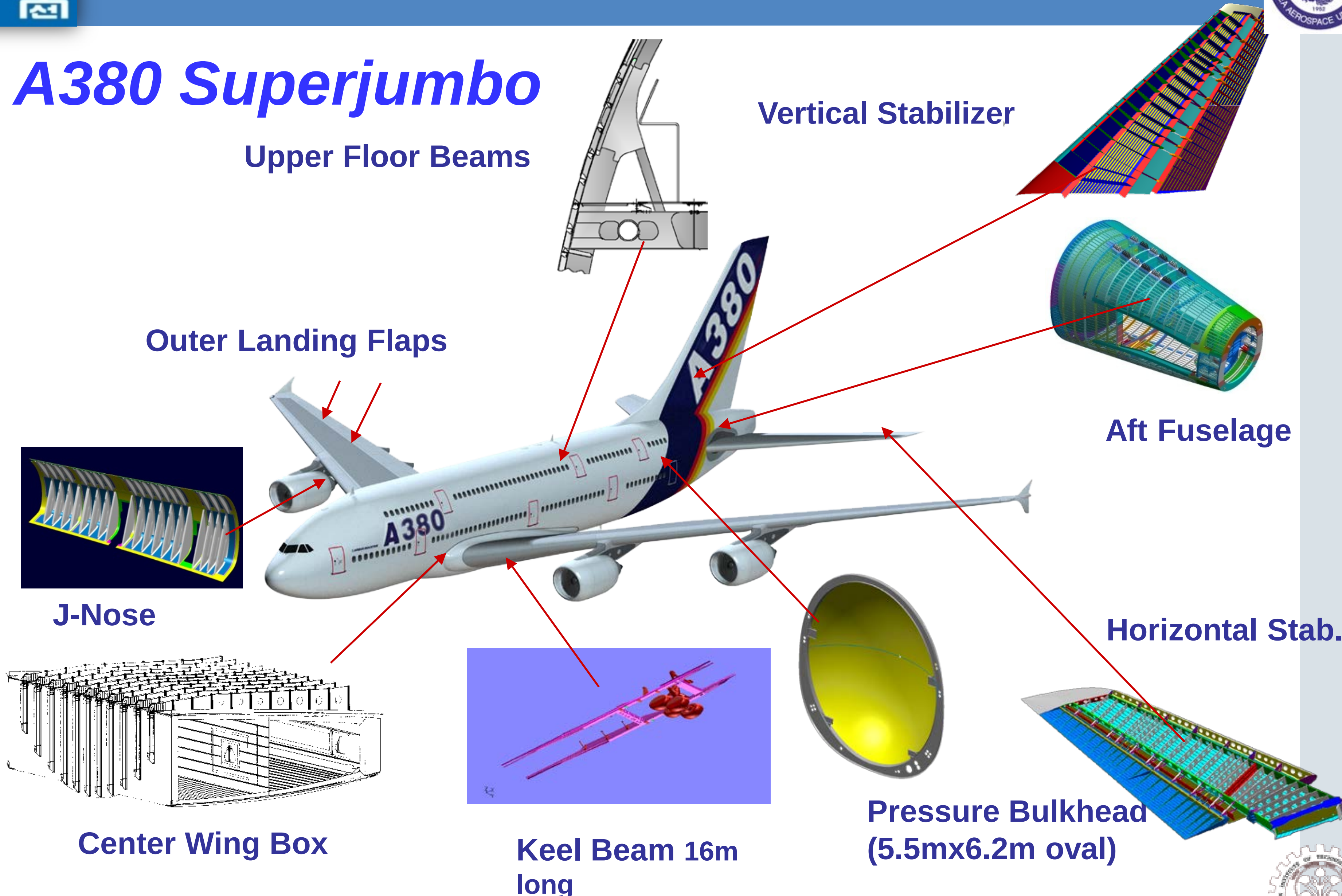




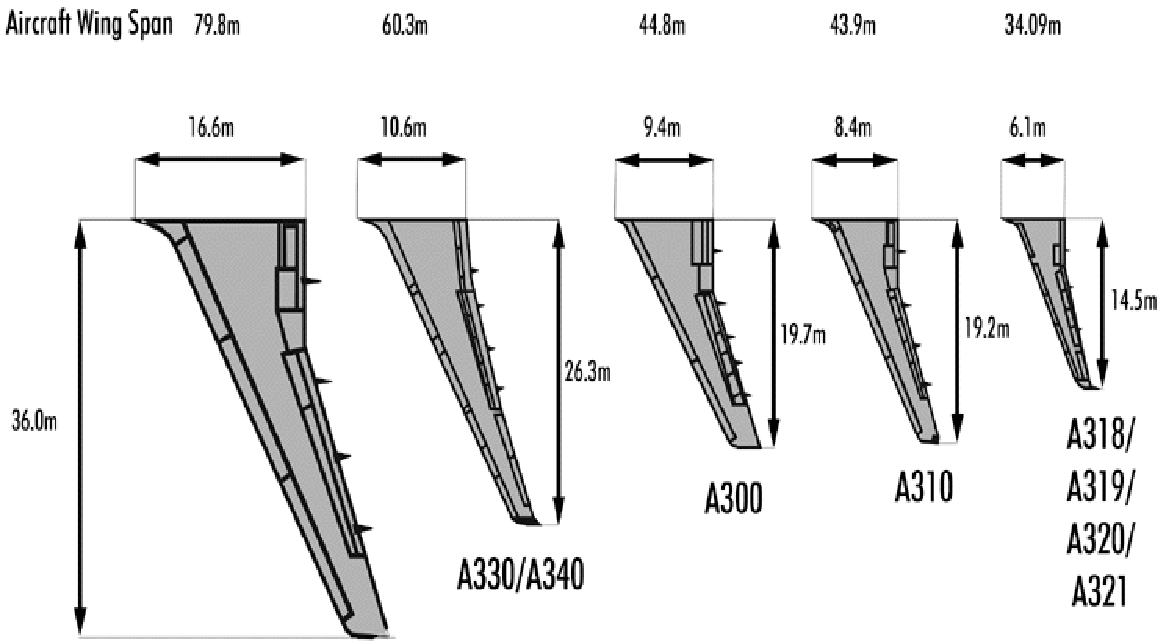
Composite Wt. ratio of B787 Airframe : 50% (Volume ratio: 80%)

➡ **Wt. Reduction : 10~ 20% (12~ 24 ton)**

A380 Superjumbo



A380 Wing



A380

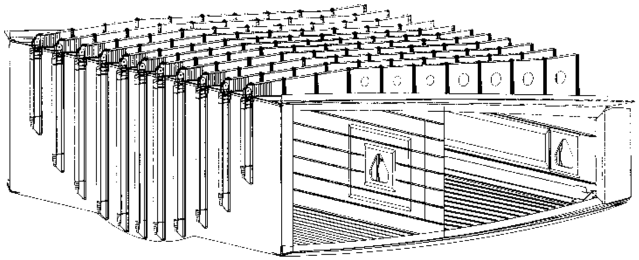
- It is the largest ever made for a civilian a/c.
- The wing weighs 35 tonnes but is flexible enough to bend 7 m at its tip
- The full length of an A320 is swallowed by just the stem of the A380 wing

A380 Wing

The Broughton factory in North Wales

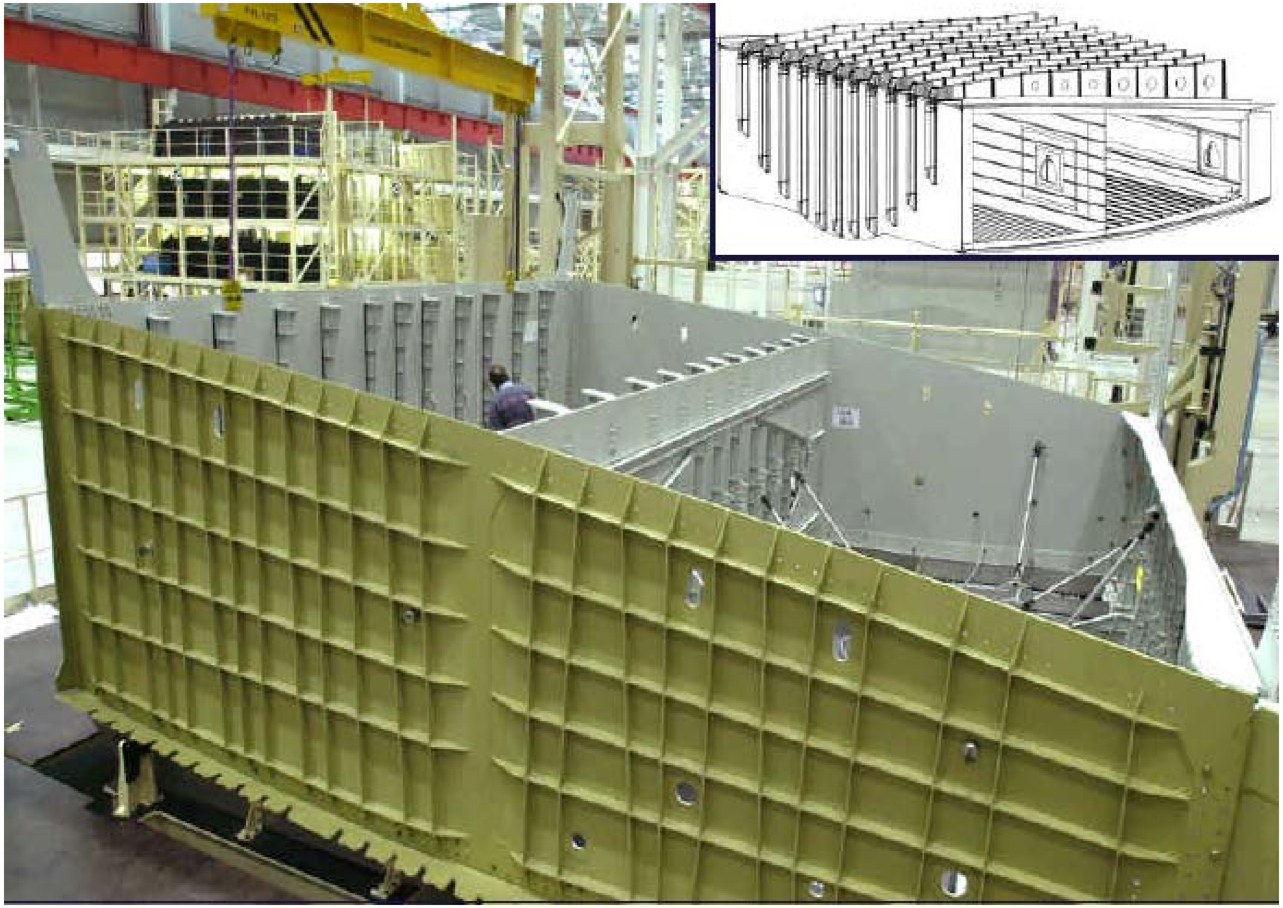
- The first set of wings left Broughton in April 2004
- Too large even for Airbus whale-shaped Beluga air freighter, they travelled by barge down the river Dee and then in a specially built cargo ship to Bordeaux. From there they were taken by road to Toulouse
- The Broughton and Filton factories employ more than 12,000 workers and another 84,000 jobs at its myriad subcontractors, 22,000 of those on A380 work alone
- Airbus spent nearly £2b in the UK on production facilities for the A380

Centre Wing Box



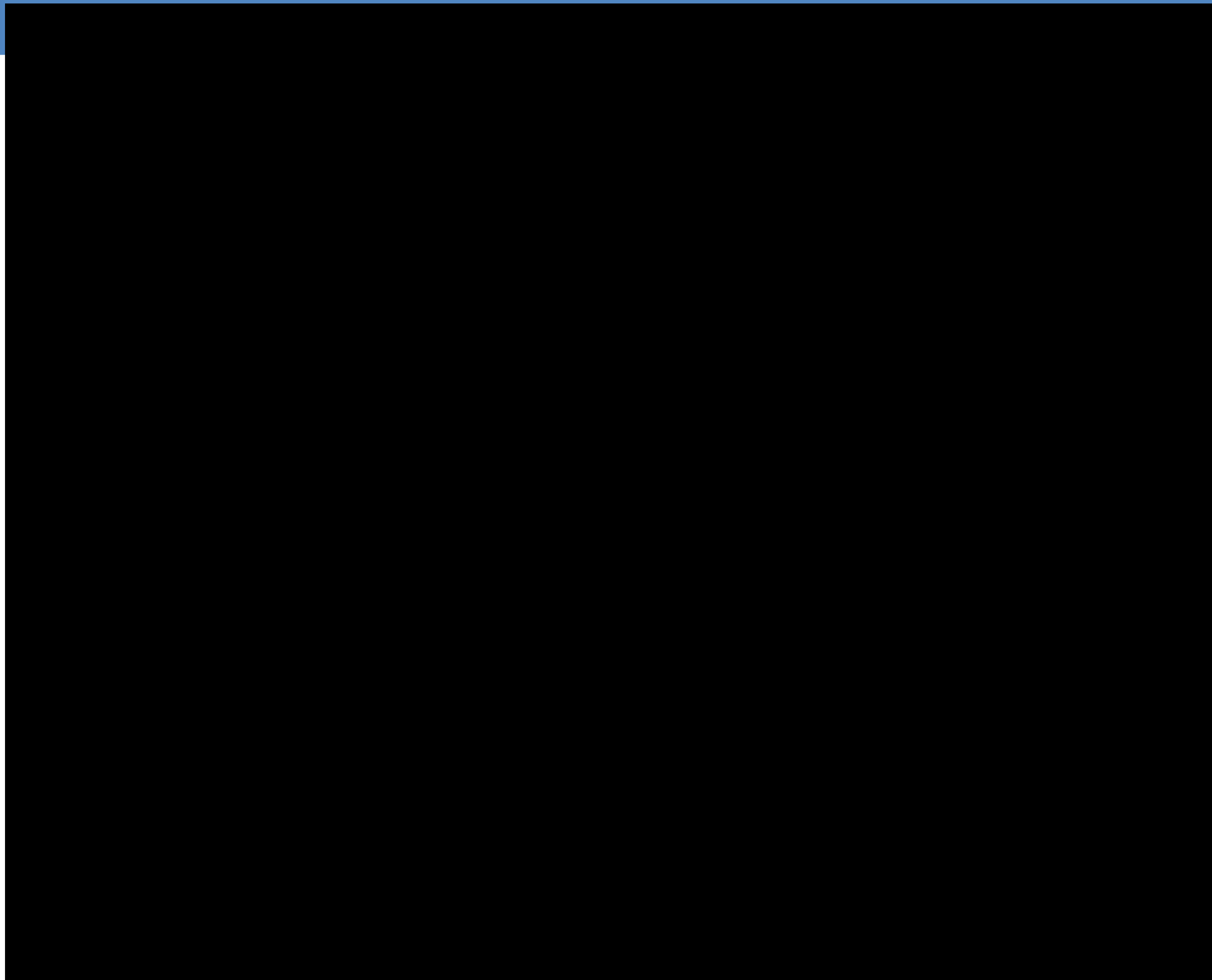
- A380 is the first aircraft with a CFRP centre wingbox
- Made by Automatic Tape Laying (ATL)
- 8.8 tonnes, with 5.3 tonnes of CFRP, saving over 1.5 tonnes compared to the metallic equivalent
- Main challenge is the wing root joint, with composites up to 45mm thick !
- Links to CFRP keel beams, each 16 m long and 23mm thick carrying 450 tonnes

Centre Wing Box



Horizontal Tailplane Composite Torsion Box Demonstrator

- ATL component
- Made by CASA
- Same size as A320 wing, 14.5m



UK Military Aircraft

- **Transport Aircraft**
  - ✓ Airbus A400M
    - 40 tonne load capacity
  - ✓ Lockheed Hercules C130J
    - 12 tonne load capacity
- **Eurofighter Typhoon**
  - ✓ In-service 2002
  - ✓ Update, Air-Ground version in 2008
- **F-35 Joint Strike Fighter, Lockheed**
  - ✓ Supersonic, STOVL propulsion system(F-35B)


A400M


Typhoon


C130J

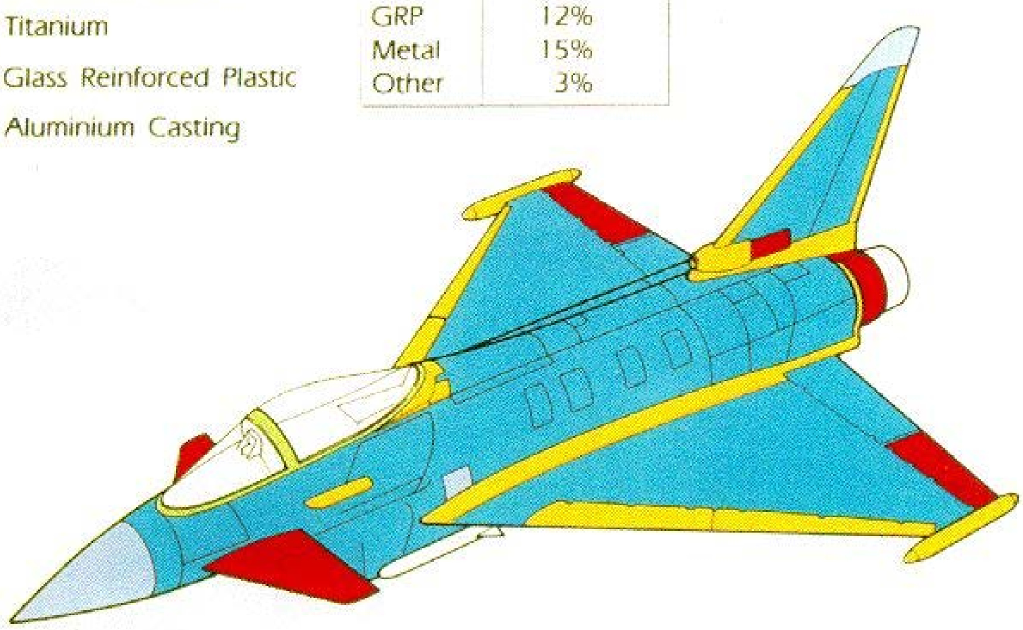

Lockheed

F-35

Eurofighter Typhoon

- Carbon Fibre Composites
- Aluminium Lithium
- Titanium
- Glass Reinforced Plastic
- Aluminium Casting

Material	Surface Area
CFC	70%
GRP	12%
Metal	15%
Other	3%



US Civil Aircraft

More than 50% non-US content!
By Risk Share Partnership!

- The 787 is 50% composites of weight, and 20,000lb lighter than the Airbus A330-200, for 3,150Km more range with 250 passengers. 20% cheaper to operate
- Laminated composites are used allowing a ‘smart layer’ of PZT transducers to be inserted for structural health monitoring
- The new RR Trent 1000 engine was chosen by Boeing (April 2004) as one of two engines that could bring £65bn to RR (or GE GENEX).
- 1st order of 50 787 by All Nippon Airways of Japan, $6bn, delivery 2008 (27 April 2004)
- Boeing hopes to sell more than 3000 of this medium size airliner

US Military Aircraft

C17

F-117

F22 Raptor

B-2 Stealth Bomber

Russian Planes

A-40 amphibian

Su47&Su27

An-70 Transport

- **Sukhoi-47 5th generation multi-functional frontal fighter**
- **Features FS composite wing structure and incorporates LO and TV**
- **FSW better performance at high AoA much needed in close-in dogfight**

Fabrication of Composites

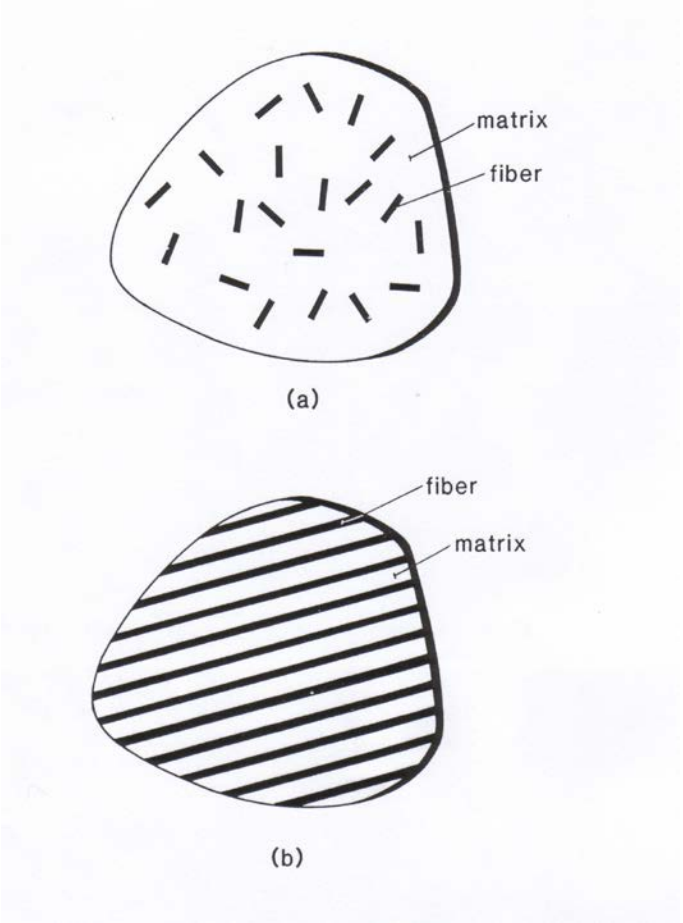
Different ways of combining fibres and resin

a) Randomly oriented short fibres in a matrix

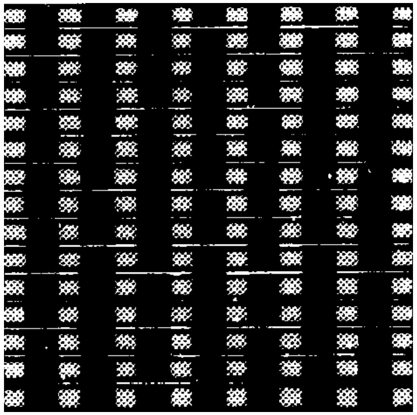
b) Unidirectionally oriented continuous fibres in a resin (UD prepreg)

c) Fibre mats

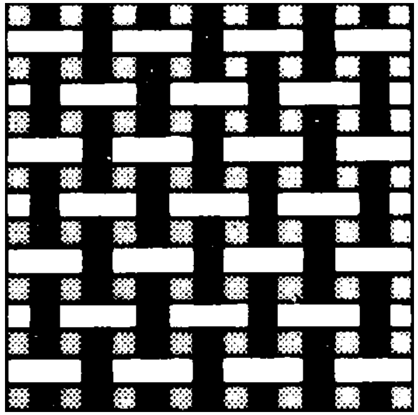
d) Woven fabrics



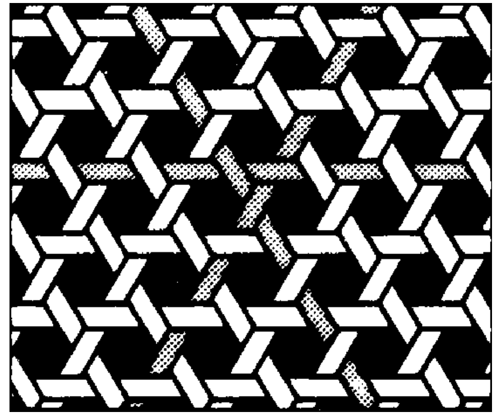
Different Reinforcing Fabric Weaves



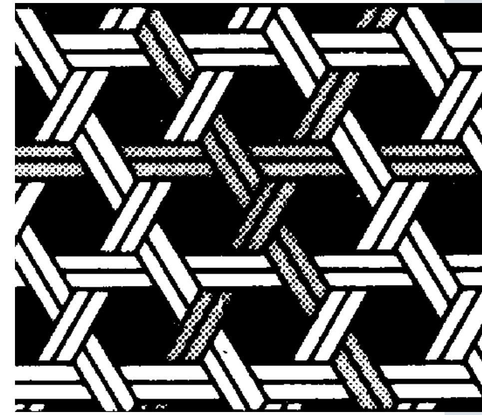
Unidirectional



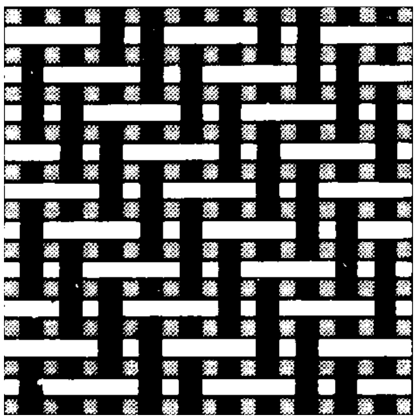
Plain



Basic (triaxial) weave



Basic basket weave



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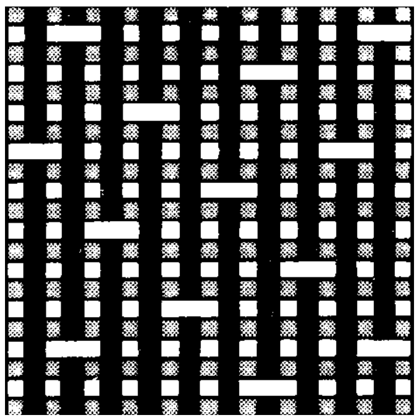
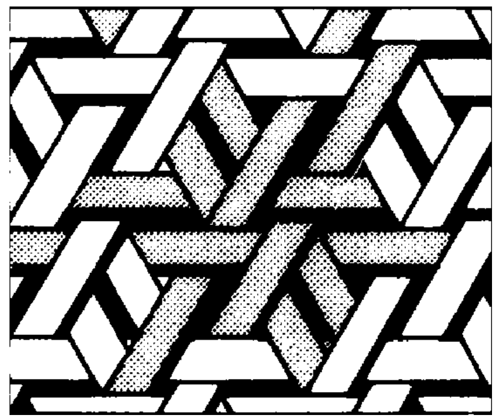
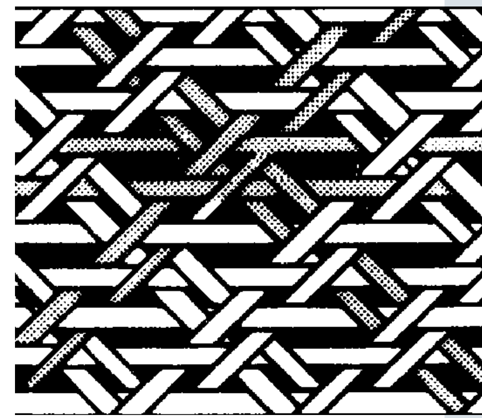


Satin 8



Bi-plain weave
(filling 60° to warp)



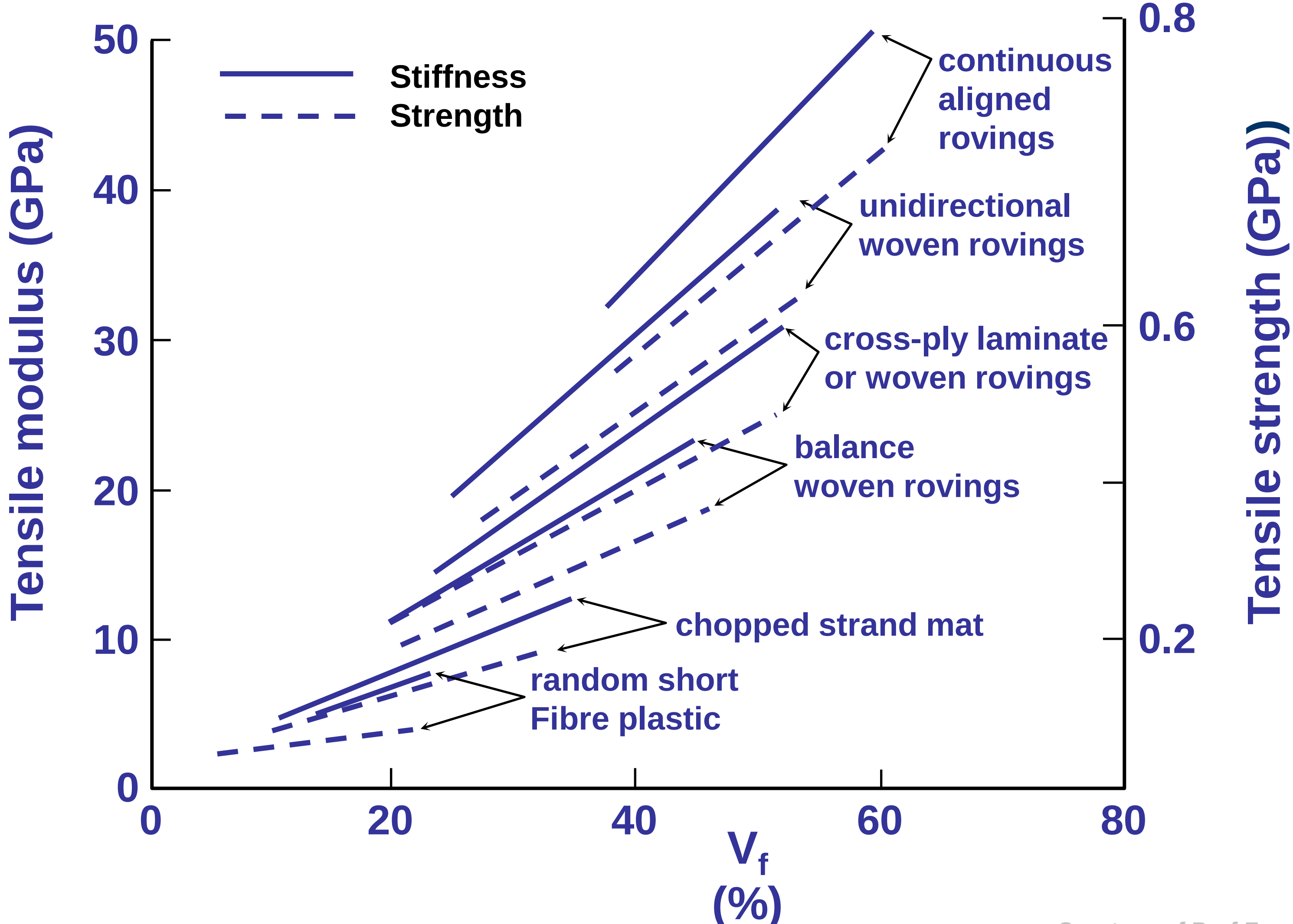
Bi-plain weave
(filling 45° to warp)

Fabrication of Composites

- Continuous or very long fibres aligned to principal stress
  - High performance
  - Anisotropic properties
  - Limited shapes
- Dispersed short Fibres
  - Complex shapes
  - High production rates
  - Poor performance
- Fibre mats
  - Simple shapes but more complex curvatures
- Woven continuous fibres

  * Compromise between speed – complexity - performance

Stiffness and Tensile Strength of Polyester-Glass Laminates

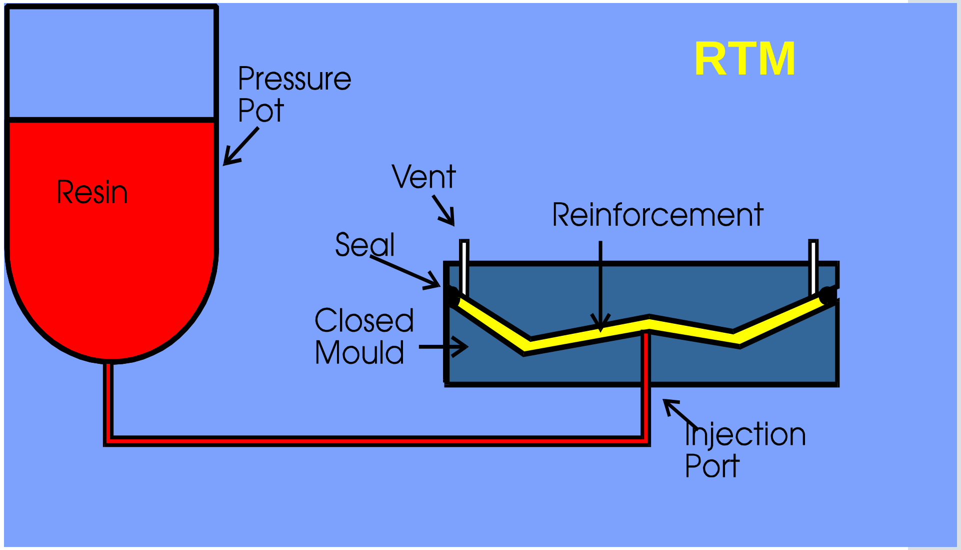


Courtesy of Prof Frank Jones

★ Manufacturing methods

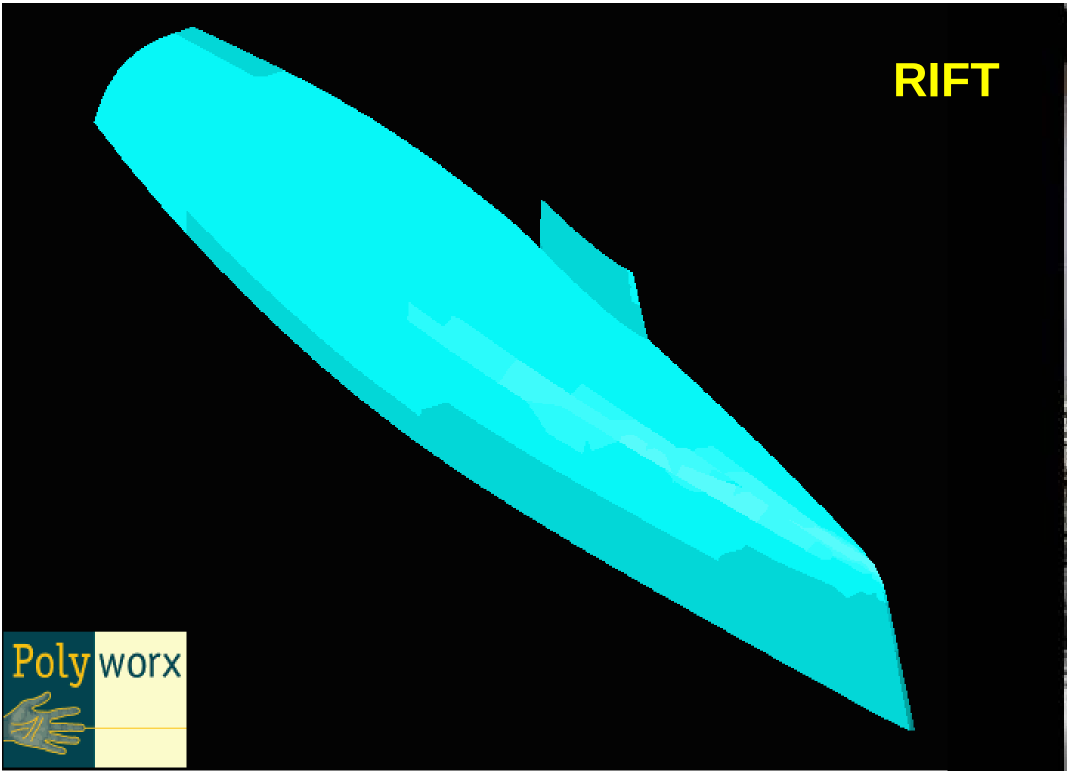
- Autoclave
- Resin Injection
- Filament winding
- Pultrusion
- Hand lay-up moulding
- Spray-up-moulding
- RTM, VARTM, RIFT, ATP

*Resin Transfer Moulding (RTM)
*Resin Infusion under Flexible Tooling (RIFT)



Courtesy of Prof Frank Jones

Liquid composite moulding

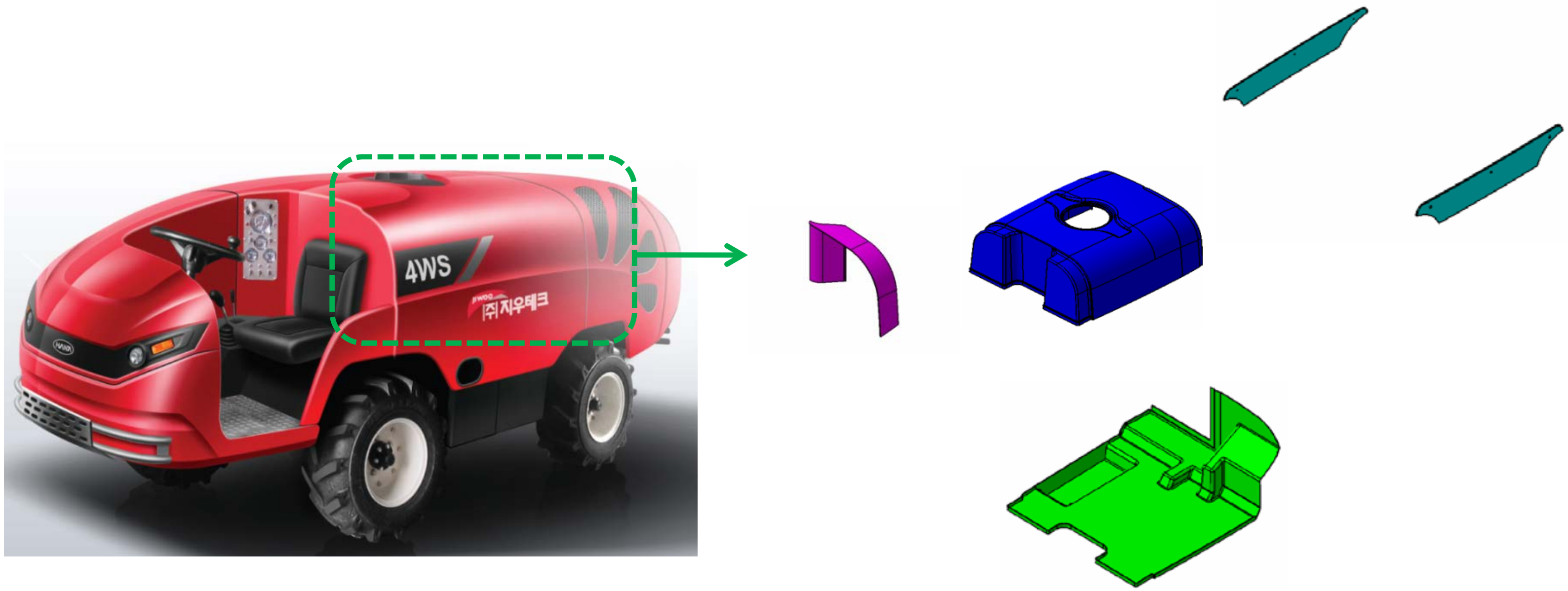


Filling pattern for the hull

Controlled Vacuum Infusion of the hull of a 64’ carbon/epoxy sailing yacht

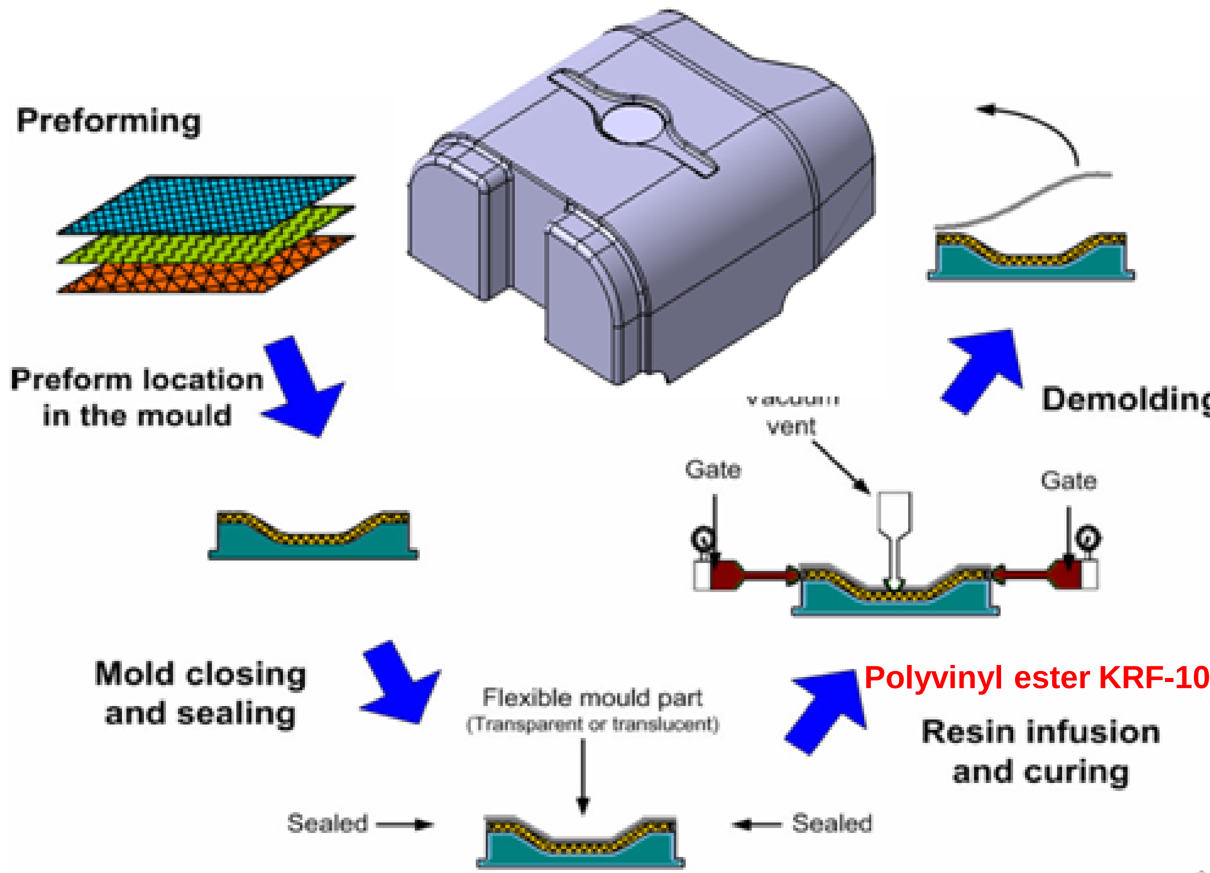
Vacuum Assisted Resin Transfer Molding-Light (VARTML)

- **Development of flax/vinyl ester natural fiber composite agricultural chemical container using Vacuum Assisted Resin Transfer Molding-Light(VARTML)**



✓ *Application of VARTM-Light manufacturing technology*

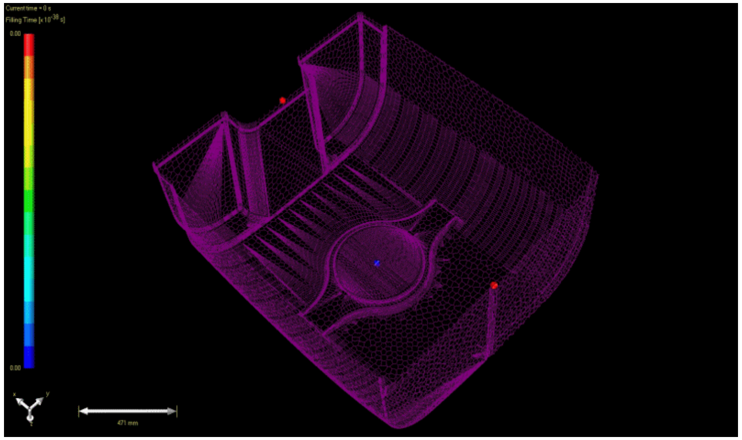
Flax biaxial woven fabric (600g/m^2)



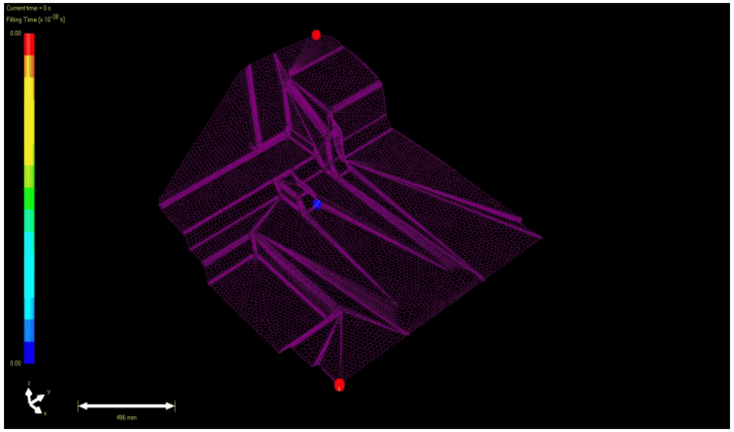
Polyvinyl ester KRF-1031

Resin flow analysis results using Polyworx

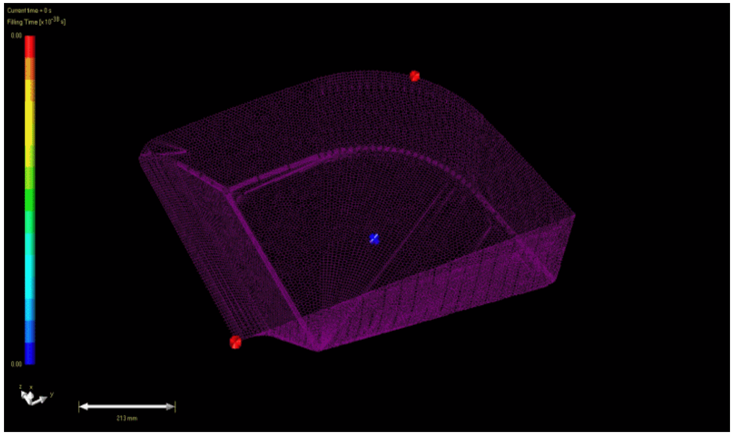
- Upper Part



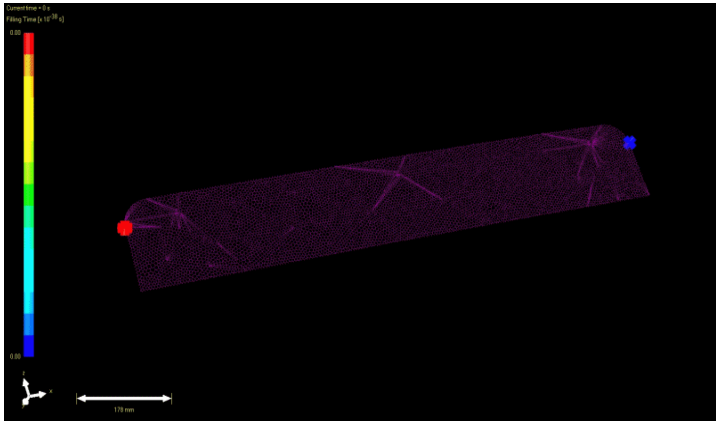
- **Lo**wer Part



- Front Part



- Side Part

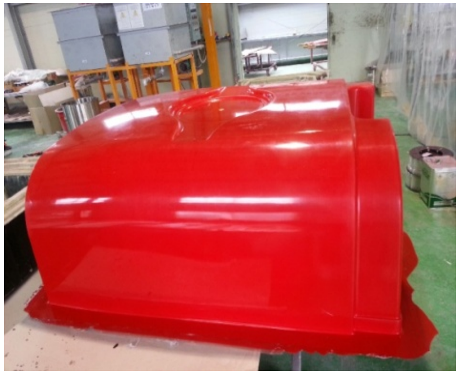


Manufacturing using VARTM-L

Tank upper part mould
(inner surface)

Tank upper part mould
(outer surface)

Flax fabric preform
laying-up and resin
injection



Manufactured tank upper part

Manufacturing using VARTM-L

Parts manufactured by VARTML


Main Tank UPR. Part Product


Main Tank LWR. Part Product


Tank FRT. Part Product


Tank Side(LH.RH) Part Product

Tank assembly by bonding

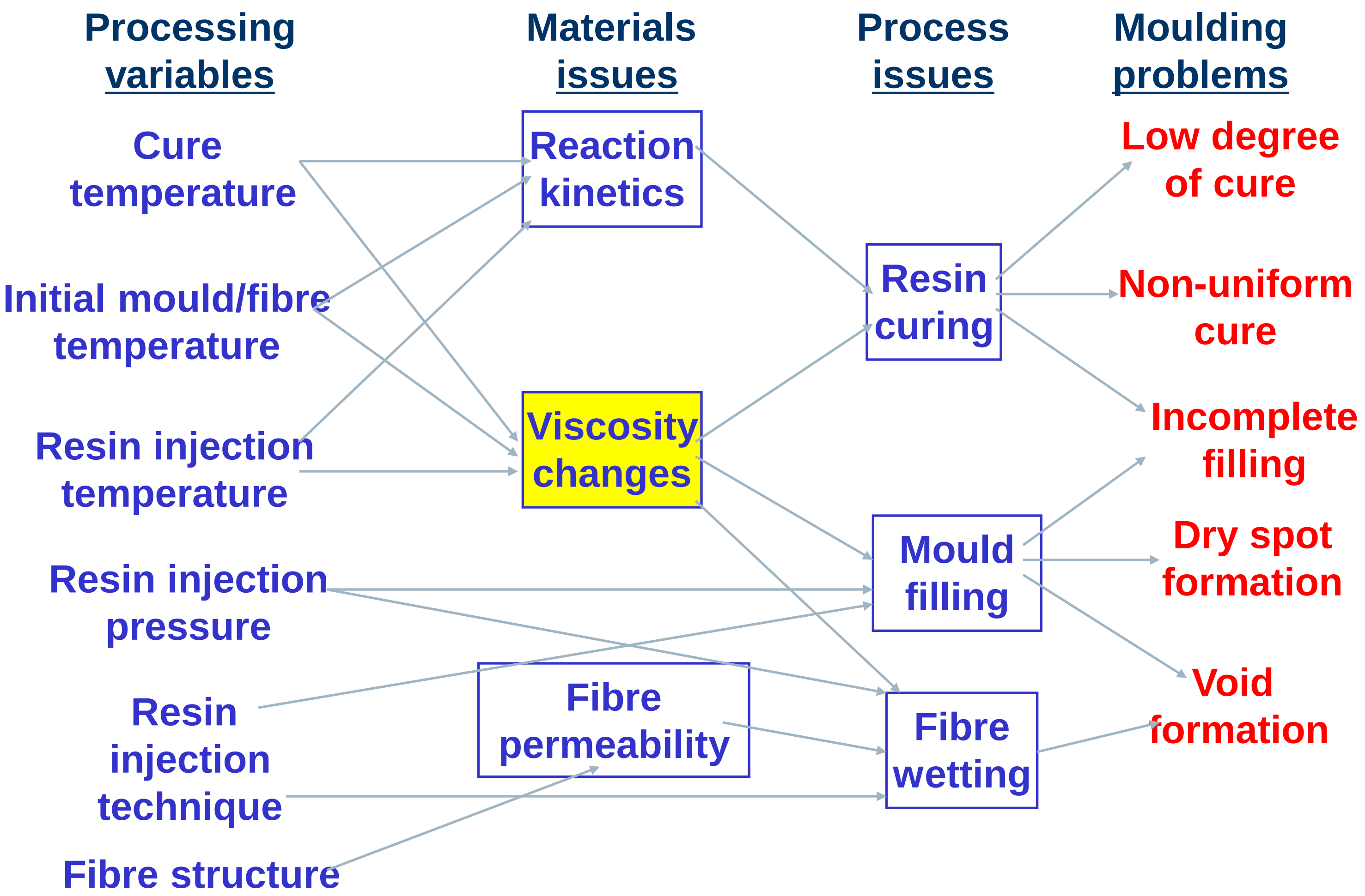

Product Bond'g Assembly


Product Bond'g Assembly


SSWT-1000 Tank

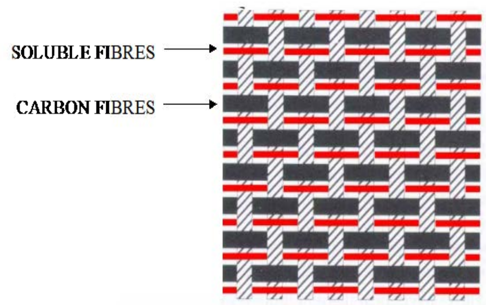
Visual and UT NDT Inspection, Hydrostatic pressure proof test and sealing test

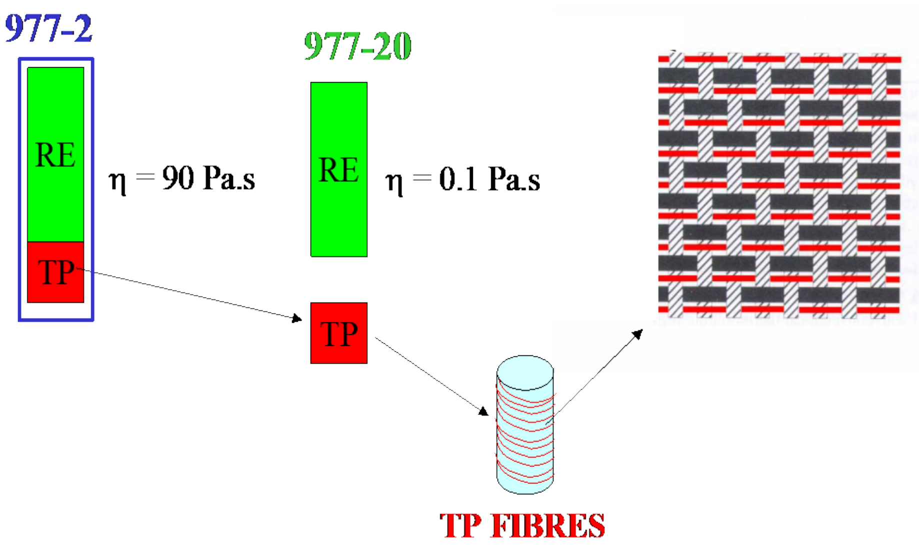
Problems in liquid composite moulding

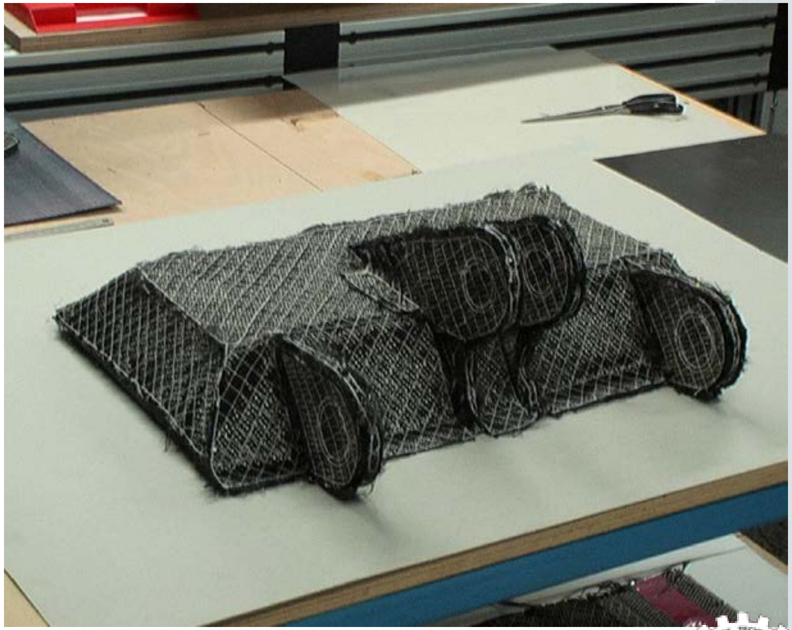


EPOXY SOLUBLE THERMOPLASTIC FIBRES & RTM

- This removes the viscosity constraint, and makes the in-situ formation of a highly toughened, damage-tolerant composite structure via liquid resin infusion process

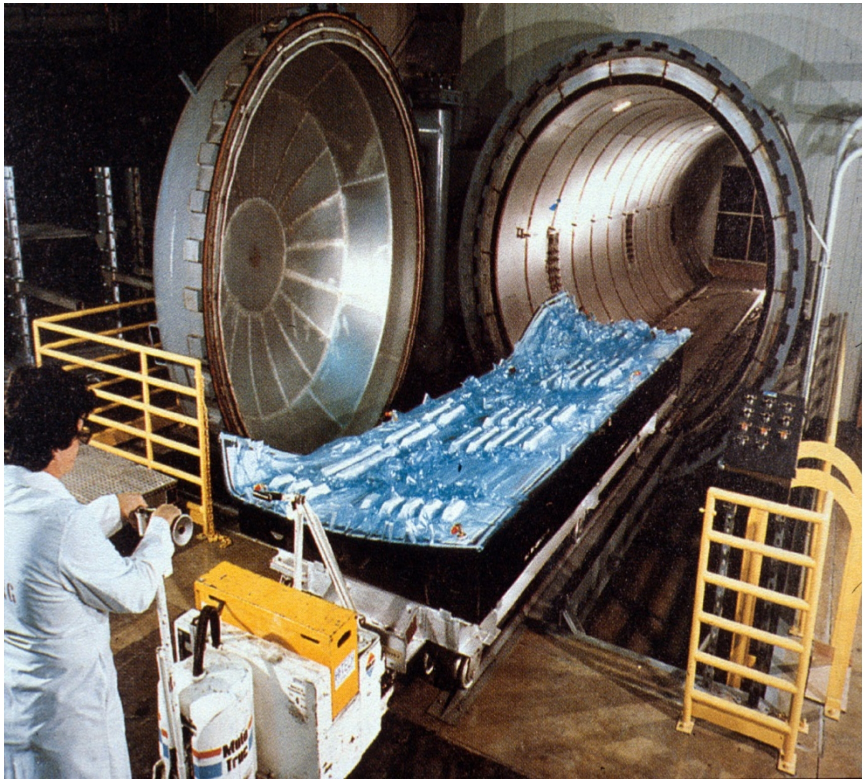


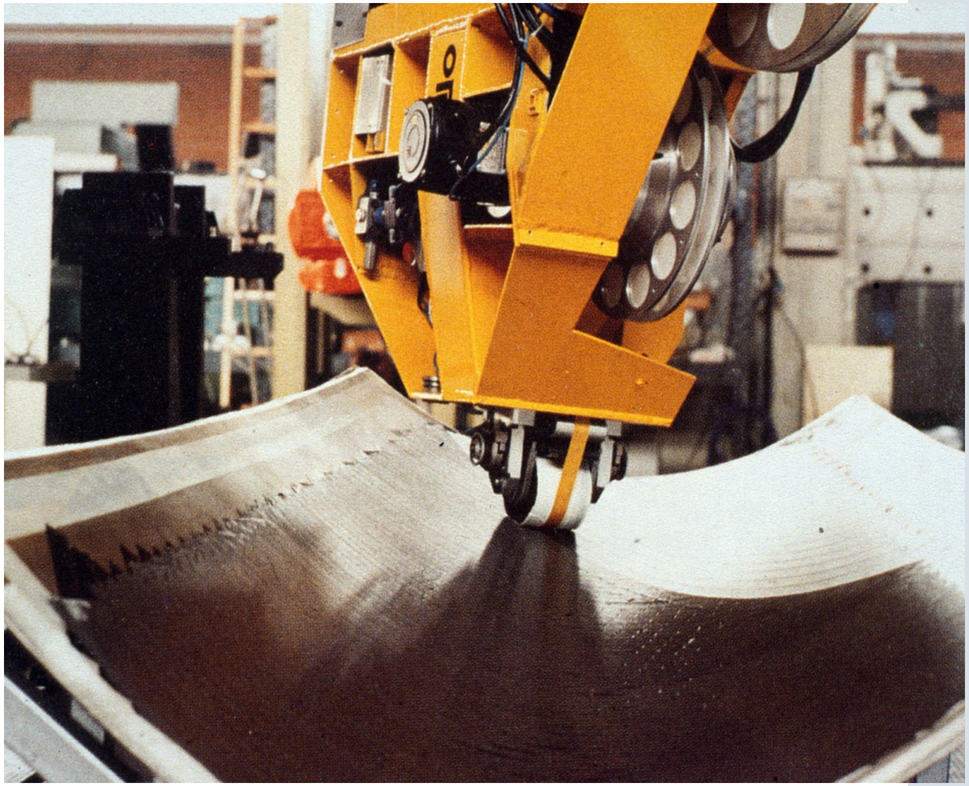




Part preform of A380-600 spoiler

★ *Manufacturing methods*

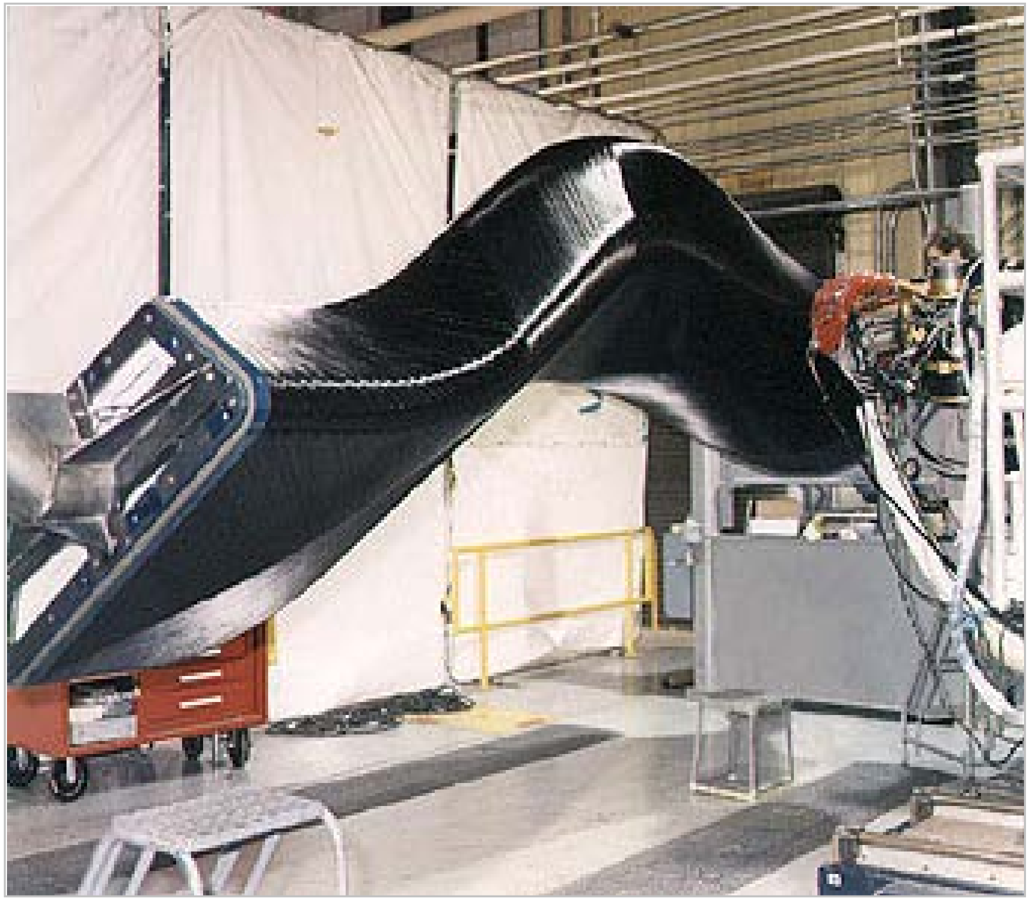




Autoclave **Advanced Tape Placement**

Thermal oven processing could save 90% of autoclave processing time and energy & hence 50% of the cost. Radiation and electron beam methods have been recently developed for curing composite structures

Complex inlet duct manufacture (JSF) by ATP

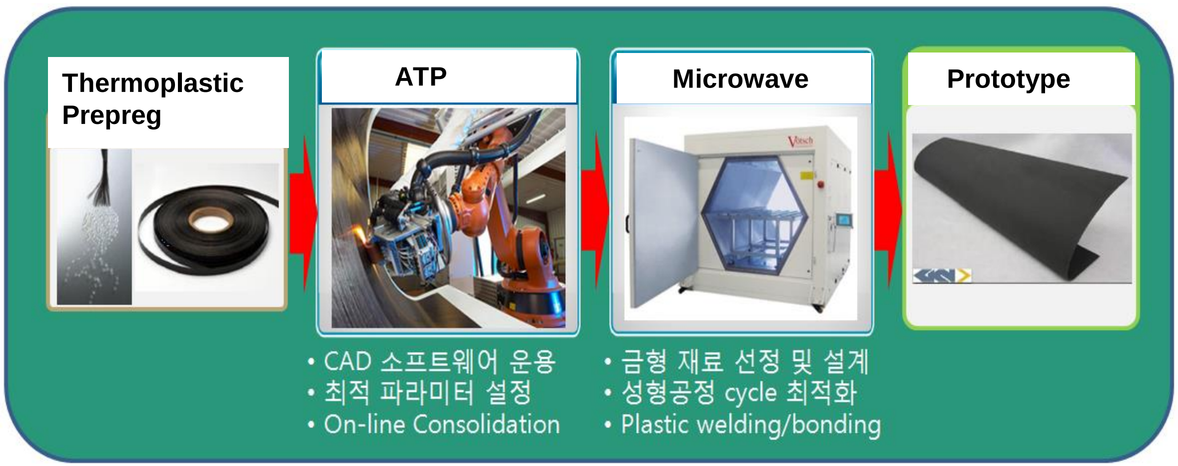


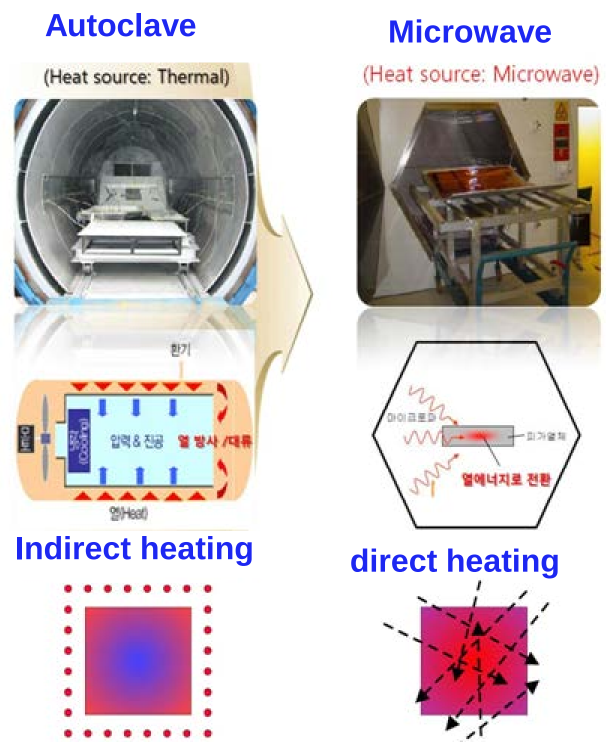
JSF/F-35

★ *MICROWAVE Curing Method*

- **Microwave Curing Method can reduce 40% curing time and 80% energy consumption comparing to Autoclave Curing Method.**

  ➡ **Reduce greatly manufacturing cost**



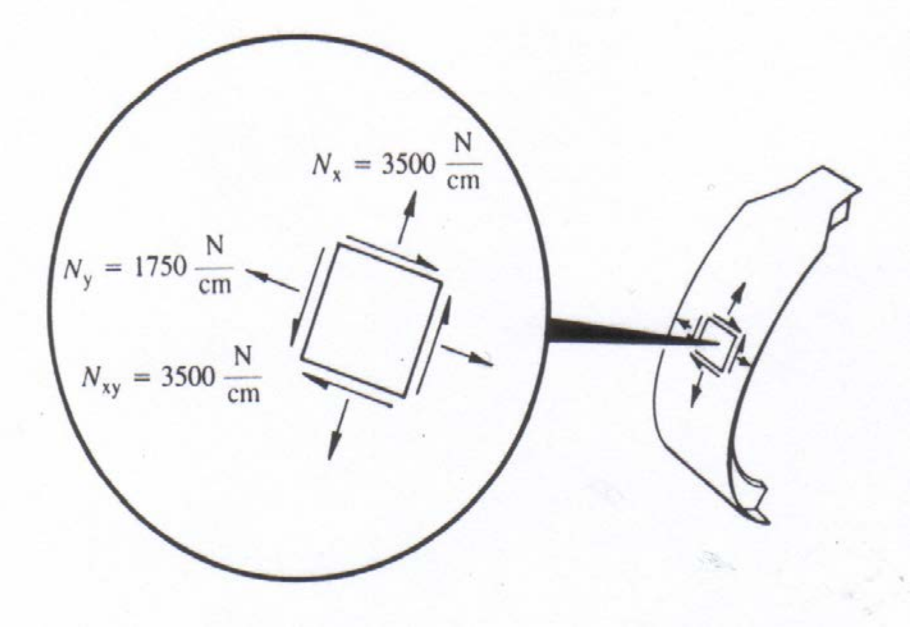


Laminates

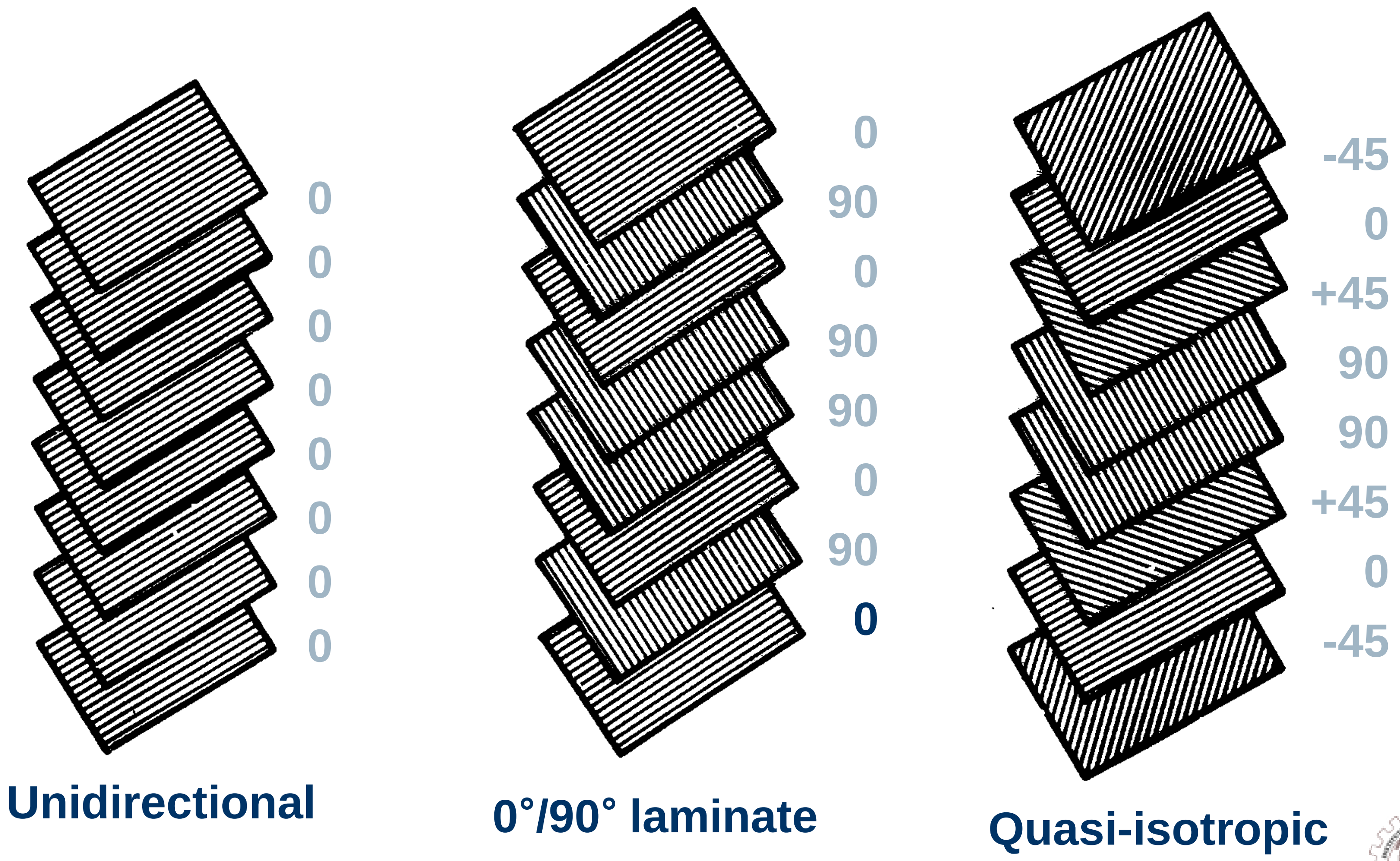
- Used to tailor directional mechanical properties
- Multiple fracture of individual lamina
- Provide toughness

To satisfy these stress conditions we need:

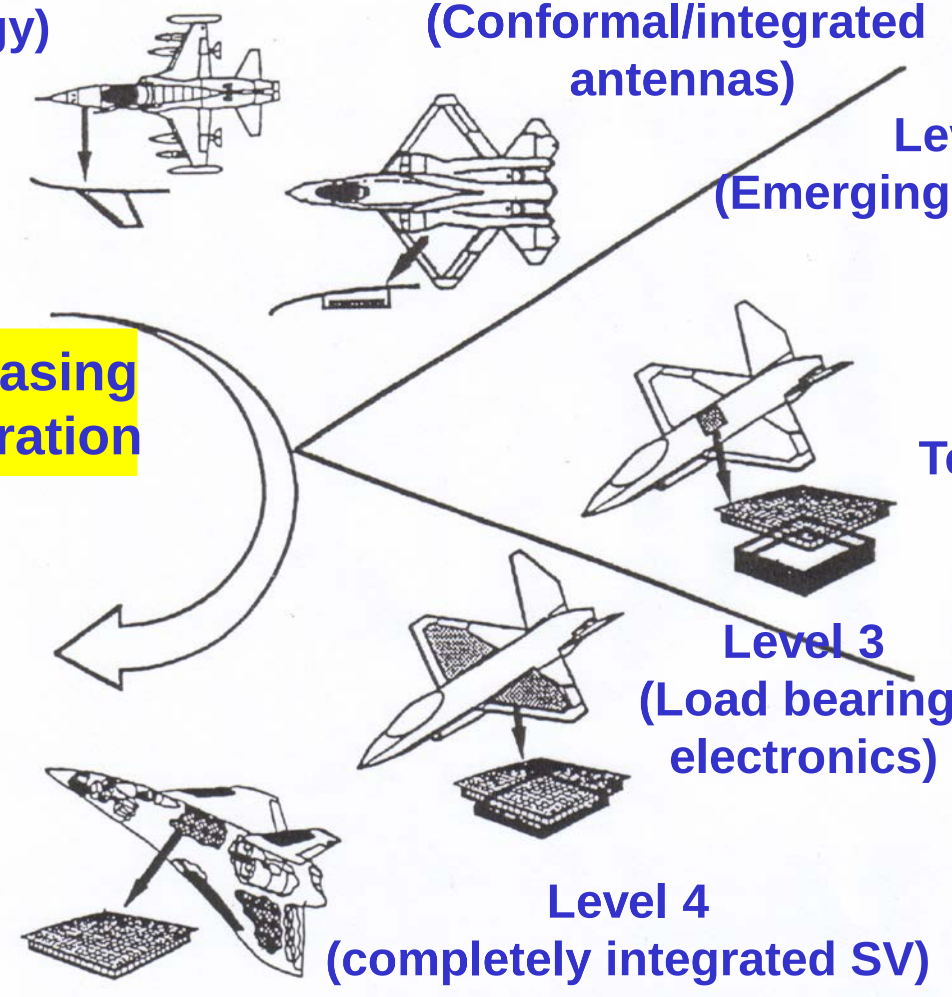
2 plies in x-direction,
4 +/-45 plies
1 ply in the y-direction



Typical Laminate Assemblies



★ *Integrated smart vehicle*



Design of a Laminate

- The fundamental problems in composites are to determine the stresses and deformation within each layer in terms of known load resultants and the prediction of onset of failure in a layer and its progression towards final failure

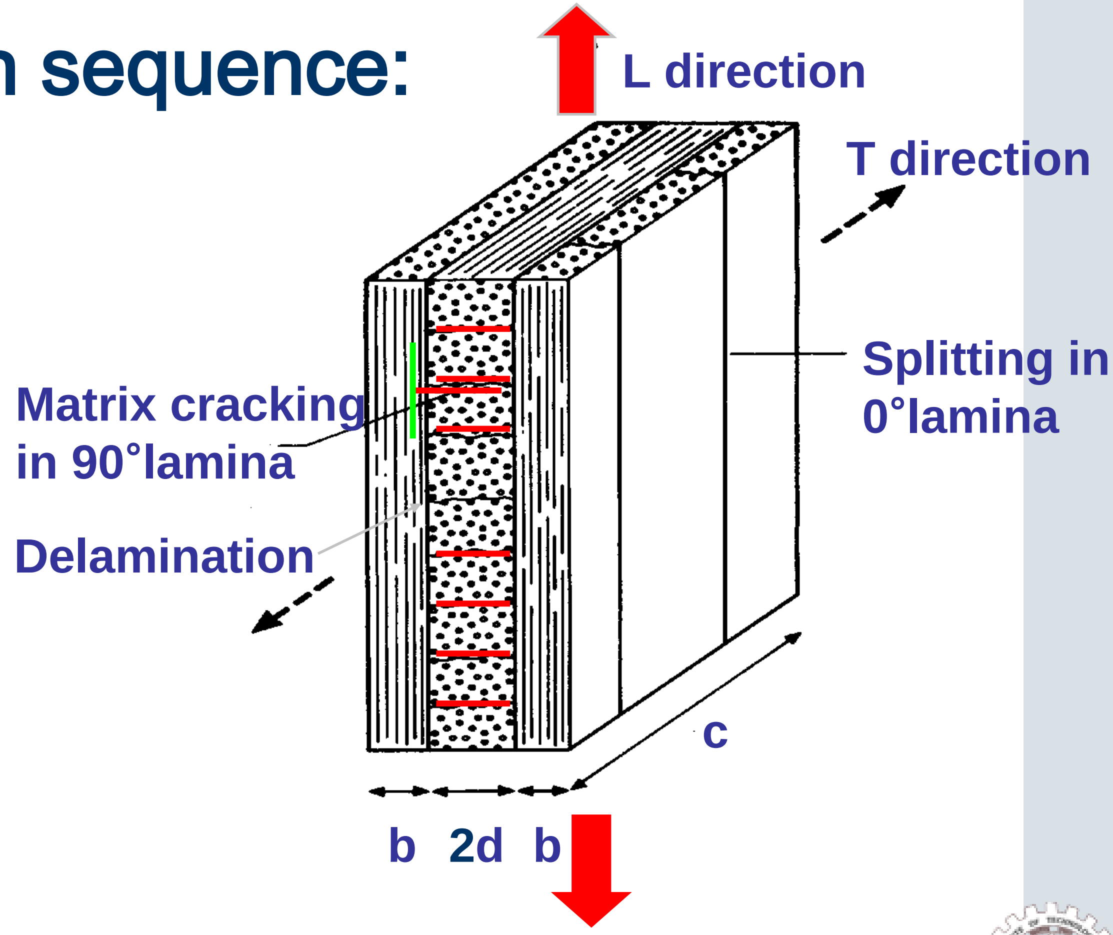
- In regions remote from boundaries and stress raisers the analysis of stresses is readily accomplished by LPT

- Prediction of failure is far less satisfactory
- Need for improved design tools to cover local stress details (OHC, impact, CAI) but also life prediction and damage and damage growth

Failure of a 0/90 laminate

Damage accumulation sequence:

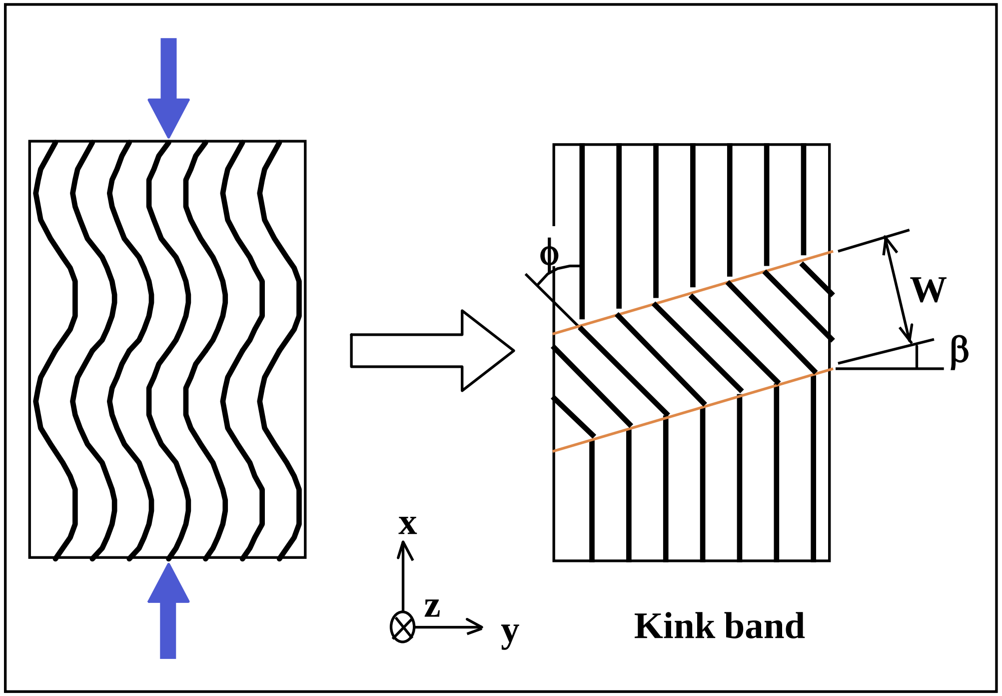
- Transverse cracking
- Longitudinal splitting
- Delamination
- Fibre fracture

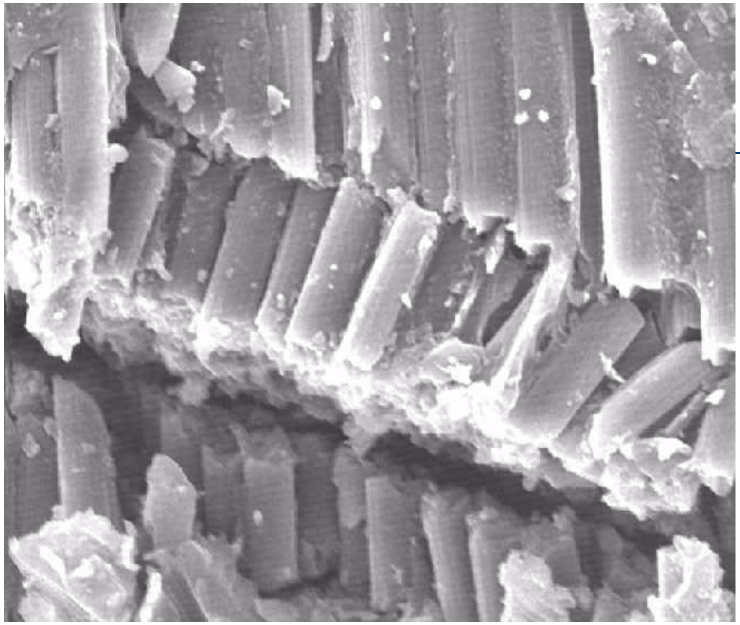


Damage Mechanisms under Compression: Fibre microbuckling

(Berbinau, Guz, Soutis)

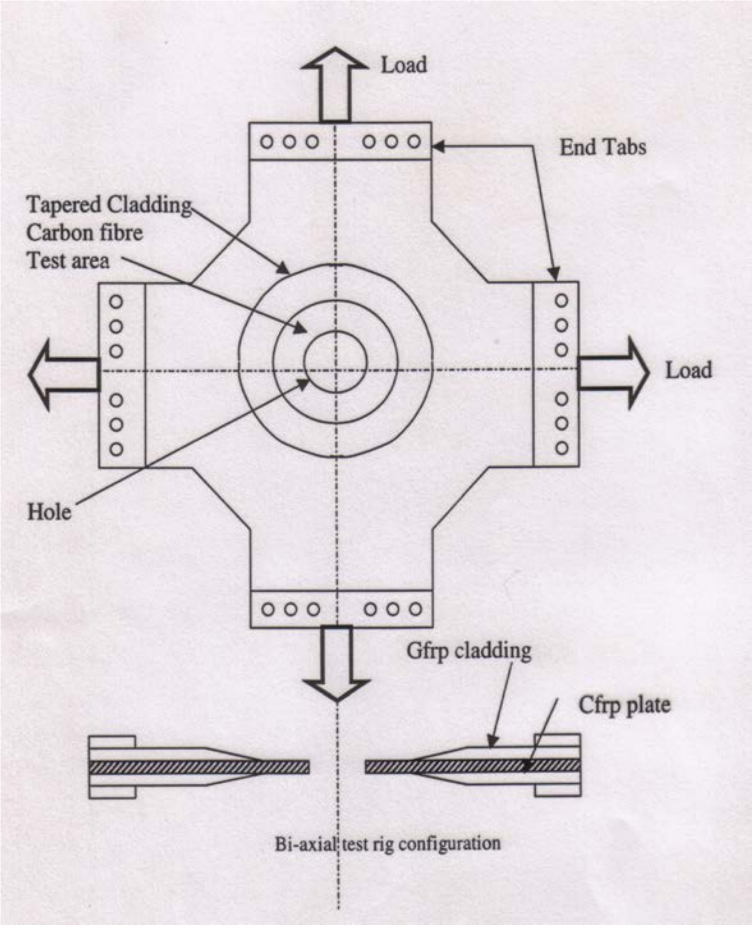
Compression failure of laminates occurs by fibre kinking of 0°-plies, immediately followed by delamination (catastrophic failure).





Kink band in multidirectional T800/924C laminate

Mechanical response of a laminate with an open/filled hole



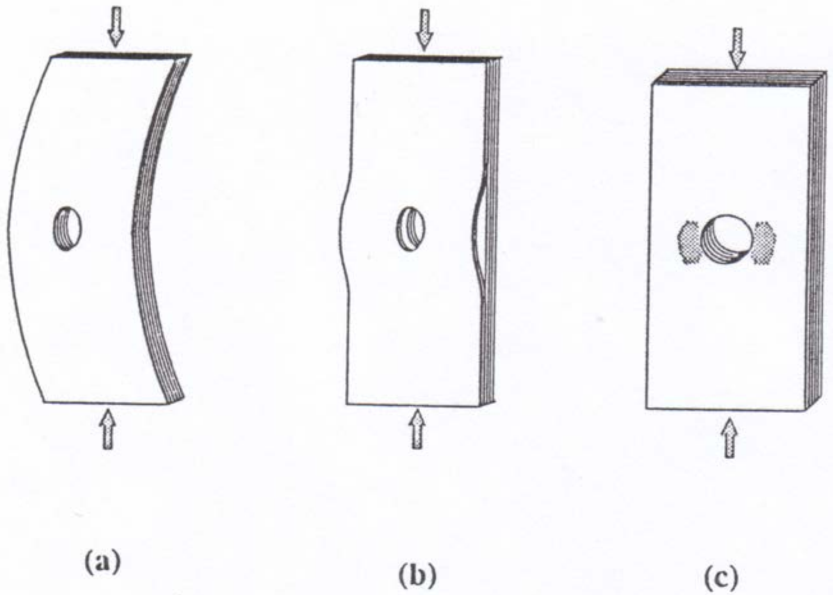
- **Composite failure is a hot topic, particularly for biaxial stress fields**

- **Tests on plates with holes because of weakness of CFRP to stress concentrations**

- **Compression is of particular interest due to fibre microbuckling**

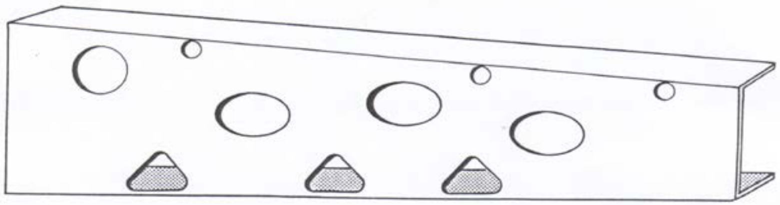
AA587, A300-600 fin

Compressive response of a composite laminate with a hole



Compressive failure modes:

a) Euler buckling
b) Sublaminate buckling
c) Local damage due to in-plane stresses
(fibre microbuckling)

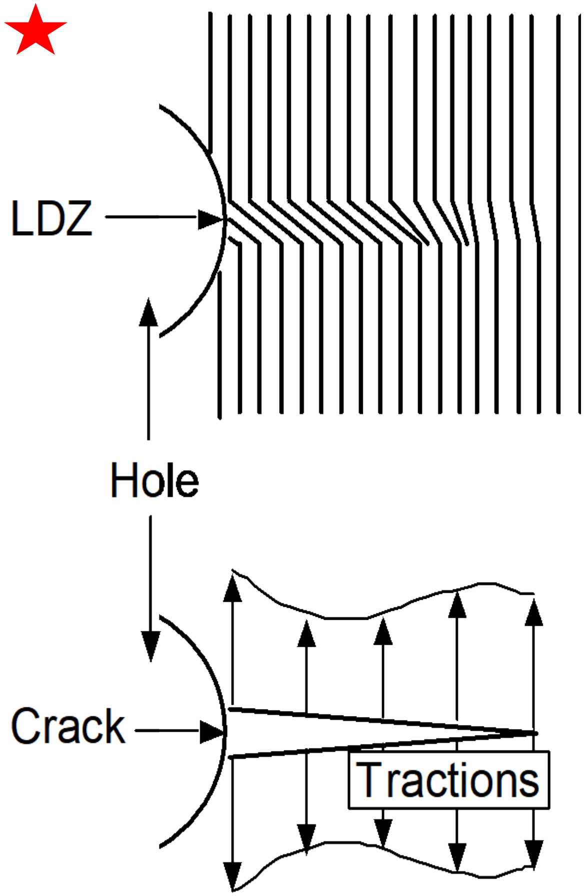


A schematic of a typical CFRP composite beam structure in an a/c wing

A schematic of a typical CFRP beam structure in an a/c wing

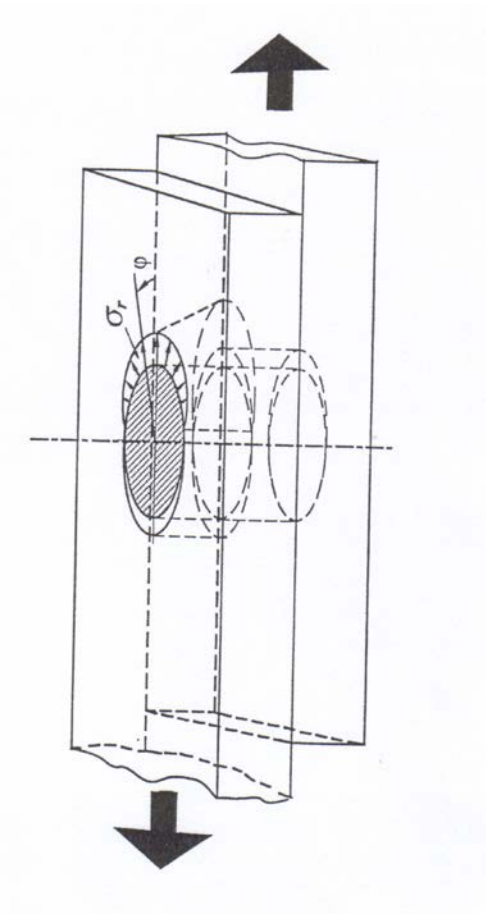
Damage Zone Modeling

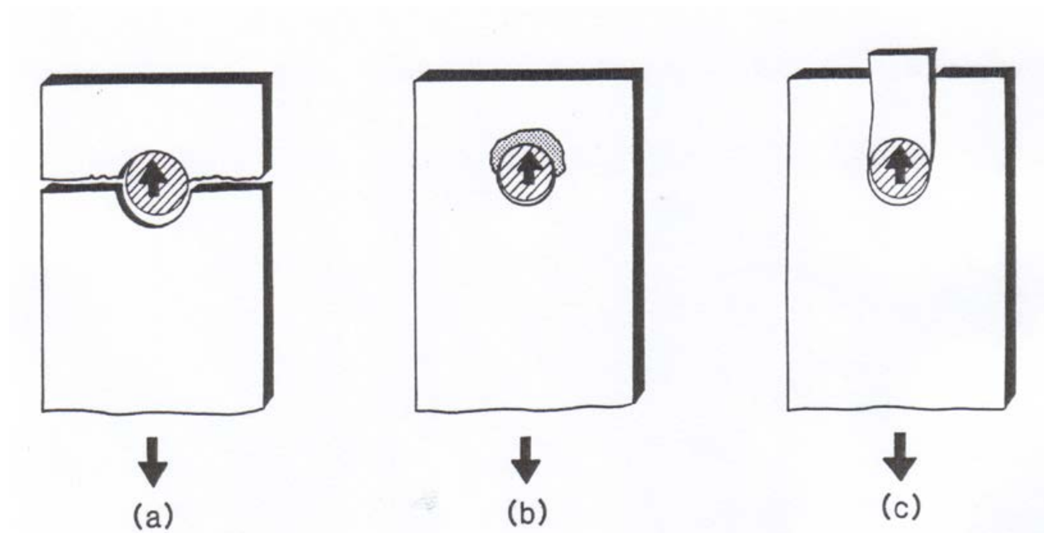
★



- The DZ is treated as an equivalent crack
- The traction distribution describes the load transfer characteristics of the damage zone
- Damage propagation is controlled by *traction law* and applied loading
- Three experimentally measured phenomena are predicted with a consistent physically-based model: DZ growth, critical length, ultimate failure load

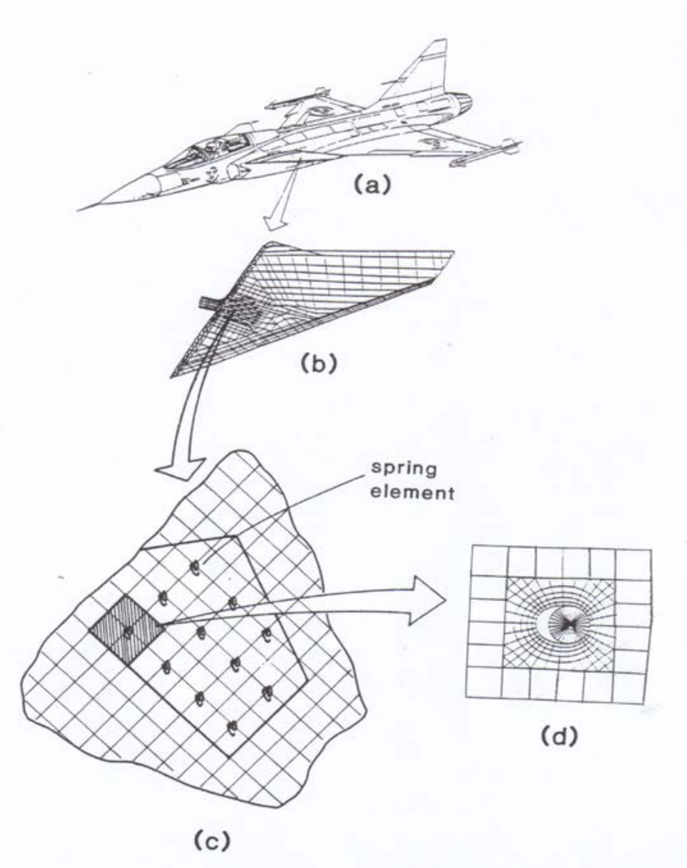
Stress analysis of bolted joints in an A/C structure

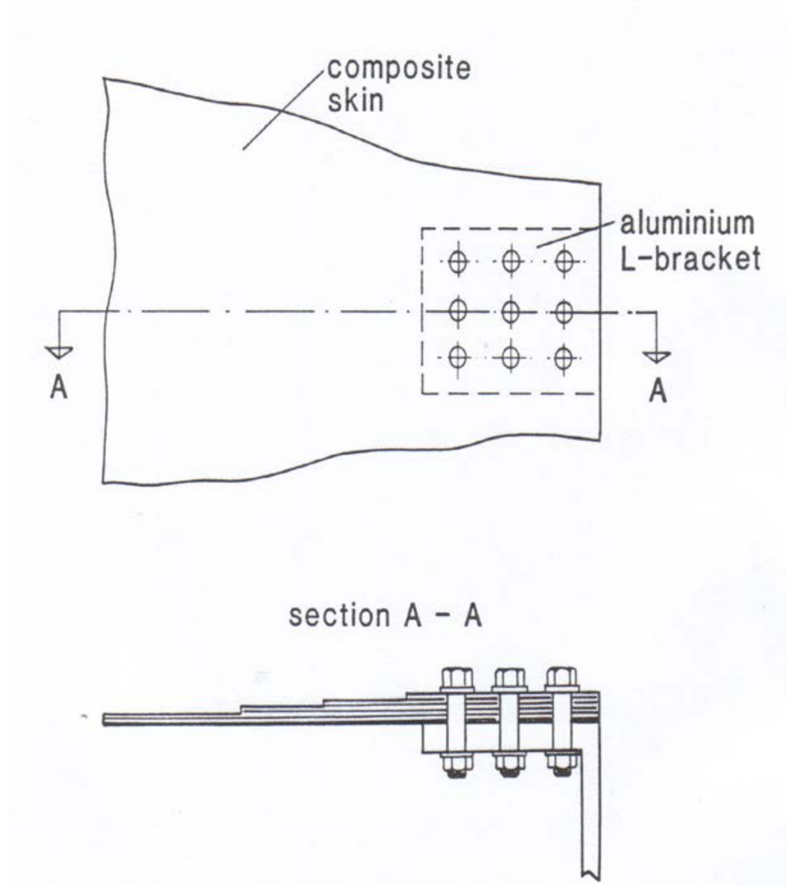


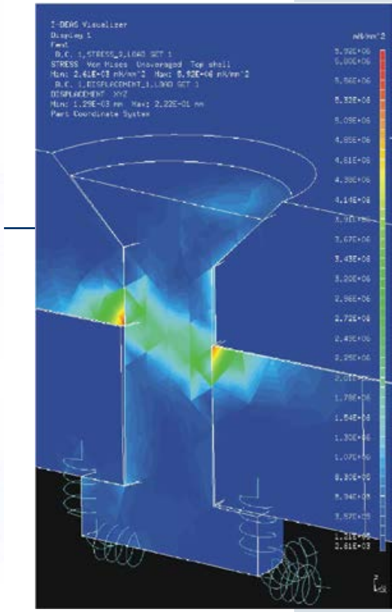


Tensile failure **Bearing failure** **Shear-out failure**

Stress analysis of bolted joints in an a/c structure



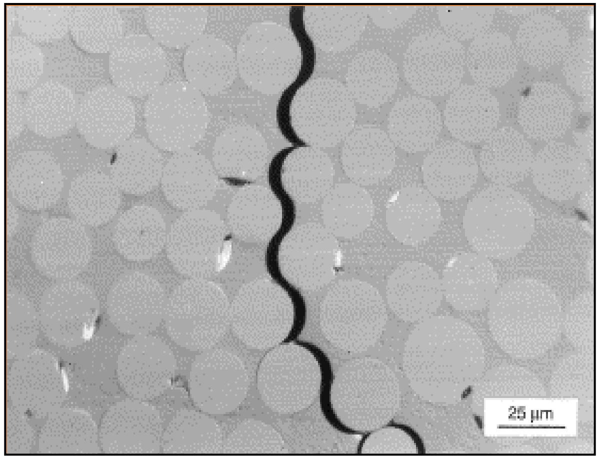


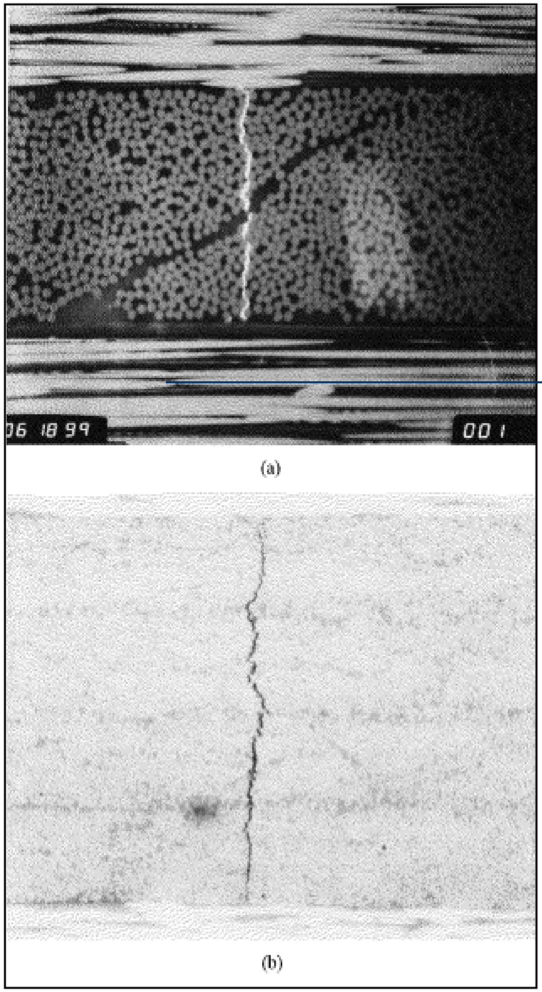


Composite wing skin bolted to a metallic L-bracket

Damage Mechanisms under Tension

- **Matrix Cracking causes degradation of the overall stiffness properties of the laminate**
- **Triggers development of other damage modes, delamination and fibre breakage**

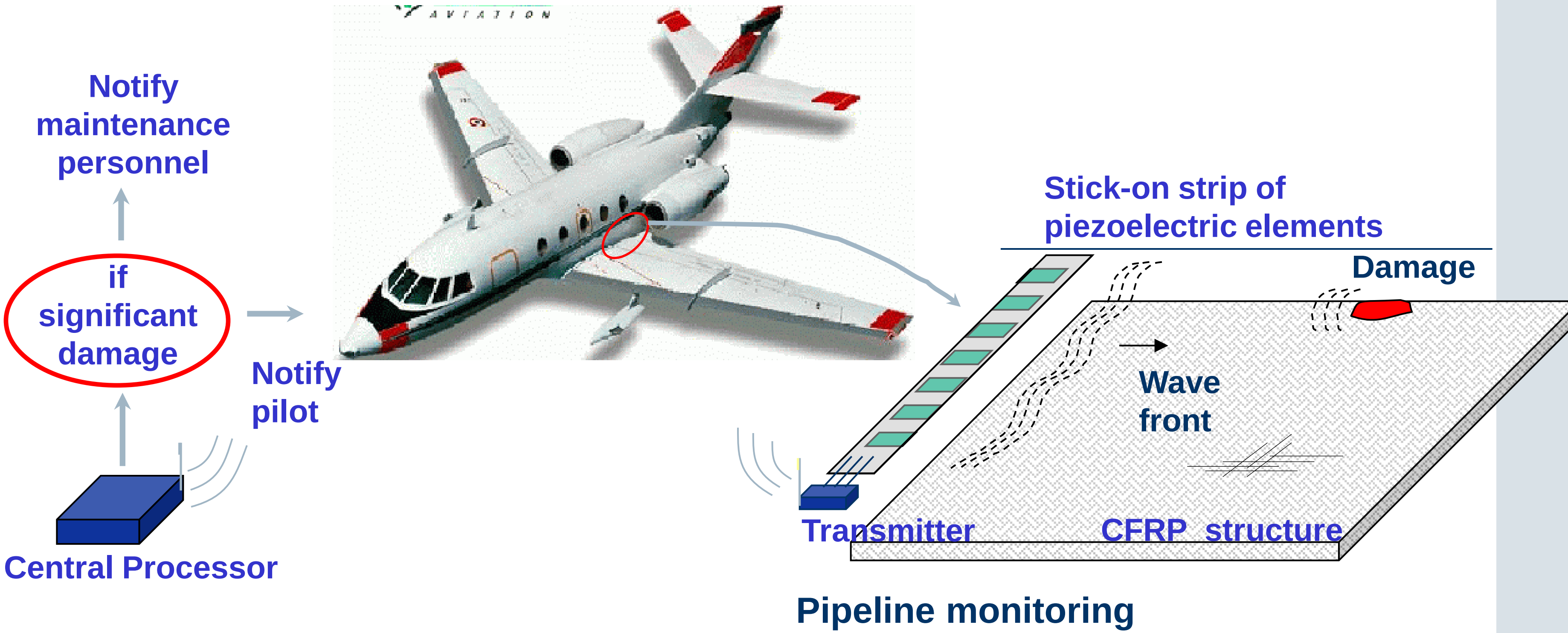




(a)

(b)

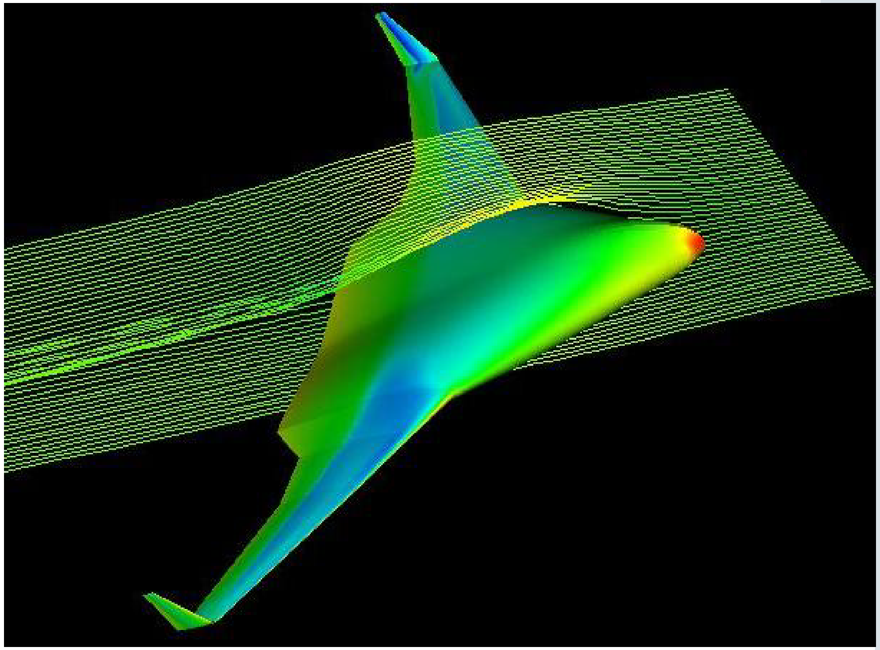
In-Service monitoring

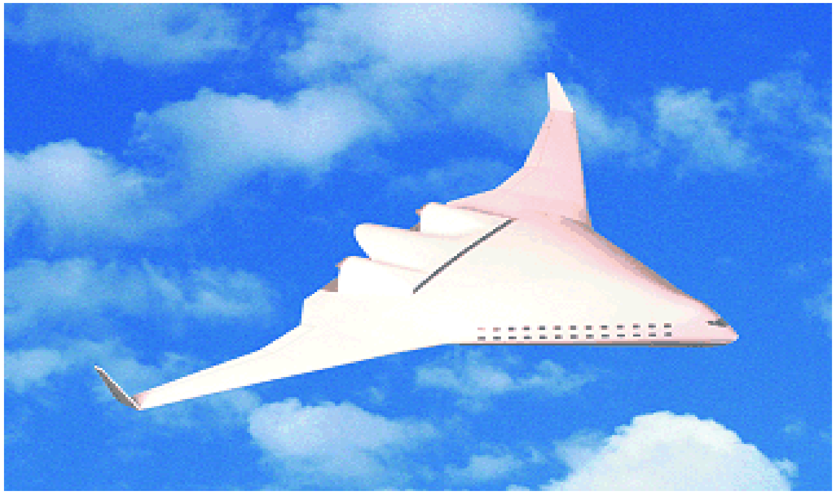


The Future?

Blended wing body civil aircraft

- **High capacity transport aircraft**
- **Transonic cruise speed: ~570 mph (912km/hr)**
- **450-950 passengers**
- **Range ~15,000 km, altitude ~10,000 m**





- **Studies:**

  Boeing/NASA/Stanford, USA

  Airbus/RR/Cranfield/Sheffield, EU

Why blended wing body?

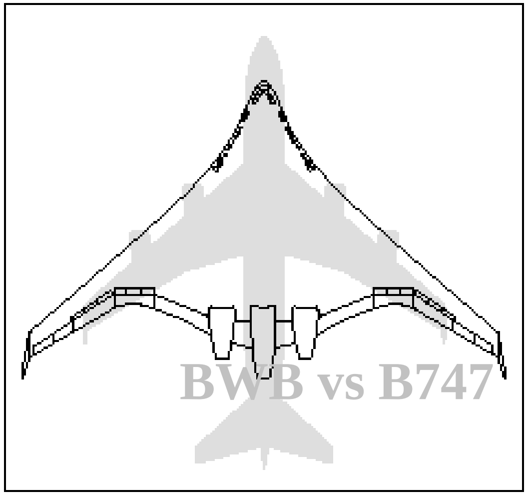
- **Main drivers for future A/C design: greener, quieter and safer**
- **Current cylindrical body/wing shapes are more than 50 years old, prohibiting substantial improvement**
- **BWB aircraft integrates body and wing**
  - ✓ Fuselage generates lift, drag↓, emission↓ (e.g. 3 instead of 4x 60,000 lbf thrust engines)

Main Challenges

✓ **Multidisciplinary integrated design**

✓ **Trim and stability at TO, cruise and landing**

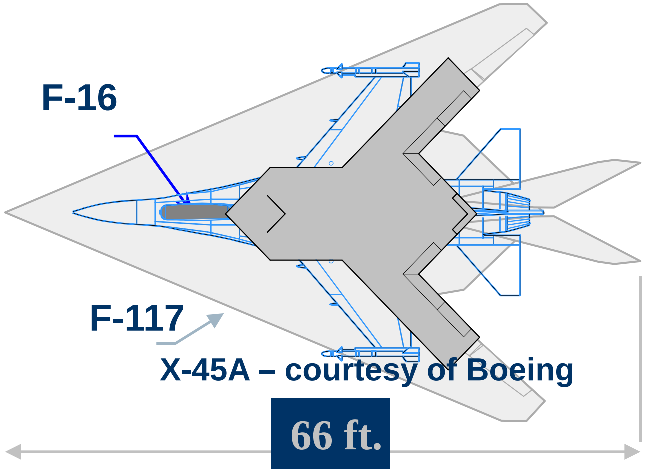
✓ **Manufacturing, public acceptance, evacuation,...**



UAVs spur composites use

- Unmanned Aerial Vehicles are viable options for atmospheric research, surveillance, combat and ground attack roles (UCAV)
  - X-45A is just 8m long, could drop 2,000-lb munitions

Boeing X-45A UCAV



Must consider

- New materials and fabrications routes
- Novel structural designs (Folded / detachable / inflatable wings)
- SHM & life prognosis
- Airworthiness

Courtesy of Prof Paul Curtis

Cost & Manufacture

- Reduction of Whole Life Cost (WLC) has become a key driver (cost of purchase, maintenance over service life of platform and disposal)
- UCAVs are projected to cost up to 65% less to produce than future manned fighter A/C
- Most promising manufacturing routes are Resin Transfer Moulding (RTM) and Resin Infusion under Flexible Tooling (RIFT)

X47A Pegasus– Courtesy of Northrop-Grumman

Rheinmetall Defence Electronics Taifun UCAV

Concluding Remarks

- **Composite Materials properties are excellent**
  - But still challenges to be met, especially in fabrication & design
- **Usage of Composites is growing at an increasing rate in Civil Aerospace**
  - Airbus A380, A350 & Boeing 'Dreamliner' B787 made major use of composites
- **In military systems, composites are becoming the 1st choice**
- **Future military strike aircraft may be unmanned**
  - Brings materials problems and challenges
  - Balance performance, stealth and cost

Need to reduce cost of all stages through design, materials and fabrication!

MAV

Concluding remarks

Priority Topics on composites:

- ✓ Novel materials and processes, design tools and methods
- ✓ Large-scale structures
- ✓ Inspection and Smart Structures
- ✓ Adaptive shapes/structures (morphing aircraft)
- ✓ Joining and Joints, Repair, Recycling/Disposal
- ✓ Can they be manufactured? What is the manufacturing cost?
- ✓ Maintenance cost?

….to the next 100 Years of Flight

INTRODUCTION

Composite Space Structures

What are space composite structures?

- Space Structures are launched from ground to space orbit. Therefore its size and weight are strictly limited as well as its load and stiffness conditions are severely required in orbit.
- In case of satellite structure materials, weight reduction is most important as well as high specific strength and stiffness materials are necessarily required.
- Recently satellites trend to become larger and multi-missions, so the lightness should be needed.
- Therefore light metal structures have been replaced by advanced composite structures because have better thermal and mechanical properties as well as flexibility of optimal design depending on required load conditions and types.

Part 2 INTRODUCTION

- **Recently most satellite structures are made of more than 40% composite materials.**
  - Satellite structure: High stiffness CFRP
  - Solar energy panel : Aramid or Glass fiber reinforced plastics (good electrical insulation and radio wave transmittance)

- **Satellite structure is composed of major structure to support payloads, communication and exploration antennas, solar energy panel, truss to connect between payload equipment, attitude control rocket motor pressure vessel**
  - **Major structure** : to endure vibratory dynamic load during launching
    . **Platform type structure** (CFRP and Aluminum honeycomb sandwich using autoclave method)
    . **Cylindrical type structure** (CFRP using filament winding method)

Part 2 INTRODUCTION

- **Communication parabolic antenna**: use **CFRP face sheets- Al honeycomb sandwich structure** due to dimensional stability requirement to temperature change in space orbit and precision manufacturing
- **Exploration antenna**: use **hybrid composite panel composed of reflection panel using Aramid FRP (KFRP) and CFRP** supporting plate due to electrical insulation and dimensional size stability requirements.
- **Truss and Pressure Vessel**: use **CFRP and KFRP using filament winding method**
- **Solar energy panel: CFRP frame with net type membrane using filament winding method** due to supporting solar energy battery

Part 2 INTRODUCTION

- Satellite materials should be selected by considering not only lightness due to limitation of size and weight but also operation environmental conditions.

- To meet this requirements high specific strength and stiffness as well as the following requirements are needed;

① High strength and damping behaviors to endure dynamic and static loads at launching

② Dimensional size stability at severe temperature environment (-200~250˚ C)

③ Weight reduction rate should be less than 1% in high vacuum environments (-10-13torr)

④ Excellent creep behavior due to long time use in space

Part 2 INTRODUCTION

- **Composite materials have lightness such as high specific stiffness and strength as well as good dimensional size stability in severe space environment due to zero or negative thermal expansion coefficient (carbon fiber). Moreover it has design flexibility by tailoring depending on loading direction as well as by selecting different composite materials and various manufacturing methods.**
- **Even though satellite structure weight is about less than 5% of total launching weight, its lightness gives very high economic effectiveness.**

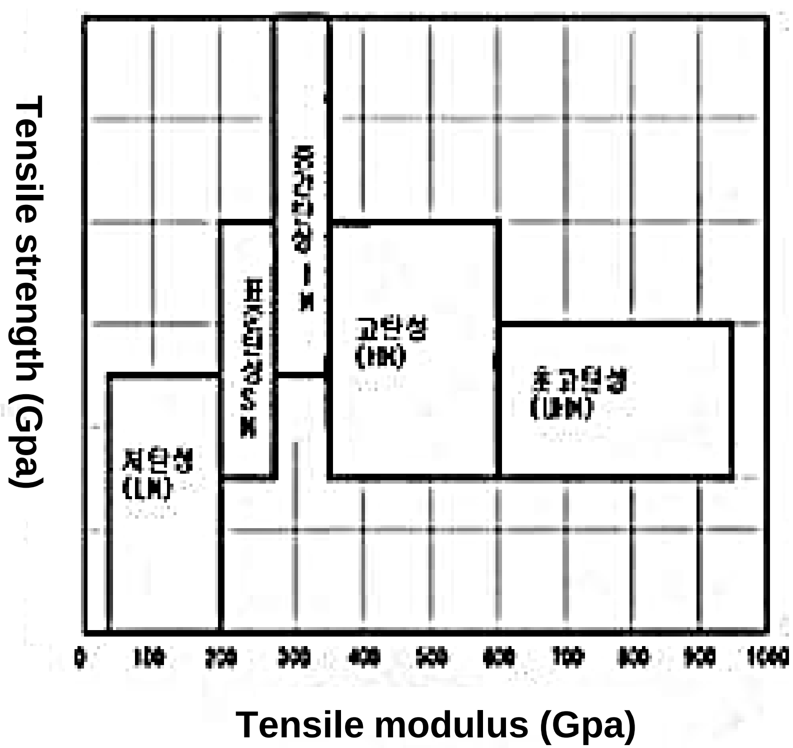
Part 2 INTRODUCTION

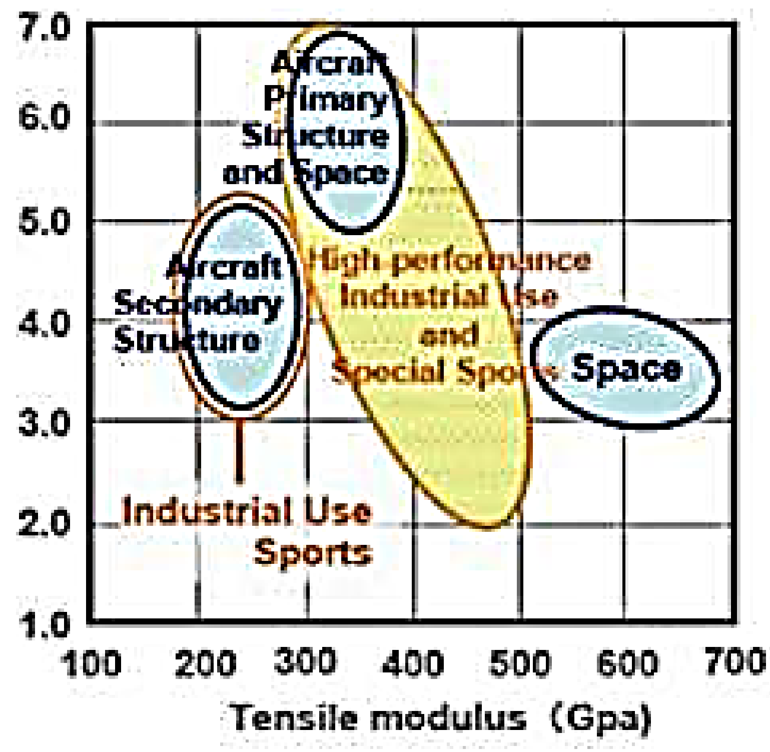
✓ Comparison of mechanical properties of various materials

Properties	Unit	Carbon Fiber: TR5DS	Duralumin : 2024-T7	Glass Fiber: E glass	Aramid Fiber: Kevlar 49	Stainless: SUS 304
density	□g/cm³□ □□	1.82	2.77	2.55	1.45	8.03
Tensile strength	GPa	4.9	0.4	3.4	3.6	0.5
Tensile Modulus	GPa	230	74	74	131	197

Part 2 INTRODUCTION

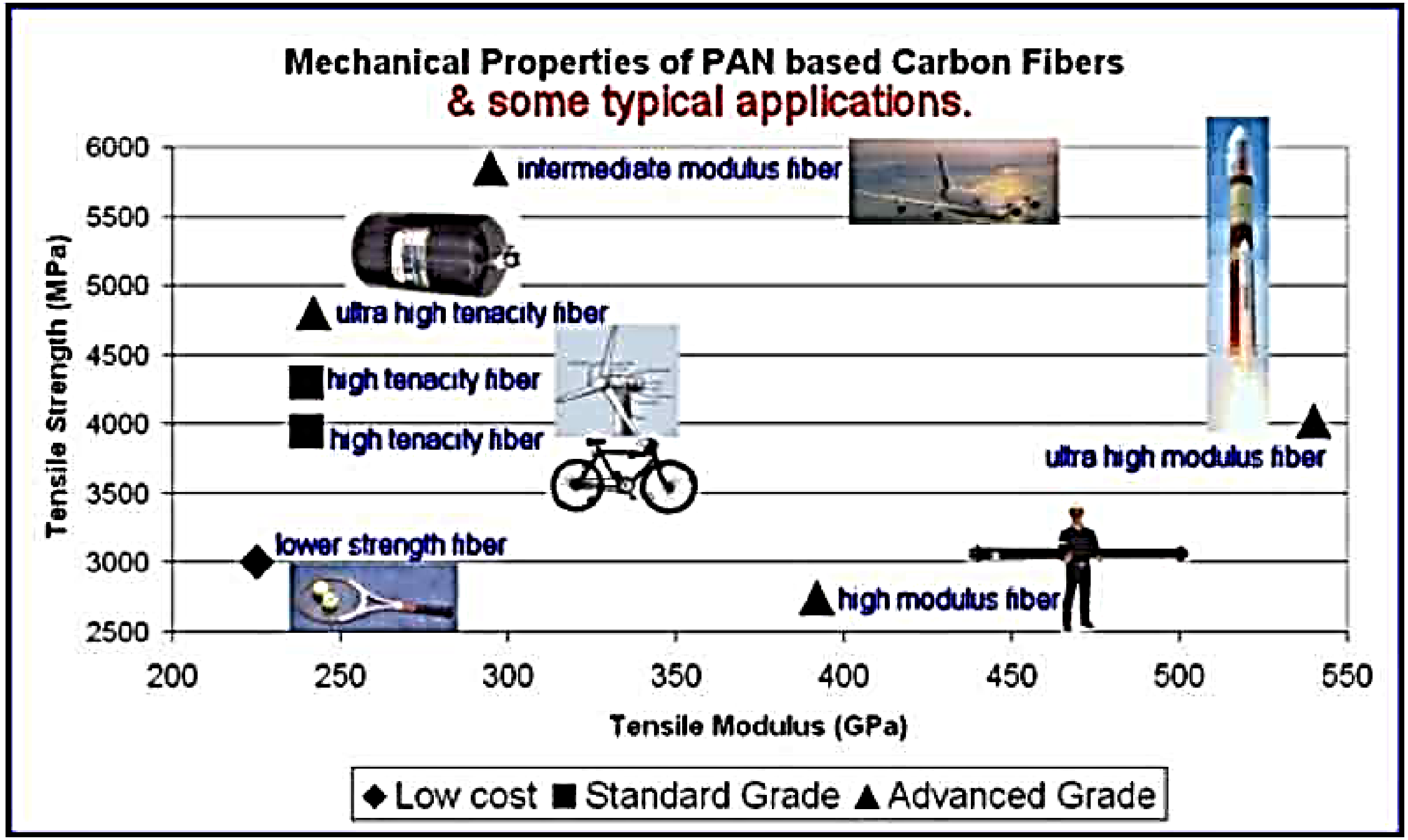
✓ **Mechanical performance and application Carbon fiber**



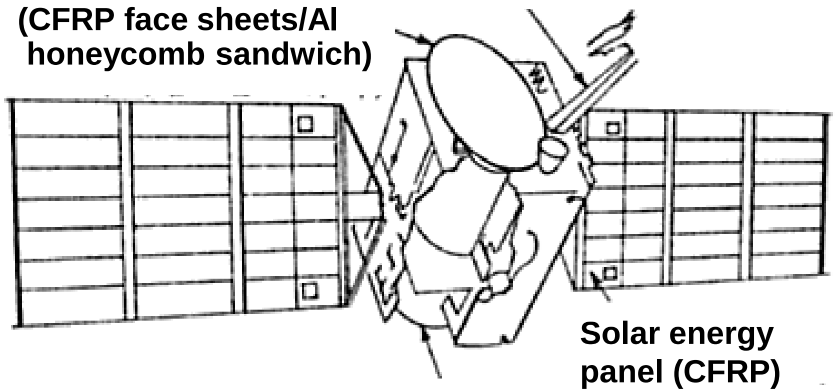


Part 2 INTRODUCTION

✓ **Mechanical properties and application of PAN Carbon fiber**



Part 2 INTRODUCTION



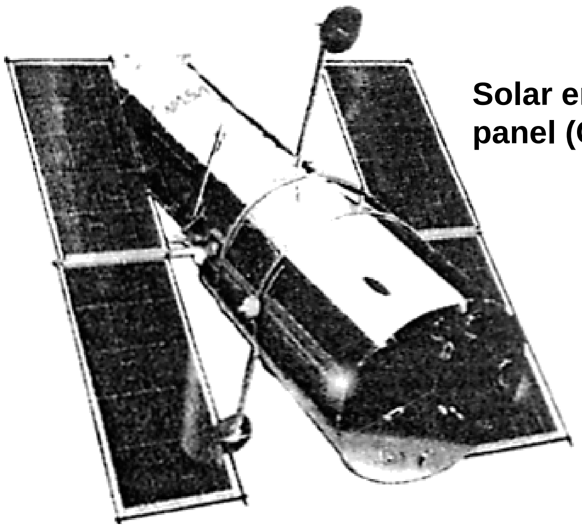


Fig. 3D Control Satellite Structure

Fig. Hubble Satellite Telescope

Part 2 INTRODUCTION

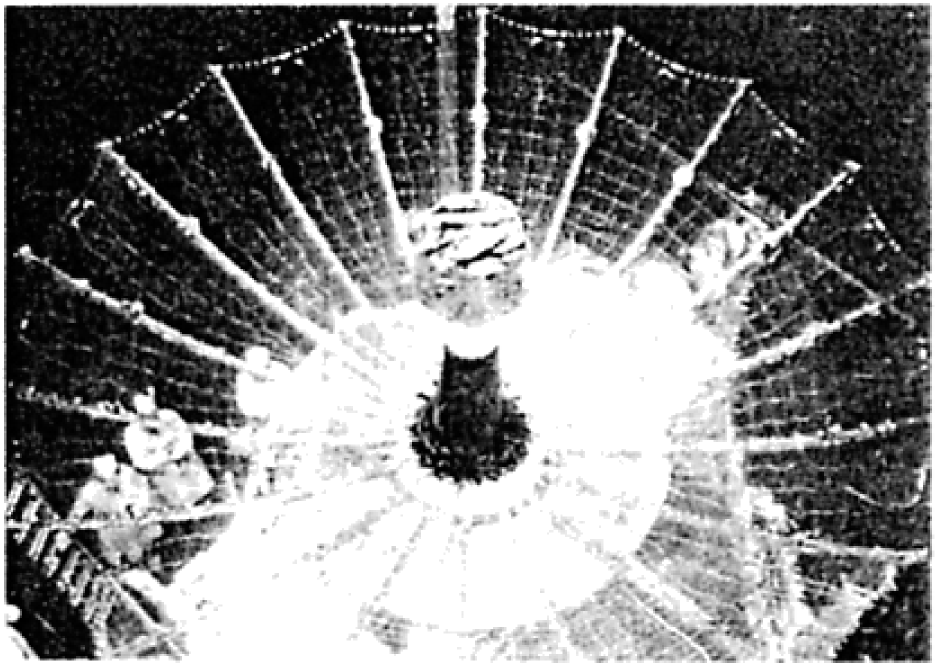


Fig. 3D Data Transmittance and Tracking Satellite Antenna (CFRP support structure and net type structure)

Thank you for your kind attention!