Future aerostructure for the next generation green civil aircraft

A. Amendola, G. Iannuzzo, P. Cerreta, R. Pinto

Alenia Aeronautica

Aerodays 2011

Madrid
Y2003 was the centennial celebration of the Wright Brother’s First Flight.

Only 5 years later aeronautics faced one of the most critical crisis, in the Y2008 more than 25 air carriers went bankrupt, the price of oil barrel more than quintupled to stable over US$100.

Growing competition from ground transportation, in fact in the same year (Y2008) the Chinese HVT set a speed record of 394,3 km/h between Beijing and Tianjin, reducing travelling time to 30 mins centre to centre.

Changing Aircraft Requirements?

• A380 first flight April 27th, 2005
• B787 first flight December 15th, 2009
The severe economical situation after 2009 pushed airlines to optimize the use of their assets,

- higher load factors,
- higher aircraft utilization
- more reliability and versatility,
- reduced capacity due to growth of regional aviation

The financial crisis of 2008 and the recession in 2009, caused a decline in the average air traffic growth

---

**Average annual growth (%)**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger-kilometres Performed (PKPs)</td>
<td>5,3</td>
<td>4,7</td>
<td>4,3</td>
</tr>
<tr>
<td>Freight tonne-kilometres performed</td>
<td>7,4</td>
<td>6,6</td>
<td>2,6</td>
</tr>
<tr>
<td>Mail tonne-kilometres</td>
<td>4,0</td>
<td>1,2</td>
<td>-2,7</td>
</tr>
<tr>
<td>Total tonne-kilometres performed</td>
<td>5,8</td>
<td>5,2</td>
<td>3,7</td>
</tr>
</tbody>
</table>

**Trends in Total Scheduled Air Traffic (1979-2009) 2009 ICAO Provisional Data**

<table>
<thead>
<tr>
<th></th>
<th>1979</th>
<th>1989</th>
<th>1999</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger load factor (%)</td>
<td>66</td>
<td>68</td>
<td>69</td>
<td>76</td>
</tr>
<tr>
<td>Aircraft Utilization (hours per aircraft per year)</td>
<td>2,068</td>
<td>2,193</td>
<td>2,770</td>
<td>3,502</td>
</tr>
<tr>
<td>Average aircraft capacity (seats)</td>
<td>149</td>
<td>181</td>
<td>171</td>
<td>166</td>
</tr>
</tbody>
</table>

**Developments in Selected Elements of Airline Productivity (1979-2009) 2009 ICAO Provisional Data**

Data Source ICAO Statistics Program
The effect of oil price by type of aircraft

Long Range 30/bl (2002)

- Personnel: 15%
- Acquisition Cost: 23%
- Fuel: 24%
- Maintenance: 7%
- Miscellaneous: 24%
- Taxes & fees: 8%

Long Range 150/bl (2008)

- Personnel: 17%
- Acquisition Cost: 18%
- Fuel: 44%
- Maintenance: 8%
- Miscellaneous: 5%
- Taxes & fees: 8%

Short Range $30/bl (2002)

- Personnel: 28%
- Acquisition Cost: 21%
- Fuel: 22%
- Maintenance: 8%
- Miscellaneous: 10%
- Taxes & fees: 11%

Short Range 150/bl (2008)

- Personnel: 35%
- Acquisition Cost: 8%
- Fuel: 13%
- Maintenance: 31%
- Miscellaneous: 17%
- Taxes & fees: 8%

To-day fuel cost represent the most critical economical factor affecting aircraft operation.
Commercial traffic will grow anyway

Emerging Economy (Asian Pacific, Latin America, Middle East) will lead a continuous growth of air transport demand

Particular attracting for regional aviation the will remain domestic North- America and China and Intra- Europe)

More than 44000 new aircrafts are expected to be introduced by 2036 – Source ICAO
Aircraft Efficiency

- higher load factors,
- higher aircraft utilization,
- more reliability and versatility,
- reduced capacity due to growth of regional aviation

Fuel Saving
- Increasing fuel efficiency
- Reducing direct operating costs

Maintenance
- Weight Reduction
- Aerodynamic Efficiency
- Engine Efficiency
- System Monitoring

Economy

Environment

Market

Oil
Typical a/c weight breakdown

Narrow Body

- **Empty weight**
  - Structure
  - Powerplant systems
  - Fuel
  - Payload

Fuselage weight breakdown (%)
- Skins
- Stringers
- Frames
- Floor & others

Wing weight breakdown (%)
- Skins
- Stringers
- Spars
- Ribs

Airframe typical weight breakdown
- Fuselage
- Wing
- Empennage
- Landing gear
- Movable parts

www.cleansky.eu

ALeniaAeromutica
A.Rcnicoa Company
Weight reduction impact on fuel consumption

Weight reduction impact should be evaluated at A/C level to account for the well-known snowball effect.

<table>
<thead>
<tr>
<th></th>
<th>Weight (kg)</th>
<th>Weight reduction (kg)</th>
<th>Saving (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airframe weight</td>
<td></td>
<td>-2500</td>
<td>-12%</td>
</tr>
<tr>
<td>OEW</td>
<td>41000</td>
<td>-2500</td>
<td>-6%</td>
</tr>
<tr>
<td>Payload</td>
<td>13600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>8800</td>
<td>-300</td>
<td>-4%</td>
</tr>
<tr>
<td>Take-off Weight</td>
<td>63400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td></td>
<td>-220</td>
<td>-3%</td>
</tr>
</tbody>
</table>

A typical aluminium single-aisle (OEW/MTOW = 0.56) a reduction of 12% of structural weight will result in about 6% of OEW reduction with subsequent roughly 7% of less fuel burn.
Aircraft Efficiency and Environmental Impact

Green Aircraft Deliveries

Impact of Green Technologies on Operating Costs

Savings up to 2029

- Fuel burnt - million t: 16.0
- Fuel Cost - billion $: 12.5
- Maintenance Costs - billion $: 1.5
- Taxes Expenses - billion $: 5.0
- CO2 Emissions Savings - million t: 50.4

2010 World Regional Fleet: 9300 a/c
2029 World Regional Fleet: 10800 a/c

Fuel Price est.: 100$/barrel

Fuel consumption reduction: -20%
Green aircraft deliveries: 50%
Yearly flight: 1800
The biggest share consists of propulsion (SFC -40%) and aerodynamics (L/D +15%).

The structure efficiency of aluminium aircraft concept did not change too much.

However structural efficiency, measured in terms of the ratio of operating empty weight (OEW) versus maximum take-off weight (MTOW) tended slowly to shift towards number higher than 0.50. Modern aircraft effectively OEW/MTOW is ranging among 0.50 and 0.66.

Since the 1960’s most aircraft efficiency improvements came from technological development outside the field of aircraft materials, structures and manufacturing.

Many further potential improvements in weight reduction mainly were annulled by other technological improvements that became constrains such reliability, durability, passenger comfort and safety.
Structure efficiency as OEW/MTOW (Operating Empty Weight/Maximum Take Off Weight) for aluminium aircraft increased from 0,53 (B737) to 0,56 (A320-200) due to safety and comfort reasons.

Down sized aircraft are generally less efficient (as example A318) from 0,60 to 0,66.
Evolution and Trends

Weight reduction have been always achieved by the introduction of new technologies such as advanced alloys and composite materials, improved manufacturing processes and techniques and new systems (fly-by-wire for example)

- Aircraft designed in 1990’s were based on metallic structures, only 12% were built in composite;

- A380, flying since 2005, incorporates up to 25% of advanced lightweight composite that generate a 8% weight saving,

- Next generation commercial liners (B787, A350, C-series) will reach up to 50% of advanced composite structures generating a further 15% weight saving for this level of technology.
- Wing mouv. Parts
- Empennage mouv. parts
  (H/C sandwich and full depth)
- Vertical Fin
- Horiz. Stabiliz. (cocured box)
- Wing mouv. parts
- Wing panels (integral cobonded J-spar)
- Rear fuse panels
- Outboard Flap (H/C sandwich 2nd generation)
- Horizon Stabilizer (cocured multispar)
- Vertical Fin (panels & cobonded stringers)
- Rudder & Elevator
- Barrier Walls (large panels)
- Upper Beams
- Wing (Fiber placement panel)
- Horizontal stabilizer (cocured multispar)
- One Piece Barrel (RFI frames)

B767
Eurofighter
B777
ATR 42/72
A380
JSF
B787

1980 - 1995
1995-2010

CFRP Roadmap
Rethink architecture concepts

Just replacing material in order to save weight, for instance aluminium by carbon fibre reinforced epoxy (black metal structure), was the most straightforward, but resulted to be inattentive and poor productive.

- The use of advanced materials will lead in future structure design a rethink of basic structural concepts.

- As an example well-designed cross sectional dimensions, plate thickness, stringer pitch, stringer height and of course stringer cross-section design itself, are major parameters to improve the load carrying capacity per unit weight.

- However, many applied stringer configurations were in the past not selected for their efficiency but for reasons of manufacturing and assembly cost reduction.

- Metal solution attractive for numerical machining, bonding or riveting, might not be the appropriate solutions for lighter CFRP.
Future and breakthrough technologies

Clean Sky GRA technologies:

- Advanced Metallic Material

- Advanced Composite Material:
  - Multilayer-multifunctional (metallic meshes, veil damping, toughened, thermoplastic)
  - Nano reinforced resins
  - Dry-fiber infusion process
  - Automated Fiber placement

- Structural Health Monitoring
Advanced Metallic & Composite Material (AMM & ACM)

LWC - Advanced Metallic & Composite Material (AMM & ACM)

AMM & ACM

Technology Readiness Level (TRL)

Coupons Test: First Down Selection

Panel Test: Second Down Selection

Static & Fatigue test by full-scale Ground Test - Demonstration


Ti wires
Aluminium Litium alloy (2139) - Laser welding activities

- Tension test / joint parallel to load direction
- Shear tension test (static)
- Compression/tension test

- welded samples provide good static strength for both heat treatment conditions, higher than 6xxx alloy light weight potential;
- higher yield strength of the welded sample than for the base material
- fracture strain of welded sample is at least reduced down to 50% compared to the base material

(Coupons manufactured and tested by FhG)
The future will see multidisciplinary optimization approach looking for high level of efficiency by integrating different functions and different combination of materials, structural concepts and manufacturing technologies.

Investigation on all the solutions that may allow for considerable weight reduction, from the improvement of current composite materials with more innovative solutions such as:

- **Multi-functional Layer**
- **Multi-layer architectures**
- **Nanomaterials**

that can ensure impact resistance, electric conductivity and lightning resistance without additional special items - i.e. with no additional weight - and a better acoustic insulation.

Multi-functional Single Layers and Multi-layers - to improve and integrate in the structure additional capabilities (lightning, hail protection)

Nanomaterials: to improve electrical conductibility characteristics by means of nano-particles dispersed in the resin

Advanced Composite Material: Multifunctional Layer configuration of a Carbon Fabric pre-preg with Titanium wires interwoven. *(Coupons manufactured by HAI)*

A view of two specimens manufactured and a cross section of a specimen *(Coupons tested by Cira)*
Advanced Composite Material: Nano reinforced Composites

- Metallic free bucky-paper for ice protection and the nano reinforced resin systems for lightning protection: an attractive solution for future applications

- Nano-filled resin system to produce an innovative prepreg (nano-filled thermosetting resin and Carbon Fiber) for the manufacturing of composite panels with increased impact behaviour

Impact test stand used to investigate the effect of bucky-paper on impact induced delaminations.

(Coupons manufactured and tested by FhG)
Advanced Composite Material: Nano reinforced Composites

An automatic system was developed for the deposition of epoxy microfibers loaded with carbon nanotubes on carbon fibre laminated panels. It applies automatically epoxy microfibres with carbon nanotubes in a surface of 2000 mm x 1000 mm and in several laminate positions.
Structural Health Monitoring: GRA LWC “Sensors Enabling Technologies”

Prognosis-Diagnosis fusion

- Load Monitoring
- Strain Sensors
- Stress Measurement
- Fatigue Life Analysis
- Impacts Detection
- Corrosion Detection
- Defects Detection
- Damage Monitoring
- NDI/NDE
- Health Monitoring Equipment (HME)

Prognosis: Health Management System (HMS)

HMS on-board connected to the ground support structure
SHM system by means Distributed Optical Sensors
The distributed optical sensor technologies to be analysed are:

- Optical Backscattering Reflectometer (OBR),
- Distributed Sensors System (DSS).

**OPTICAL BACKSCATTERING REFLECTOMETER (OBR)**
The OBR technology allows the continue capture, on a simple optical fibre (single mode), of the mechanical and thermal strain on a fiber optic cord with a length up to 70 meters.

**DISTRIBUTED SENSOR SYSTEM (DSS)**
The DSS technology allows the continue capture, on a fiber optic cord using a series of Bragg gratings.
Turin, 18 November 2010 at 08:30 GMT: Alenia Aeronautica C-27J Spartan flight test aircraft took off from Turin for a successful 2 hours long flight, to evaluate a Structural Health Monitoring System based on Fibre Optic Bragg Grating (FOBG) sensors Technology, on the path towards FOBS technology validation through flying demonstration on ATR 72-600 aircraft in 2015 year.

A “Rosette Strain Gage” was internally applied to compare the measures of the innovative optical sensors with the conventional ones. Dedicated manoeuvres were performed to measure:

- mechanical and thermal strains at different altitudes (h=30000ft and T=-50°C).
- electrical interfaces compliant equipment were inserted to interrogate the FOBG sensor.

FOBG technology will strongly contribute to lower a/c weight configuration and maintenance costs, by allowing “On Condition” maintenance operation and avoiding execution of structural inspections at pre-defined timeframes.
Existing pre-preg based technologies have drawbacks, including high material costs, limited shapeability, complex, expensive and time-consuming manufacturing, and short materials shelf life.

Alternative manufacturing methods are based on Liquid Resin Infusion (LRI) technologies in which the resin is infused only after that all dry textiles are assembled to form the final composite component configuration.

Pre-form has the advantages: lower material and material storage costs, indefinite shelf life (for the textiles) and the ability to manufacture integrated structures having complex geometries only limited by shapeability of the dry pre-forms.

Infusion-molding processes use a mold or a tool draped with dry reinforcement, preforms, or core materials. RTM uses a two-sided tool with resin pumped in, while VARTM typically uses only one tool, and the resin is drawn in. In VARTM, a vacuum bag surrounds the entire assembly of an open tool filled with reinforcement—the bag pressure forms the part on the side opposite the tool.
Resin Film Infusion (RFI) is a process of infiltration of a dry preform with resin during the phase of curing in the autoclave. Non crimp fabric

- Alternate layers of U.D. fibers knitted together within the thickness

Braided preform

- Multiple filament wound tows in a tubular shape preform

Infusion Technologies cont’d

Tango European research program - Full RFI fuselage panels

Tango European research program - Hybrid RFI wing upper panel

Infused Window Frame

National funded R&D project, aimed at acquiring a structural data base for an innovative, patented material & process (dry tow placement + resin infusion).

Multi-head embroidery machine for dry tow placement
Automated Fiber placement

The availability of fiber-placement robots created a breakthrough for technologies based on pre-impregnated fibres, tows and tapes, this in changing aircraft structure manufacturing.

To some extent similar to what happened in the 50s due to the integral aluminium structures blade stiffened and numerical milling machines.

Fiber Placement is an automated composites manufacturing process of heating and compacting resin pre-impregnated non-metallic fibers on typically complex tooling mandrels. The fiber usually comes in the form of what are referred to as "tows".

Advanced Fiber Placement machines is going to be used for the manufacture of large-scale, complex-shaped structures.
The most remarkable example is the B-787 that at 50 percent composites, by weight. The advantages of significantly increased use of composites go beyond the more obvious weight/economy benefits. Greater cabin pressure, larger windows, less corrosion and extended maintenance schedules were key drivers in the 787 design.

In the near future an important ambitious goal is the development of downstream manufacturing techniques for the fibres structures in primary assemblies, dry and draped in “unlimited size”, moulds and “frozen” into solid structures after vacuum assisted impregnation process.
In 2015 an integrated Flight-Test will demonstrate the application of:

- multifunctional CFRP advanced fuselage panel
- structural health monitoring SHM

An experimental modified ATR72-600 will be used.
Today seems aeronautics structures at the beginning of a step-change from all-metallic to hybrid structure technologies, based on carbon textile-reinforced polymers locally “blended” with metal elements.
Aknowledgements

The authors wish to thank all the GRA members and associates that have kindly contributed to this work through the GRA Steering Committee members, therefore many thanks to:

Javier Sacristan (EADS-CASA)
Valerio Carli (Fraunhofer)
Elodie Herail (Liebherr)
Uwe Hessler (Rolls-Royce)
Marius Goutines (SAFRAN)
Marc Fabreguettes (Thales)
Aniello Cozzolino (Air Green)
Francis Maurel (ATR)
Marcello Kivel-Mazuy (Cira-Plus)
Zaira Marioli Riga (HAI)
Jean-Luc Godard (ONERA)
Thanks for your attention!