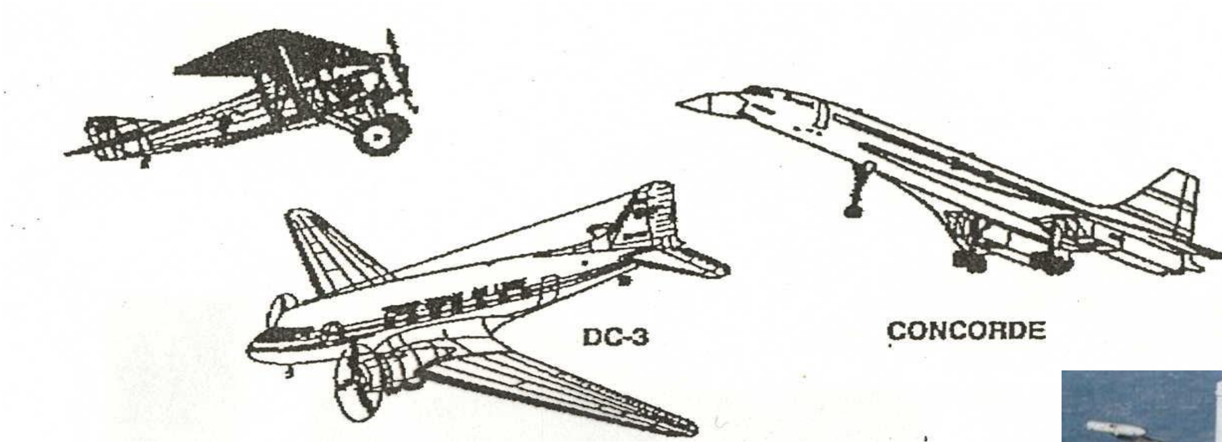
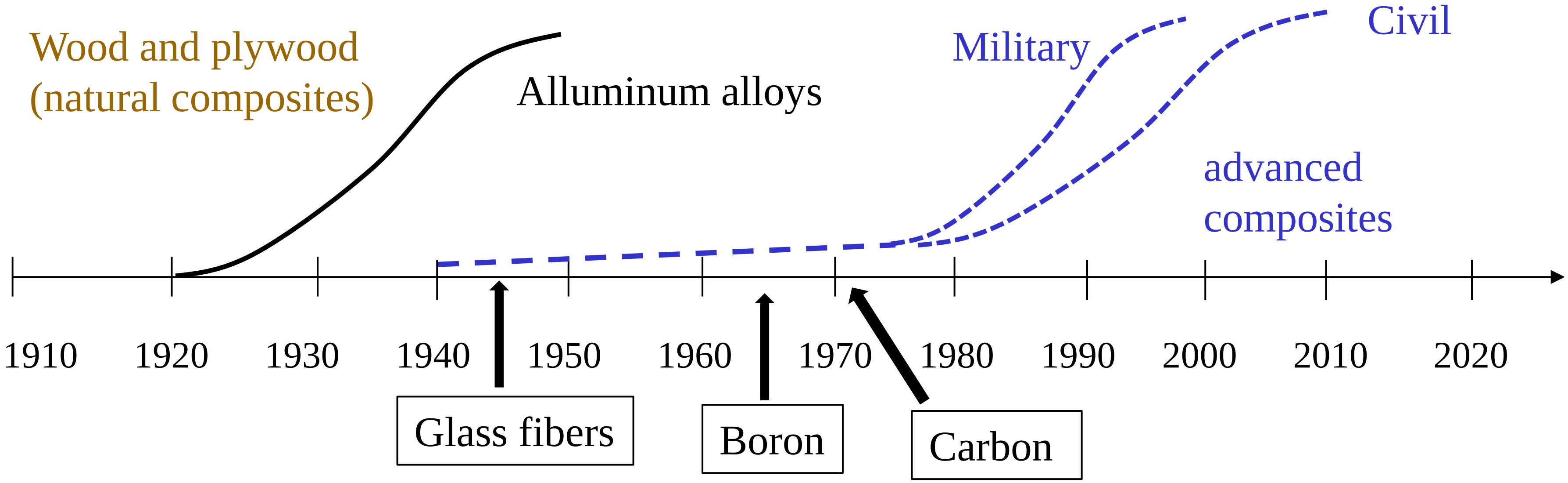
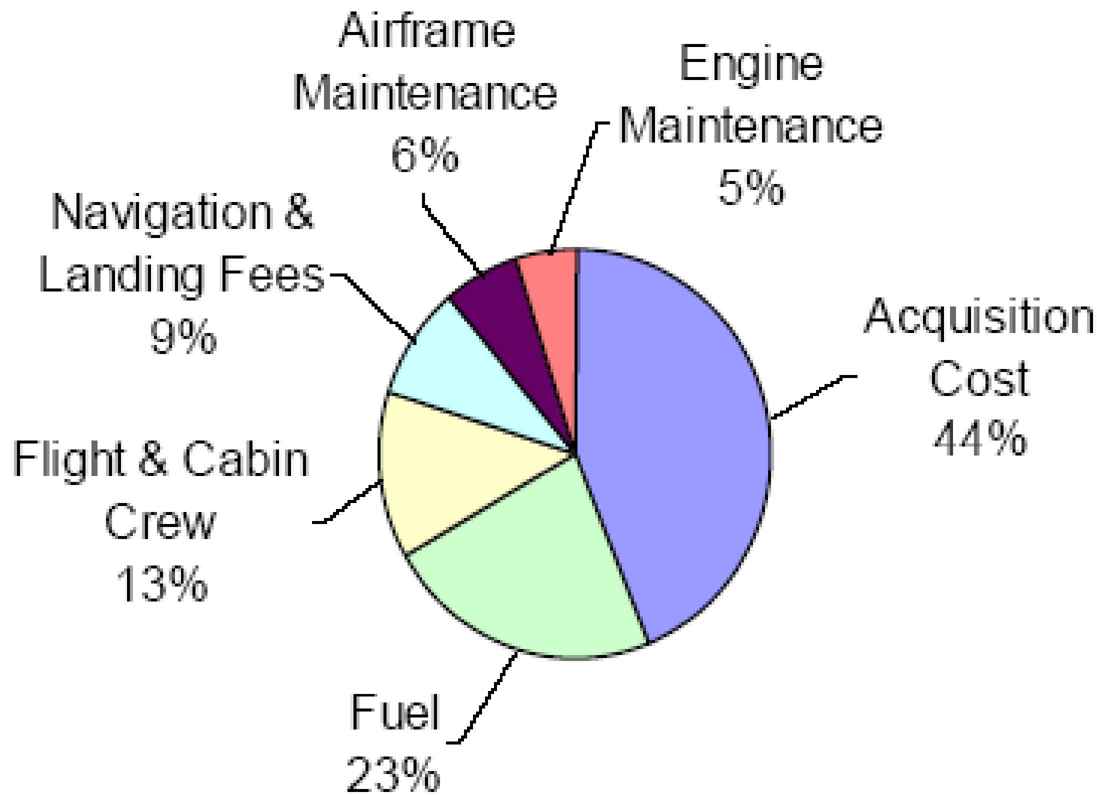
The three ages of materials in aerospace



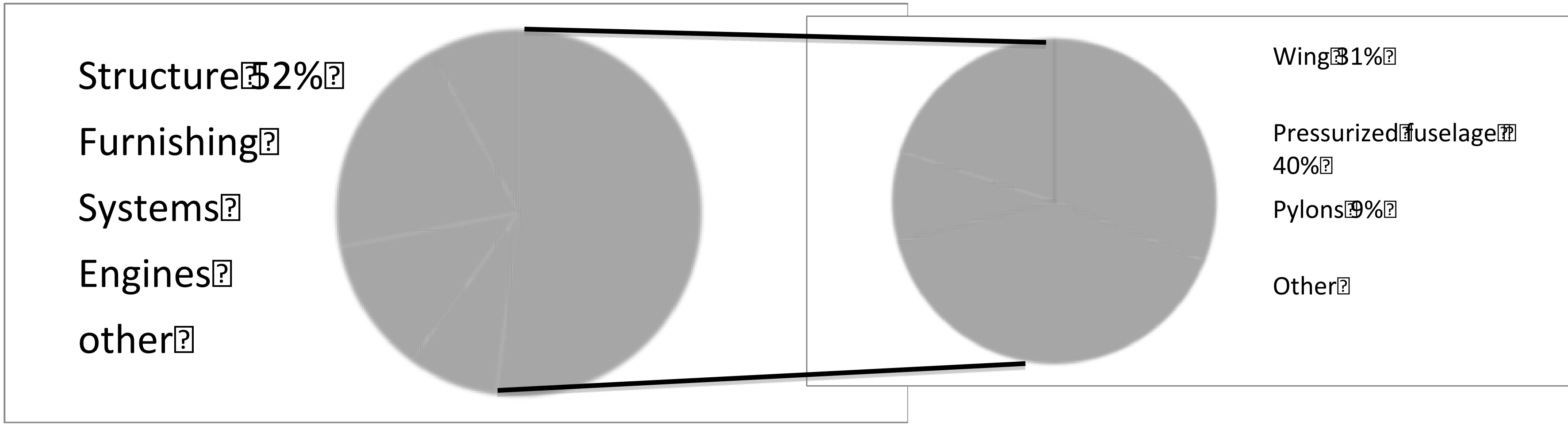


Direct Operative Costs of a long range airliner

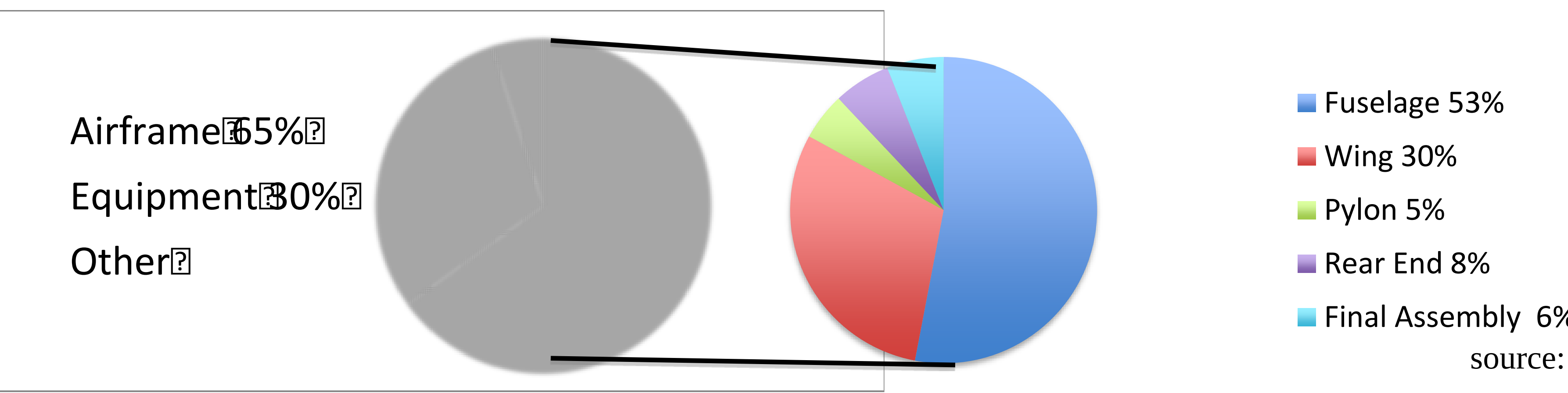


Typical DOC's for Long Range Airliner

Weight of large aircrafts structures



Costs of large aircrafts structures (without engines)



source: Airbus

Where and how much composites will be used

- Air traffic should double in the next 15 years
- Boeing’s forecast predicts a growth up to 42000 airplanes flying in 2037. Airbus predicts 37000
- In 2018 there are 21000 airplanes flying
- About 11000 aircrafts will substitute those circulating in 2018 and 26000 will be due to market growth
- Nowadays 36% of total volume and 56% of total value of carbon fiber composites are consumed in aerospace

Which is and will be the amount of composites that will be used in next generation airplanes?

Composites in civil aircraft

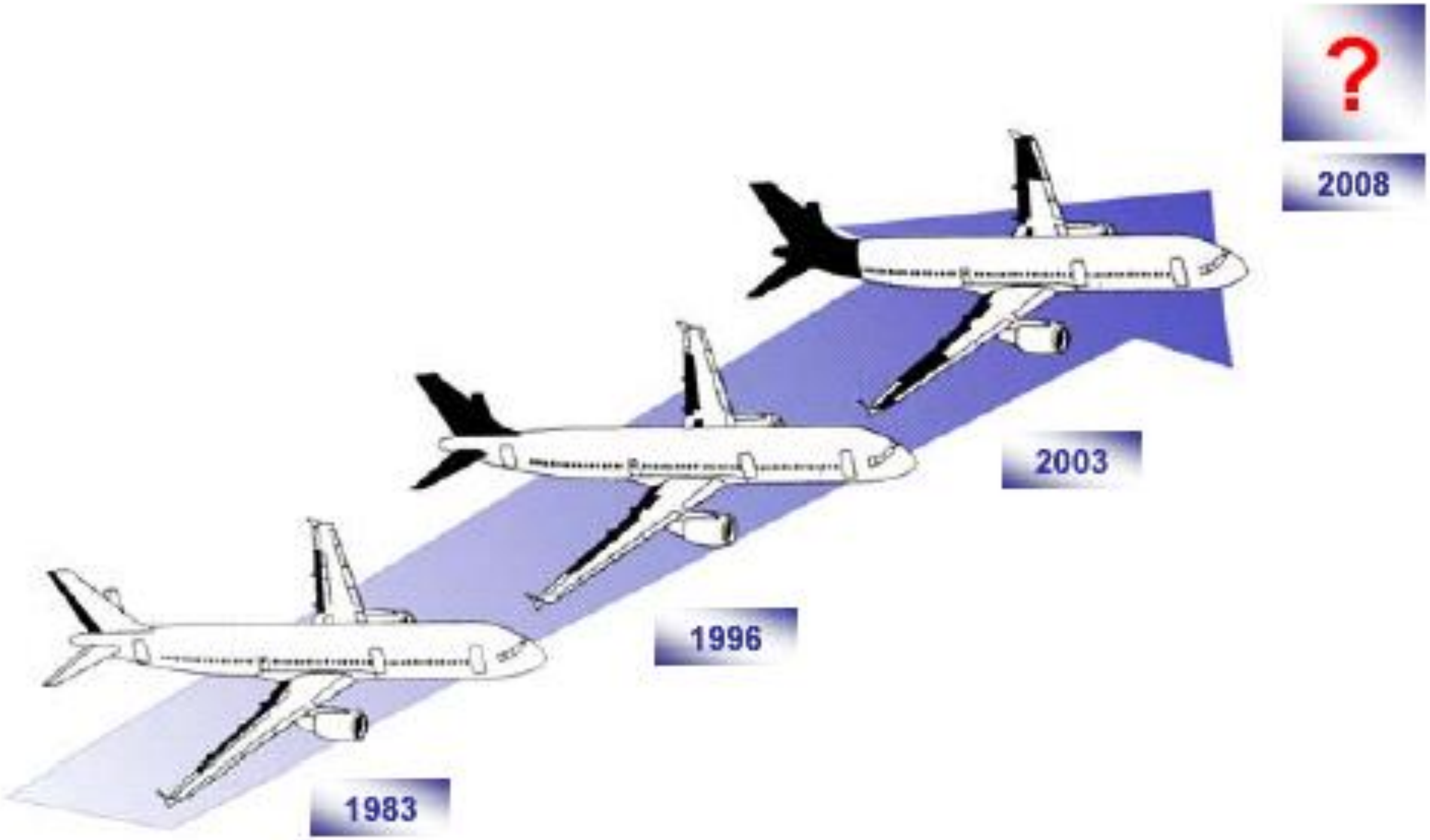
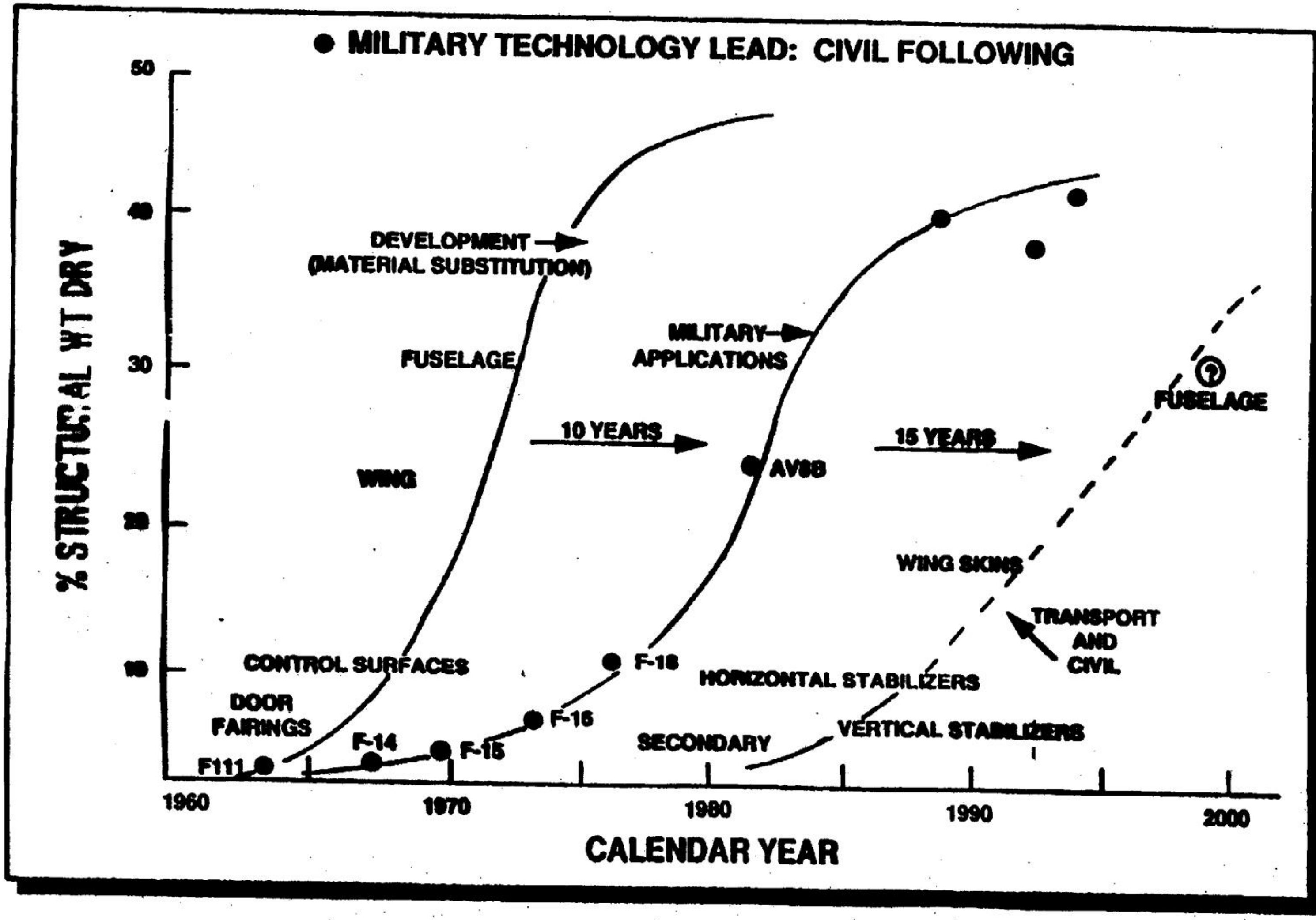
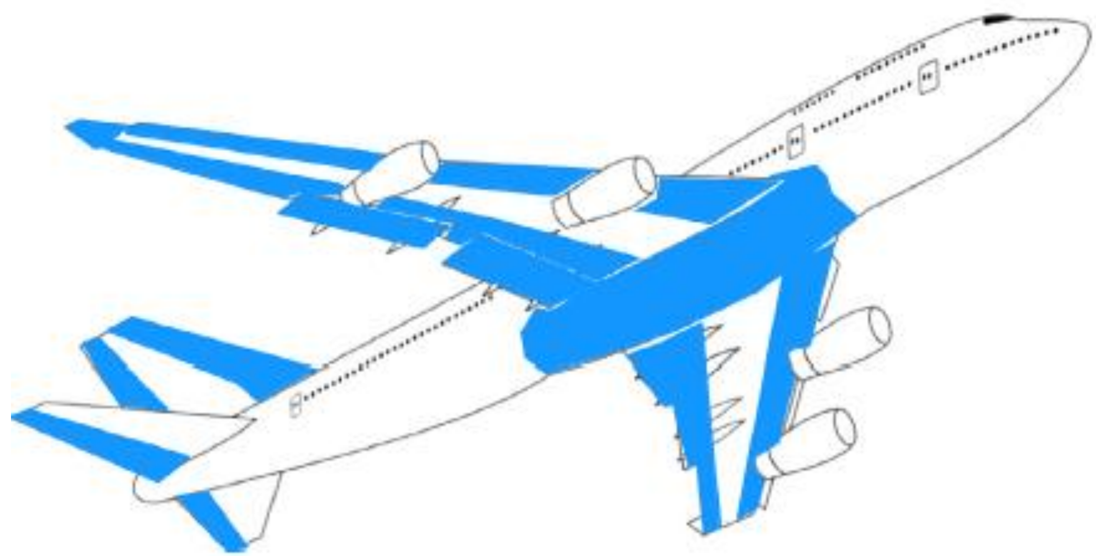


Figure 4 – development of composite applications (highlighted in black) from the A300 to the A380

THE TRANSITION TO COMPOSITE AIRFRAMES



B747 sandwich panel applications
Mostly Al skin and honeycomb



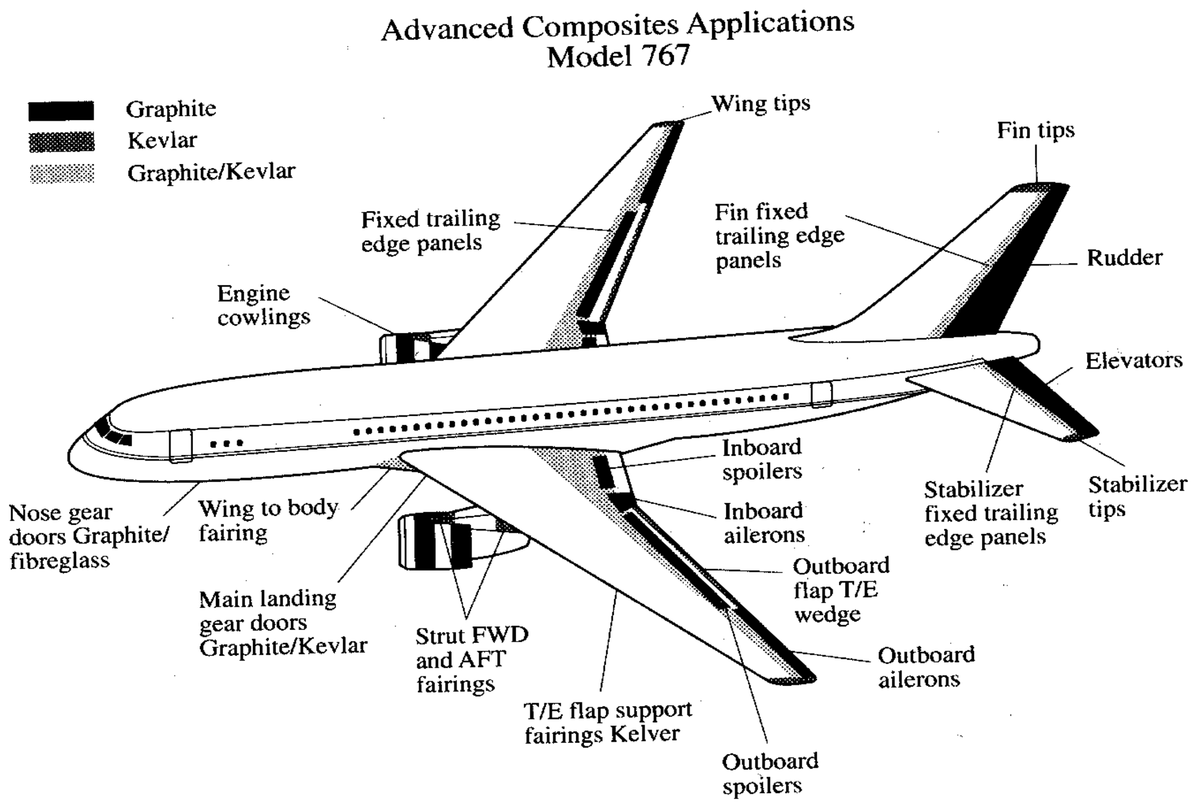
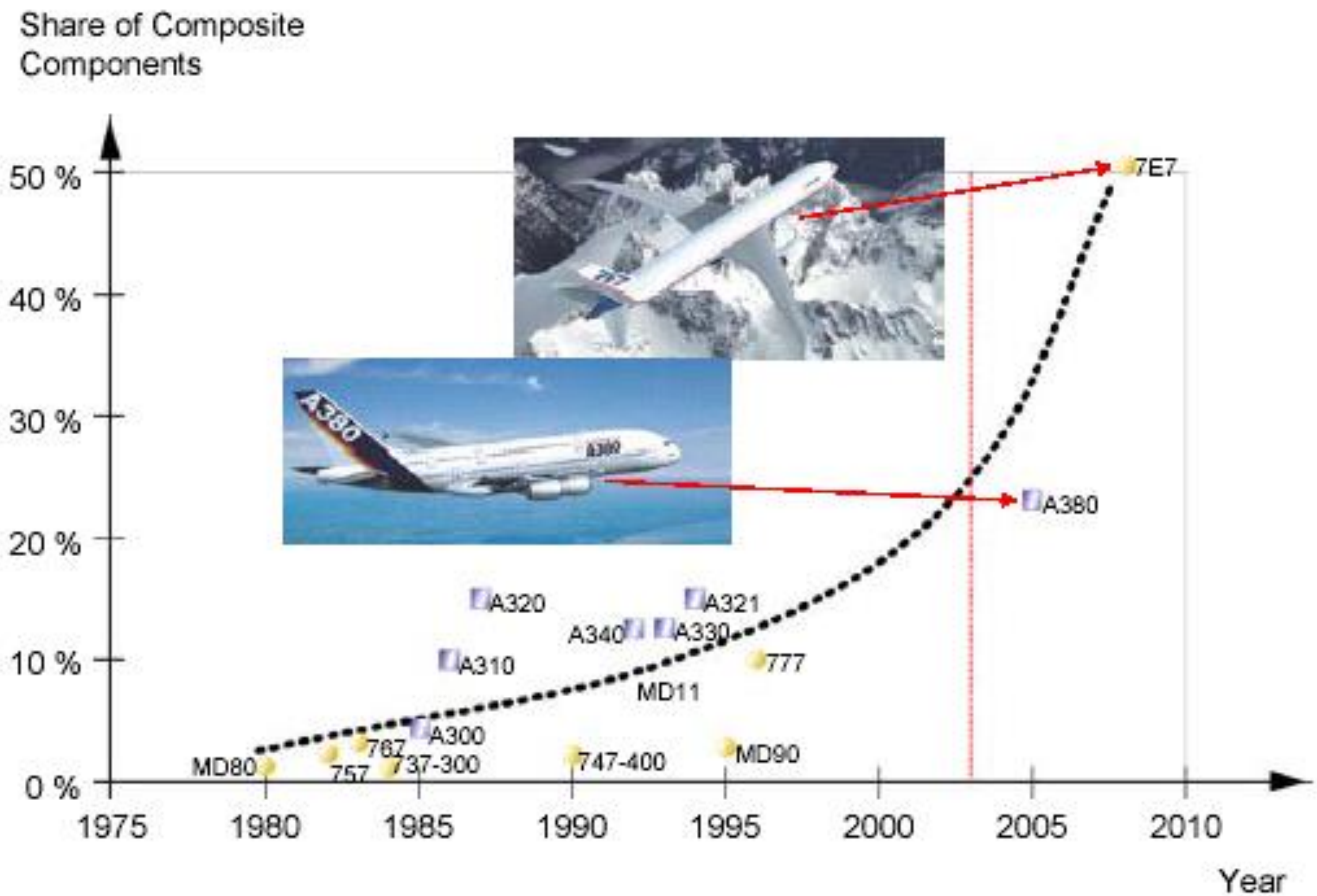


FIGURE 1.12
Composite applications on the Boeing 767 airliner. (*Courtesy of Boeing.*)

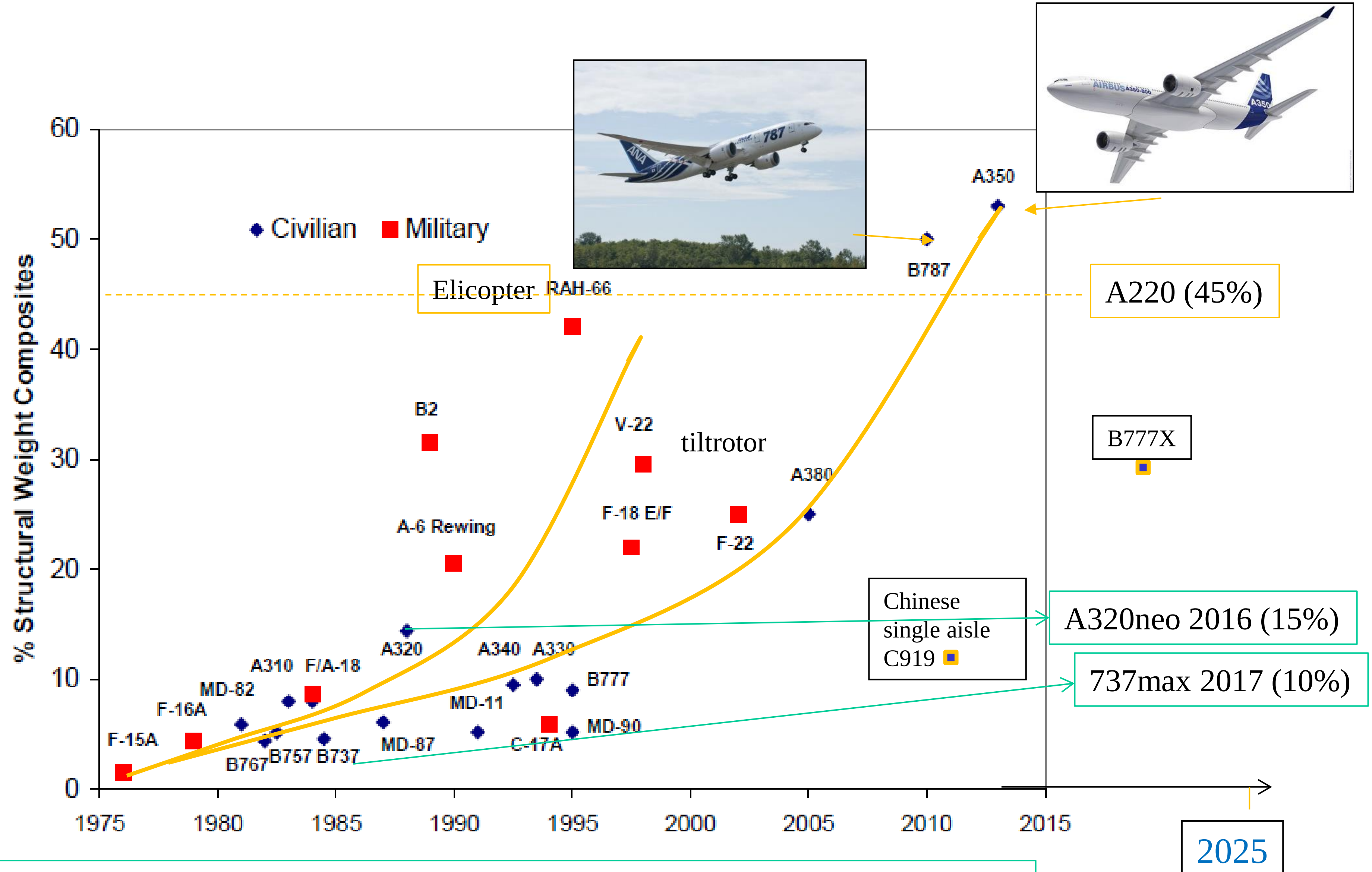
Composites in civil aircraft

Figure 6 – composite parts of the Boeing 777 (source: Boeing)

Composite materials in civil aircraft before B787



Composite materials in military and civil aviation



A320neo and 737max account for nearly % of available seat miles own globally (B737is based on a design originating from 1960s)

Composite world July 2024

787 Dreamliner

- Using prototype tools and robots, Boeing and its 7E7 partners in Japan, Italy and the United States must perfect new manufacturing processes for the 7E7, which will be the first large commercial jetliner with a nearly all composite structure instead of traditional aluminium
- Program launched april 2004, *expected* delivery *2008*, *but* the delivery of first plane was *sept. 2011*

787 Dreamliner

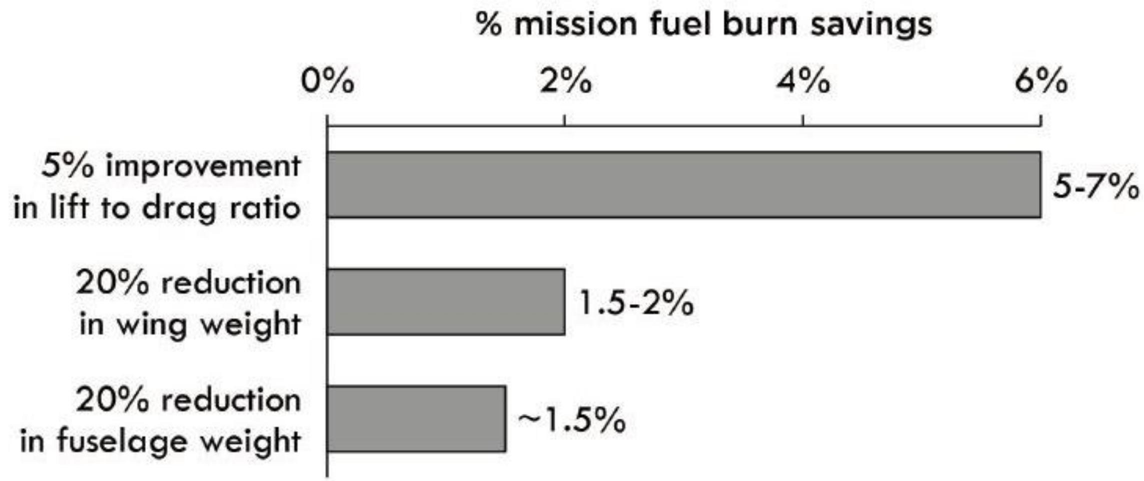
- Frank Statkus, Boeing's vice president of technology, In an interview (year 2003), he said Boeing had built its last aluminium airplane.
- "If you want to be part of the future of commercial aviation, you better be able to do composites," he said yesterday.

B787 vs. B767

Thinner wings are associated to less drag. Similar approach was adopted for B777X

Composite fuselage in single aisle aircraft

Aerodynamic changes using composites can have a greater impact than weight savings alone



Composite world July 2024

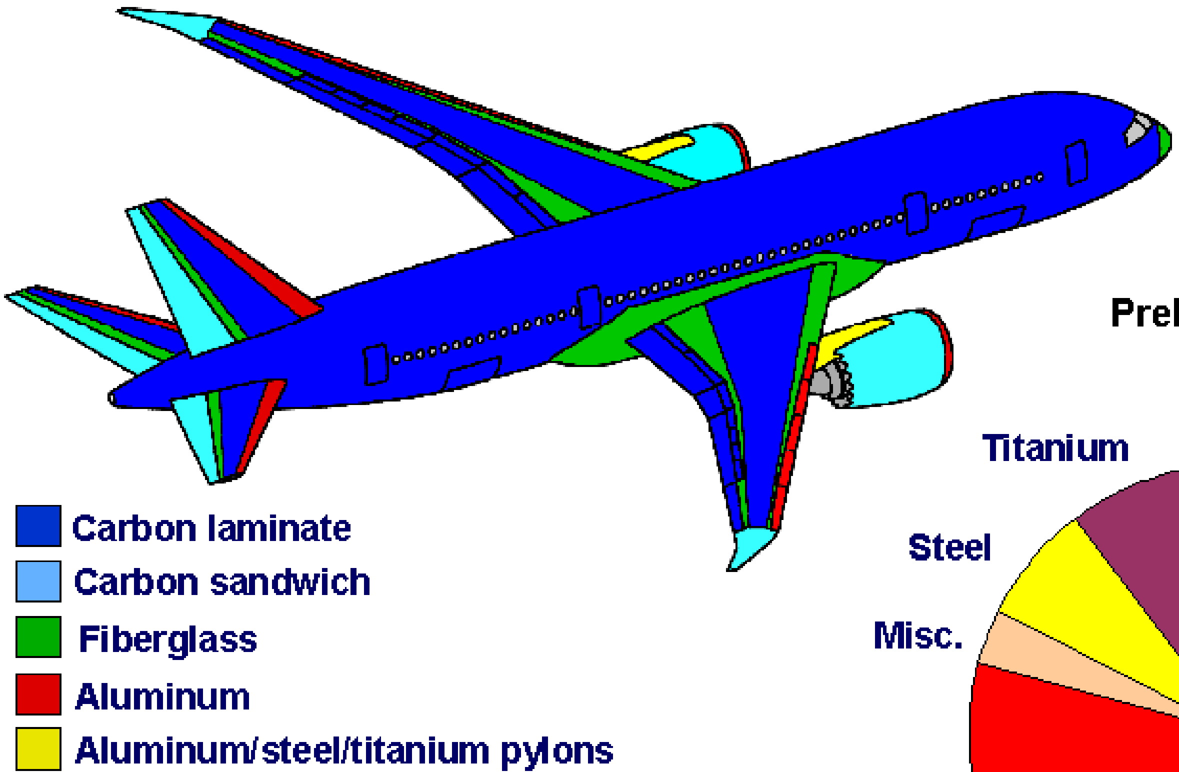
July 8th 2007 **(**0**7**/0**8**/200**7)**

787 Dreamliner (about $100 milion)

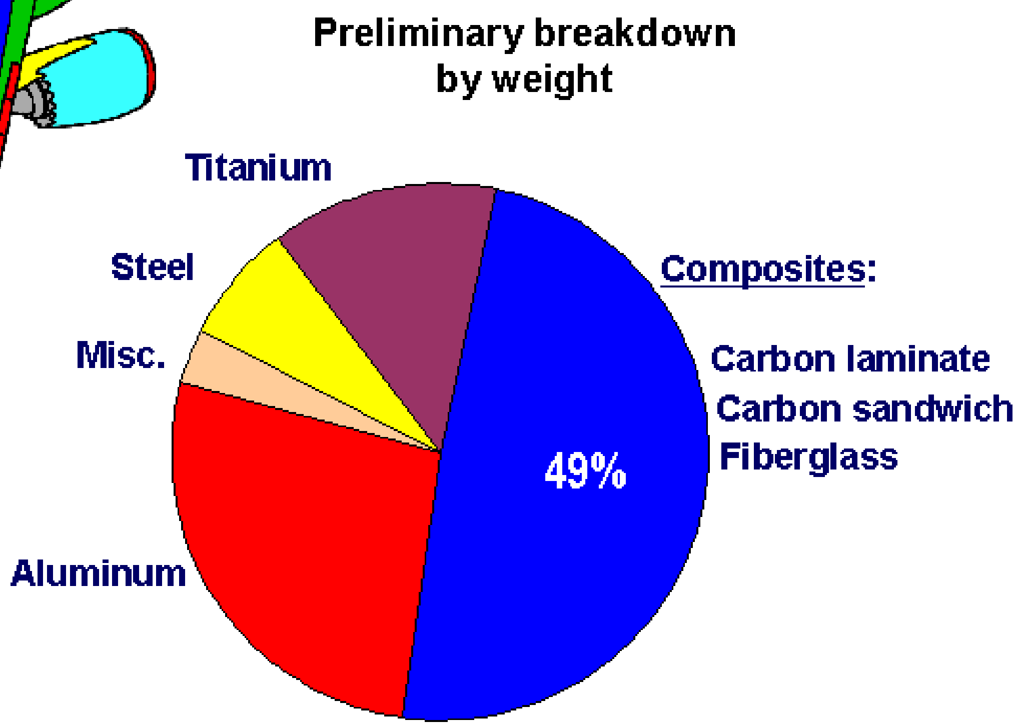
Dec. 2009

787 Dreamliner (in flight Sept 2011)

Boeing 787

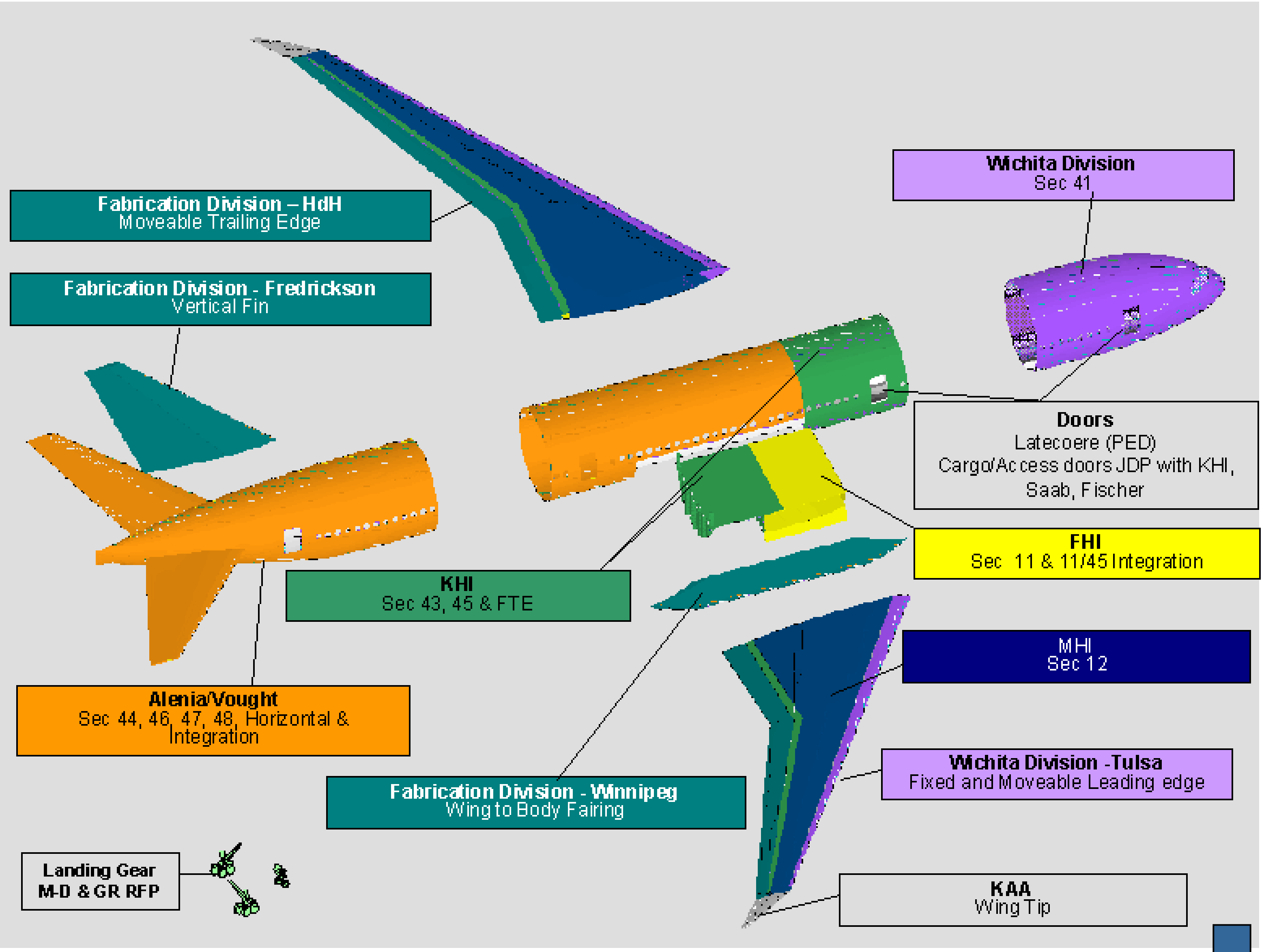


Carbon laminate
Carbon sandwich
Fiberglass
Aluminum
Aluminum/steel/titanium pylons



Preliminary breakdown
by weight
Titanium
Steel
Misc.
Aluminum
Composites:
Carbon laminate
Carbon sandwich
Fiberglass
49%

Boeing 787



Giappone

Boeing

Who makes the parts and where the engineering jobs are

Numbers of engineers are projections for the end of 2005 made by Boeing's first-tier partners, and may not include all engineering specialties. Production workers are not included.

ENGLAND

COMPANY	ENGINEERS
Messier-Dowty	30

Main landing gear

Nose landing gear

SWEDEN

COMPANY	ENGINEERS
Saab:	NA

Aft cargo door

Forward cargo door

ITALY

COMPANY	ENGINEERS
Alenia:	770

Midfuselage sections

Horizontal stabilizer

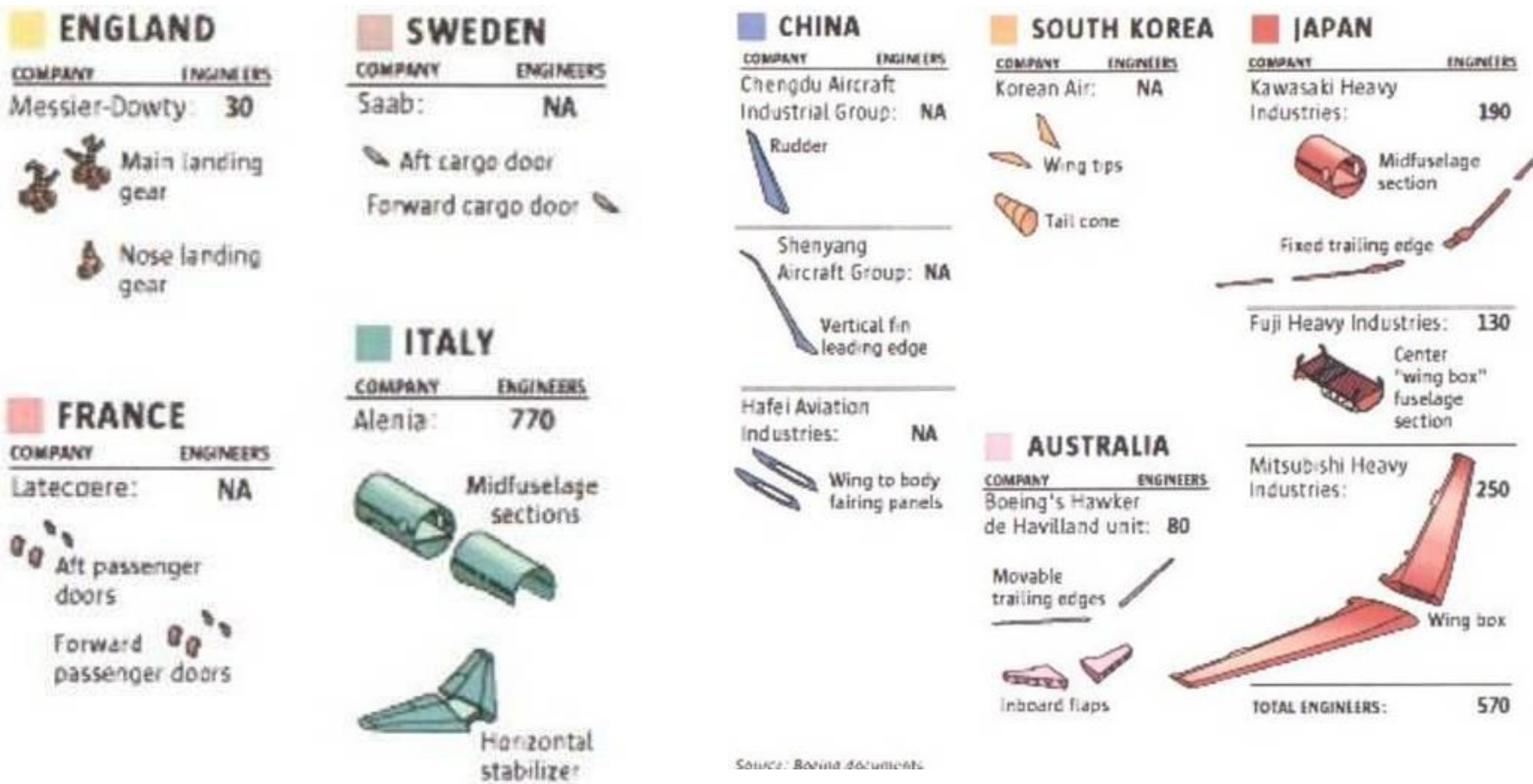
FRANCE

COMPANY	ENGINEERS
Latecoere:	NA

Aft passenger doors

Forward passenger doors

Boeing 787



ENGLAND
COMPANY ENGINEERS
Messier-Dowty: 30
Main landing gear
Nose landing gear
FRANCE
COMPANY ENGINEERS
Latecoere: NA
Aft passenger doors
Forward passenger doors
SWEDEN
COMPANY ENGINEERS
Saab: NA
Aft cargo door
Forward cargo door
ITALY
COMPANY ENGINEERS
Alenia: 770
Midfuselage sections
Horizontal stabilizer
CHINA
COMPANY ENGINEERS
Chengdu Aircraft Industrial Group: NA
Rudder
Shenyang Aircraft Group: NA
Vertical fin leading edge
Hafei Aviation Industries: NA
Wing to body fairing panels
SOUTH KOREA
COMPANY ENGINEERS
Korean Air: NA
Wing tips
Tail cone
AUSTRALIA
COMPANY ENGINEERS
Boeing's Hawker de Havilland unit: 80
Movable trailing edges
Inboard flaps
JAPAN
COMPANY ENGINEERS
Kawasaki Heavy Industries: 190
Midfuselage section
Fixed trailing edge
Fuji Heavy Industries: 130
Center "wing box" fuselage section
Mitsubishi Heavy Industries: 250
Wing box
TOTAL ENGINEERS: 570
Source: Boeing documents

Boeing 787: sez. 46

Boeing 787: skin and systems

B747 freighter-dream lifter

Alenia milestones in 787 program (Grottaglie and Foggia Plants)

Finmeccanica/Alenia Aermacchi's key milestones of the Boeing 787 programme:

- June 2003 – Boeing announces its intention to launch a new aircraft called 7E7.
- April 2004 – Boeing launches the 787 Dreamliner programme, announcing an order for 50 aircraft by the Japanese ANA.
- September 2005 – Alenia and Boeing sign a partnership as part of the 787 Dreamliner programme.
- April 2005 – Start of works for the building of Alenia's Monteiasi-Grottaglie plant.
- April 2006 – Start-up of production activities at the Monteiasi-Grottaglie plant.
- March 2007 – First delivery of 787 Dreamliner fuselage sections.
- April 2007 – Delivery of the first Boeing 787 horizontal stabiliser made at Alenia's plant in Foggia.
- July 2007 – Roll-out in Seattle, USA, of the first Boeing 787 Dreamliner.
- March 2008 – Successful tests performed in Pomigliano D'Arco at "last load" on the Boeing 787 Dreamliner horizontal stabilizer.
- July 2008 – Positive result of a "breaking" test on the Boeing 787 Dreamliner horizontal stabilizer.
- December 2009 – Maiden flight of the Boeing 787 Dreamliner.
- September 2011 – First Boeing 787 Dreamliner delivered to the launch client ANA.
- March 2012 – First fuselage section of the Boeing 787 Dreamliner longer variant produced in Monteiasi-Grottaglie.
- May 2012 – First landing of the 787 Dreamliner in Italy, by Monteiasi-Grottaglie.
- October 2012 – Alenia Aermacchi achieves the crucial milestone of one hundred 787 fuselage sections delivered to Boeing.
- July 2013 – 7 shipsets/month delivered.
- December 2013 – 9 shipsets/month delivered.
- April 2014 – 11 shipsets/month delivered.

Source: Jec composites april 2014

2019 14 shipset/month delivered, 2020-21 only 6!

Advantages of a composite fuselage

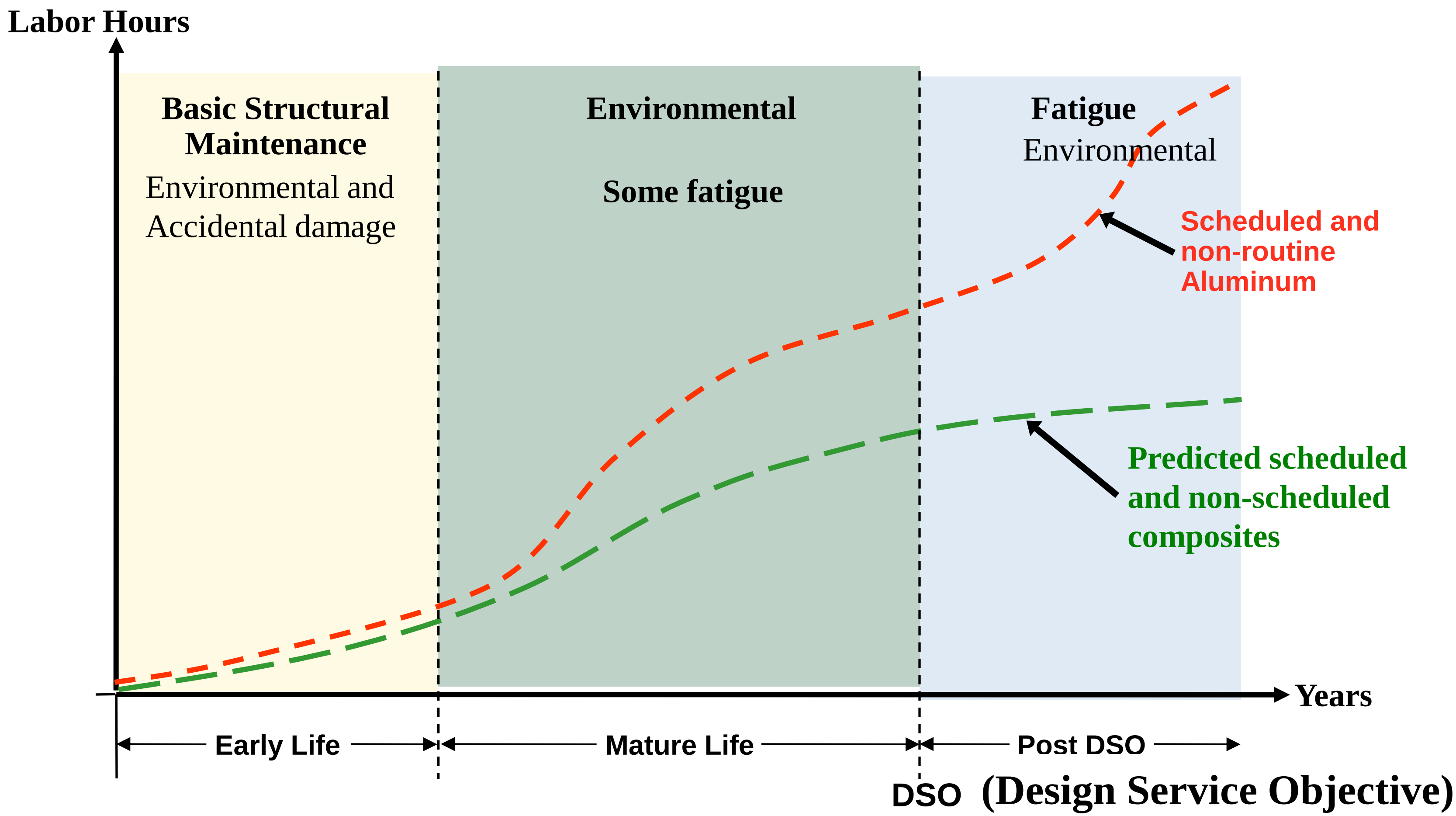
- Structural weight reduction
- Improved fatigue strength and hence:
  - Increase of air pressure in the cabin (better comfort)
  - Larger windows
- Reduction of maintenance costs being removed the risk of corrosion
- Reduction of the number of parts

B787 will be equipped with GE o Rolls Royce engines characterized by a lower fuel consumption

- Main drawbacks:
  - Impact resistance (and detectability of impacted areas)
  - Maintenance and reparability
  - Fire resistance

→ Additional qualification tests

Life Cycle Maintenance



- **Lower maintenance for composites translates into reduced ground time for maintenance and higher residual value**

New B777X 350 seats: CFRP wings

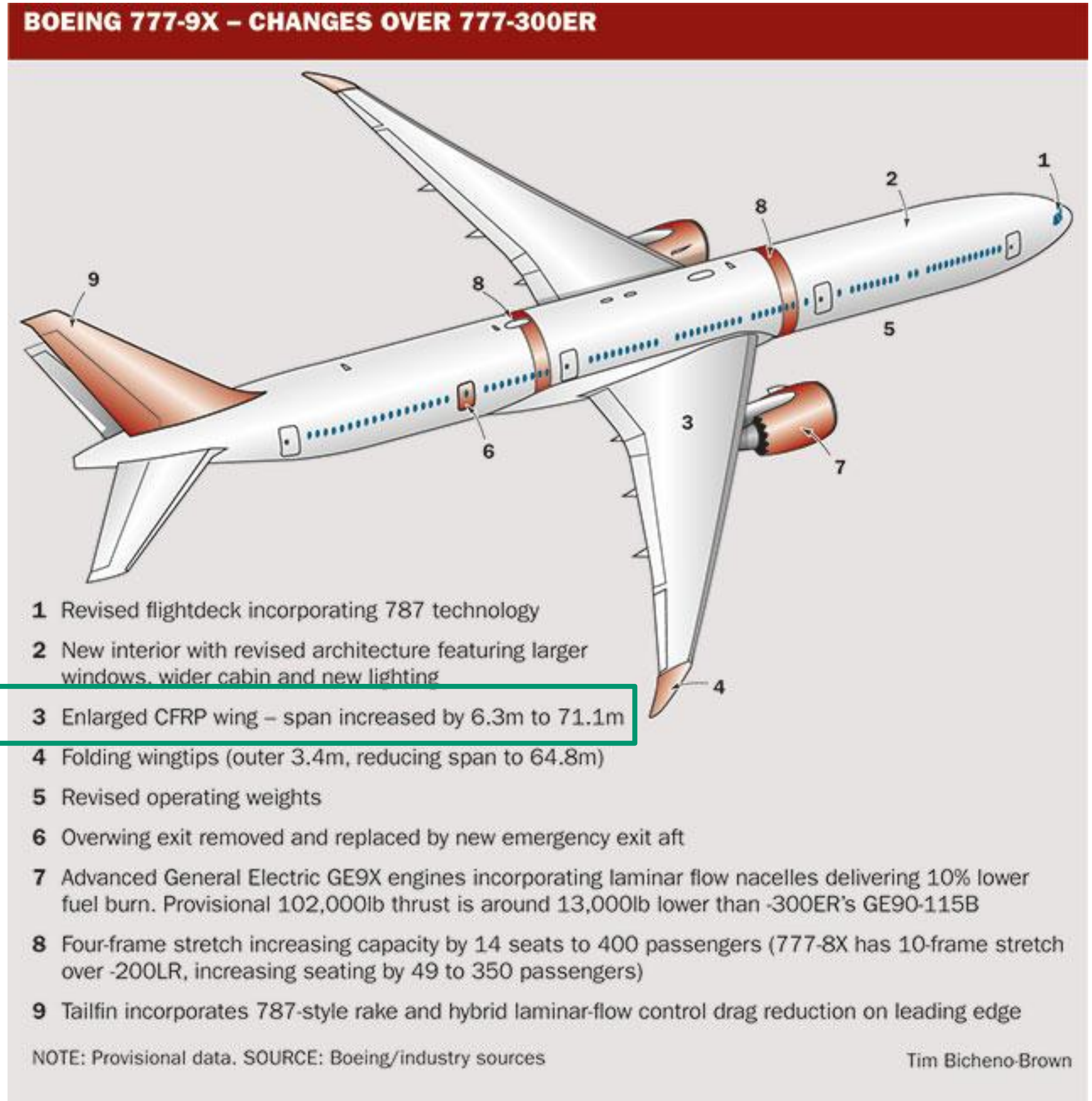
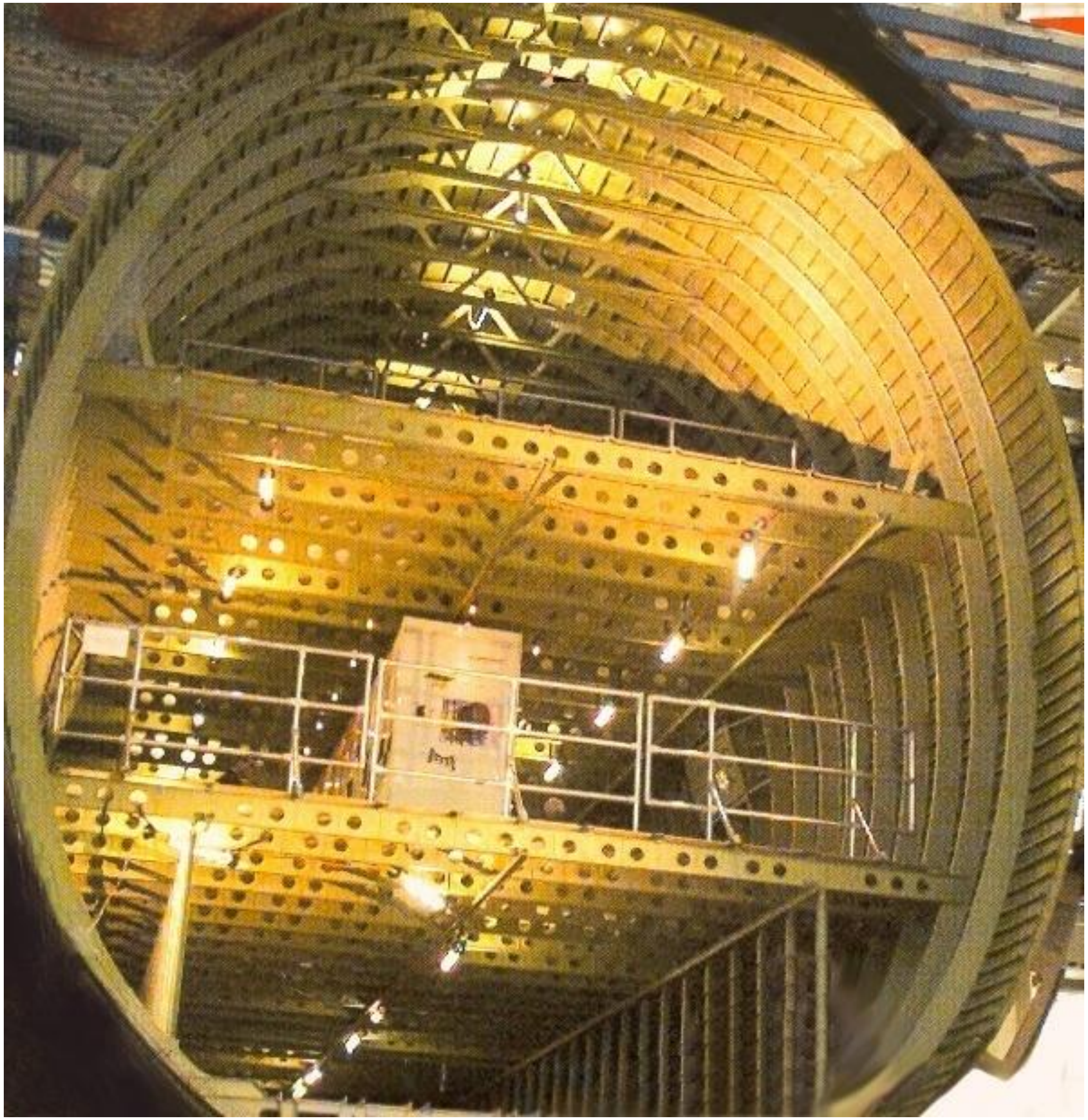


FIGURE 1. A380 outer dimensions.

First deliveries of the double-decker A380 are scheduled for Spring of 2006. Inset shows relative size comparison between the A380, the wide-body A340 and the single-aisle A320.

AIRBUS A380



COMPOSITES IN THE A380

- Up to 40 per cent of the A380's structure and components will be manufactured using carbon composites and advanced metal materials.
- A380 was the first civil aircraft offering a weight saving of up to one-and-a-half tonnes using Carbon Fiber Reinforced Composites (CFRP) compared to the most advanced aluminium alloys.
- The aircraft's fin box, rudder, central wingbox, and elevators will be made of CFRP as well as the upper-deck floor beams and rear pressure bulkhead.
- A notable innovation on the A380 will be the use of GLARE, which is being used to manufacture the upper fuselage shell of the aircraft. GLARE is a laminate constructed from alternate layers of aluminium and strong fibreglass to create a material that is extremely tough and resistant to metal fatigue. GLARE is about 10 per cent less dense than aluminium.

Materiali compositi nell A380

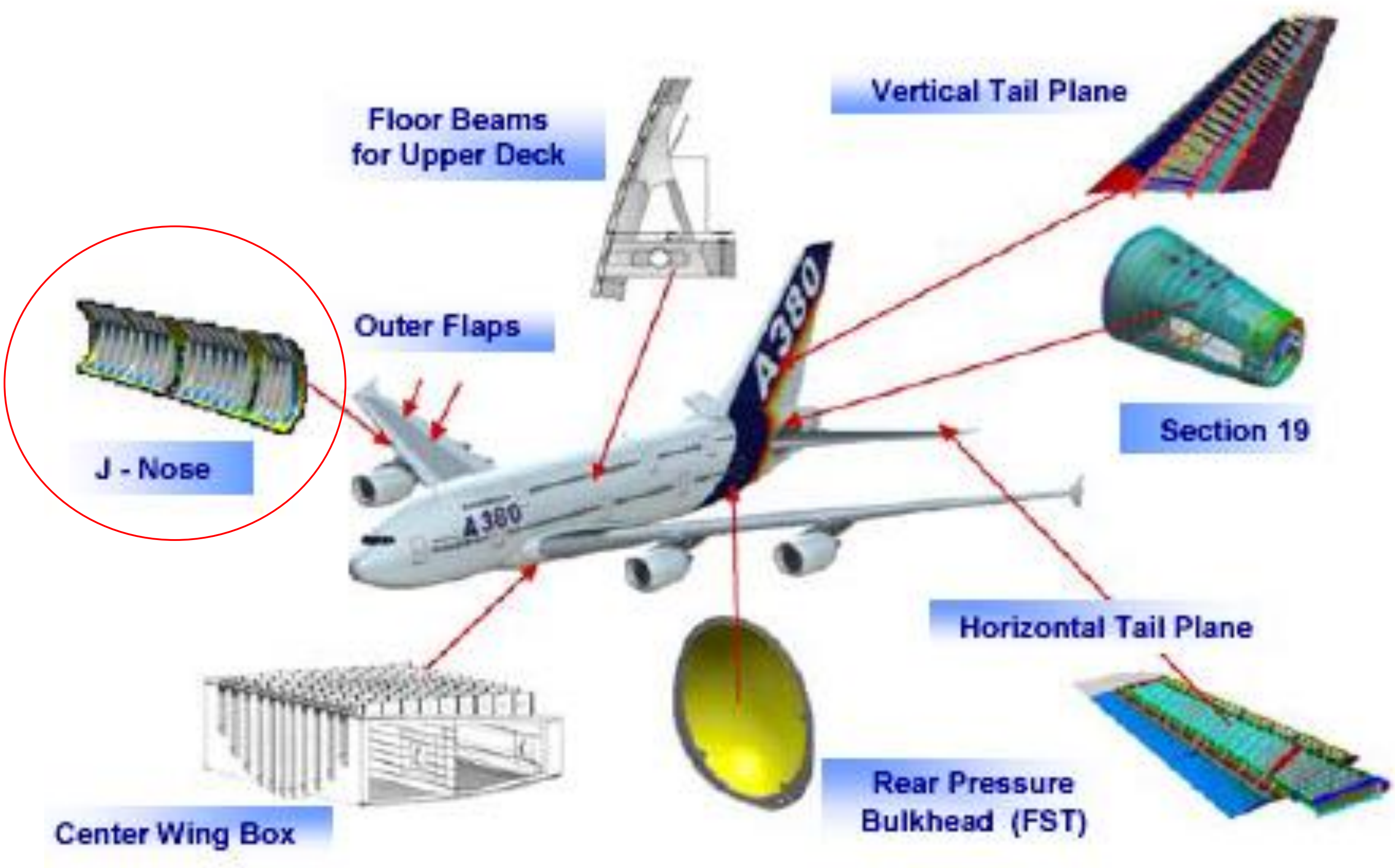
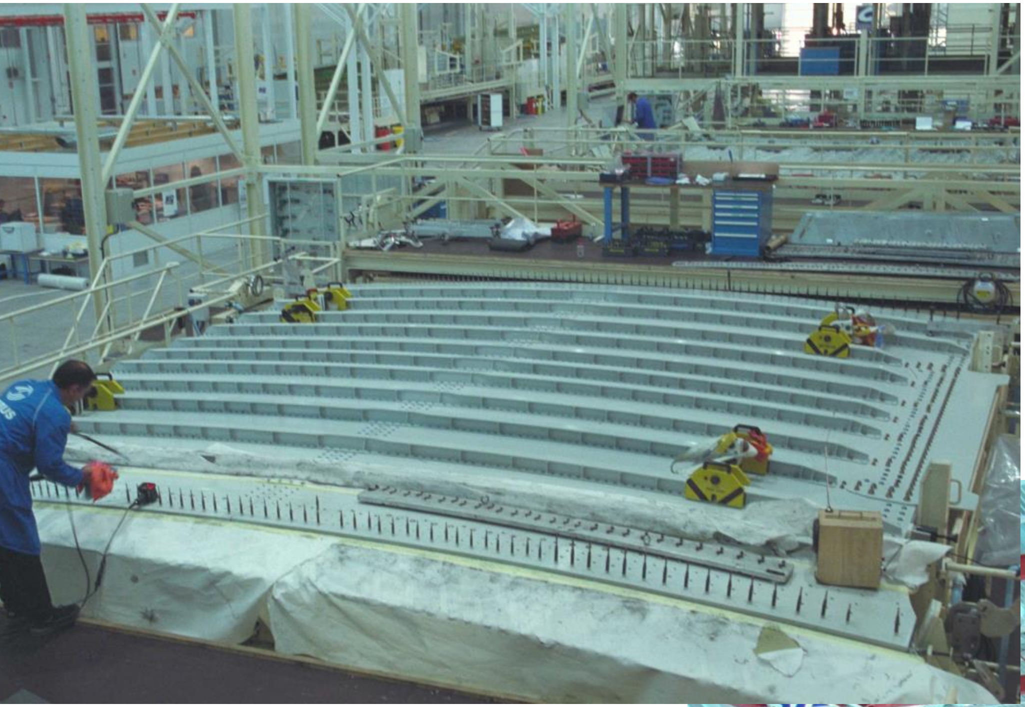


Figure 8 – planned composite applications for the A380 (source: Airbus)

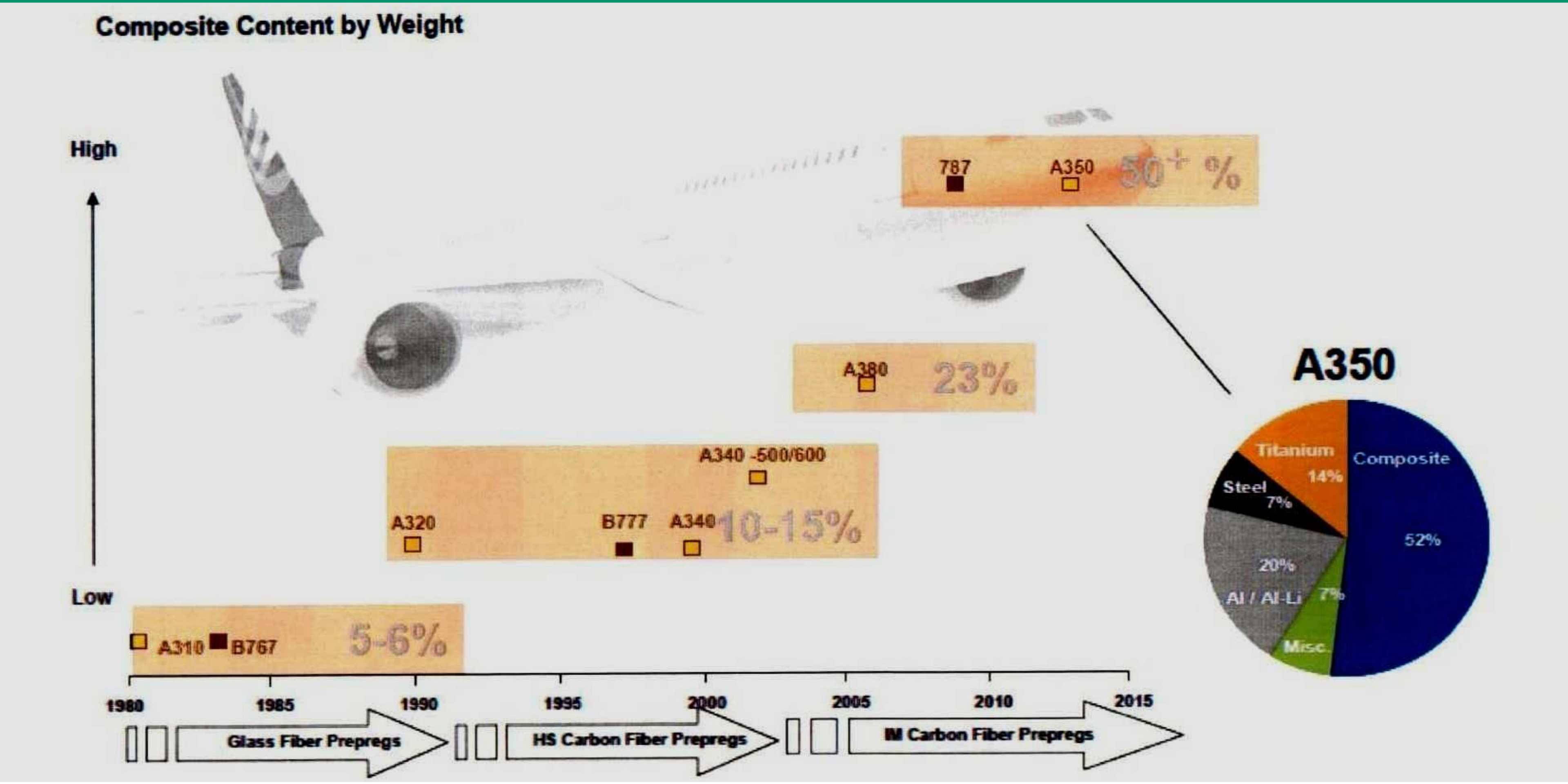
A380 CENTRE WING BOX PRODUCTION

- The A380 will be the first large commercial aircraft with a carbon fibre reinforced plastic (CFRP), or composite, centre wing box. The centre wing box is the piece of the aircraft that links the fuselage to the wings. Its importance to the aircraft is similar to the importance of the keystone in an arch.
- The A380’s centre wing box dimensions are some 49sq.m by 2.5m high. The upper and lower skin panels and all three spars are composite, representing a weight saving of up to one and a half tonnes compared to the most advanced aluminium alloys.

A380 Center Wing Box



AIRBUS A350



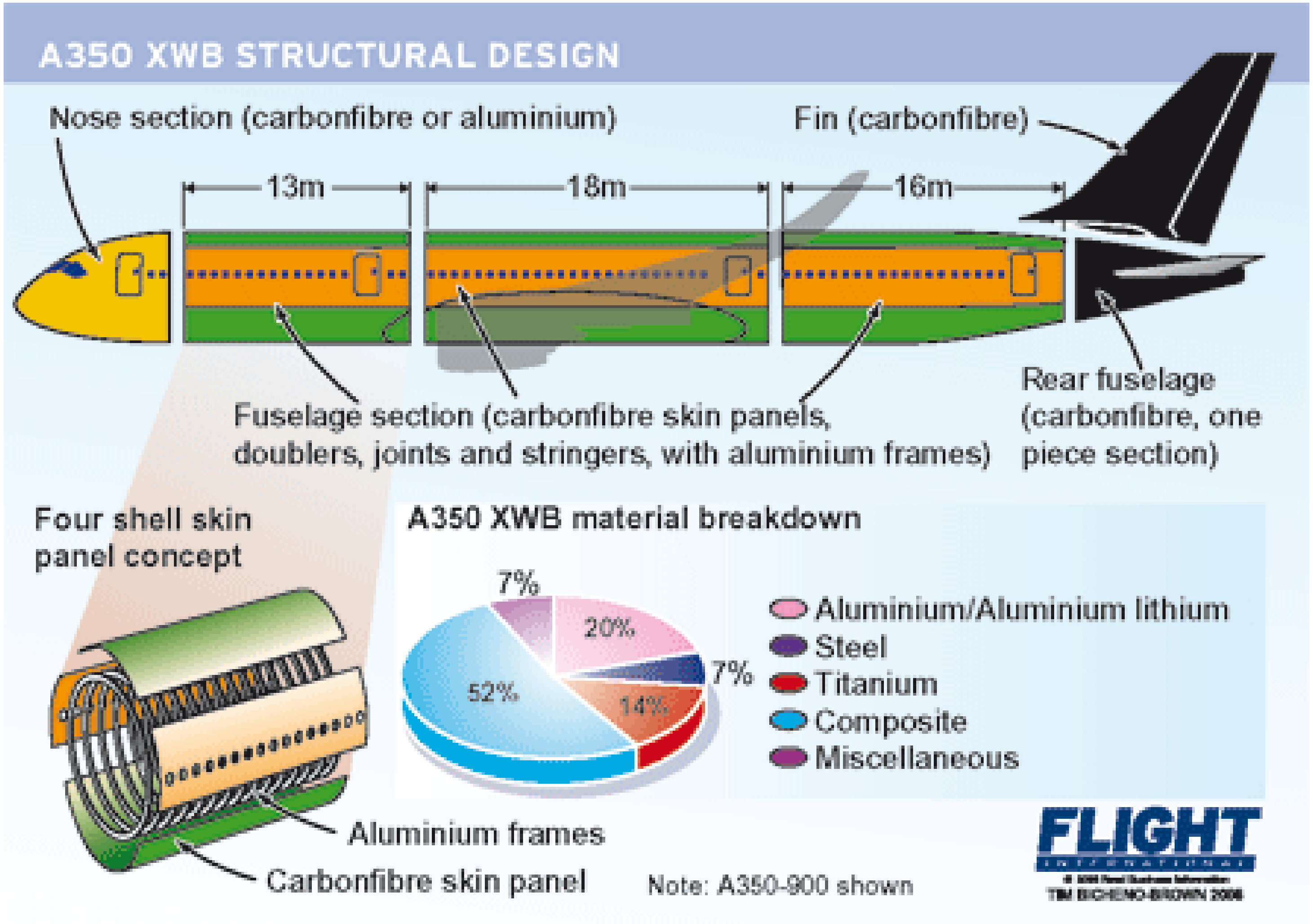
Composite Content by Weight
High
Low
787
A350
50+ %
A380
23%
A340 -500/600
A320
B777
A340
10-15%
A310
B767
5-6%
1980
1985
1990
1995
2000
2005
2010
2015
Glass Fiber Prepregs
HS Carbon Fiber Prepregs
IM Carbon Fiber Prepregs
A350
Titanium
14%
Composite
Steel
7%
52%
20%
Al / Al-Li
7%
Misc.

AIRBUS A350

Conceived as a comprehensive medium-capacity aircraft Family with an extra-wide fuselage cross section, the A350 XWB will have a cruise speeds of Mach 0.85. Featuring a cross section 5.9 meters, the A350 XWB will benefit from the widest fuselage in its category.

AIRBUS A350

- Over 60 per cent of the airframe will be made of new materials (including composites). Carbon Fibre Reinforced Plastic (CFRP) paneled fuselage skins will be used (1st fligth 14° June 2013)
- Monthly rate of 10 expected in 2026.



AIRBUS A350

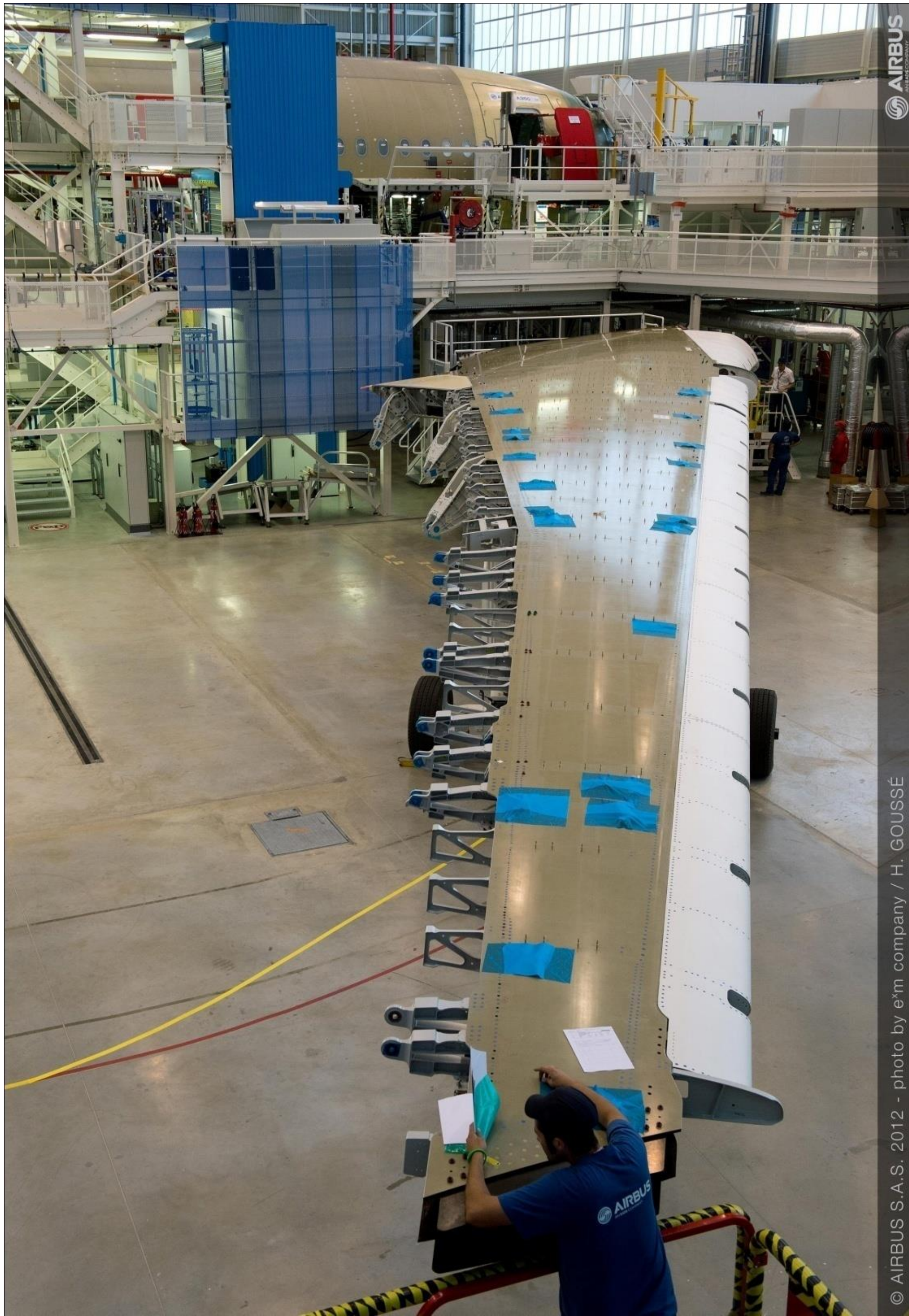
Fuselage for static tests

The fuselage for one of the A350's static airframes: Used for aircraft testing and constructed alongside the first airframe which will be used for flight testing

AIRBUS A350

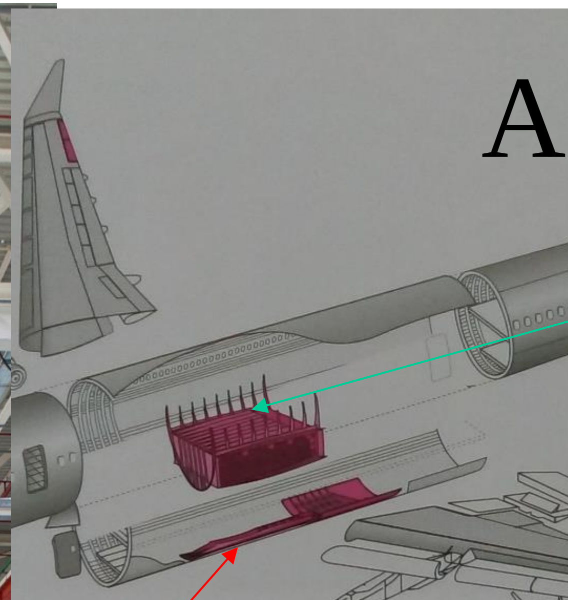
First wing (32x6 m) at Tolouse for assembly. It is destined to static tests

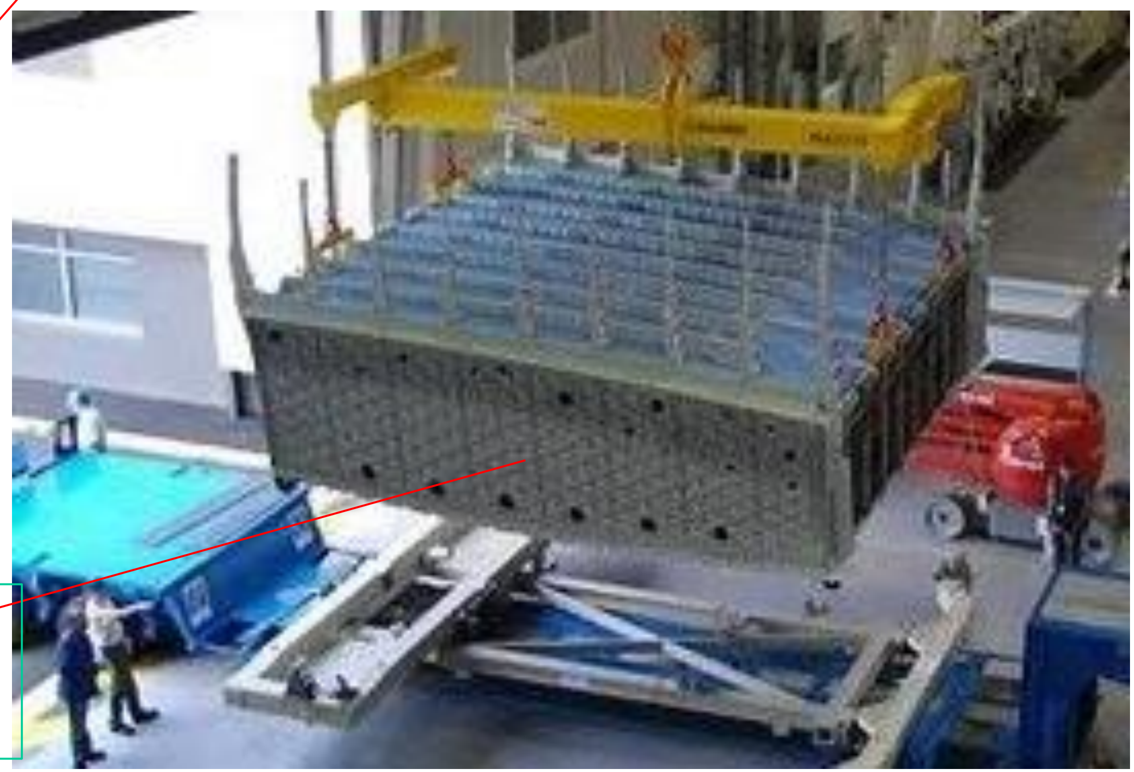
AIRBUS A350


AIRBUS
© AIRBUS S.A.S. 2012 - photo by e*m company / H. GOUSSÉ


BELUGA AIRBUS
INTERDIT

AIRBUS A350





Centre wingbox

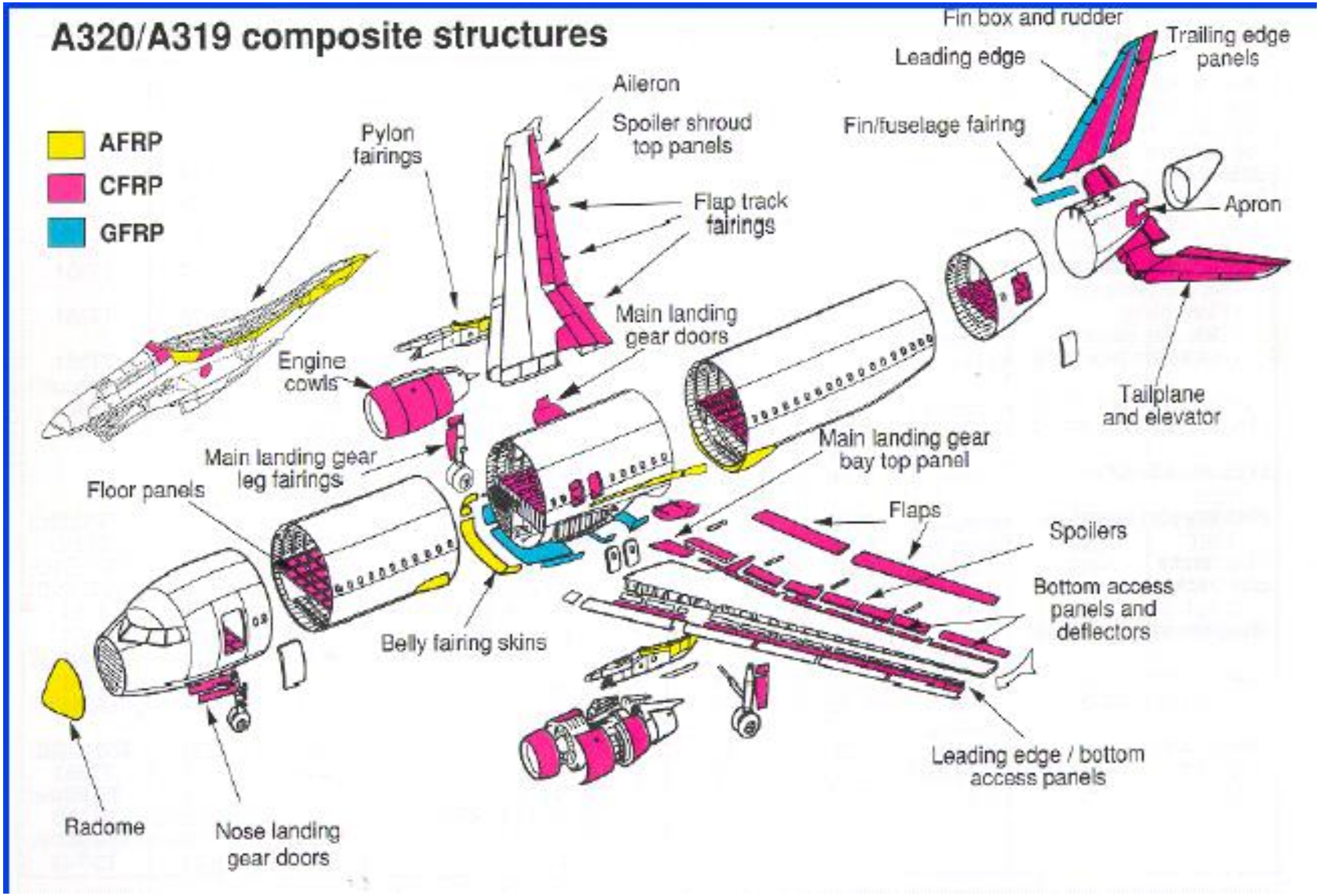
Keel beam

Connection surface to wing (alluminum)

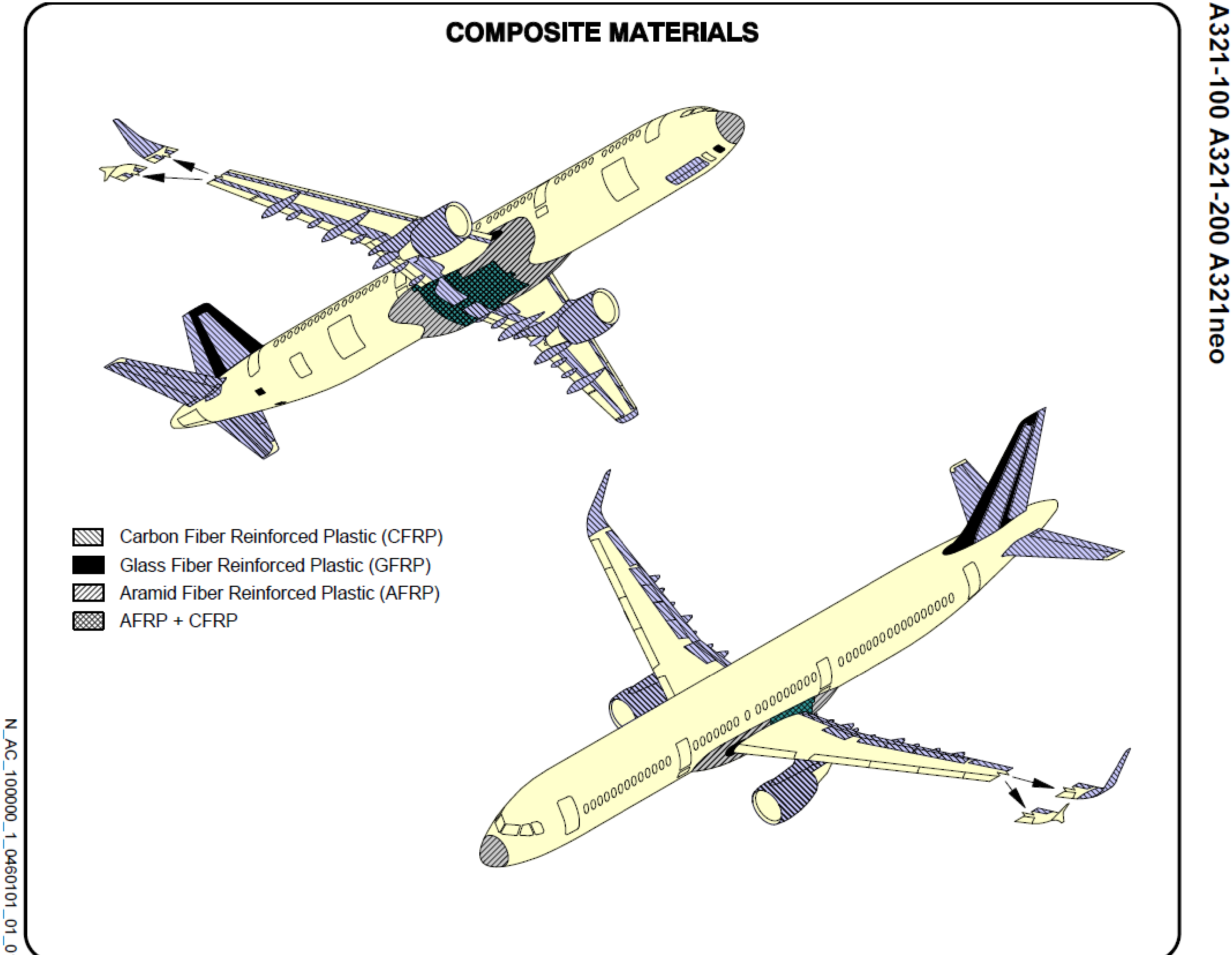
AIRBUS CENTRE WING BOXES

	Weight, t	Composite %	Length,m	Width, m	Weight gain with composites, t	N. of fasteners
A320	1.4	0	3	4.4	0	15000
A330	5.5	0	6.9	6.2	0	**35000**
A350	4.5	50	5.5	6.5	1	**15000**
A380	11.3	40	6.9	7.9	1.5	15000
A400M	2.2	50	5.5	4.2	-	9000

15% of composites since 90s



A320-21 NEO and XLR



Bombardier C-series 100-150 seats. Now A-220

First flight on sept 16th 2013. First demonstration flight of CS100 with 100 passengers June 3rd 2016. Currently under certification flights

Spoilers, flaps and landing gear doors built in Brindisi, tail surfaces in Foggia

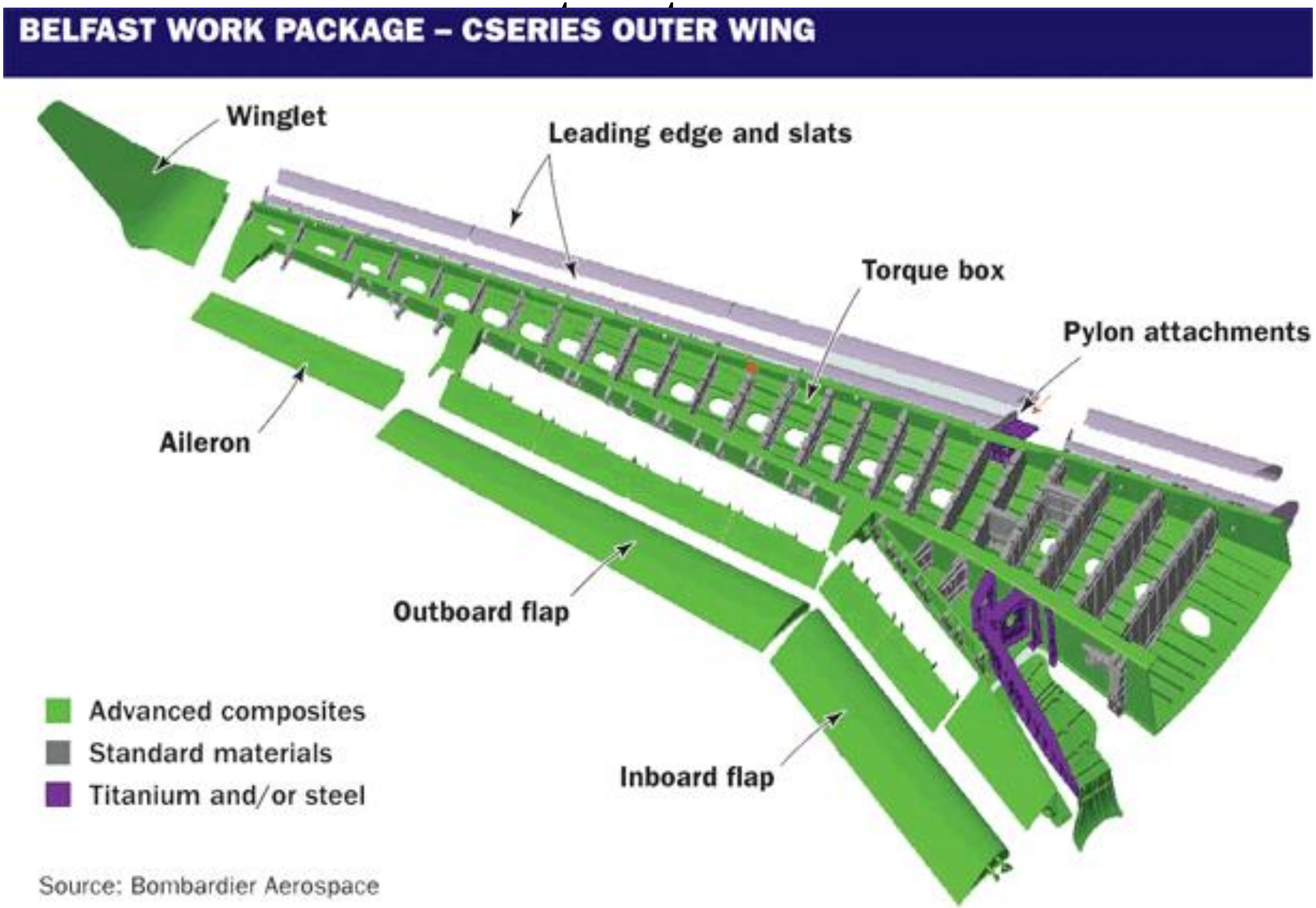
The A220 ramp-up continues toward a monthly production rate of 14 aircraft in 2026

From 2018 Airbus A220-100 and Airbus A220-150: Airbus bought 51% of the program.
Compared to A319 “But the A220-150 is 12,000 pounds lighter, and offers over 10% lower operating costs with a larger cabin, overhead bins, wider seats, and unmatched technology.”

Airbus A-220 (Bombardier C-series). Job share

the *CSeries* composite wing (and their tip-end winglets) are built in Britain [coloured grey]. Wing leading edges are from Belgium [gold]. The wing trailing edge surfaces are made in Italy, (Alenia and Salver) [bright green] and their actuators in the US [blue]. The fuselage, doors, etc. are built in sections in China [red]. Tail surfaces are from Italy (Alenia) [bright green]. The undercarriage is made in Germany [fuchsia], the wheels and brakes in the US [blue]. Engines and their nacelles, pylons, etc. are from the US [blue] under the control of Pratt & Whitney

Airbus A-220 (Bombardier C-series). Wing



Leonardo ATR-72

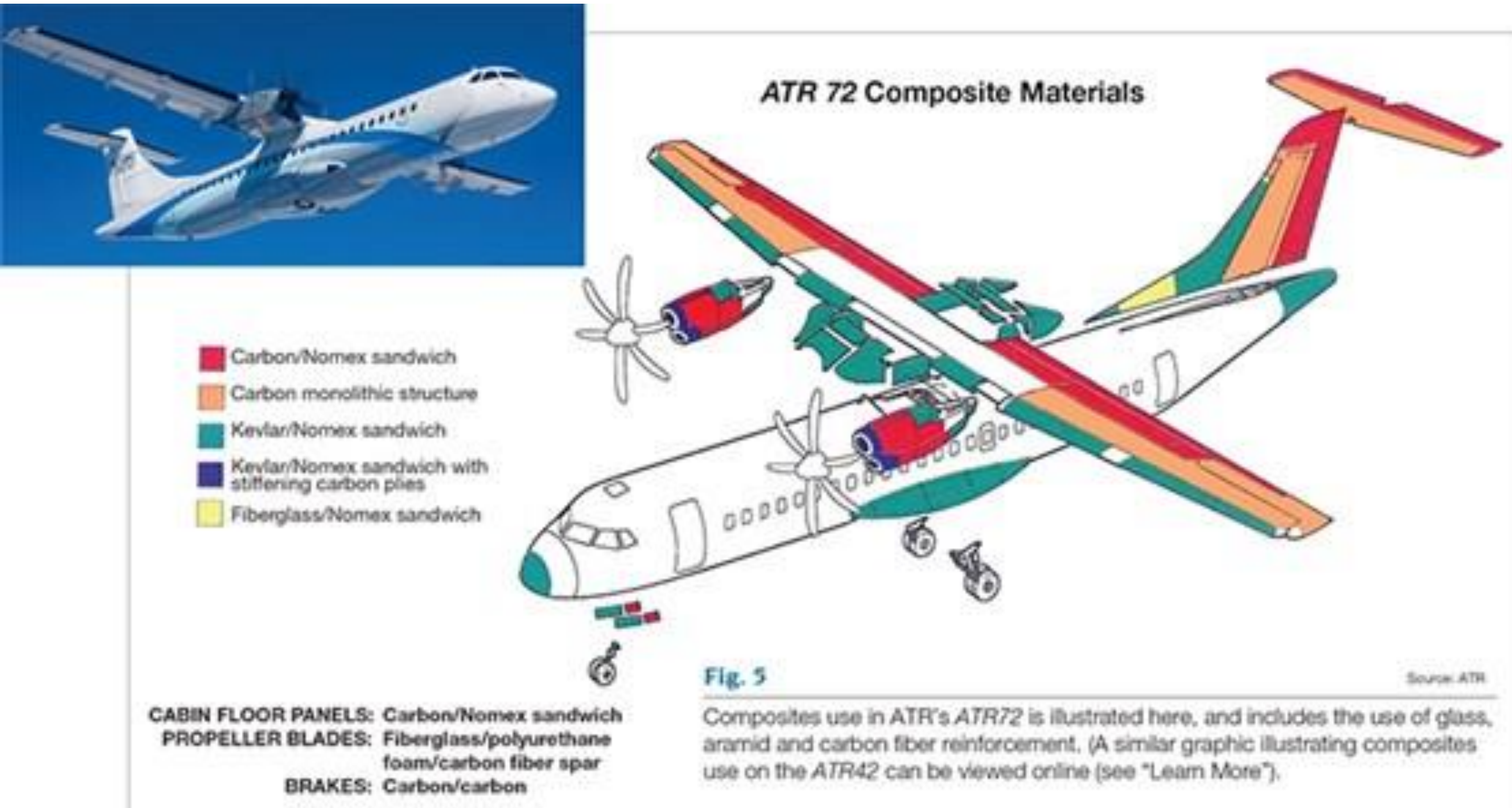
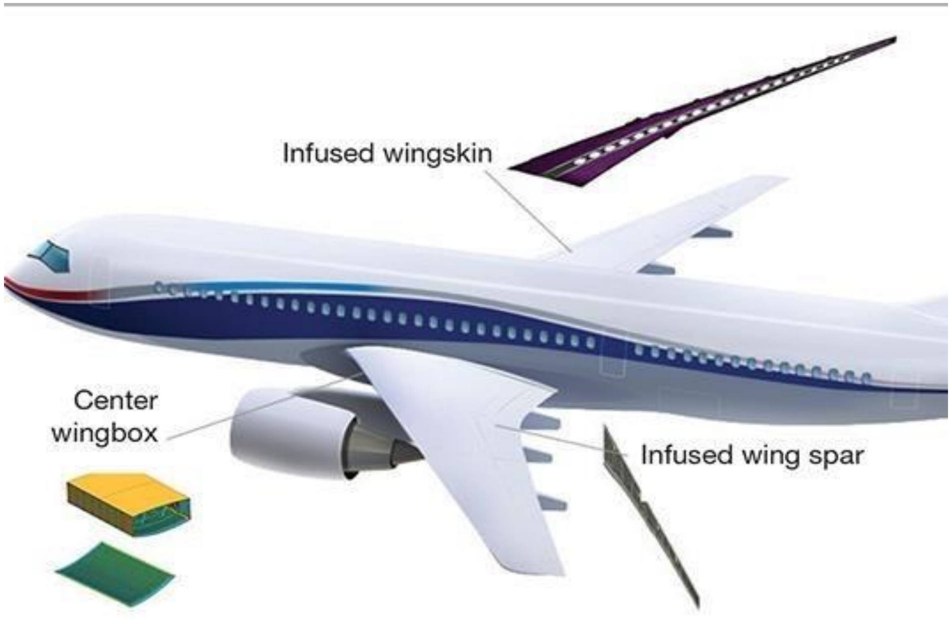


Fig. 5

Composites use in ATR's *ATR72* is illustrated here, and includes the use of glass, aramid and carbon fiber reinforcement. (A similar graphic illustrating composites use on the *ATR42* can be viewed online (see "Learn More").

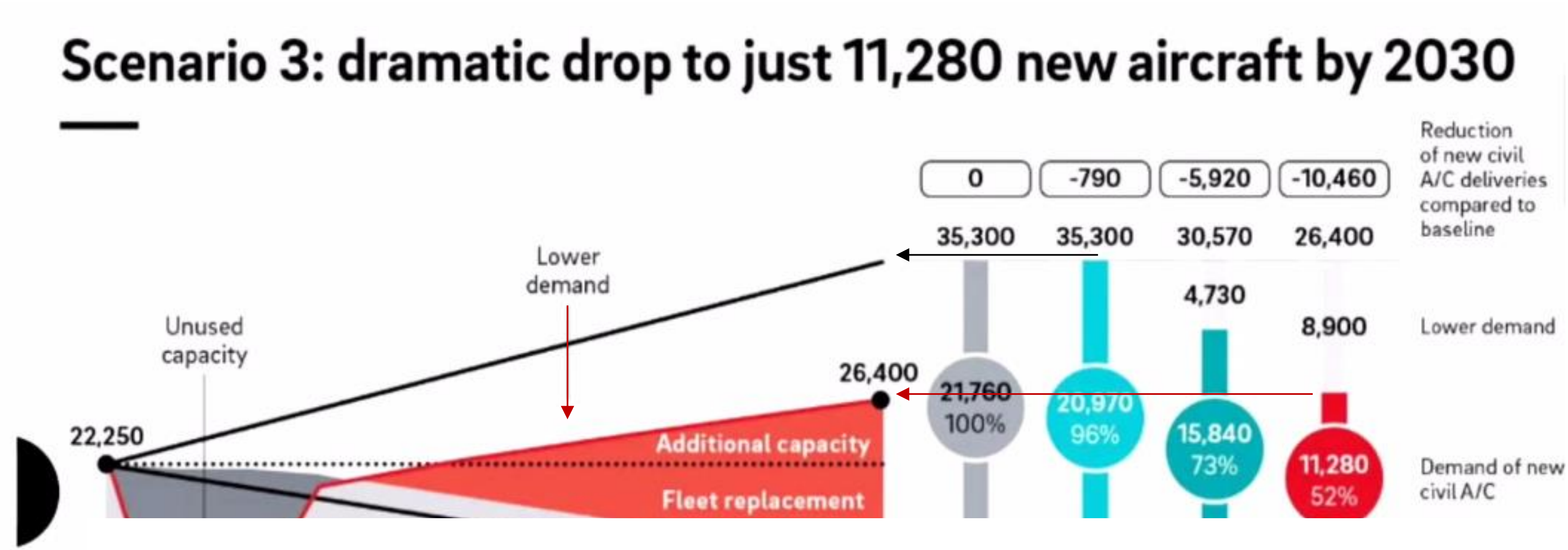
MC-21-300 (MS-21-300)

- The MS-21-300 (Irkut Corp. (Irkutsk, Russia) (160-211 passengers), the rolled out on June 8, began flight testing in 2016 *and earned certification in 2019*.
- *MS-21* Centre wingbox, wing stringers and skins are co-molded in one piece, with the spars and wing box fabricated separately.
- October 2017: first flight
- February 2019: first EASA certification flight
- Dec. 2019: fourth test aircraft completed



Fourth aircraft

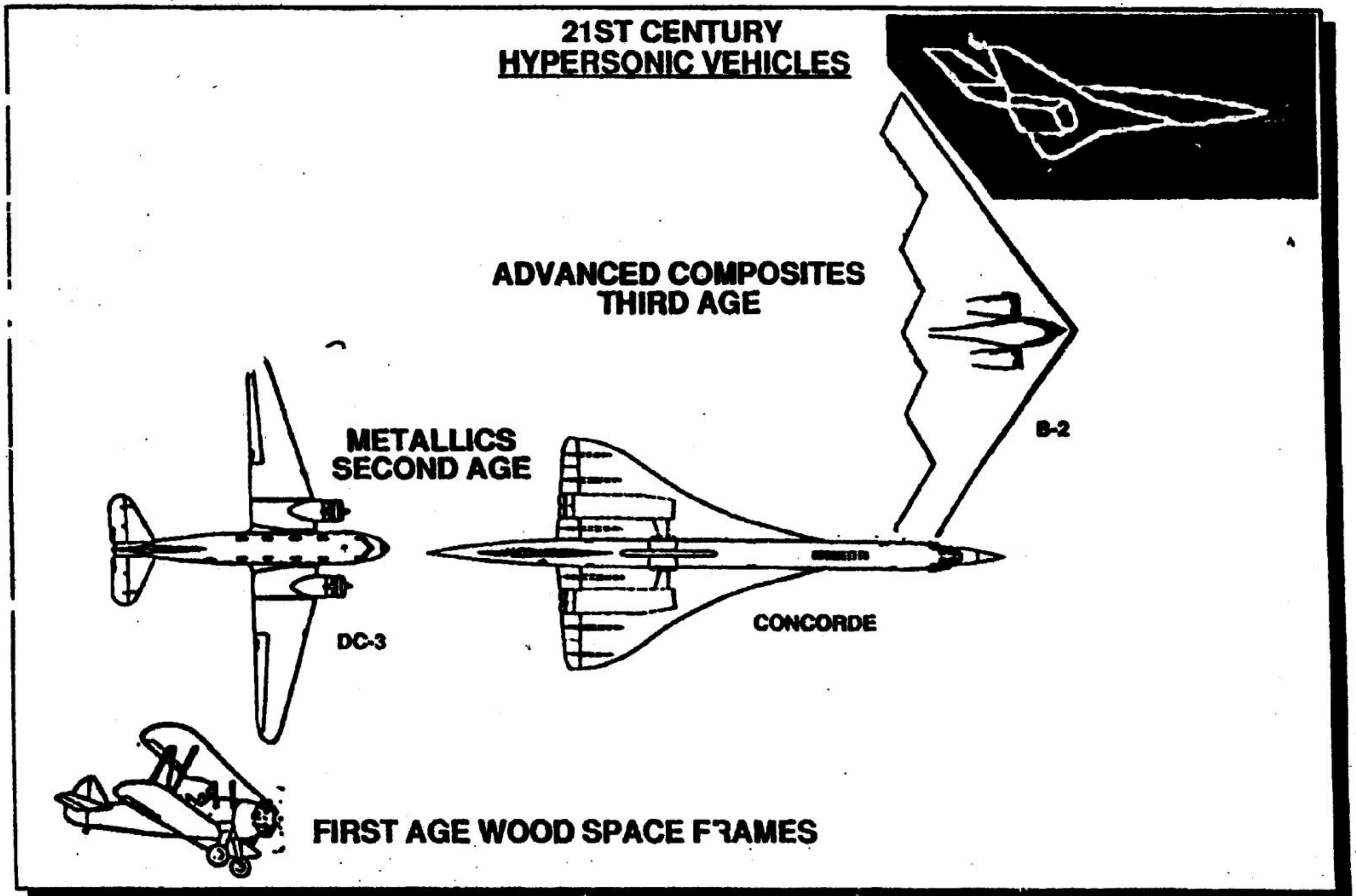
Civil Aircraft market forecast



SELL PERSPECTIVES (*To be revised after pandemy*)

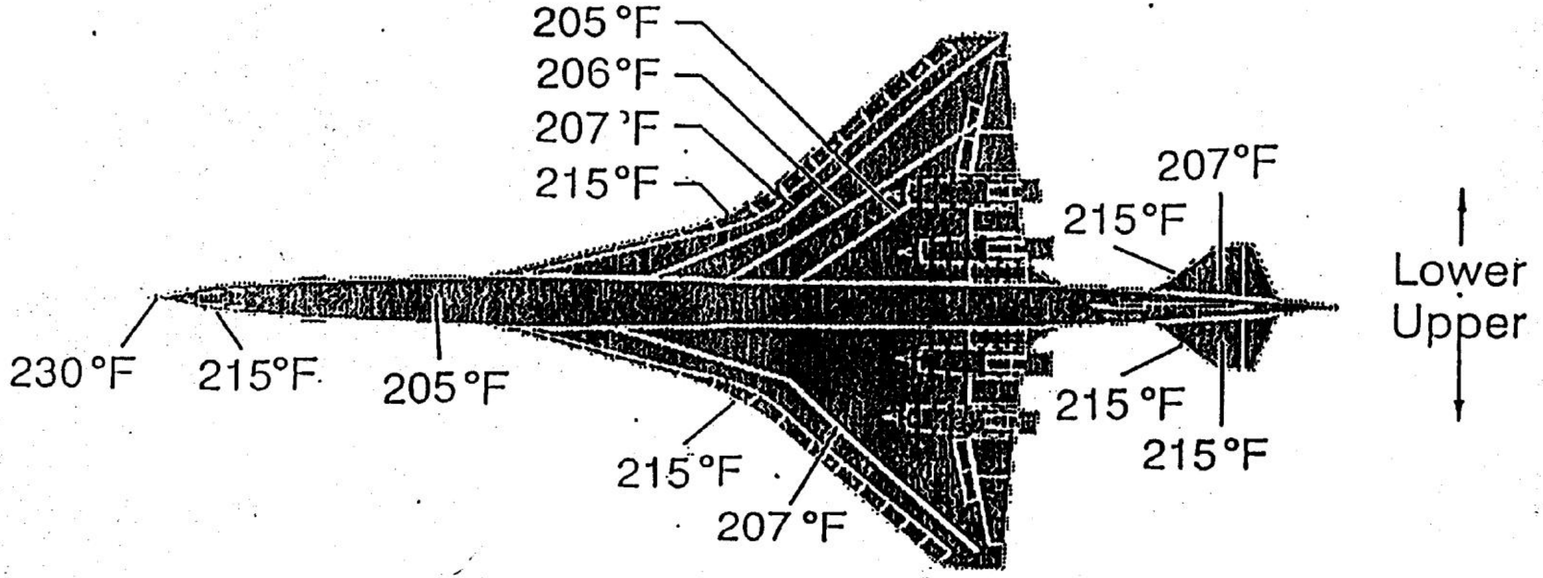
	Ordered (Total)	**Delivered (half 2019)**	**Backlog**	**Prod. Rate (aircraft per month)**	**Time for prod of backlog orders**
B787	1464	882	582	14	3.5 years
A350	913	300	613	10 ramping to 13	4 to 5 years

THE FOURTH AGE: HYPERSONIC VEHICLES/MATERIALS



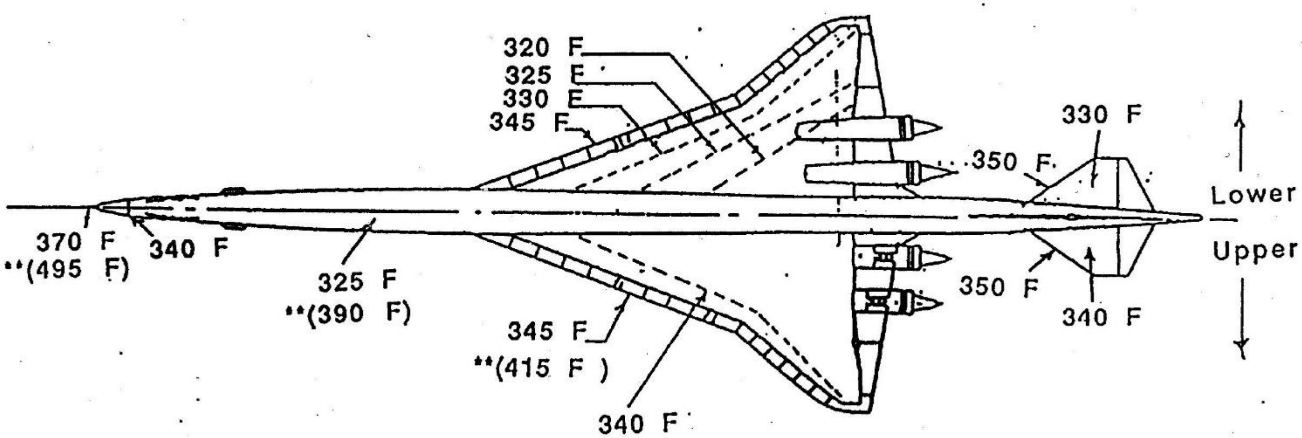
Skin Temperatures for M 2.0 Transport

Bare Surface

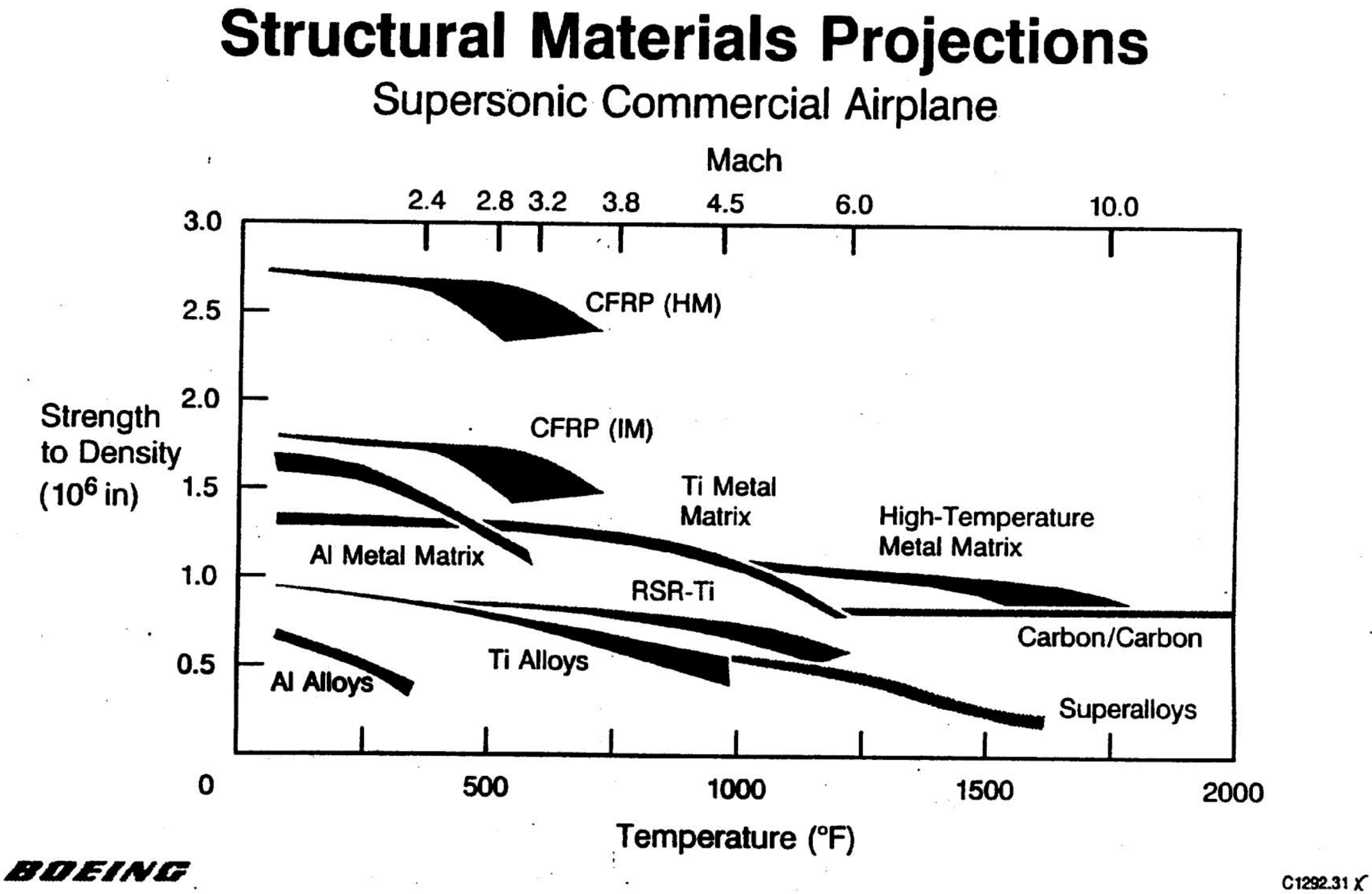


Cruise conditions
40 to 70,000 ft altitude
U.S. standard day

M 2.4 TEMPERATURES



'(T @ M_C)
**(T @ M_D)

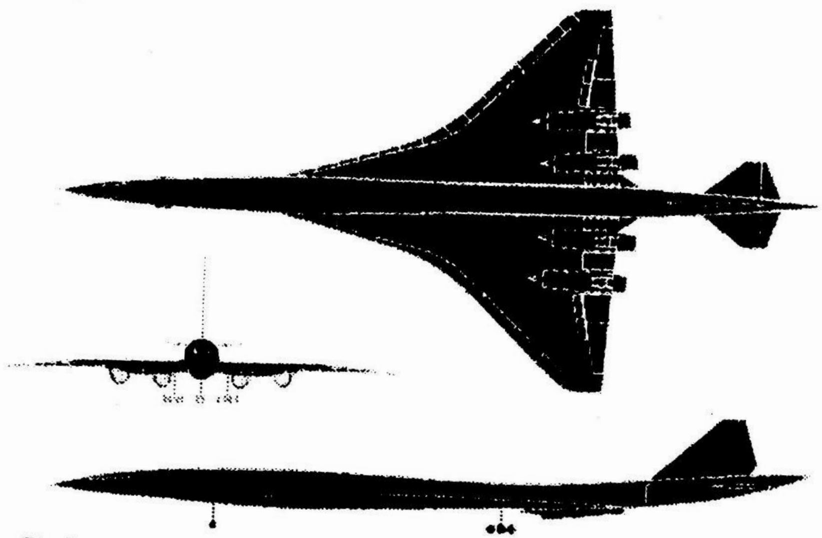


1990 Proiezioni Boeing

SST Studies

Supersonic Commercial Airplane

Mach 2.4 Configuration



Primary structure material:

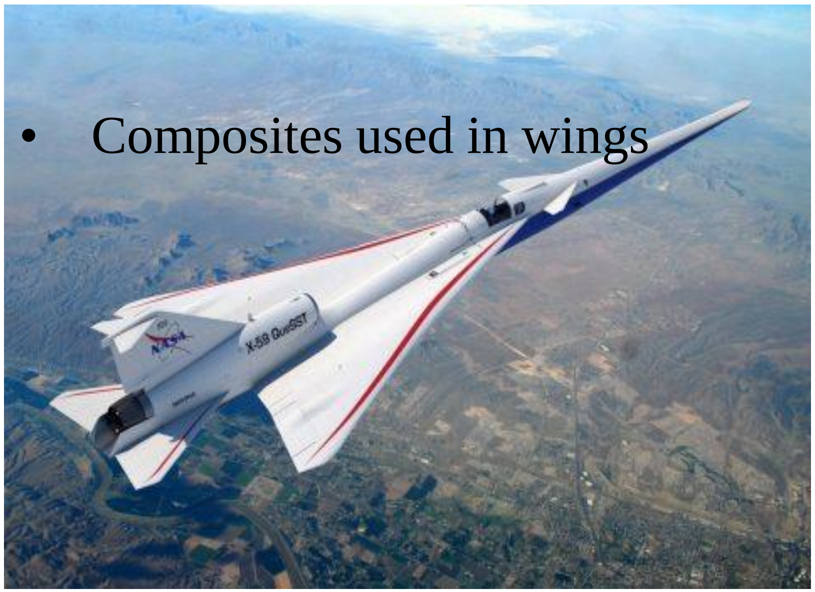
- Polymeric composites
- High-temperature aluminum
- Titanium fittings, fasteners, and leading edge

BOEING

C1292.30 R1

1990 Boeing

The X-59 QueSST a research jet shaped to reduce the loudness of sonic boom



- Composites used in wings

2020 NASA and Lockheed Martin. 1st flight in 2021

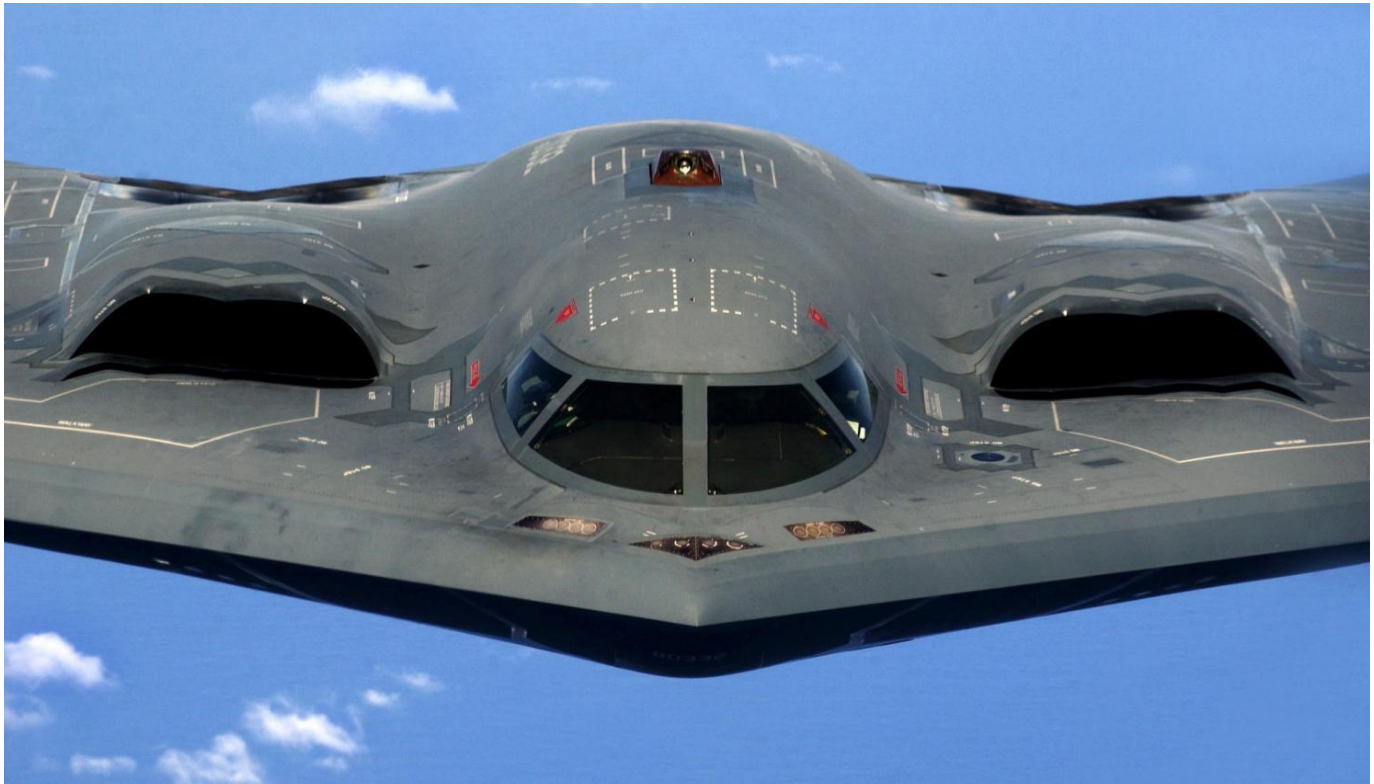
Boom Tech. (USA) is launching a supersonic aircraft, “composite intensive” (Mach 2.2)
Small demonstrator XB-1 is 71 feet long

Leonardo as the primary engineer lead for major fuselage structural components, including two major fuselage sections of XB-1, and the wingbox.

Aerion, partner of Boeing, Spirit, GKN and GE, is developing a 12 seats 1.4 Mach supersonic operating with synthetic fuel made with carbon recovered from CO_2 emissions

B-2 and new B-21 Stealth

- The B-2 makes heavy use of titanium for structural elements, with much of the rest of the aircraft built of carbon-reinforced plastic (CRP) material. Large CRP skin assemblies are used to make the aircraft as "seamless" as possible, reducing radar reflections.
- High temperature materials required, up to 350 ^{o}C continuous use



Composites in military aircrafts

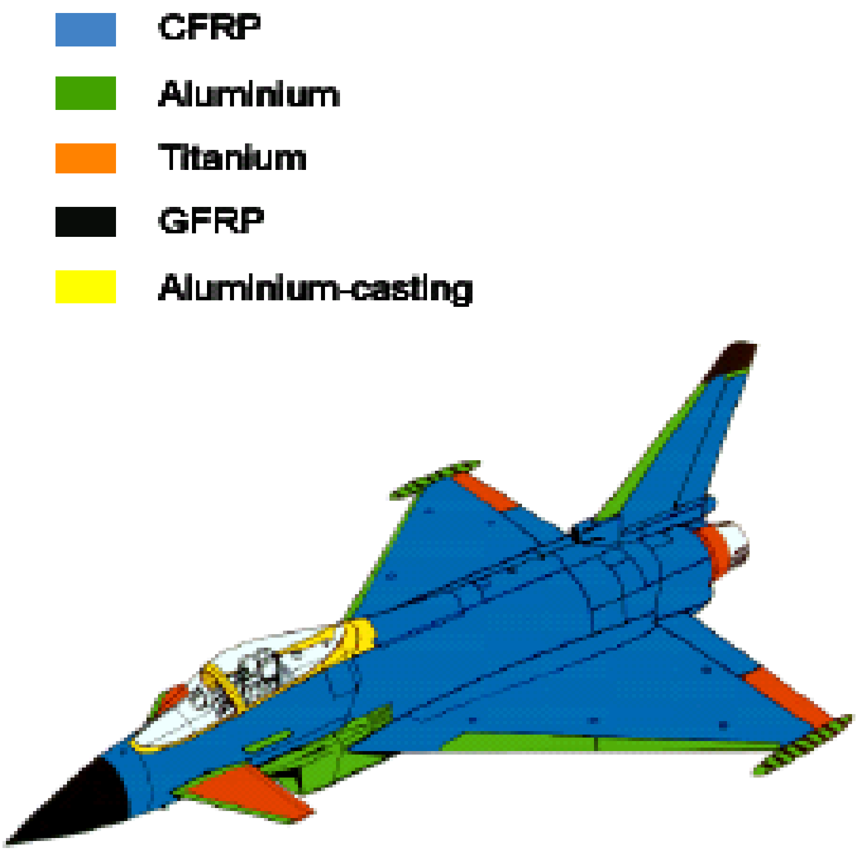


Figure 11 – composite parts of the Eurofighter

Military aircrafts: Eurofighter Typhoon

European designed and built air supremacy aircraft
EU primary sales with export potential
Total program orders of 707 aircraft as of January 2008
Average cost of 77.7 Mln EUR and total program cost of 55 Bln EUR
Airframe is made up of 50% composite material by weight

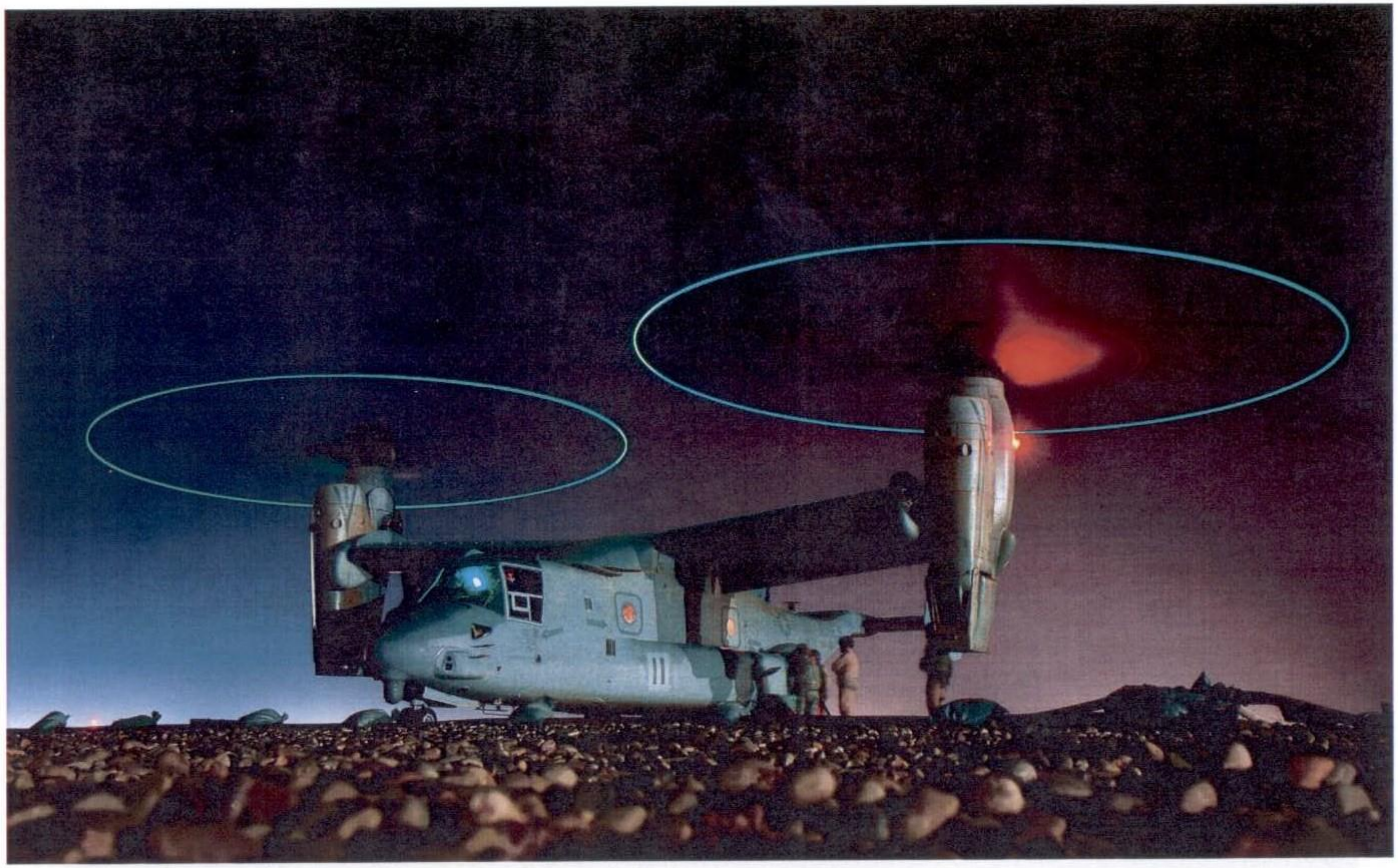
Military aircrafts : F-35 Lightning II (JSF)

US semi-stealth multirole aircraft with export potential
F-16 & F-18 replacement
Three variants: conventional take off, short take off and vertical landing, and carrier based
Average cost of $104 Mln: 3,200 unit production for a total program value of $330+ Bln
Airframe is made up of 56% composite material by weight

Military aircrafts: F-22

Most advanced stealth multi-mission air supremacy aircraft ever built
US proprietary, non-export technology
The F-22 is a replacement aircraft for the aging F-15
Average cost of $192 Mln and total program cost of $36 Bln: April '09 program decision
Airframe is made up of 64% composite material by weight

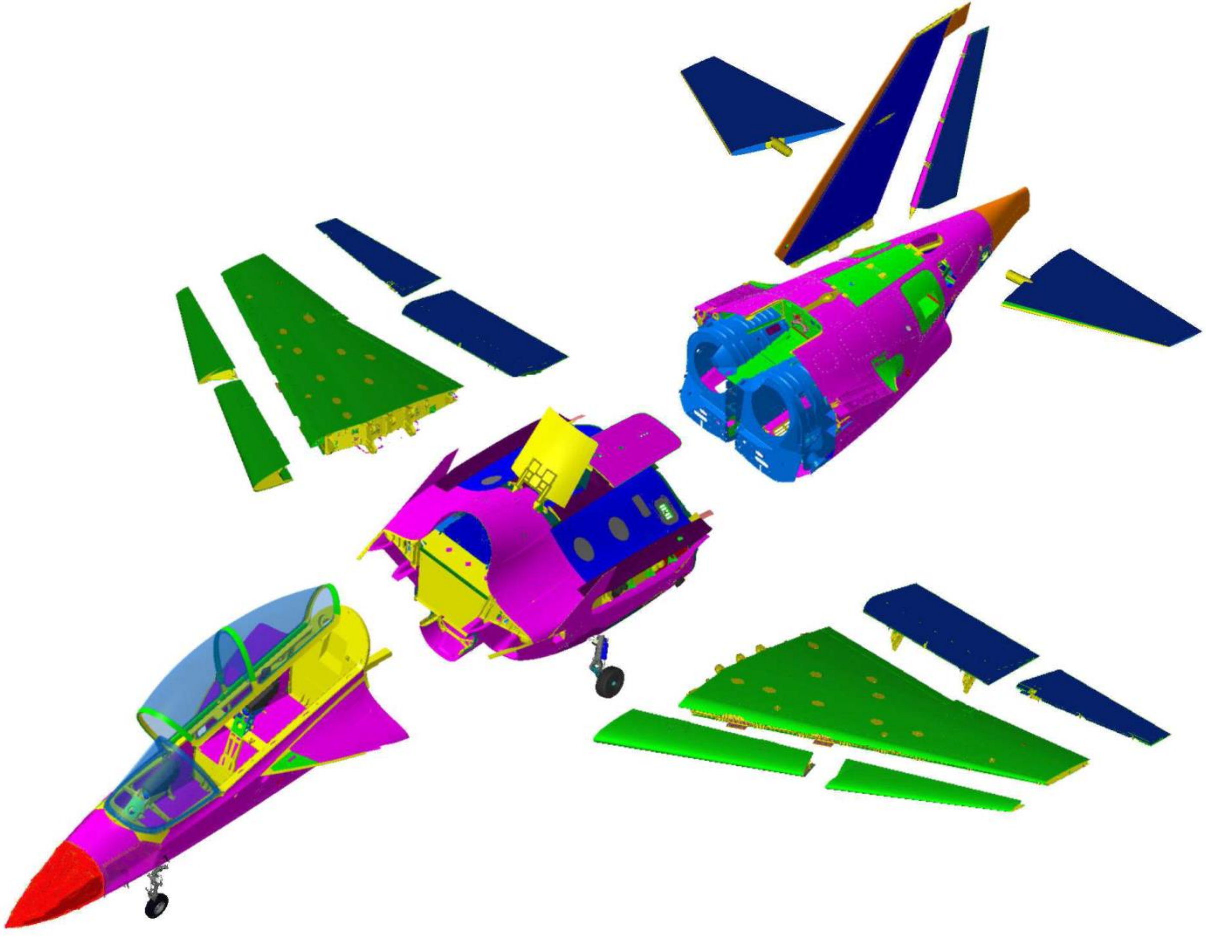
Military aircrafts: V-22 Osprey



US Marines' multi-purpose tilt rotor aircraft; 2x the speed of a traditional helicopter
The V-22 is a replacement for the aging CH-46 helicopter
Average cost of $96.6 Mln and total program cost of $44 Bln
Airframe is made up of 87% composite material by weight
First successful deployment in Iraq; now scheduled to be deployed in Afghanistan

Composite materials in tiltrotors

- AW609 from Leoanrdo helicopters features composite wings (manufactured in Brindisi)



Alenia-Aermacchi
AM-346

U(C)AV Unmanned (Combat) Air Vehicle
Predator A from General Atomic (flying since 2007)
Drones Marke in 2023 43 billions $, 2030 580 bn$

UAV for surveillance, reconnaissance etc

Sky-Y, the Alenia UAV, weighs 1200kg, 10 m long and wingspan 10m

Zephir, a solar electric High Altitude Long End. UAV:

- wingspan 18m
- Weight 30 kg
- Flight at 70000 ft

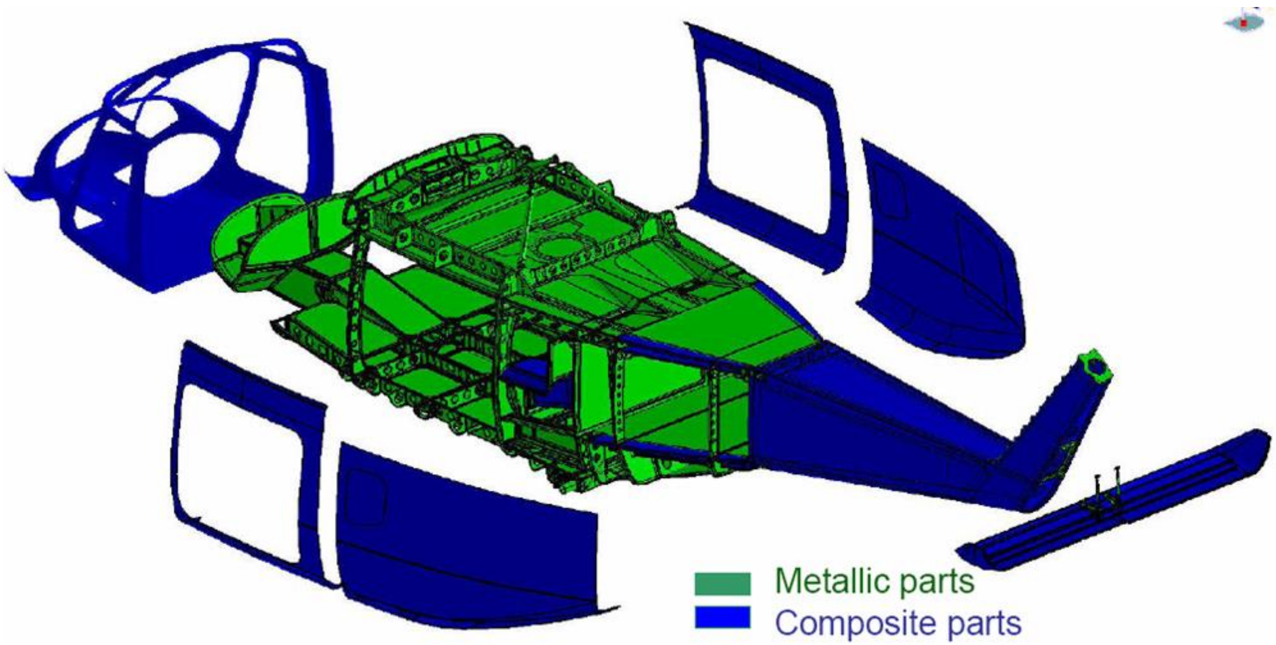
Solar impulse: electric propulsion by solar cells

Solar impulse 2: weight 2300kg, wingspan 72 m (similar to B747)
1700 solar cells, batteries energy density 4 x 260 Wh/kg (633 kg)
Full composite structures

HALE liquid hydrogen powered: Boeing phantom eye

The Phantom Eye demonstrator has a 150-foot (46 meter) wingspan. Boeing states that it can fly for more than four days at a time at altitudes of up to 65,000 feet.

composite materials in helicopters, since 80's



Cockpit, main cabin lateral panels and tail unit are of composite construction.

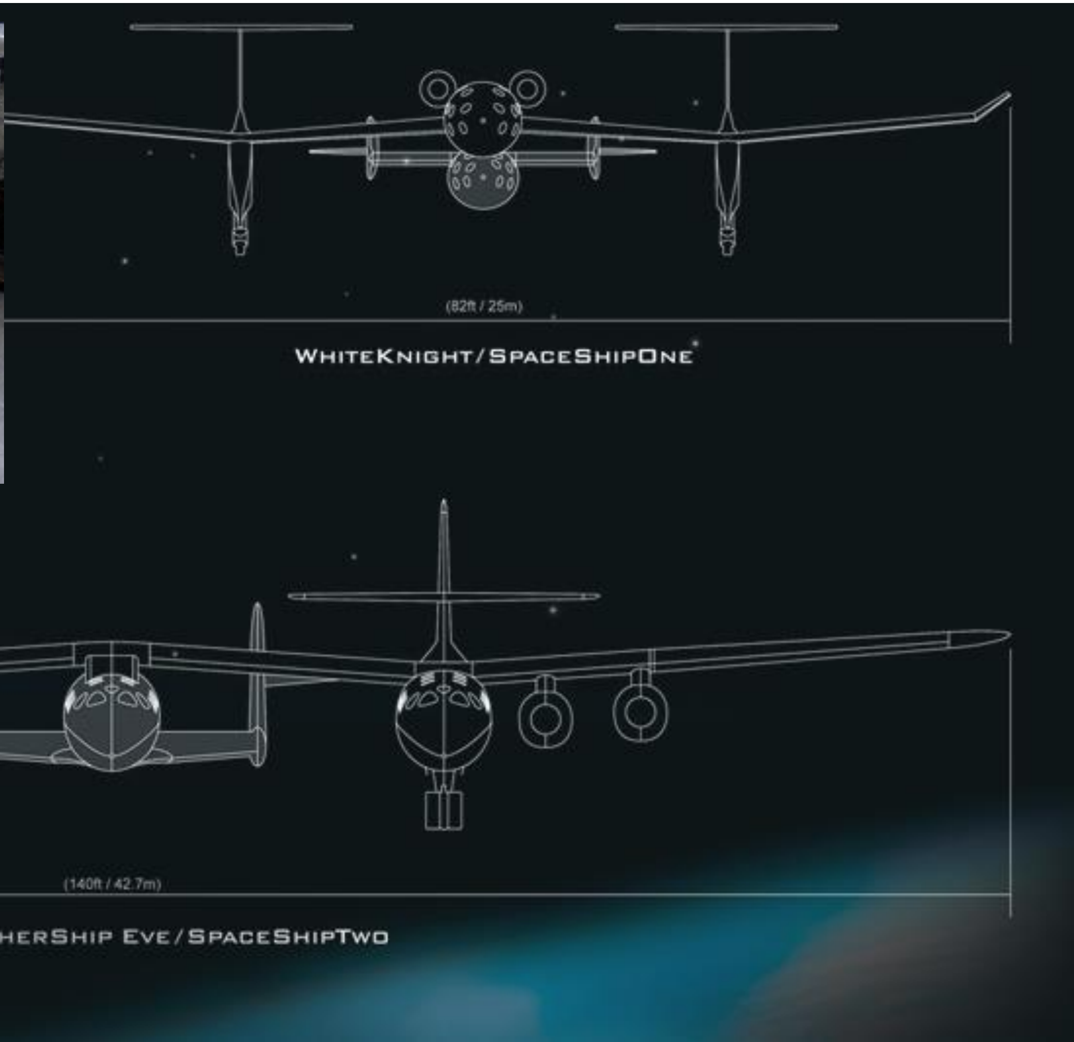
- The metallic parts are often sandwich panels bonded with adhesives
- In new programs all fuselage parts have been made in composites (AW139-AW169 fuselage manufactured in Brindisi)

Space ship two and white knight two

"the 140 foot long wing spar is the largest carbon composite aviation component every manufactured"

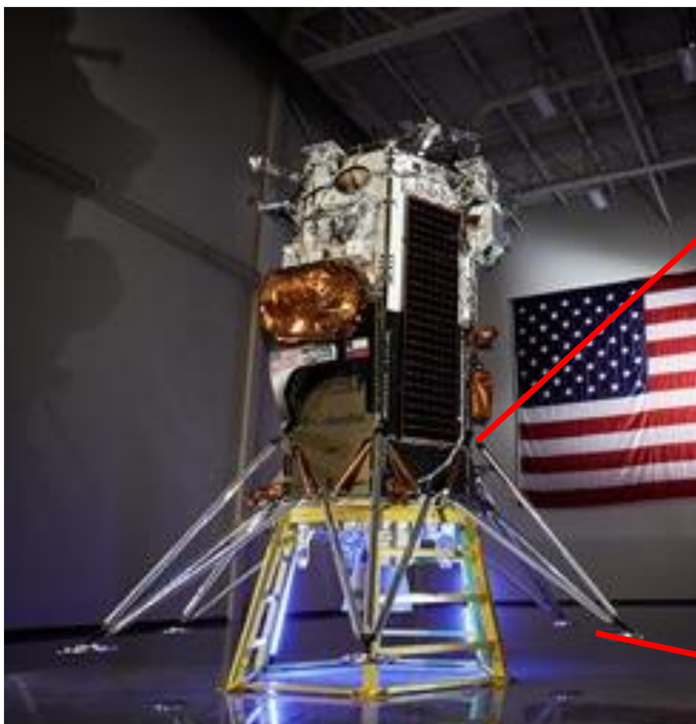
Space ship two and white knight two

"the 140 foot long wing spar is the largest carbon composite aviation component every manufactured"

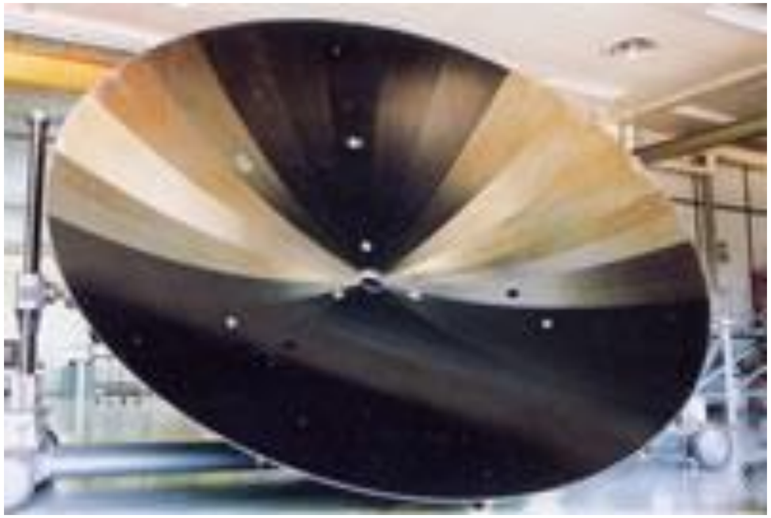


IM-1 lunar mission (NASA 2024)

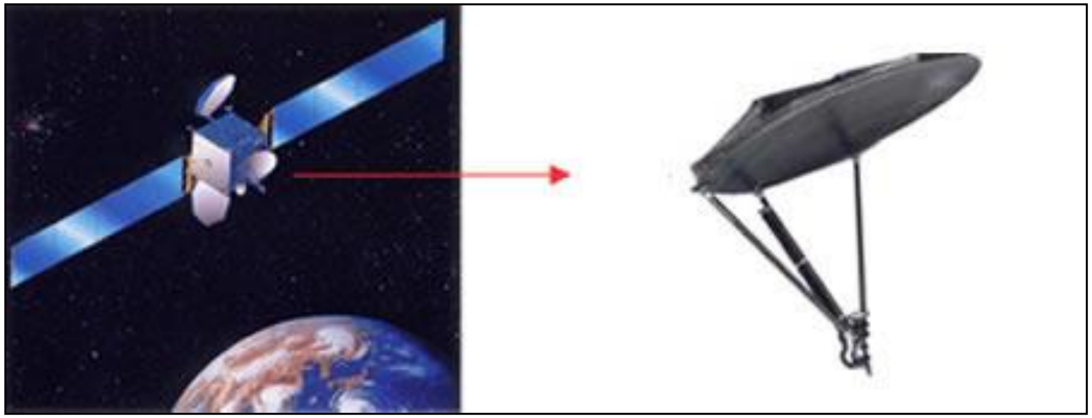
- Unidirectional carbon fibers struts of lander Odysseus
- Circular and rectangular tubes with and without titanium fittings



Satellites reflectors



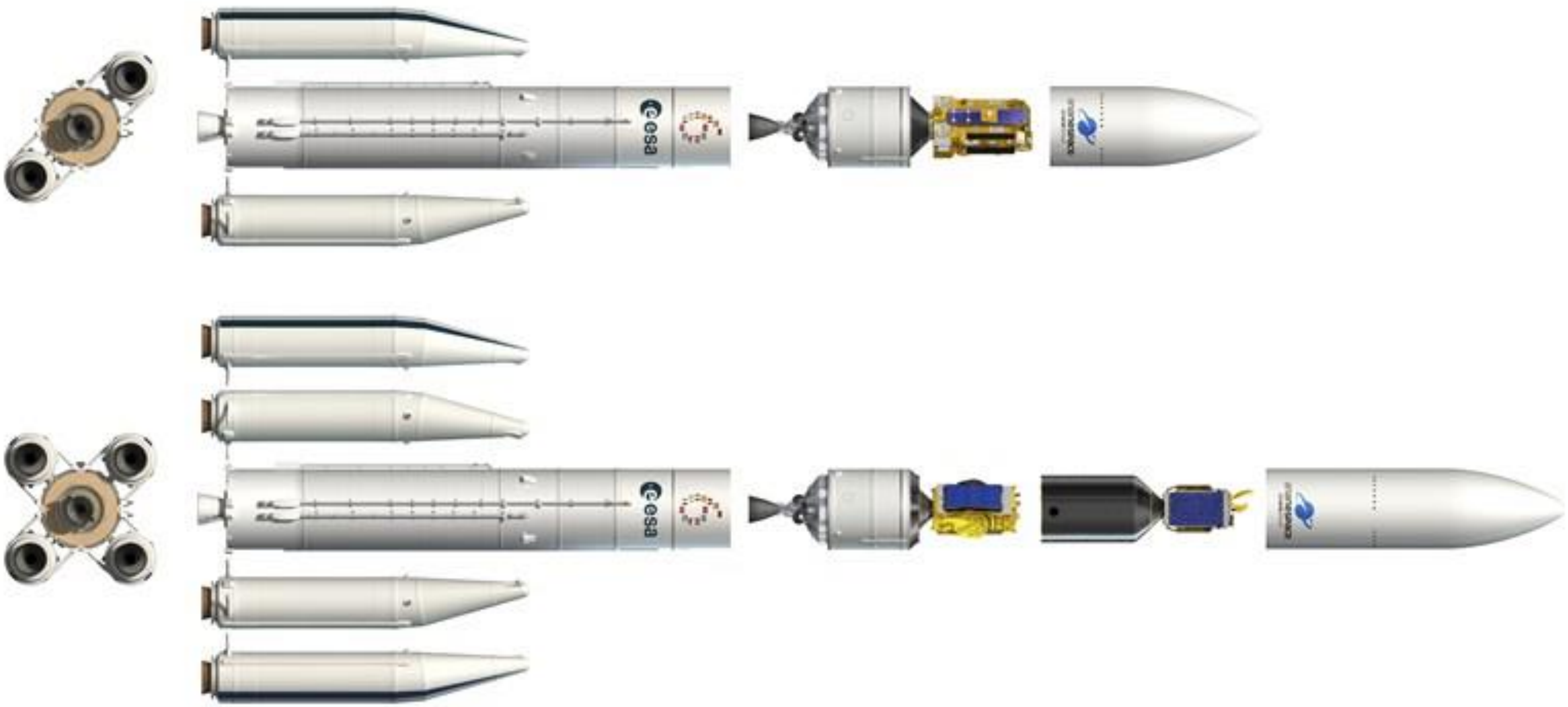
Antenna reflector
Thales Alenia SpA



Antenna reflector

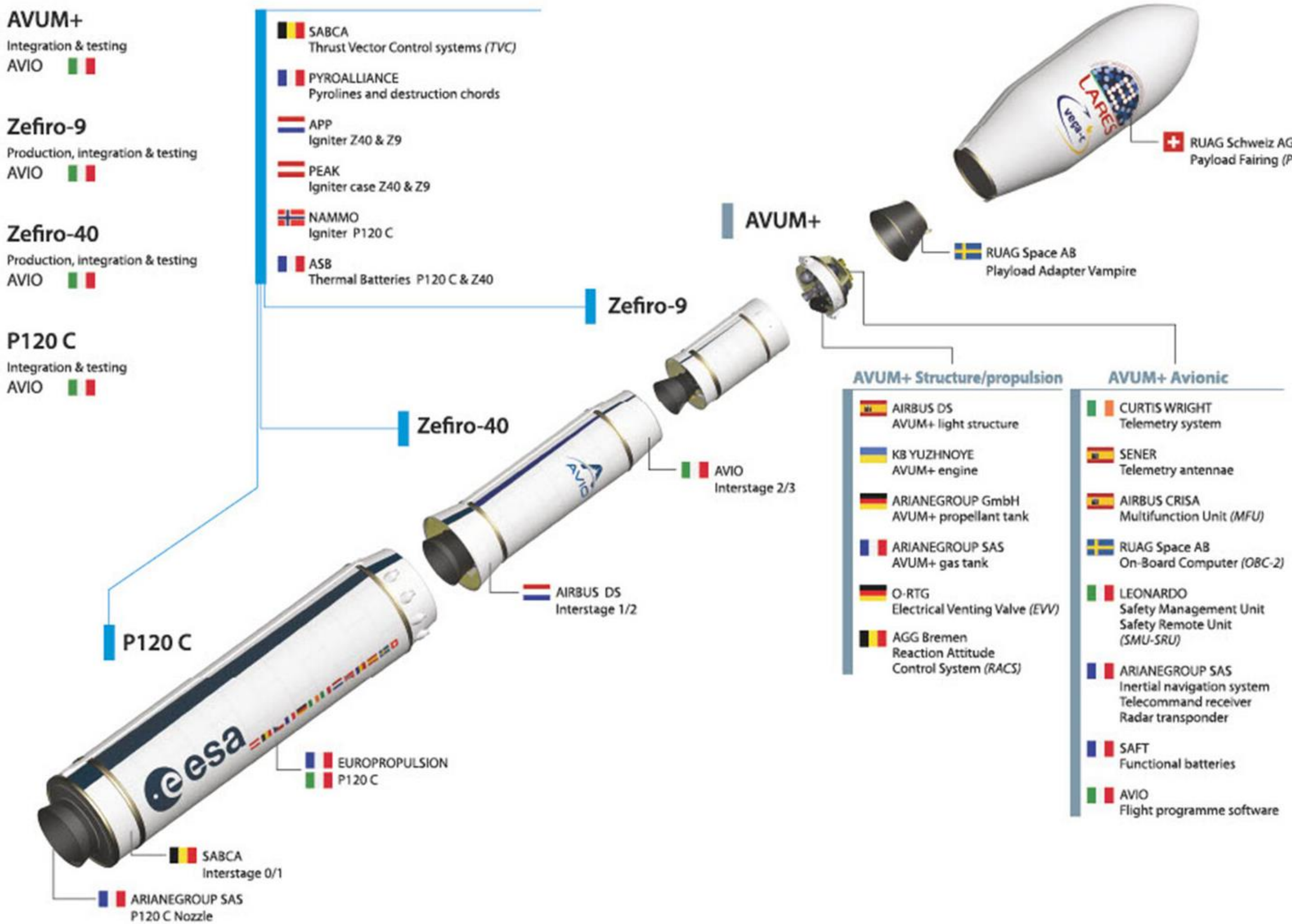
Launchers

Ariane 5 fairing (nose cone) is 5.4 meters in diameter and made of carbon fiber



Launchers

Vega first three stages and payload fairing are made of Carbon fiber composites by Avio Space in Colleferro - Italy



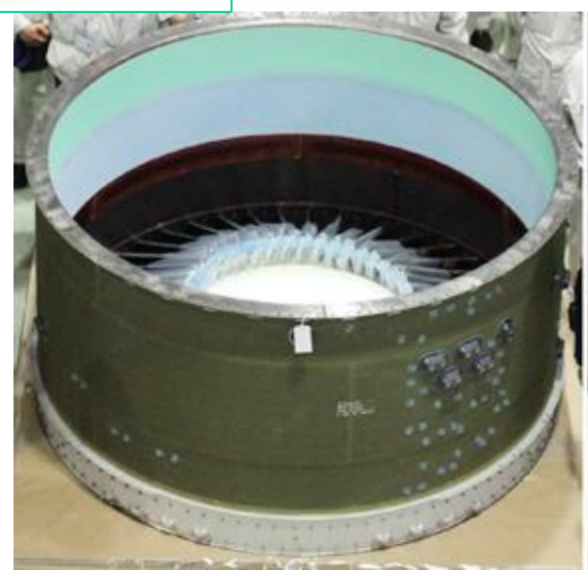
Aeronautic engines

The GE90, in 1995, was the first production jet engine for commercial use to have carbon fiber fan blades in place of traditional titanium blades

Each GE 90 engine uses 22 4 ft blades; each weighs just 50 lbs and, over more than 6 mln flight hours, <u>only 3 blades</u> have been replaced

Fan case and Structural guide vane (JEC award 2017)

IHI AEROSPACE For Japan Aero Engine and Pratt and Whitney (A320 Neo)



Composite Materials

Composite Materials

- **Matrix**
  - **Polymers**
  - **Metals**
  - **Ceramics**
- **Reinforcement**
  - **Fibre**
    - **Glass**
    - **Carbon**
    - **Polymers**
  - **Particulate**
    - **stiff**
    - **Rubbers**
- **Coupling agents:** to improve fibre wetting promoting chemical bonds at fibre/matrix interface
- **fillers:** to lower costs and decrease process shrinkage

Market data:

Polymer matrix, Glass Fiber Reinforced Composites: 90% by volume 85% by value