Overview of Advanced Composite Materials and Structures

About these slides:

- The center on Advanced Materials In Transport Aircraft Structures (AMTAS):
  - was established in 2003
  - is part of the FAA Center of Excellence program
  - involves 6 colleges/universities: UW (lead), WSU, EdCC, OSU, UoU, and FIU
  - involves several aerospace companies (primarily Boeing)
  - maintains a website with additional details:

http://depts.washington.edu/amtas/

Overview of Advanced Composite Materials and Structures

About these slides:

- A composite short course intended for practicing engineers was developed by AMTAS participants
- These slides were extracted from the AMTAS short course

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Overview:
Advanced Composite Materials

What is a ‘Composite Material’?

“A composite material is one in which two (or more) materials are bonded together to form a third material.”

… is a material consisting of:

93.5% Al, 4.4% Cu, 0.6% Mn,1.5% Mg

a composite?

(this material is known as the 2024 aluminum alloy)

- No, 2024 Al is not considered to be a composite
- Definition is missing a reference to physical scale

Overview:
Advanced Composite Materials

What is a 'Composite Material'?

"A composite material is a material system consisting of two (or more) materials that are distinct at a physical scale greater than about 1 x 10^{-6} m (1 μm), and which are bonded together at the atomic and/or molecular levels."

To put this physical scale in context:

…the diameter of the human hair ranges from 30-60 μm

…objects with a dimension of 1 μm can be easily seen with an optical microscope

Overview:
Advanced Composite Materials

- Composites typically consist of:
  - Relatively strong and stiff *reinforcing material*, that is
  - Embedded within a relatively weaker and more compliant *matrix material*

- Composites have been used for centuries (clay bricks reinforced with straw; papyrus reeds embedded in a natural pitch matrix; etc)

- Composites occur naturally:
  - Wood: cellulose fibers in a lignin matrix
  - Bone: collagen fibers in a (mostly) calcium phosphate matrix

Overview:
Advanced Composite Materials

- 'Advanced' (or 'modern') composites are engineered materials developed within ~past 80 yrs
- First commercially successful advanced composite is commonly known as 'fiberglass': glass reinforcing fibers embedded within a polymer matrix (usually polyester, vinyl ester, or epoxy)
- Advanced composites often classified according to
  - Type of matrix material, or
  - Physical form of reinforcing material

Overview:
Advanced Composite Materials

- Classification by type of matrix material:
  - Polymer Matrix Composites (PMCs)
    - e.g., polyester, epoxy, bismaleimide, phenolic matrices
  - Metal Matrix Composites (MMCs)
    - e.g., aluminum, titanium or magnesium matrices
  - Ceramic Matrix Composites (CMCs)
    - e.g., silicon carbide (SiC), silicon nitride (Si_3N_4), aluminum oxide (Al_2O_3) matrices
- Approximate maximum service temperatures:
  - PMCs: up to about 350ºC (630ºF), depending on polymer
  - MMCs: up to about 500ºC (900ºF), depending on metal
  - CMC: up to about 1200ºC (2100ºF), depending on ceramic

Overview:
Advanced Composite Materials

- Classification by physical form of reinforcing material:
  - Particulate: roughly spherical reinforcing particles with diameters ~ 1-100 μm
  - Whisker:
    - diameters ~ 5-30 μm
    - lengths < 10 mm
  - Short (or "chopped") fiber:
    - diameters ~ 5-30 μm
    - lengths 10 → 200 mm
  - Continuous fiber:
    - diameters ~ 5-30 μm
    - lengths, in effect, infinite

Chopped glass fiber

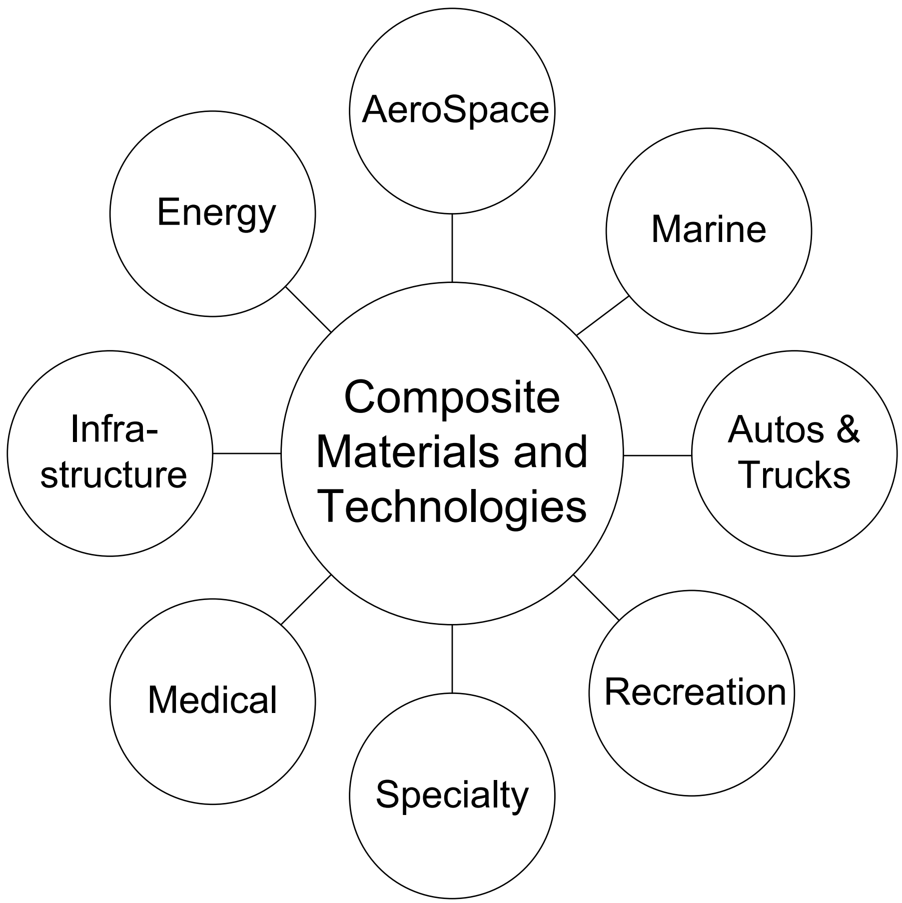
Continuous glass fiber

Overview:
Advanced Composite Materials

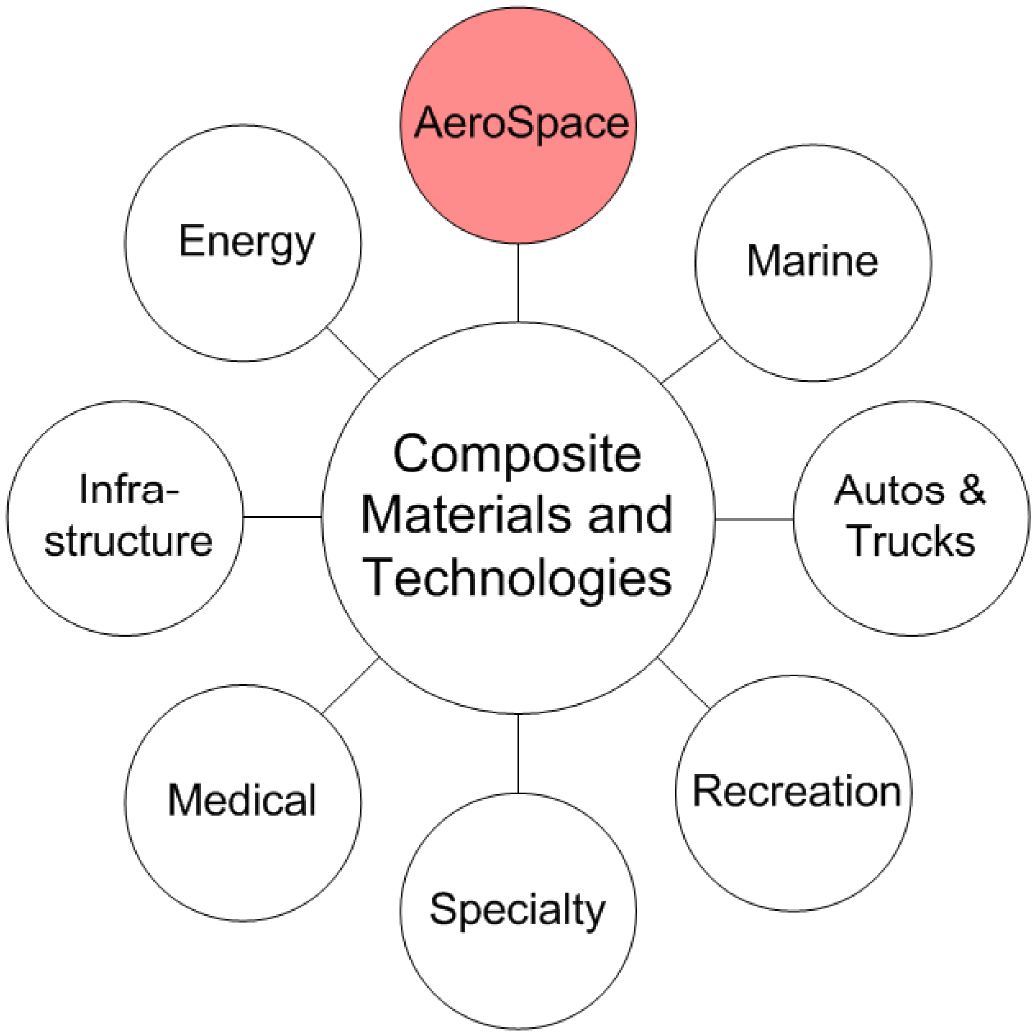
The remainder of this review (and ME450 as a whole!) is devoted to polymeric matrix composites

Overview:
Advanced Composite Materials

Although originally developed for aerospace, the use of composites has expanded into many industries



Overview:
Advanced Composite Materials



Overview:
Aerospace applications

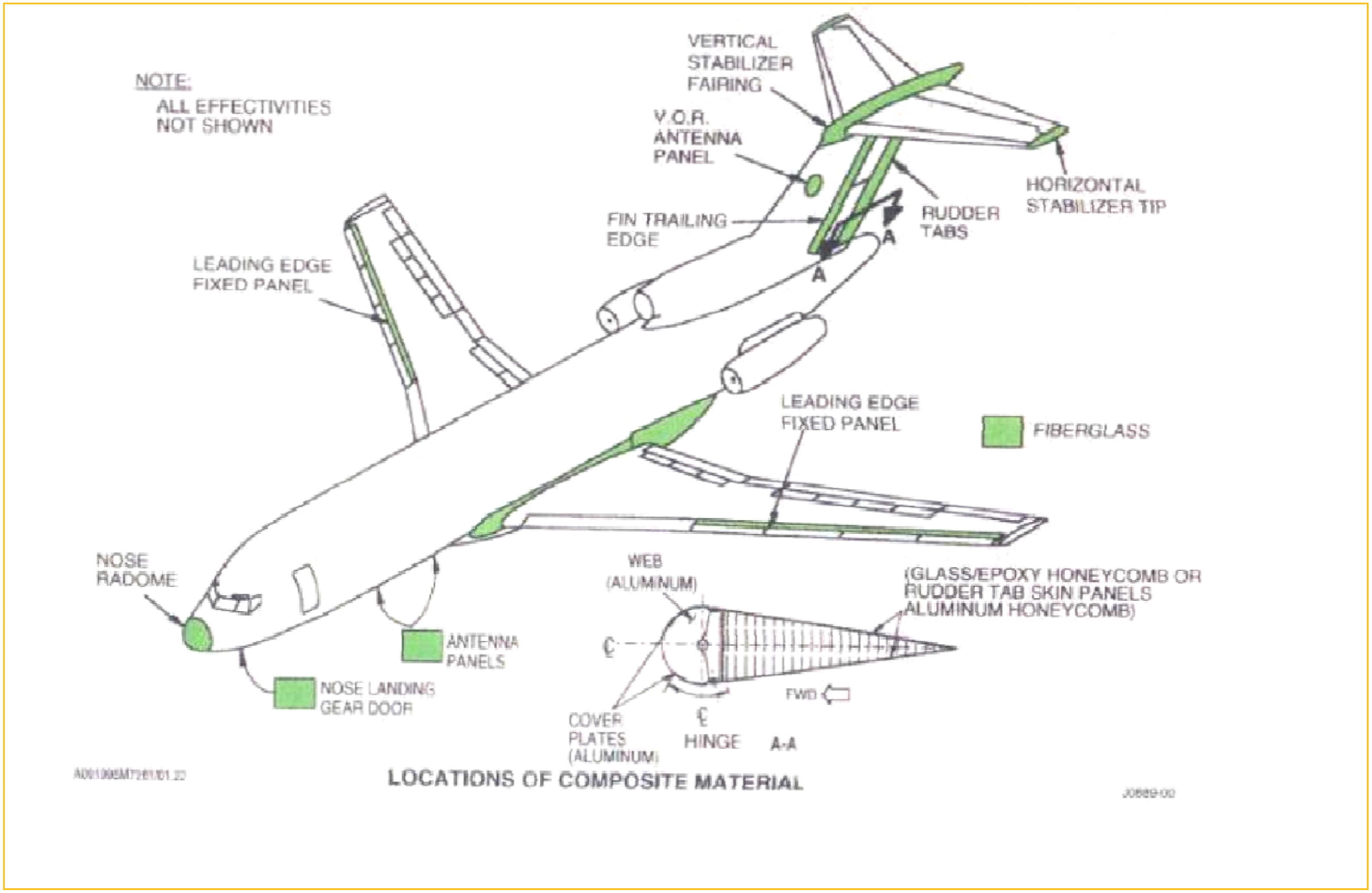
- Fiberglass introduced in 1930's (originally used in tooling) and 1940's (aircraft secondary structures)…
- Boron fibers introduced in the early 1960s…
- Glass (improved), carbon, and aramid (Kevlar) fibers introduced in the late 1960s and led to the increased use of advanced composites (particularly in military aircraft).
- Through the 1970s and early 1980s composite resins were brittle (e.g., "epoxy"), limiting (commercial) applications to *secondary* structural applications.
- In the late 1980s resin toughening technologies were developed (e.g., "rubber-toughened epoxy") paving the way for the more extensive use of composites in *primary* structural applications.

Overview:
Aerospace applications

- Boeing 777: Entered commercial service in 1995;
  - Composites account for about 10% of total structural weight
  - The graphite-epoxy empennage (i.e., the tail section) was the first composite *primary* structure used in a Boeing commercial aircraft
- Boeing 787: Entered commercial service Sept 2010
  - Composites account for >50% of total structural weight
  - Features a graphite-epoxy fuselage, empennage, and wings
  - Uses ~20% less fuel than other aircraft of similar size, primarily due to light-weight composite structure
- Boeing 777X: Enter commercial service in 2020 (?)
  - Composite wings…
  - Composite weight percent ?

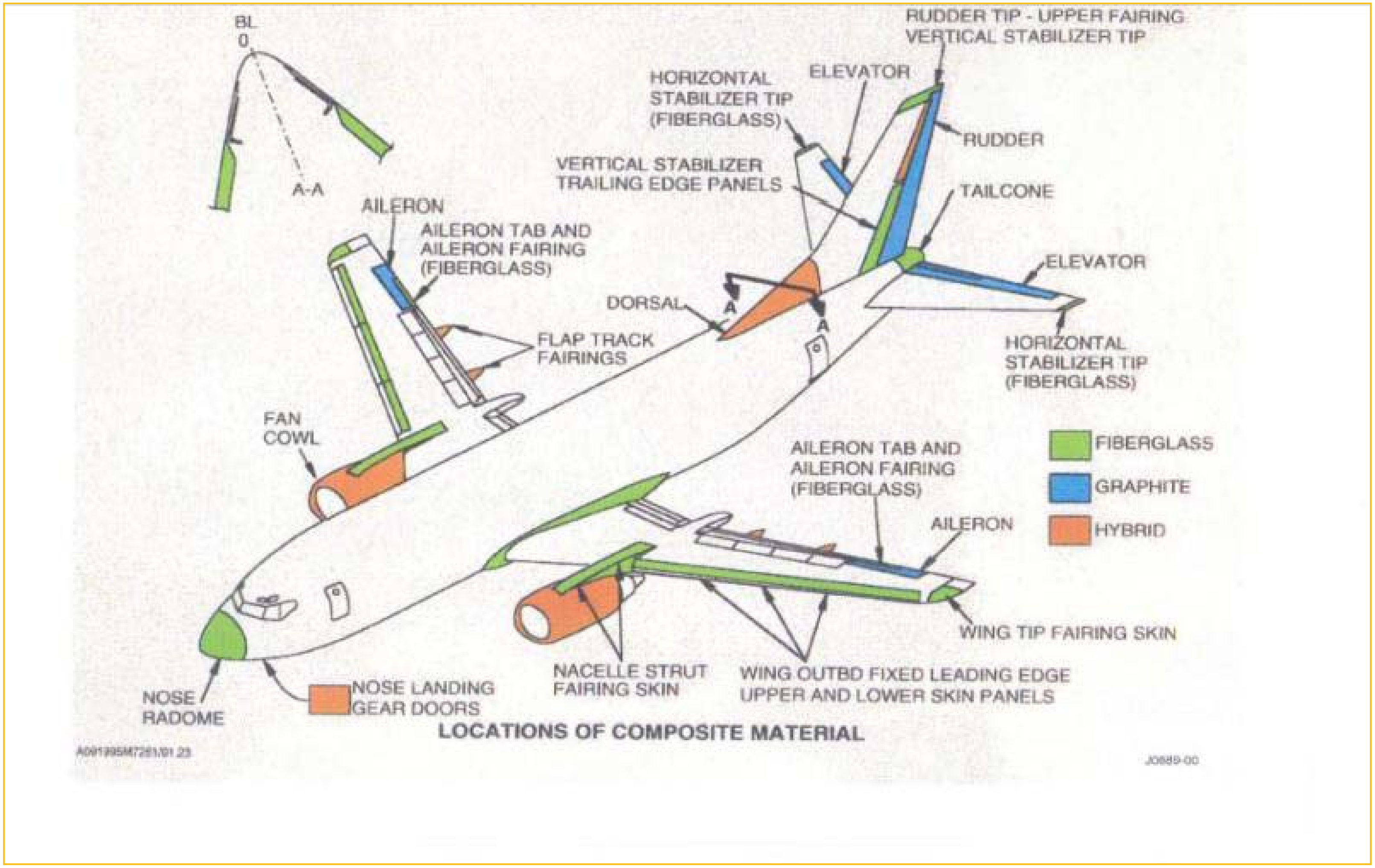
Overview:
Commercial Transport Aircraft

Use of composites in Boeing 727 (1963-84)



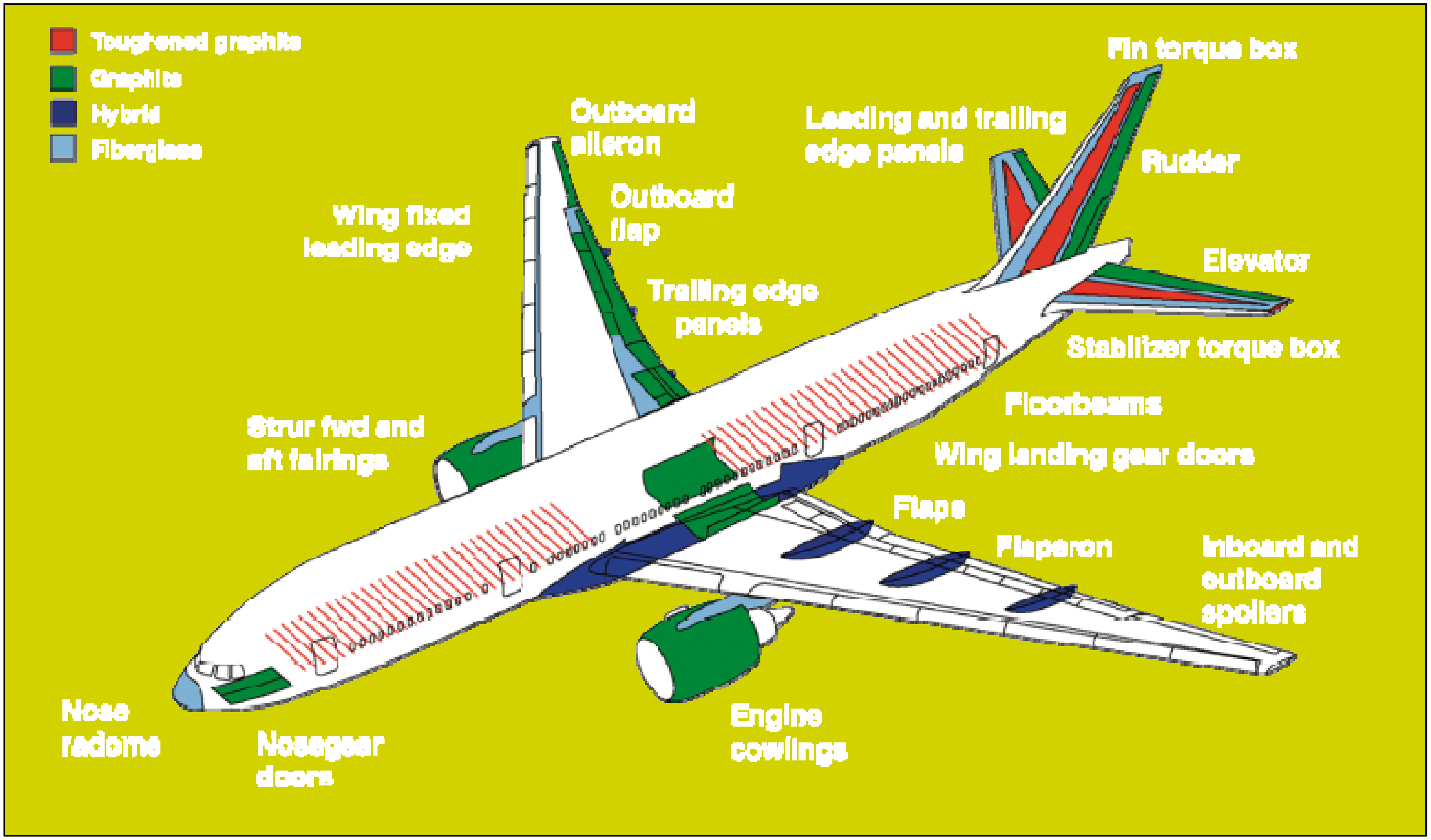
Overview:
Commercial Transport Aircraft

Use of composites in Boeing 737 (1968-present; several models)



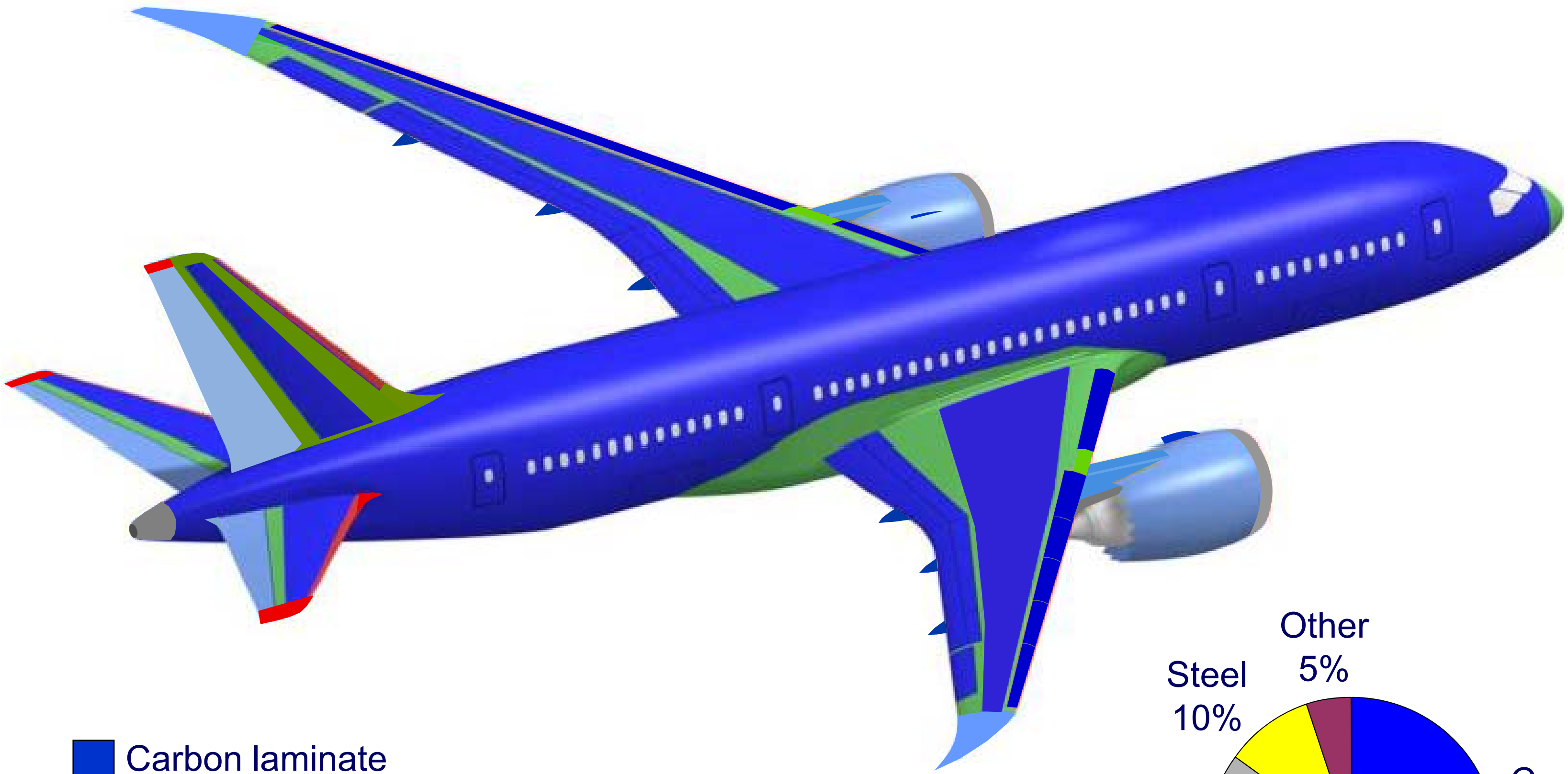
Overview:
Commercial Transport Aircraft

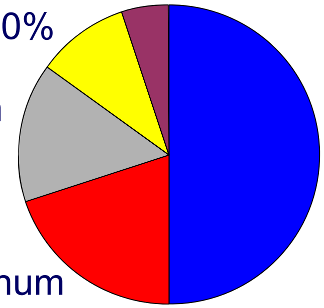
Use of composites in Boeing 777 (1995-present; several models)



Overview:
Commercial Transport Aircraft

Use of composites in Boeing 787 (Sept 2011; 3 models planned)





Overview:
Commercial Transport Aircraft

PARIS AIR SHOW 2013

The 777X

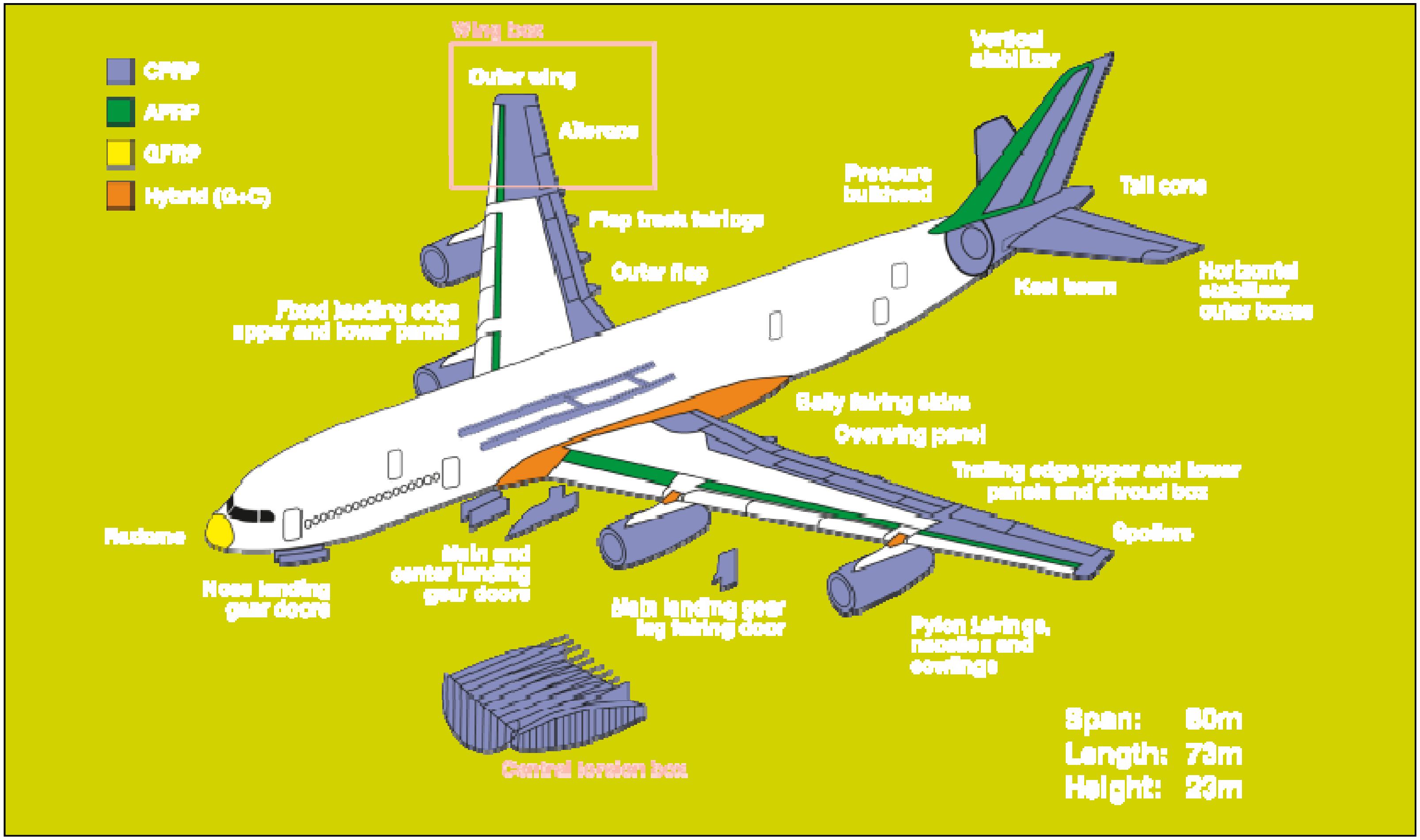
	777-8X	777-9X
Passengers	~350	~400

Improving on the world's best twin-aisle airplane

Overview:

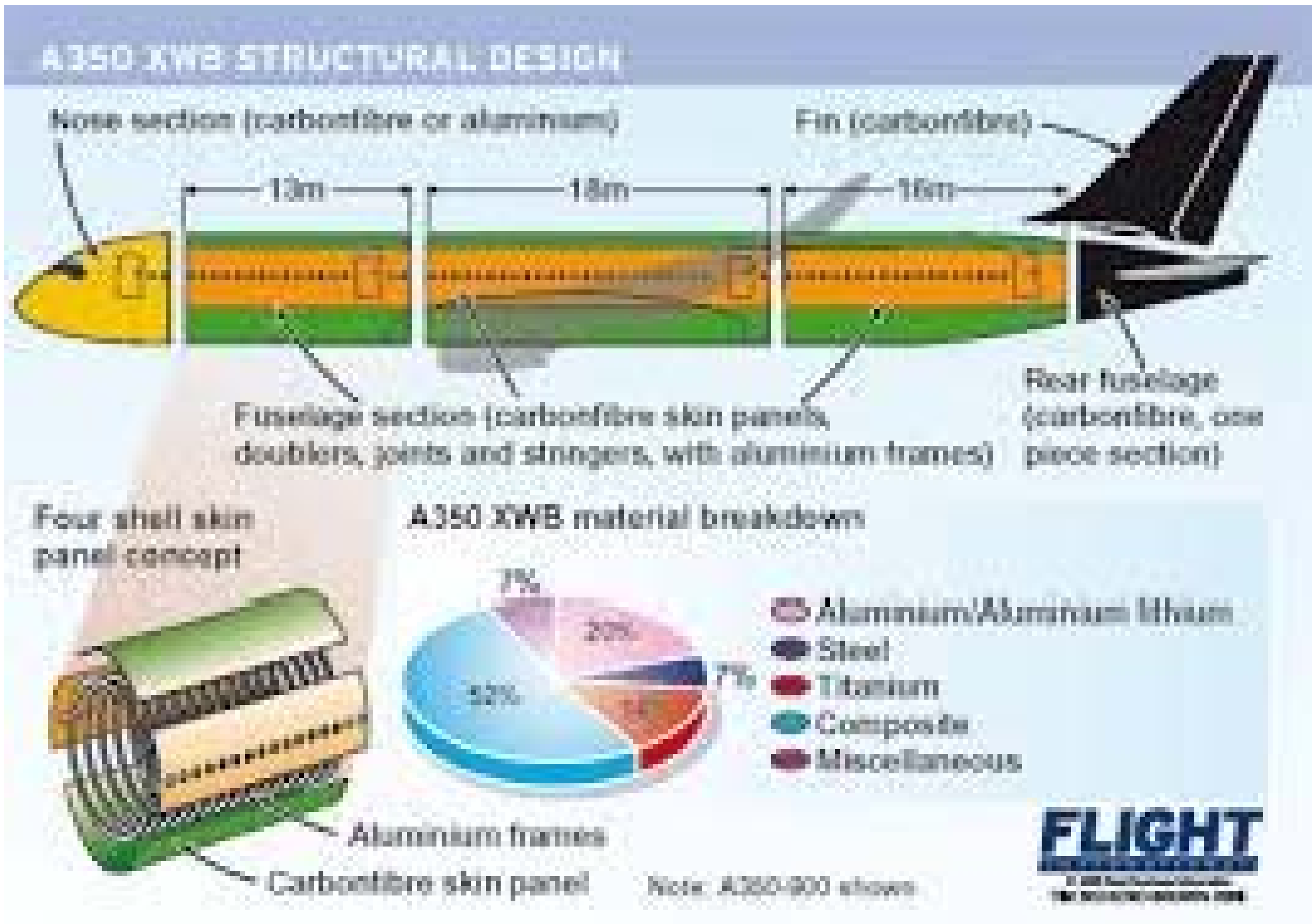
Commercial Transport Aircraft

Use of composites in Airbus 380 (2007-present; two models)



Overview:
Commercial Transport Aircraft

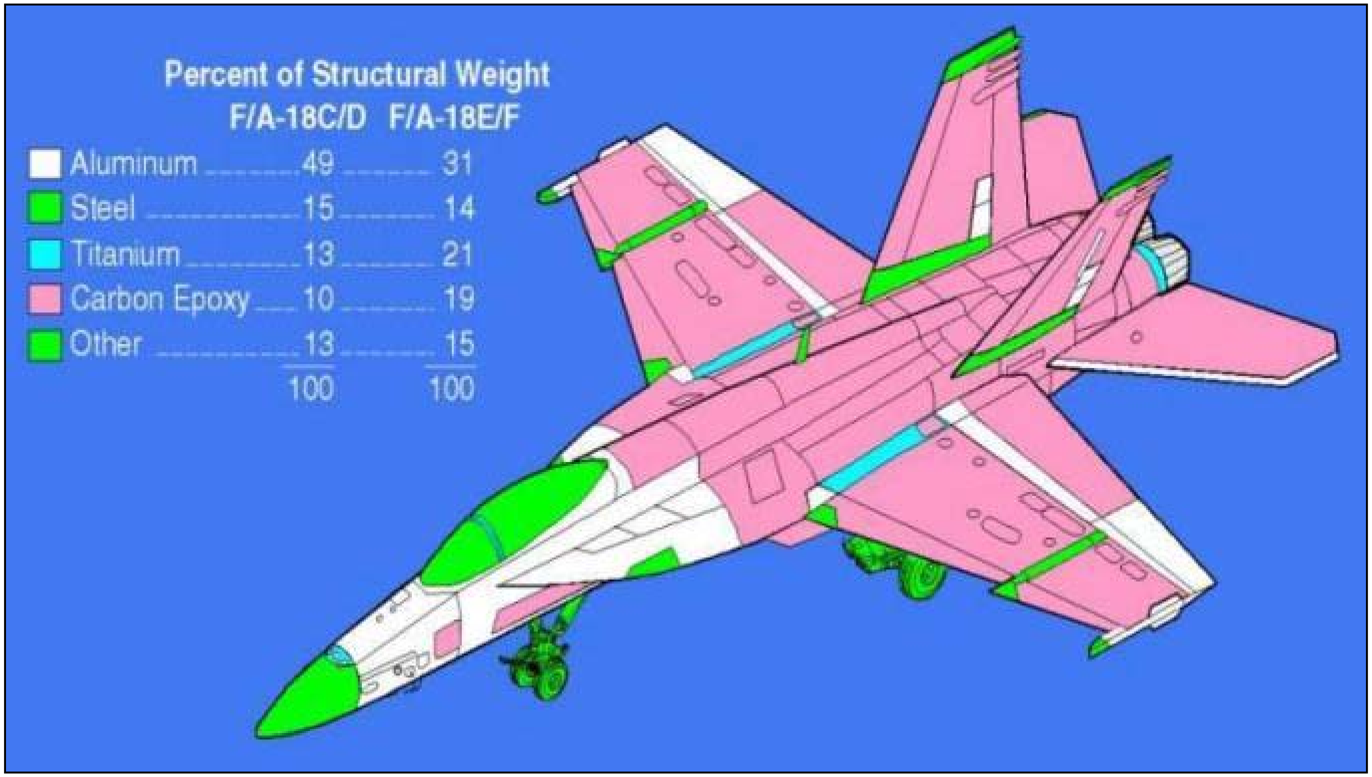
Composites in the Airbus 350 (first commercial flight: 15 Jan 2015)



Overview:
Military Aircraft

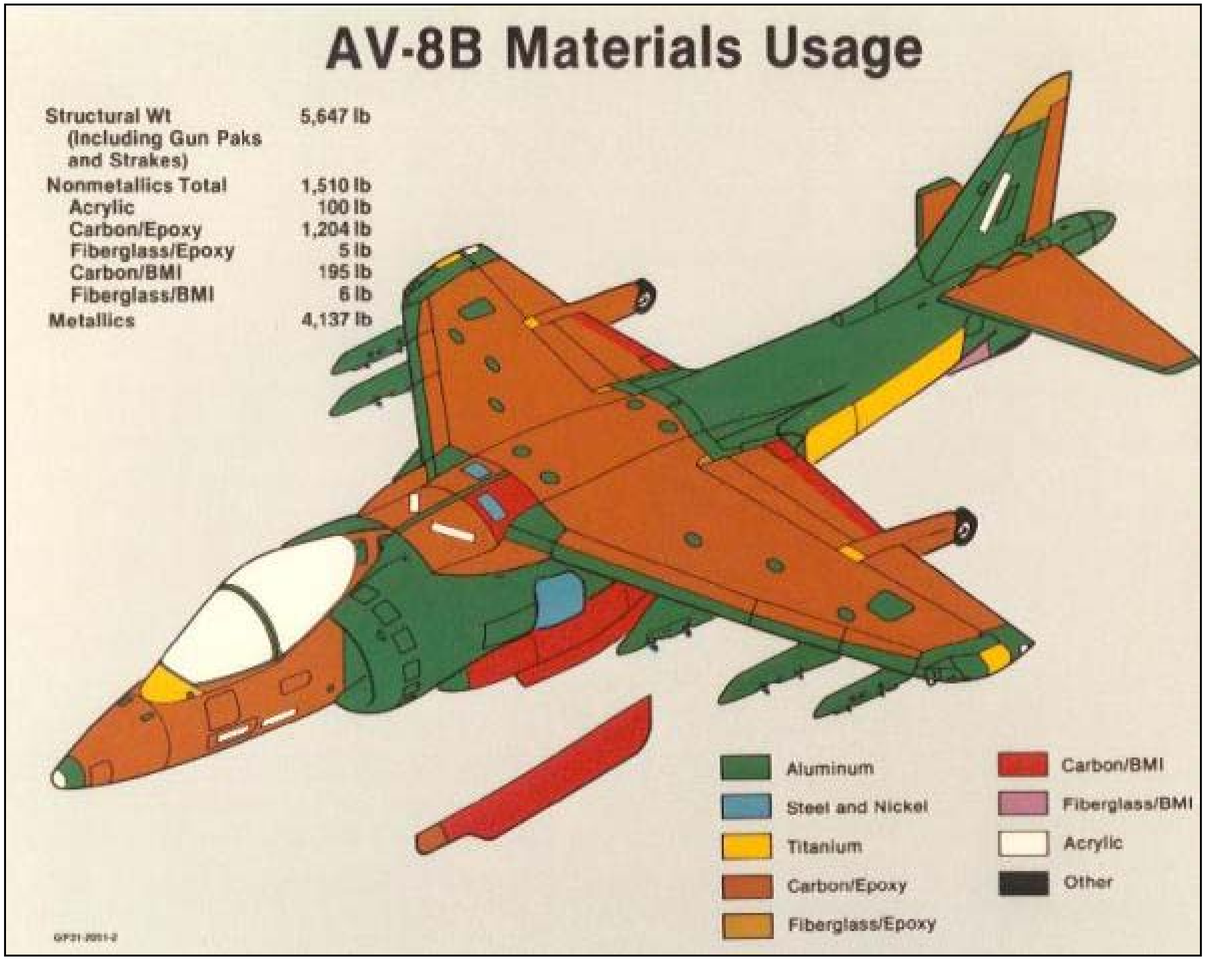
…extensive use of composites in primary structures since 1970s

F/A-18 A/B (Hornet) first flew in 1976



Overview:
Military Aircraft

AV-8B (Harrier)
first flew in 1978



Overview:
Military Aircraft

Rotorcraft (typically helicopters) have used fiberglass blades for improved fatigue resistance for decades.

Other structural components now made from carbon-epoxy to save weight and increase performance, as in the Comanche (above) and the Osprey (right)

Overview:
Space Vehicles

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Composites have been used extensively in both expendable and reuseable launch vehicles

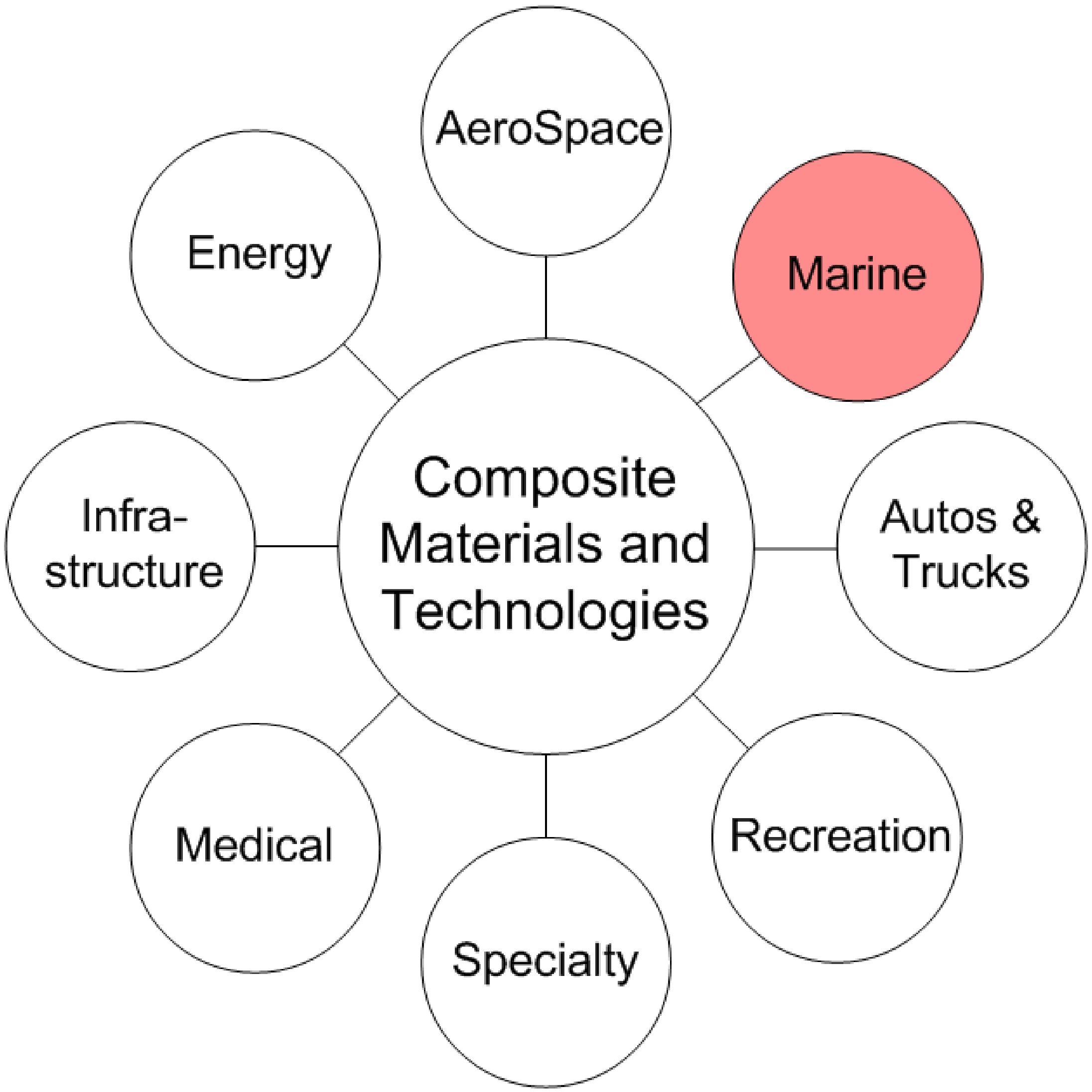
Overview:
Space Structures

Composites are used in the International Space Station

Overview:
Space Structures

All-composite crew module for Orion exploration vehicle built by NASA (engineering and tooling support from Janicki Industries)

Overview:
Advanced Composite Materials



Overview:
Marine Applications

41′ Hunter Sailboat
(www.signature-yachts.com)

147′ Gran Finale Yacht
(www.deltamarine.com)

18′ 5″ Reinell Runabout
(www.reinell.com)

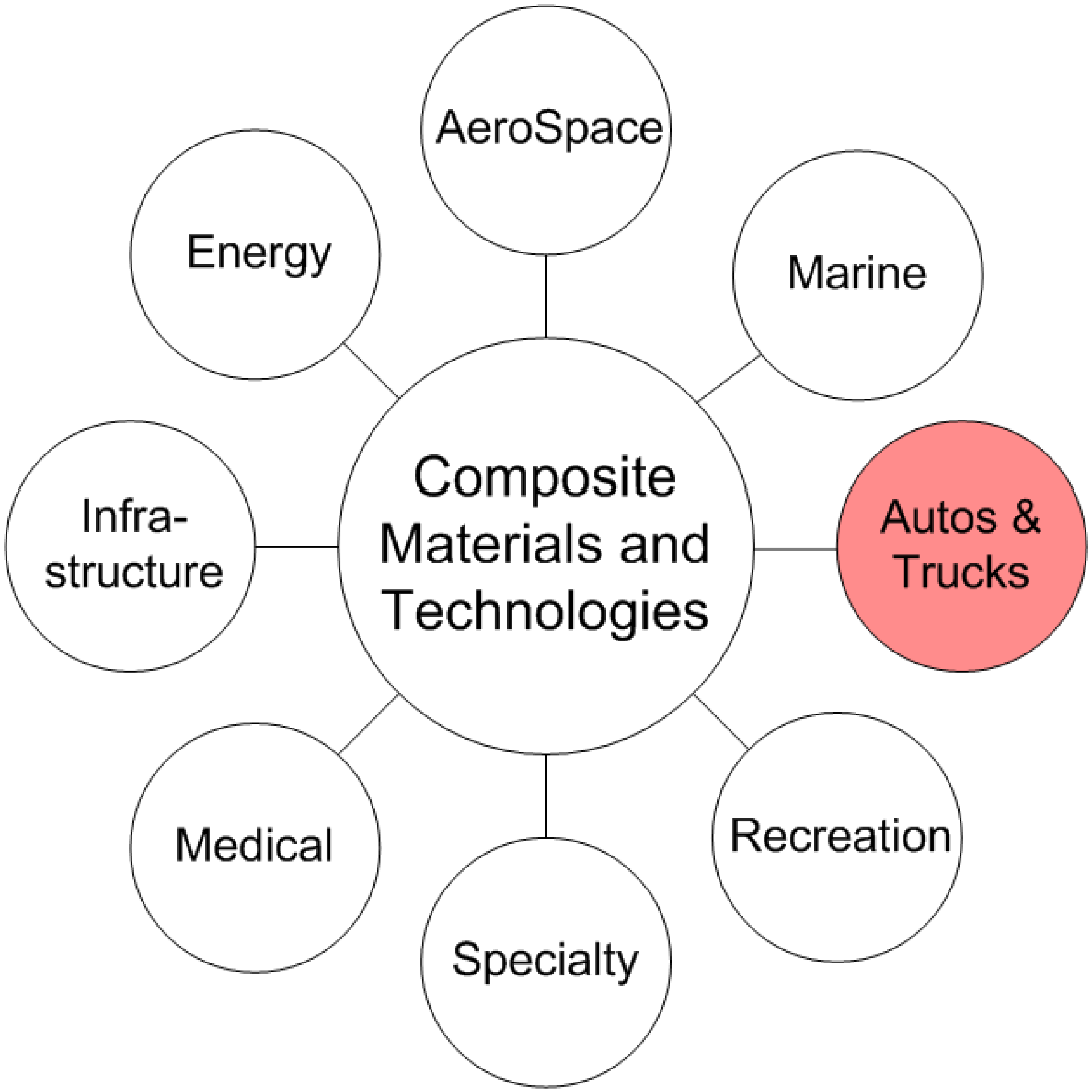
Overview:
Marine Applications

Hull, mast, & boom of the BMW-Oracle Racing Yacht produced using carbon-epoxy composites

Overview:
Marine Applications

The 58-meter carbon fiber fixed wing-sail on the BMW Oracle AC33 trimaran is larger than a B-747 wing

Overview:
Advanced Composite Materials



Overview:
Automotive Applications

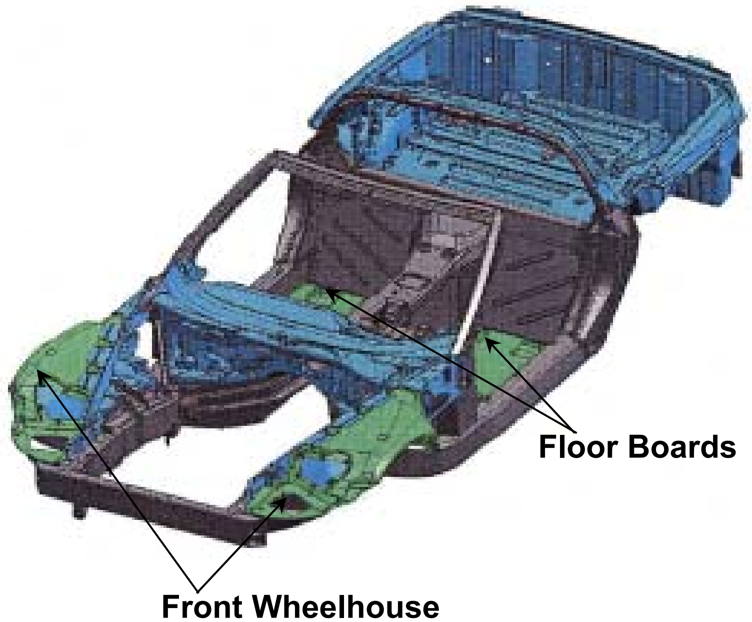
High-end, high-performance cars: ’53 Corvette featured composite body produced using fiberglass mat

http://auto.howstuffworks.com/corvette-pictures.htm

Overview:
Automotive Applications

GM Corvette Z06 (2013 model shown)

- Body: fiberglass woven fabric
- Hood: unidirectional carbon fiber
- Front wheelhouse: CMC* w/ glass microspheres for weight reduction (1.1 Specific Gravity)
- Floor boards: CMC* skins over ½” balsa wood core
- 2014: Body panels produced using new “pressure-press” equipment developed by Globe Machine Manufacturing (Tacoma)



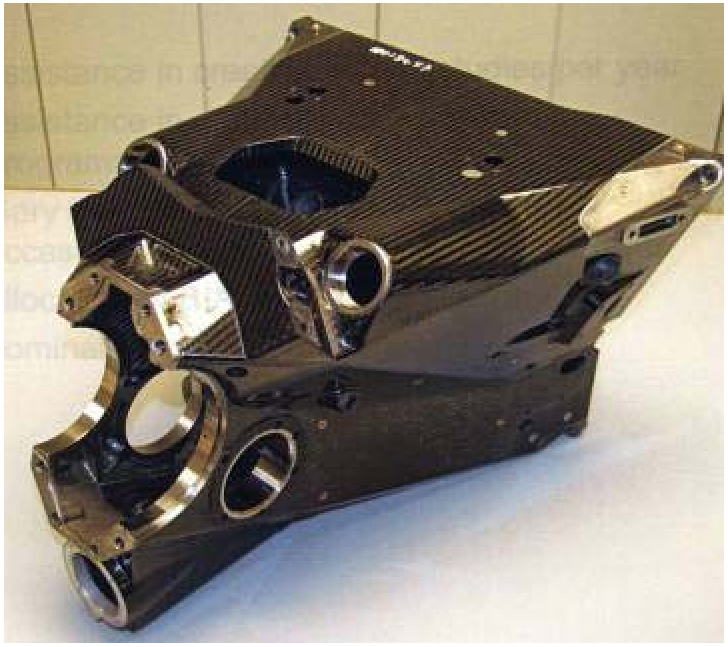
Overview:
Automotive Applications

The Lamborghini Aventador LP700-4 features many composite components, including a carbon fiber chassis produced using resin transfer molding (RTM)

http://www.netcomposites.com/newspic.asp?6674

Overview:
Automotive Applications

Advanced composites routinely used in high-performance race cars (Example: Honda F1 uses autoclave-cured carbon composite chassis, suspension, wings, gear box, and engine cover)



Overview:
Automotive Applications

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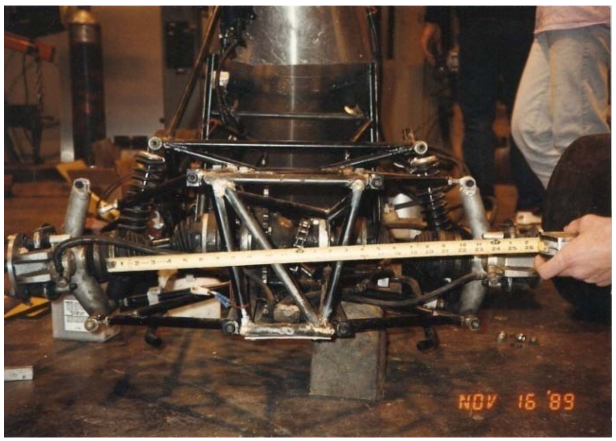
Composites in the UW FSAE Car steadily increased since 1990



*c*Car

*e*Car

Team 1 (1990)

Team 26 (2015)

Overview:
Automotive Applications

- Extensive use of structural carbon composites in high-volume production vehicles (Chevy Malibu, Ford Taurus, Toyota Camry, etc) has been inhibited due to *both* high material costs and low production rates (resulting in high manufacturing costs)

- The Automotive Composites Alliance (ACA) tracks the use of composites in (relatively) high-volume production autos:

  www.autocomposites.org/gallery/index.cfm

  (….info may be dated…)

Overview:
Automotive Applications

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Advanced Materials in Transport Aircraft Structures

Home Site Map Contact Us Join ACA

Automotive Composites Alliance
Serving the Car and Truck Industries

Member Login
Username
Password
LOGIN

ABOUT ACA | AUTO COMPOSITES 101 | RESOURCES | PHOTO GALLERY | NEWS & EVENTS | MEMBERS ONLY

Print This Pag

Photo Gallery

Composites Automotive Components

The ACA tracks production of composites used in automotive components. Below is a partial listing of cars and trucks. Select the car or truck to see what products are used on that vehicle.

Number of parts by Manufacturing Process								
Category/Vehicle	**SMC**	**BMC**	**RRIM**	**SRIM**	**LCM**	**Infusion**	**HLP**	**Total**
PASSENGER CAR								
Cadillac XLR	11		2		10			23
Dodge Viper	16		6		1		4	27
Chevrolet Corvette	5		2		9		2	16
Ford Crown Victoria	2	1	1					4
Nissan Sentra	10							1
Saturn Sky	1				1			1
LIGHT TRUCK								
Toyota Tacoma	3							3
Ford Sport Trac	5							5
Honda Ridgeline	1							1
Jeep Wrangler	1							1
Hummer H2	1							1
Chevrolet Silverado	1		1	1				3
Ford Expedition	5							5
Dodge Caravan	2			3				5
Dodge Dakota	4							4
MEDIUM TRUCK								
GM Kodiak/Topkick	6							6
Ford F-650	3							3
HEAVY TRUCK								
Freightliner Cascadia	12				6		1	19
Kenworth T-2000	1					15		16
Volvo VN 730	1				8			9

Overview:
Automotive Applications

- Increased use of structural composites in production vehicles beginning to occur due to:
  - Need for improved fuel efficiencies & lower emissions
  - Changes in design philosophies (reduction in part count)
  - Improved manufacturing processes (i.e., increased production rates)
  - “Some” reduction in material costs

Overview:
Automotive Applications

SGL/Automotive Fiber Composites facility opened near Moses Lake in 2011(a joint venture with BMW)…produces carbon fibers and fiber fabrics:

Overview:
Applications in Heavy Trucks

PACCAR Kenworth T-2000

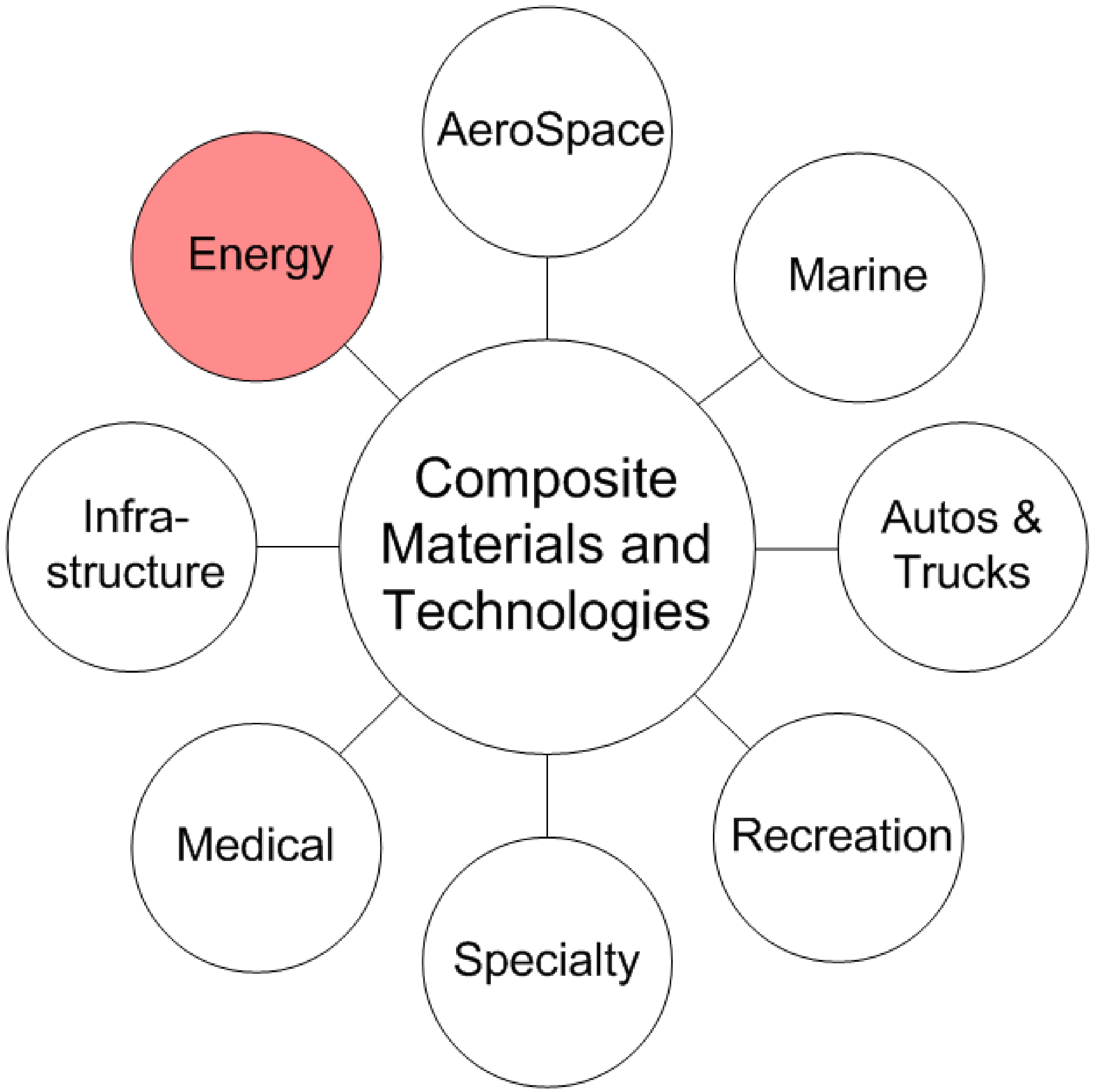
SMC

- Scoop

VIP

- Aero Roof
- A-Piller Upper – R/L
- A-Piller Rocker – R/L
- Bumper
- Cab Side Deflector – R/L
- Door Aperture – R/L
- Door Module – R/L
- Door Surround – R/L
- D-Piller Cover – R/L
- D-Piller Duct – R/L
- Firewall Assembly
- Floor Assembly
- Hood
- Storage Door

Overview:
Advanced Composite Materials



Overview:
Energy Applications: Wind

- Windmills used for hundred of years
- Many “out of the box” concepts proposed to generate electricity (windmills → wind turbines)




Photo sources:
en.wikipedia.org/wiki/Windmills
en.wikipedia.org/wiki/Wind_turbine#VAWT_subtypes
www.buzzle.com/articles/wind-turbines-vertical-axis-wind-turbine.html
thefraserdomain.typepad.com/energy/2006/04/turby_vertical_.html

Overview:

Energy Applications: Wind

- Most modern wind turbines based on horizontal axis and three composite blades
- Commercially available wind turbines range from those intended for home use...

200 W Air Breeze™
www.windenergy.com

10 kW BWC EXCEL
www.bergey.com

Overview:
Energy Applications: Wind

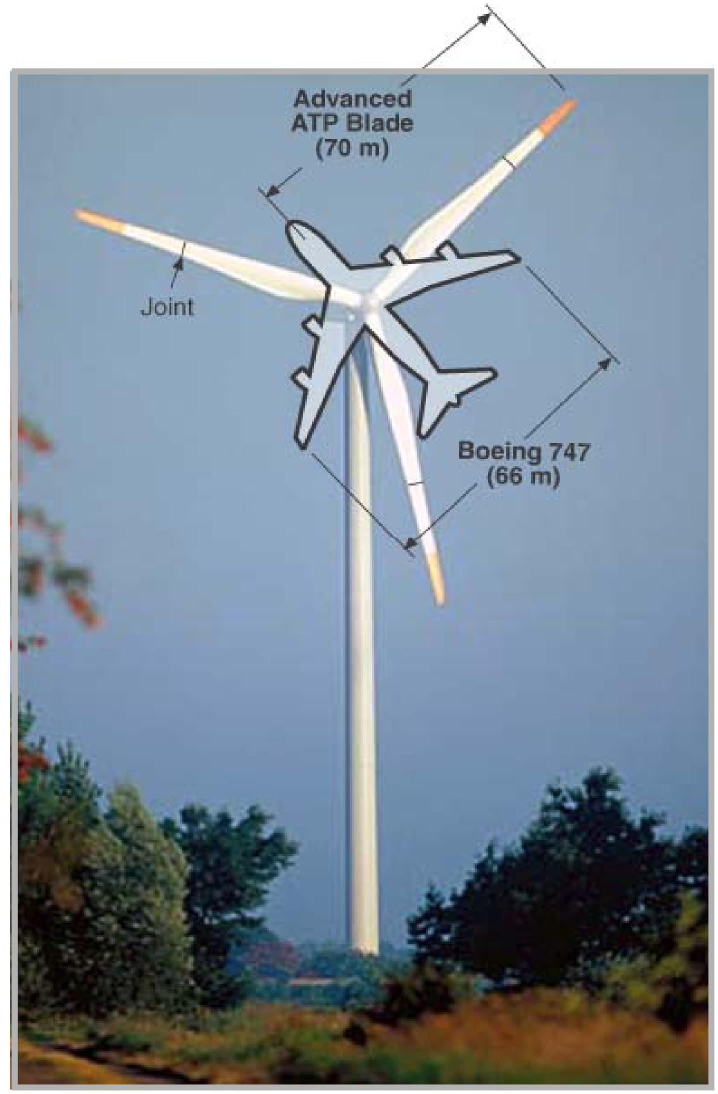
…to those used in large wind farms that provide power to entire communities

Stateline Wind Project, near Columbia Gorge, WA-OR border (www.rnp.org/Projects/stateline.html)

Danish Horn Rev offshore windfarm (www.windpower.org/en/pictures/offshore.htm)

Overview:
Energy Applications: Wind

Trend is towards very large turbines



Overview:
Energy Applications: Wind

- Composite blades traditionally produced using inexpensive fiberglass and wet-layup techniques

- As windmill sizes have increased new design drivers have emerged:
  - Gravity/wind induced bending loads
  - Blade stiffness

  } Increasing use of advanced carbon fibers

  - Transportation

Overview:
Energy Applications: Wind

Transportation issues…

Fiberglass blades produced by LM Glasfiber (Germany); photo courtesy of Dayton Griffin, Global Energy Concepts (Seattle, WA)

Overview:
Energy Applications: Tidal

- In early stage of development…site evaluations underway in Europe, Canada, and US

- Several operating test sites in Europe (www.emec.org.uk)

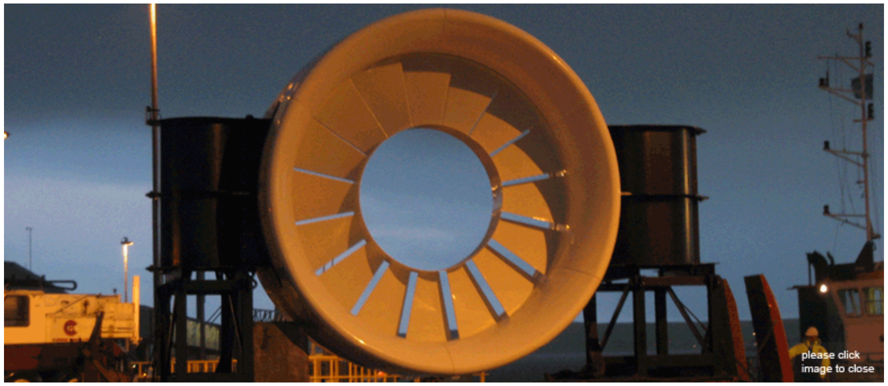
- University of Washington is member of the Northwest National Marine Renewable Energy Center (NNMERC) Seven potential sites in Puget Sound being evaluated:

  http://depts.washington.edu/nnmrec/

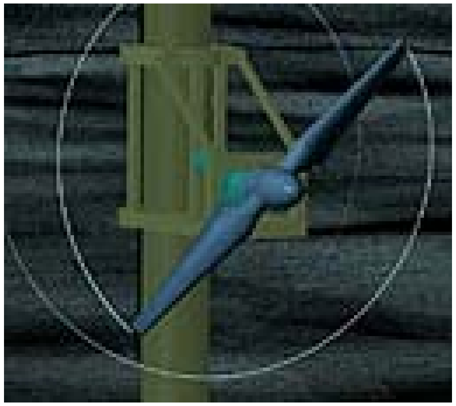
- Marine energy systems will likely utilize composites to minimize corrosion/maintenance issues

Overview:
Energy Applications: Tidal

What is optimal structural configuration?



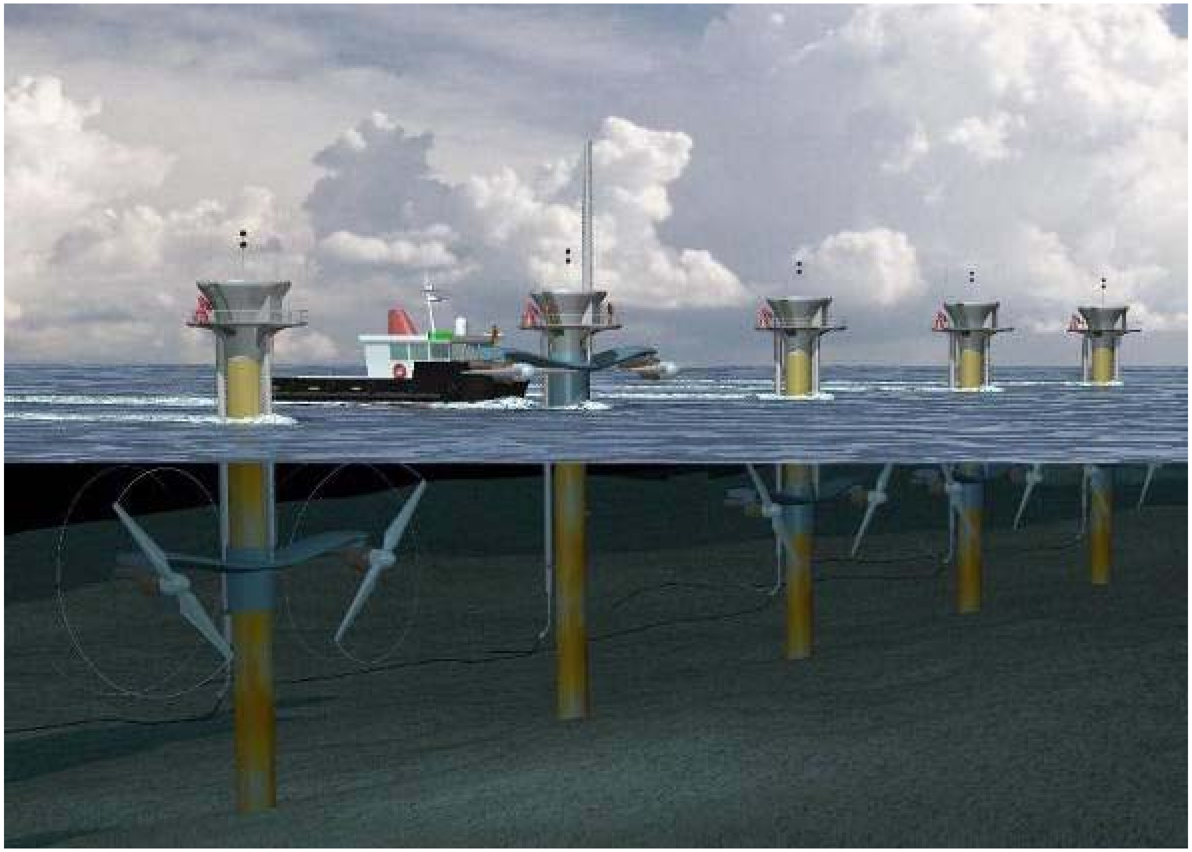
A generator akin to an axial tube fan? (www.openhydro.com)



A generator akin to a windmill (or aircraft propeller)? (www.marineturbines.com)

Overview:
Energy Applications: Tidal

Tidal energy farms envisioned



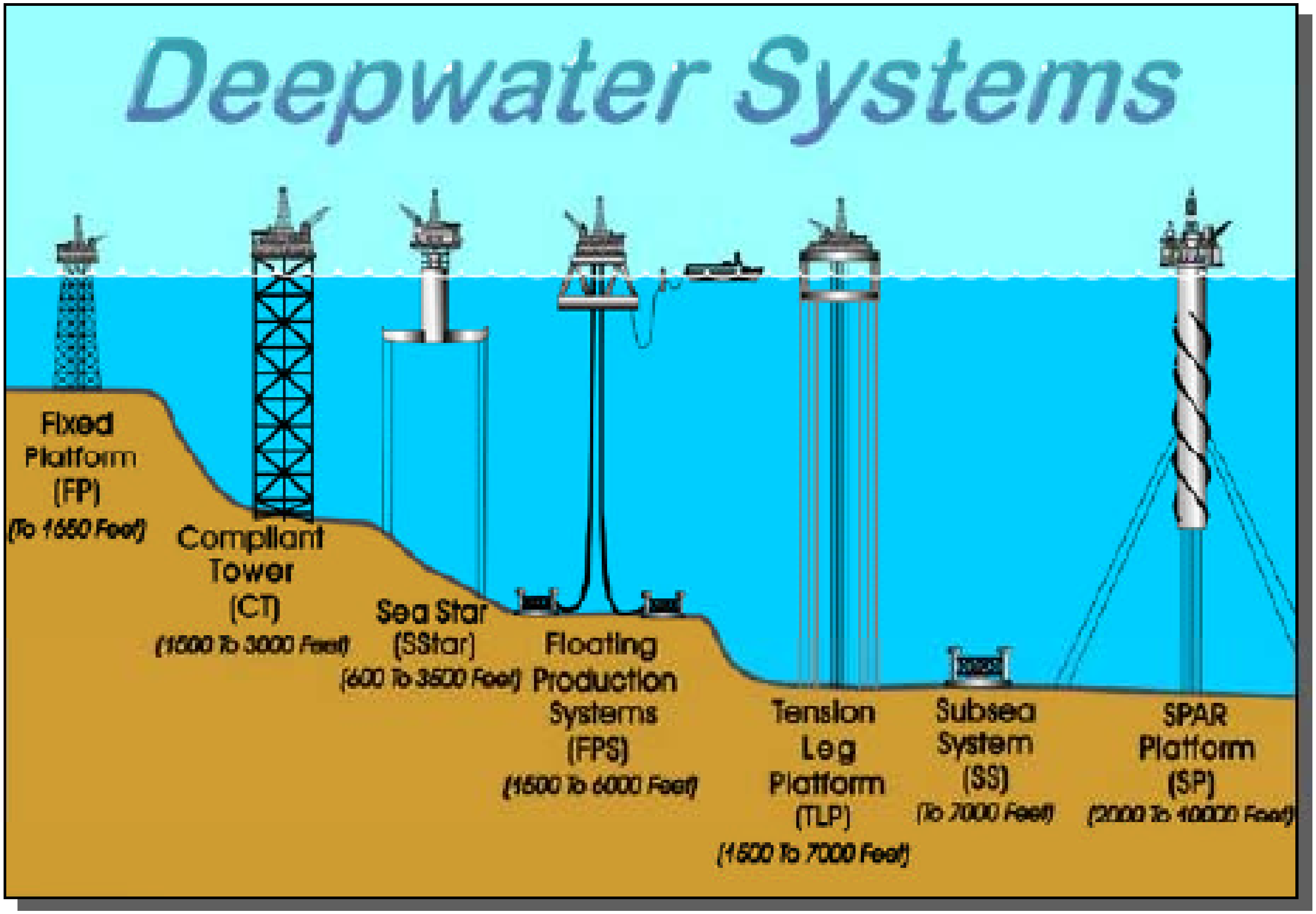
www.marineturbines.com

Overview:
Energy Applications: Tidal

Although optimal configuration TBD, composites will certainly be used

52 ft demonstration rotor made from glass and carbon fiber composites (www.marineturbines.com)

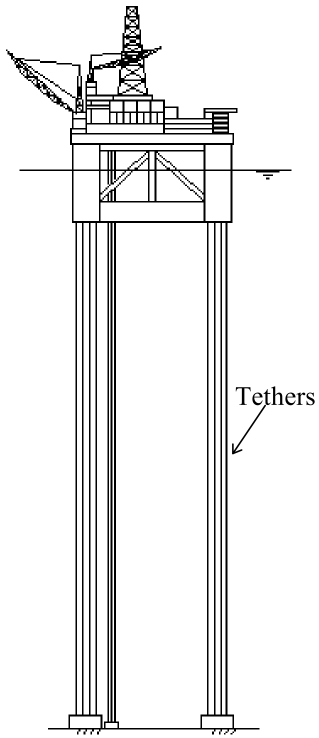
Overview:
Energy Applications: Deepwater Oil Wells



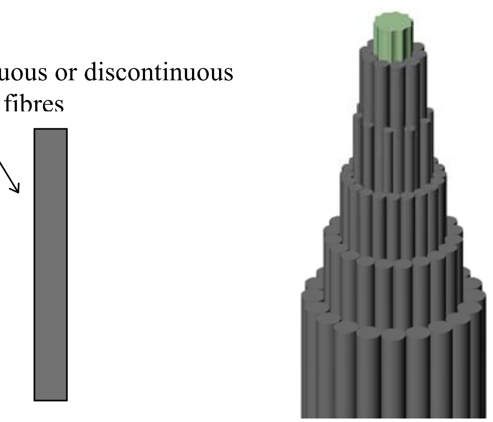
Overview:

Energy Applications: Deepwater Oil Wells

Tension Leg Platforms



Tension Leg Platform



3-5 mm rod

2-3” Strand

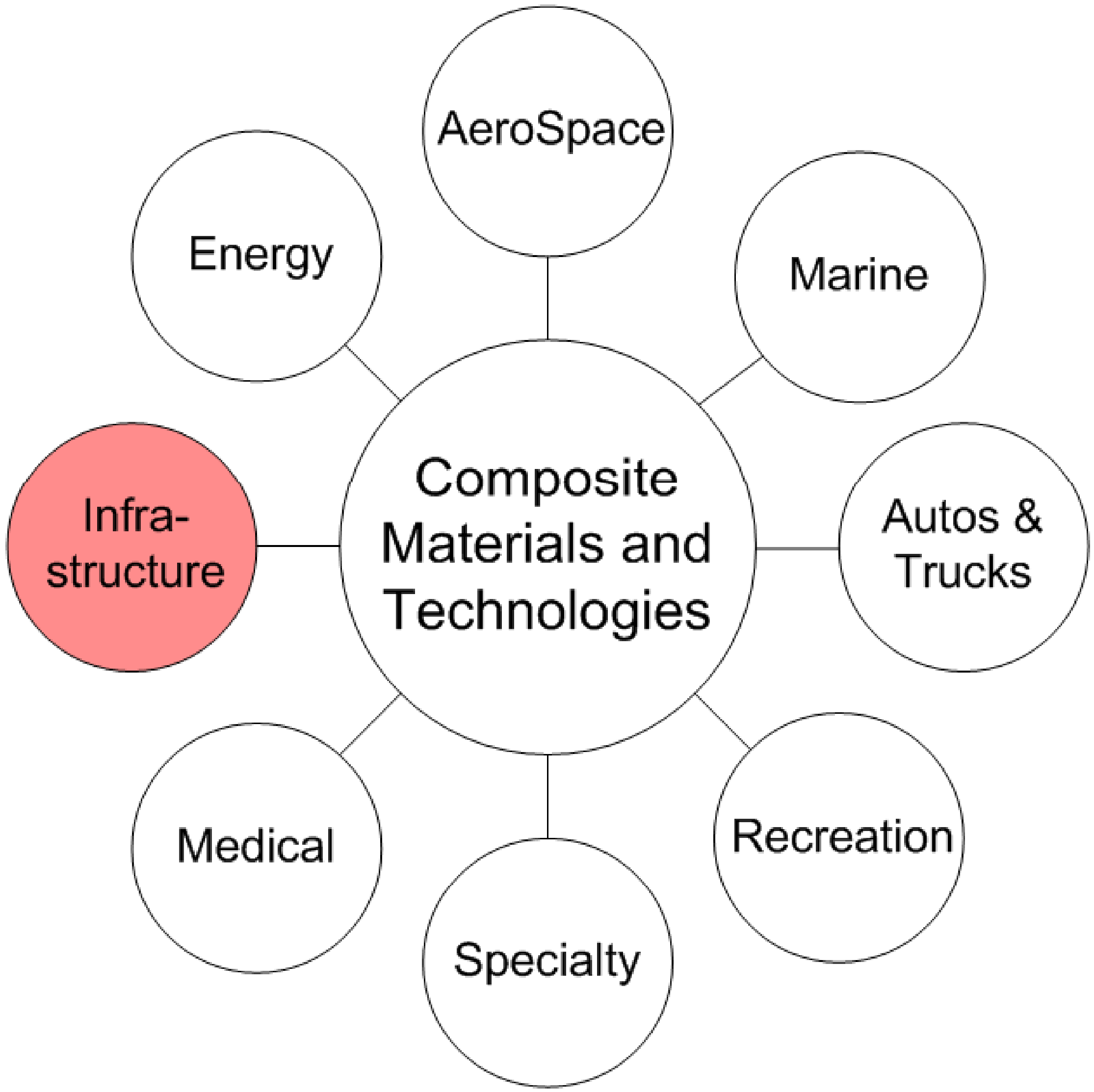
Overview:

Energy Applications: Deepwater Oil Wells

Shell's Mars TLP (about 130 miles south of New Orleans, in Gulf of Mexico) uses 195 tons of composites

- Water depth: 2940 ft (896 m)
- Production began in 1996
- Damaged by hurricane Katrina in 2005; no spill and since repaired
- Designed to produce 220,000 barrels of oil/day and 220 M ft^3 gas/day

Overview:
Advanced Composite Materials



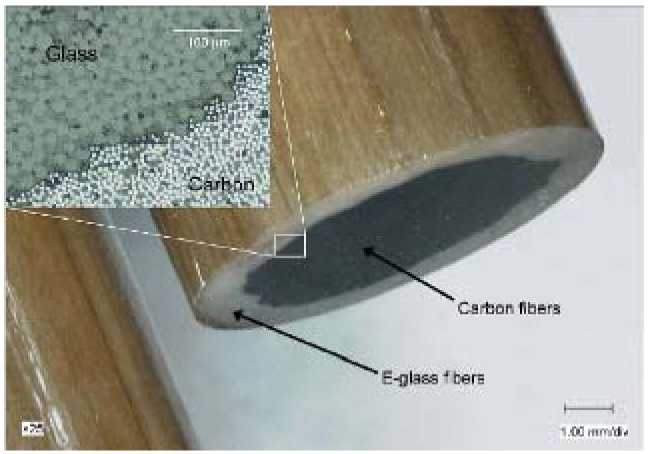
Overview:
Infrastructure applications

Composite pipes used in hydroelectric plants (www.amitech.com.b)

Light poles and transmission towers produced using composites (web.grouprsi.com/rsweb)

Overview:
Infrastructure applications

Composite electrical cables reduce weight and sag



Overview:
Infrastructure applications

Column wraps for seismic retrofits and blast mitigation

Overview:
Infrastructure applications

Floor strengthening

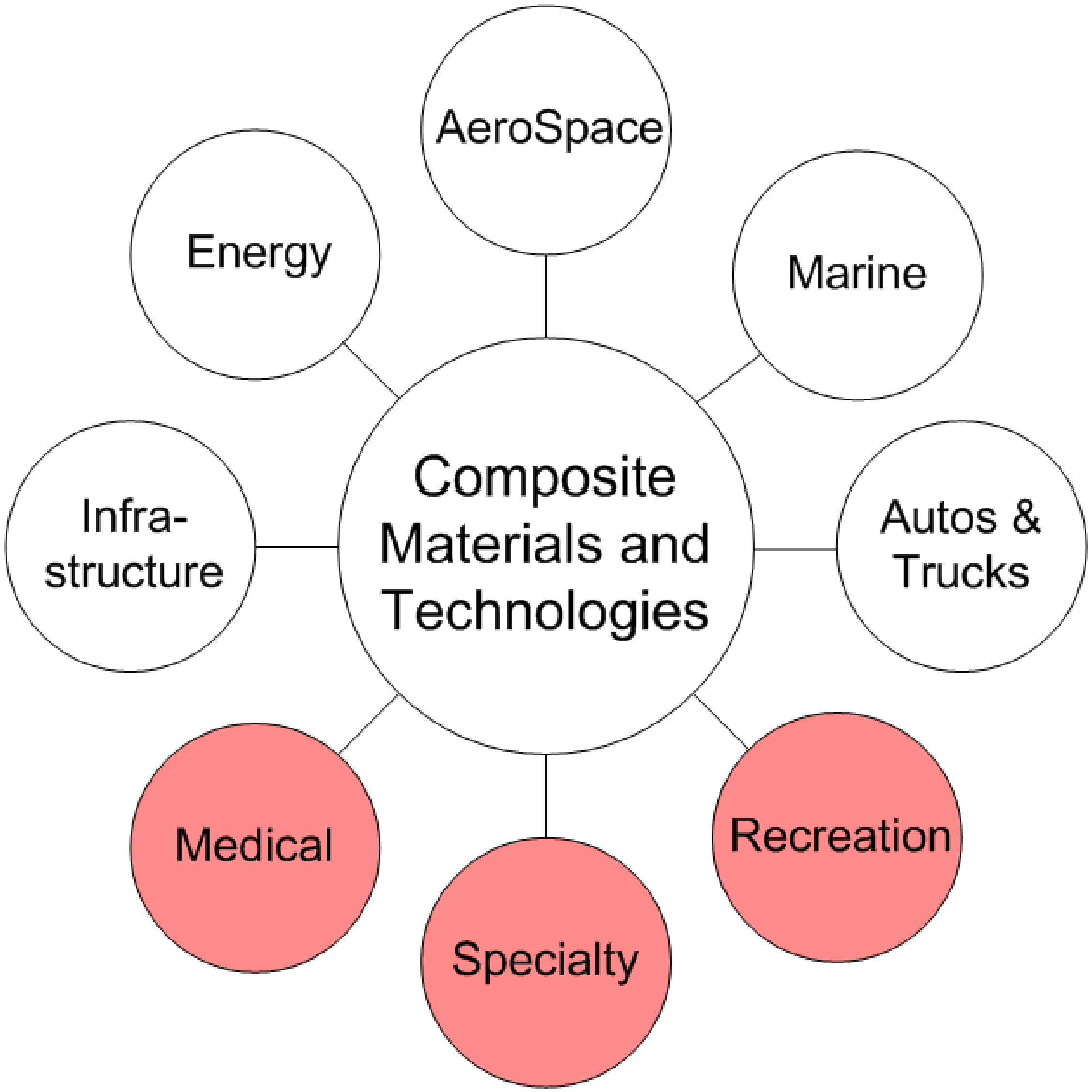
Lining large dia piping
(www.fibrwrapconstruction.com)

Overview:
Infrastructure applications

Bridge cable stays (www.compositesworld.com/ct/issues/2006/February/1180)

Composite bridge decks (www.cobrae.org)

Overview:
Advanced Composite Materials

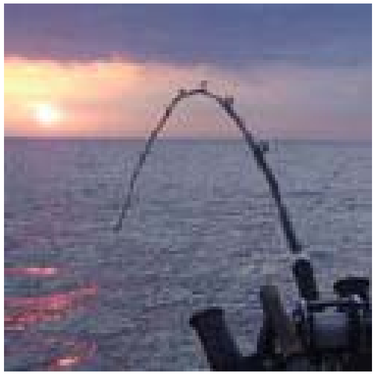


Overview:
Medical Applications

Overview:
Recreation

The Rapture™ driver features a combination titanium and carbon/epoxy head and carbon/epoxy shaft

Overview:
Recreation

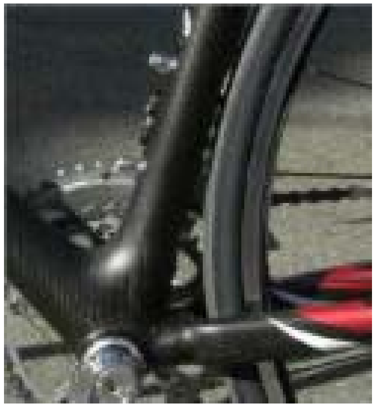


Fishing poles

Skis &
snowboards

Tennis rackets

Bicycle
frames-
wheels-rims



Overview:
Recreation

www.guitars.com

www.electricviolinshop.com

www.tedbrewerviolins.com

www.ifshinviolins.com

Overview:
Recreation

www.canbrass.com

Overview:
Specialty Applications

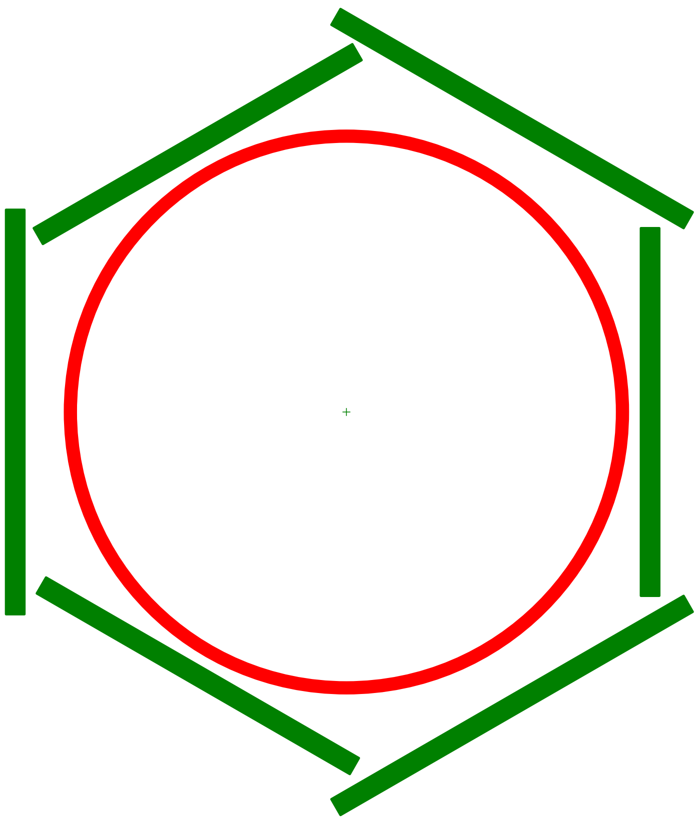
Subatomic particles are studied at Fermilab (outside Chicago)

Protons and anti-protons race in opposite directions around 6.4 km (4 mi) circular track at +99.99% the speed of light…and then collide

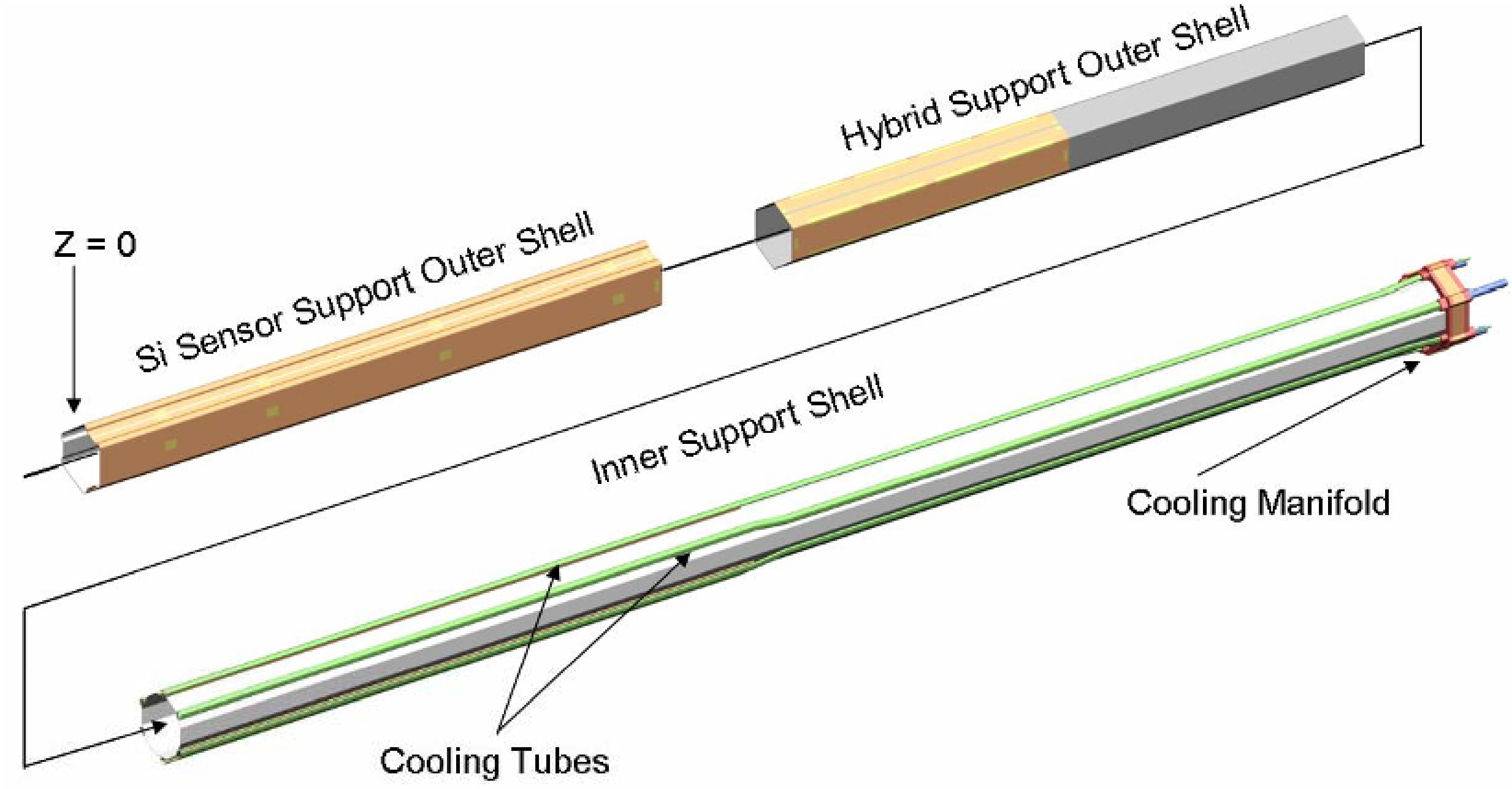
Overview:
Specialty Applications

Resulting subatomic particles created during the collision measured in several ways – one involves flat silicon detectors placed close to the collision point

Fermilab asked UW to design and build a composite support structure to hold silicon detectors in position with great precision



Overview:
Specialty Applications



Composite support structure designed and built at UW

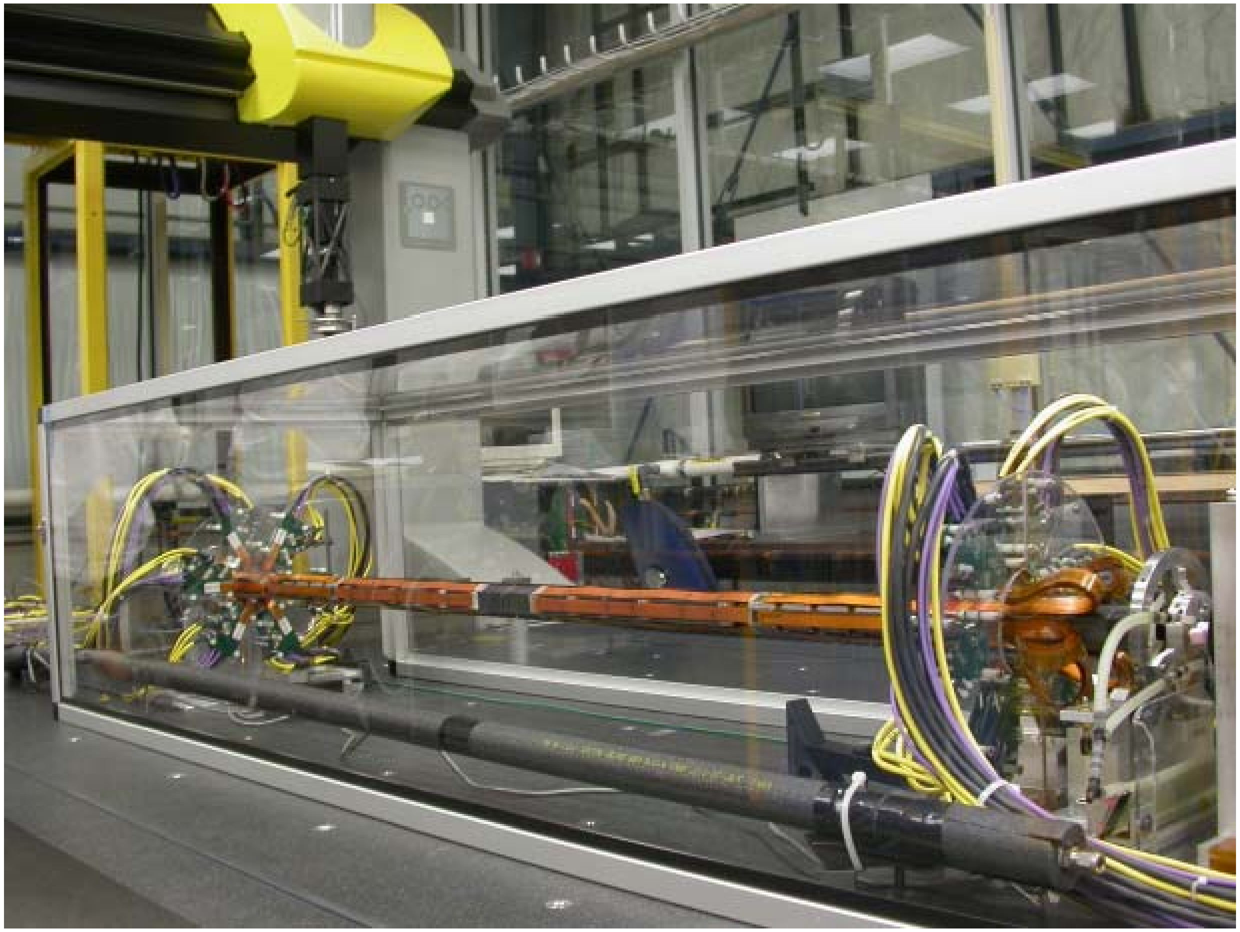
Overview:
Specialty Applications

Sensor support end showing PEEK cooling tubes, foam spacers, and inner shell

Overview:
Specialty Applications

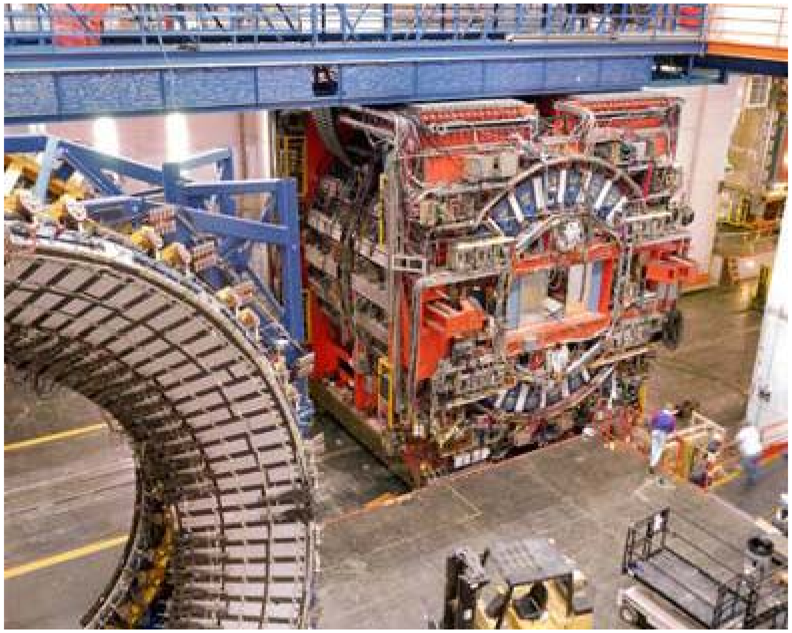
Hybrid support end showing cooling manifold

Overview:
Specialty Applications

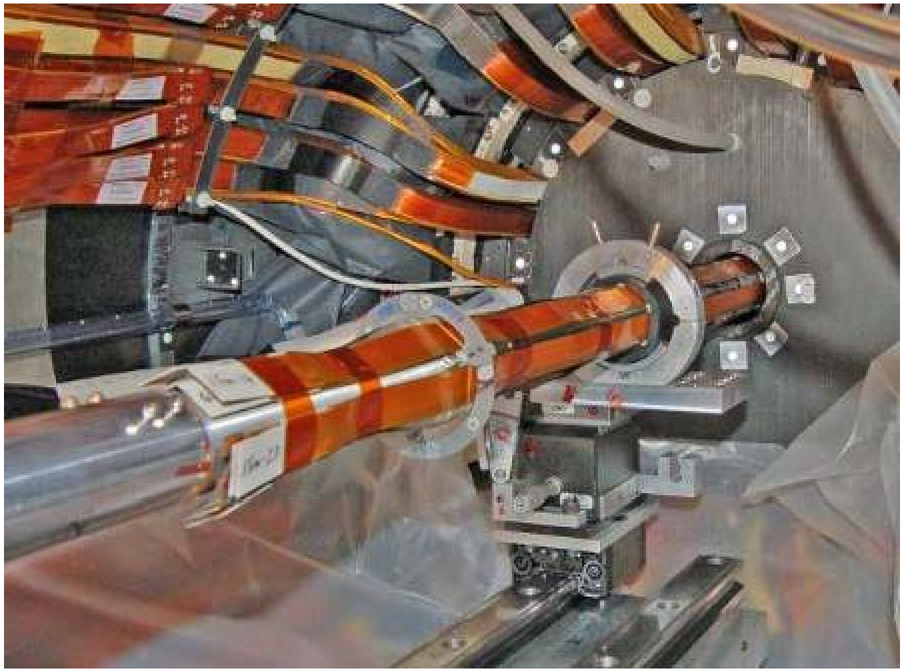


Assembled structure and sensors in Fermilab test chamber

Overview:
Specialty Applications



The complete collision detector



Insertion of instrumented UW composite structure into collision detector

Overview:
Summary

- Three classes of Advanced Composite Materials: PMCs MMCs CMCs
  - All consist of a strong/stiff reinforcing material embedded in a relatively weaker/compliant matrix material
  - ME450 is focused on PMCs
  - Particulate/whisker/short(chopped)/continuous PMCs
- Although originally developed for aerospace applications, PMCs are now used as load-bearing structural materials in many industries