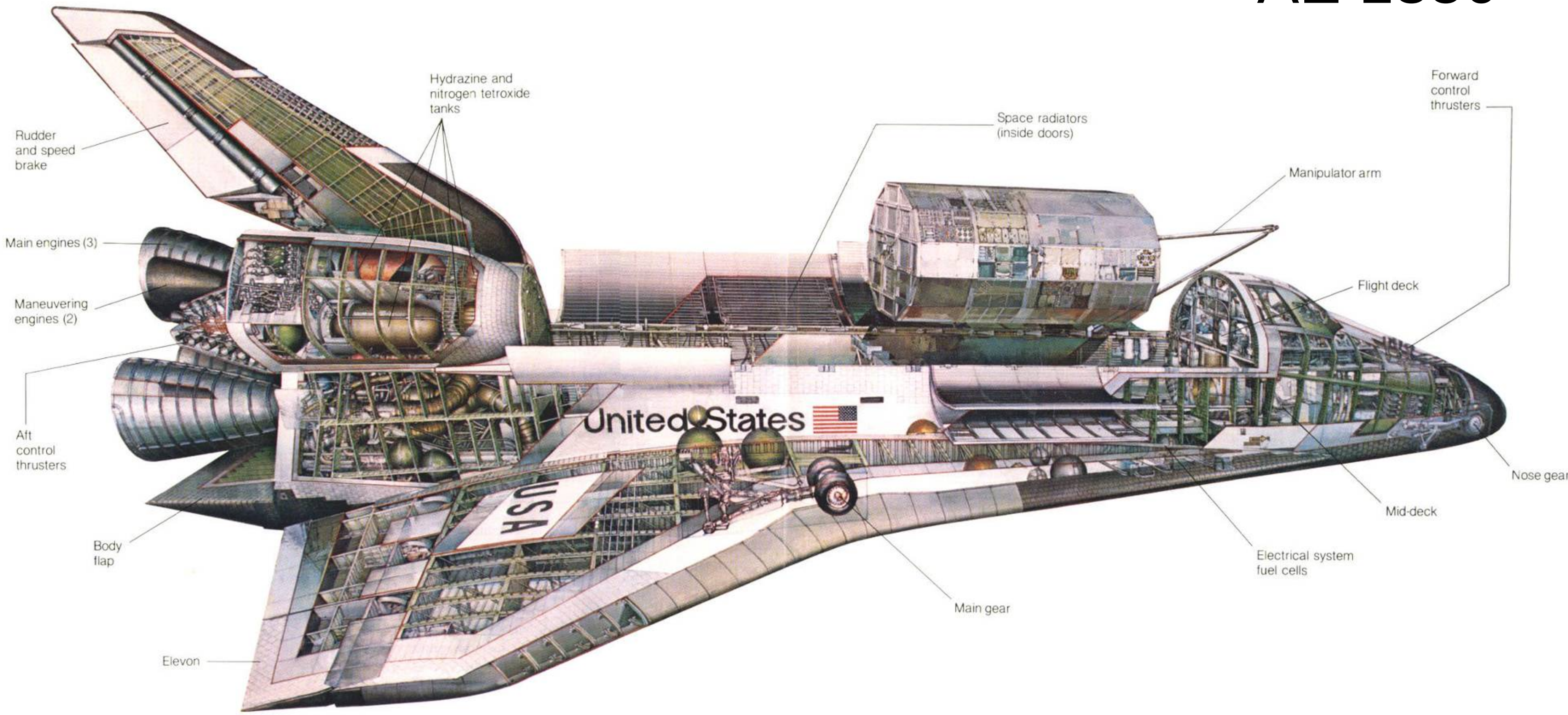
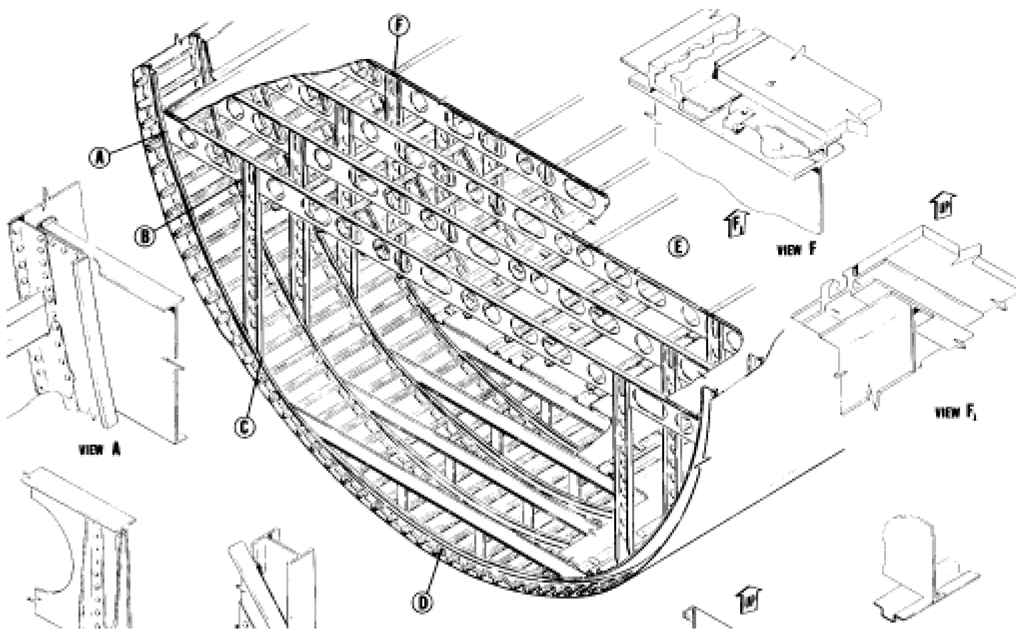
Introduction to Structures

AE 1350



Outline

- Structural Weight and Integrity
- Development of Aircraft Structures
- Elements of Aircraft Structures
- Importance of Fatigue
- Materials
- Loads



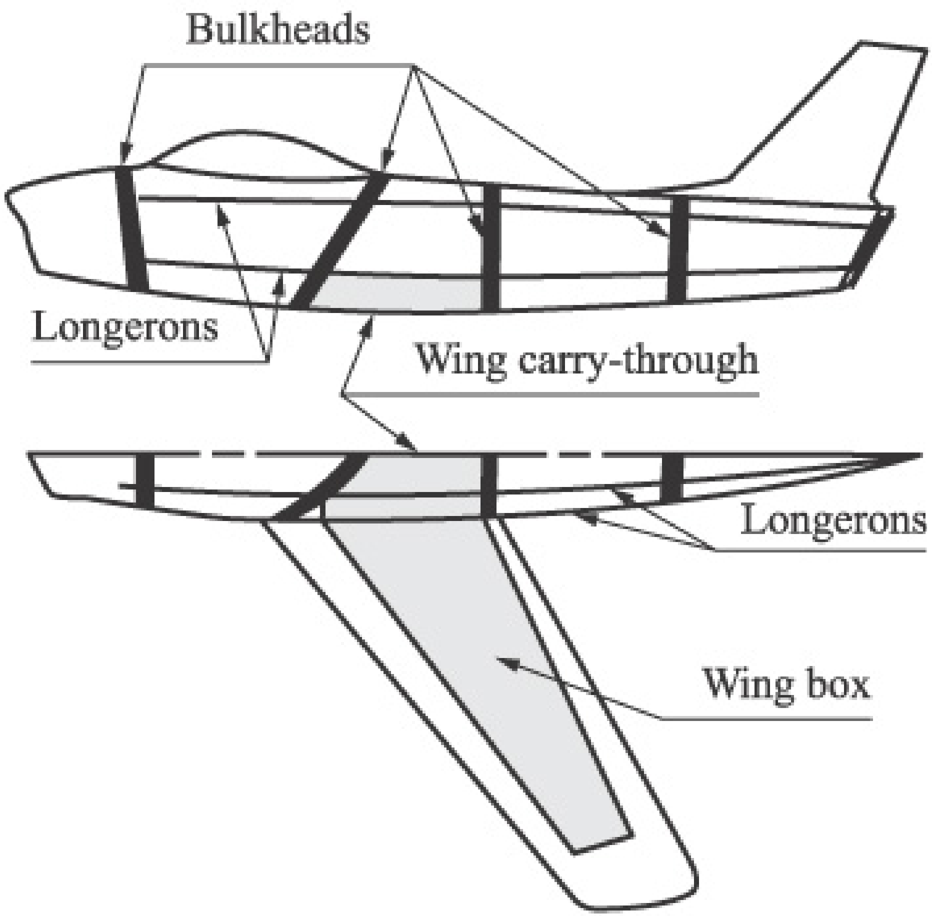
Weight and Integrity

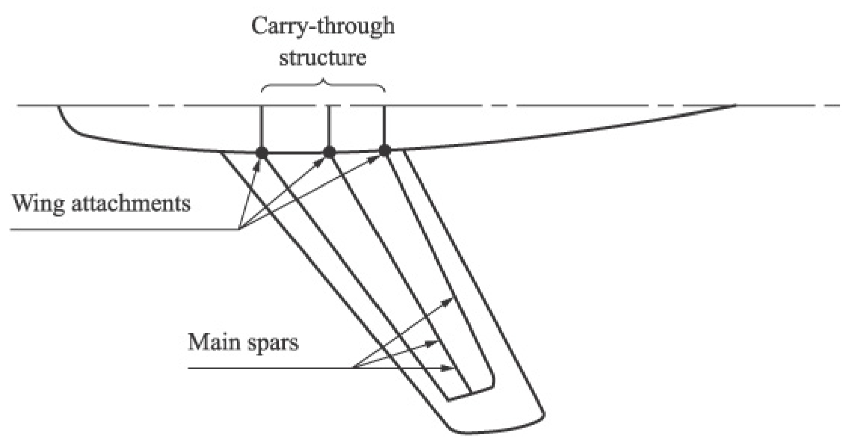
- Aircraft cost, take-off and landing distances are all highly correlated with the empty weight of the aircraft
- A pound of structural weight saved is a pound of payload that can be carried
- Structures must be strong enough to either
  - Fail safe: Will not fail during the life of the component
  - Safe fail: If a component fails, an alternate load path must be available to carry the loads, so that no single failure will be hazardous to the aircraft/spacecraft

Development of Aircraft Structures

- Early aircraft were built with light wood, tension wire, and fabric
- Next step was the substitution of metal for wood; steel and aluminum were used around 1920
- External bracing slowly disappeared; drag decreased
- Later designs relied on stressed skins, stiffened with stiffeners or stringers to carry some of the load
- The skin thickness varied from root to tip of a wing, to reduce the weight
- Fail safe design was achieved by using multiple spars – a beam that runs from the root to tip of a wing

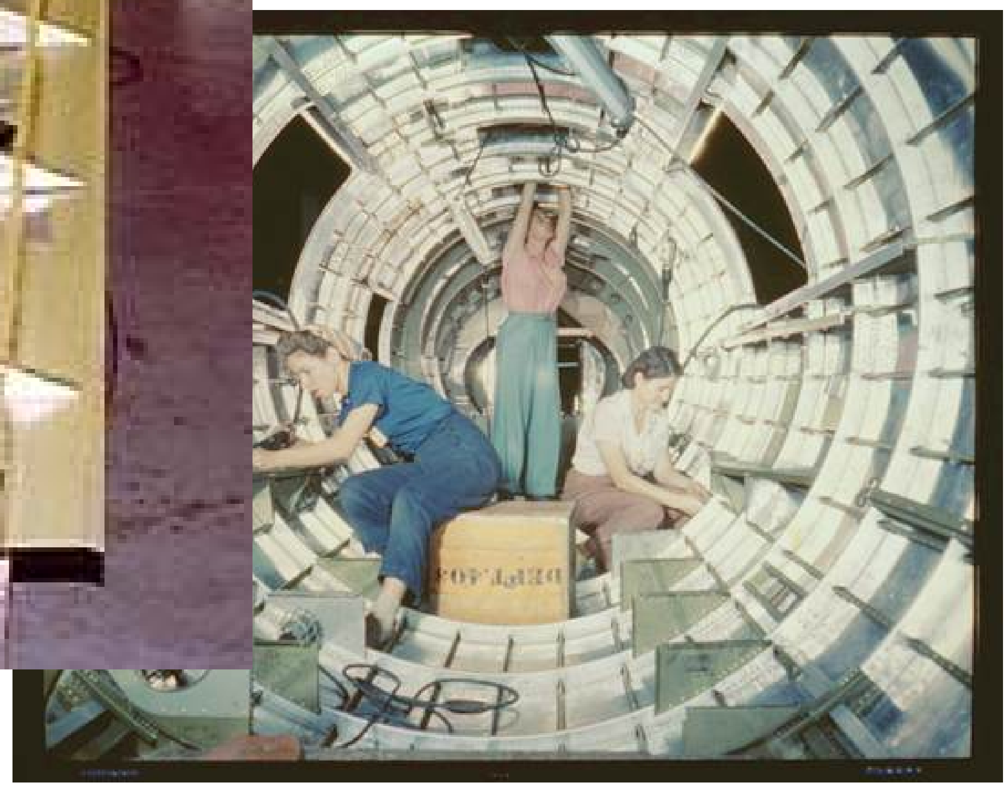
Terminology



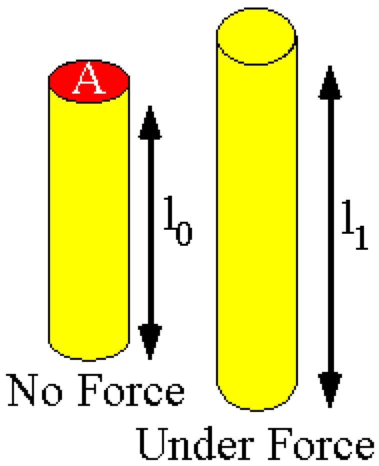


Early Wood Construction

Spars and Ribs in Aluminum, Relies on Stressed Skin



Stress σ, Strain ε and Young's Modulus E



$\sigma = F/A$ stress

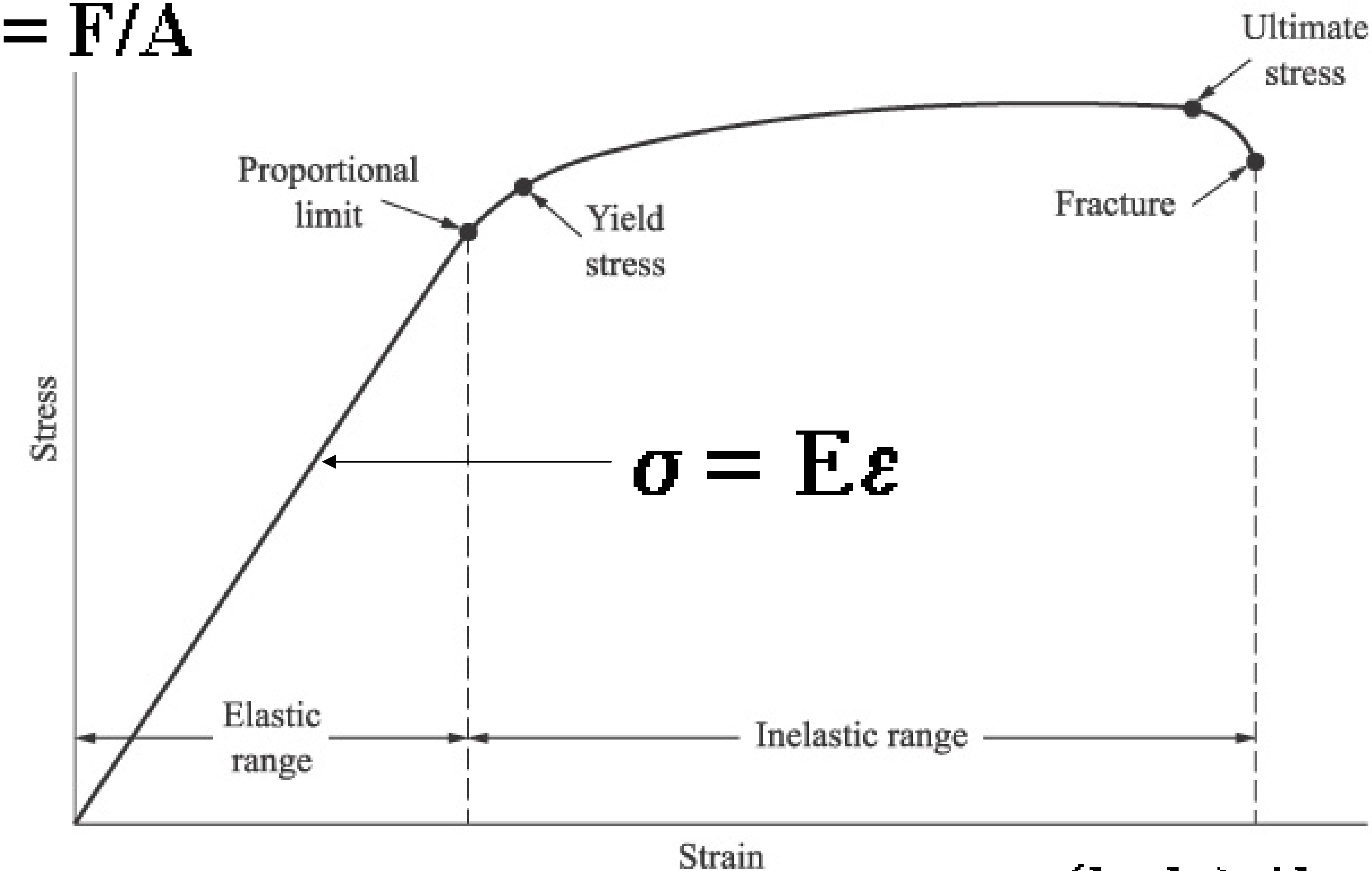
$\varepsilon = (l_1 - l_0) / l_0$ strain

$$\boxed{\sigma = E\varepsilon}$$ modulus

Here F is the force, A is the area of cross section

Stress vs. Strain

$$\sigma = F/A$$



$$\sigma = E\varepsilon$$

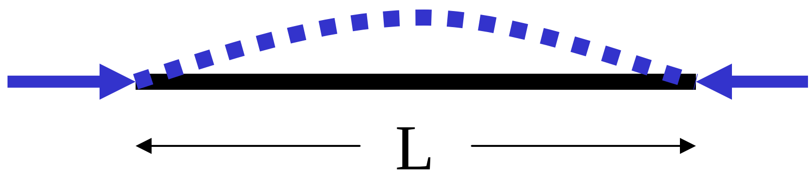
$$\varepsilon = (l_1 - l_0) / l_0$$

Young's Modulus for Typical Materials

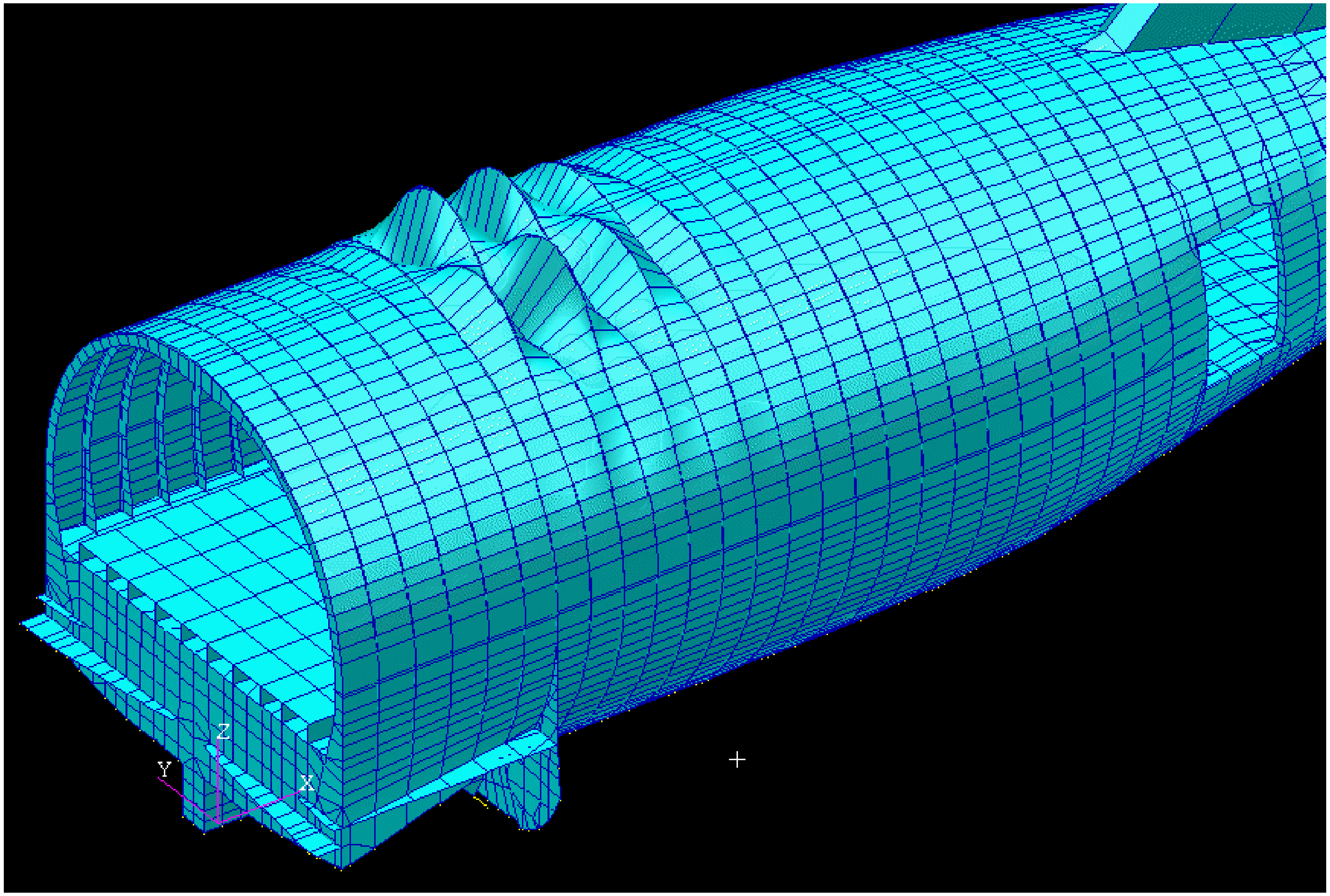
Material	**Modulus (GPa)**		
Metals:			
Tungsten (W)	406	Chromium (Cr)	289
Berylium (Be)	200 - 289	Nickel (Ni)	214
Iron (Fe)	196	Low Alloy Steels	200 - 207
Stainless Steels	190 - 200	Cast Irons	170 - 190
Copper (Cu)	124	Titanium (Ti)	116
Brasses and Bronzes	103 - 124	Aluminum (Al)	69
Polymers:			
Polyimides	3 - 5	Polyesters	1 - 5
Nylon	2 - 4	Polystryene	3 - 3.4
Polyethylene	0.2 -0.7	Rubbers	0.01-0.1

Buckling

- We Have:
  - Stress: Axial Force applied to an element (beam, stiffener or skin) divided by its cross sectional area
  - Strain: Linear deformation of the element divided by its original length/size
  - Young's Modulus, E: Stress/Strain in elastic region
- To Predict Bucking:
  - I : Moment of inertia of the cross section
  - A rod of length L will buckle if the critical load exceeds $\pi^2 EI/L^2$



Example of Skin Buckling



Analyzing Aircraft Structures

- Three common structural elements are used to describe the structure:
  - Skins
  - Stiffeners
  - Beams
- Requires determination of
  - Loads (forces/moments)
  - Mass properties (weights)
- Materials may experience both tension, and compression
  - Check for parts exceeding yield stress
  - Check for strain-induced aerodynamic issues (including aeroelastic phenomenon)
  - Check for buckling

Loads

- The loads (forces/moments) depend on the flight condition
  - Speed / dynamic pressure
  - Acceleration
  - Mach number
  - Landing impacts
  - …and more
- FAR-23 criteria (general aviation aircraft), and FAR-25 criteria (transport aircraft) require that the structure must be designed to withstand load factor “n” (n = Total Lift/Aircraft Weight) above 2.5
- Military aircraft may have to meet n above 7 or 8

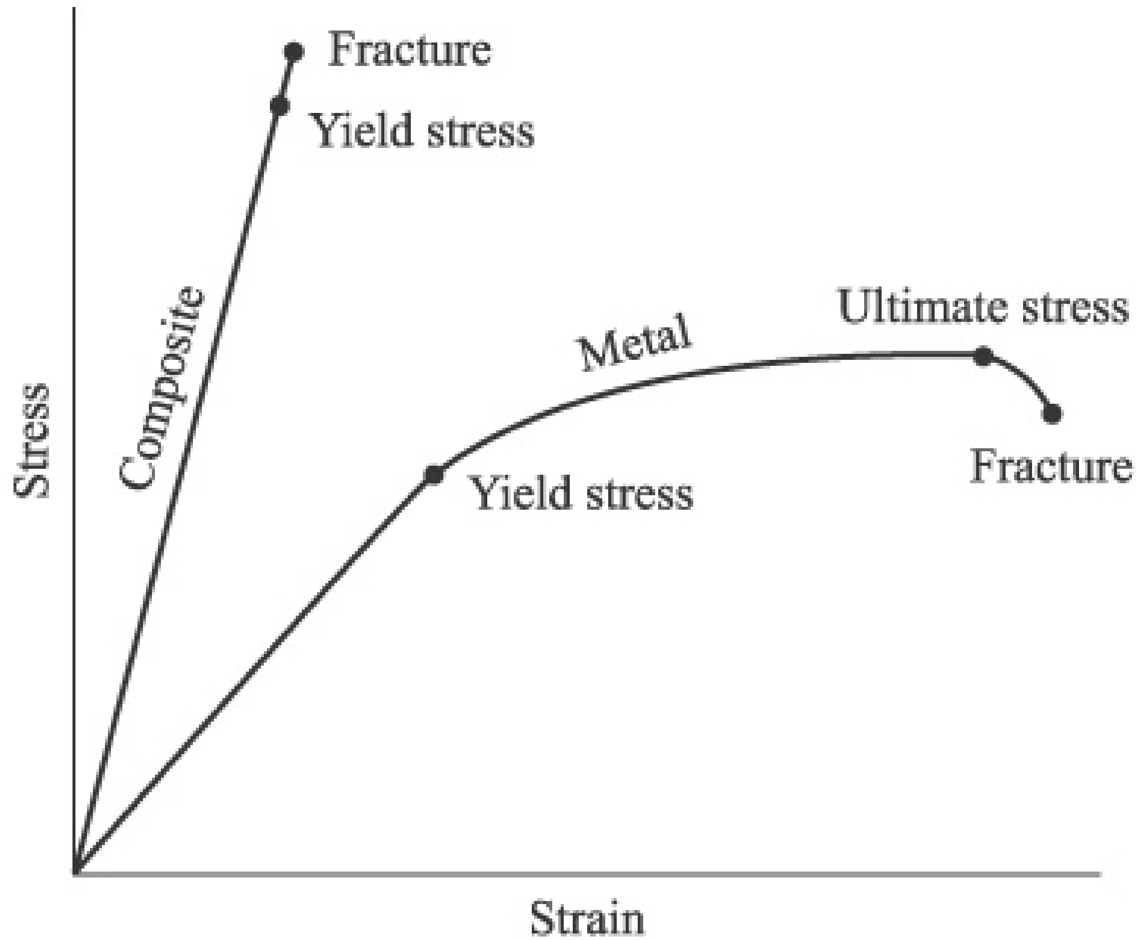
Fatigue

- Structural fatigue occurs when an element is subjected to repeated application and removal of loads
  - Pressurization/depressurization per flight
  - Wing experiencing unsteady gusts
- The number of load cycles a material can tolerate depends on the stress level
- Smaller cross sections, will have higher stresses, easily fail
- Structural analyses can identify “hot spots” where fatigue will first occur

Materials on Typical Commercial Transport

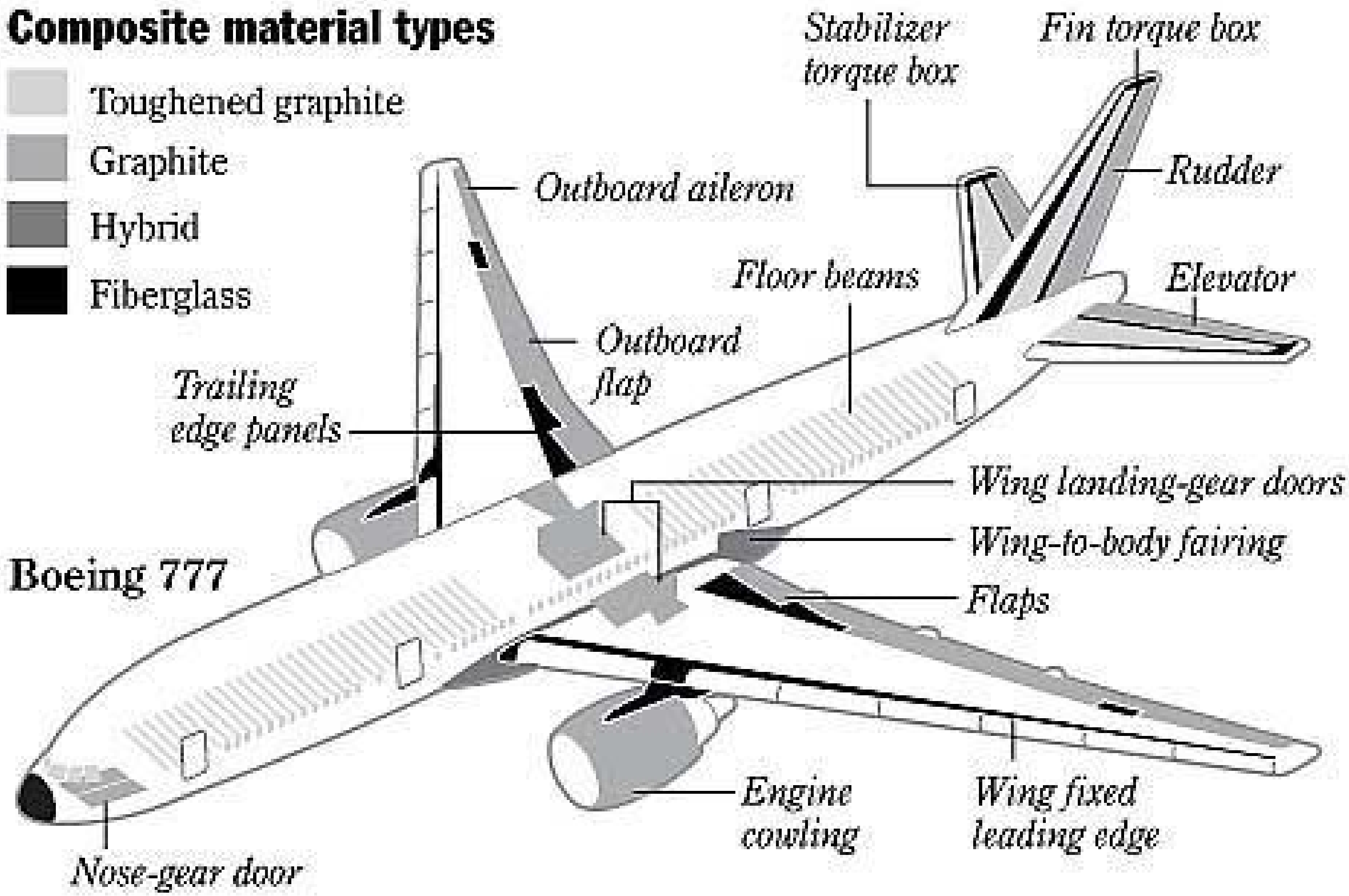
- Aluminum (80%), steel (17%) and titanium (3%) are used for load carrying elements (spars, stiffeners, skins)
- Graphite and Boron composite materials are commonly used for their light weight, in non-load carrying parts- flaps, spoilers, fuel tanks, etc.

Stress vs. Strain



Composite materials in the 777

The 777 is Boeing's most advanced current jet and the one that makes greatest use of composites. For the 7E7, a team in Boeing's Frederickson plant has developed a plan to use composites for almost the entire main wing in addition to the vertical fin and horizontal winglets on the tail. This would make the 7E7 the first civilian airliner built with composite wings.

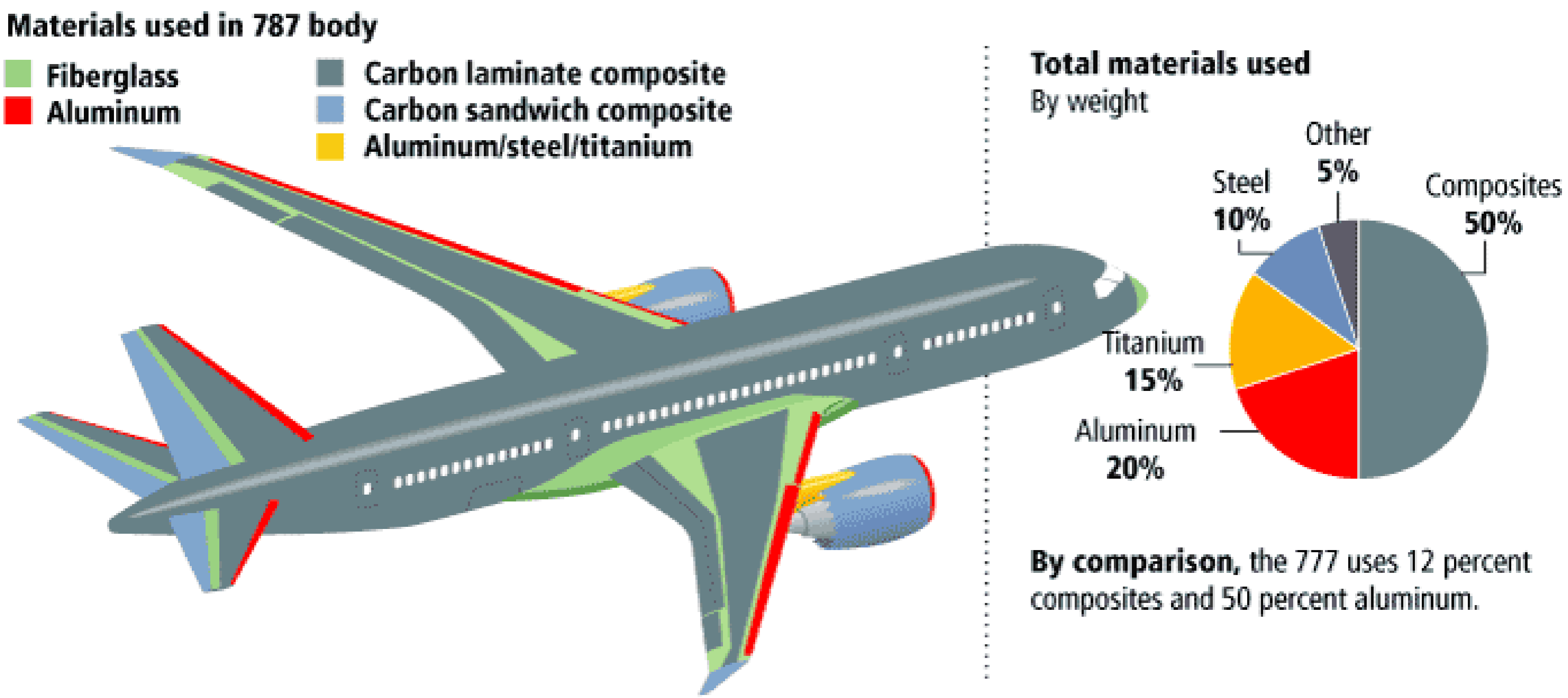


Source: Boeing

THE SEATTLE TIMES

Boeing 787

- 50% composite (mostly carbon fiber reinforced plastic)



From: Seattle PI