AE 321 Aerospace Structures I

Chapter 0 – Introduction

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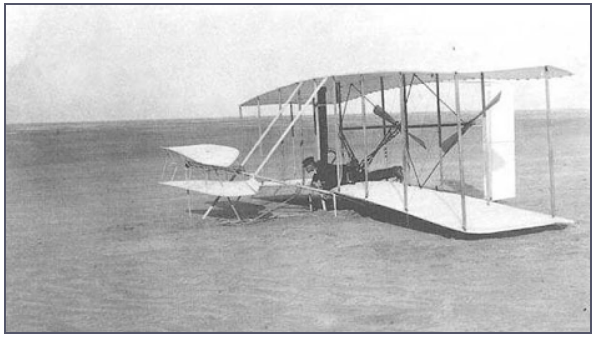
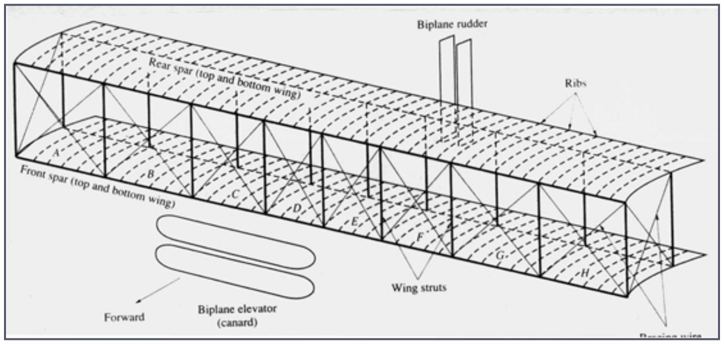
Evolution of Aircraft Structures

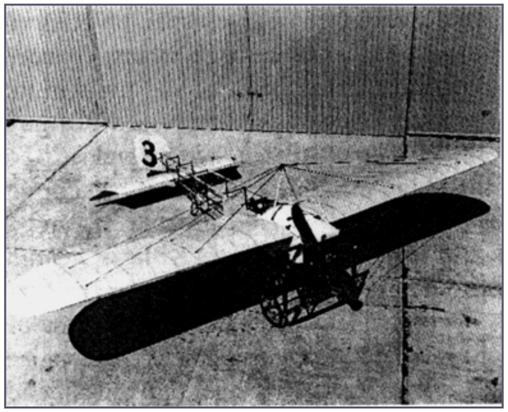
- **1890s : Octave Chanute (Civil Engineer)**

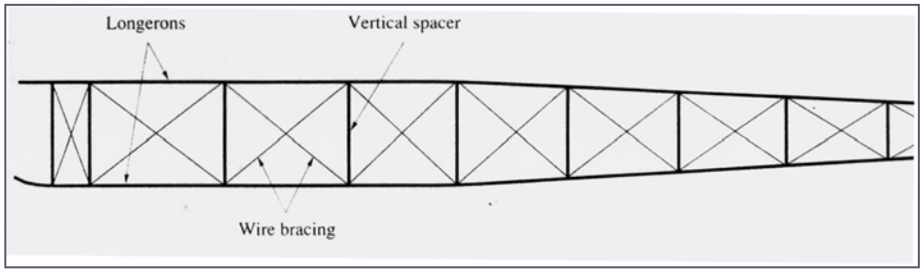
- **1904 : Wright brothers**





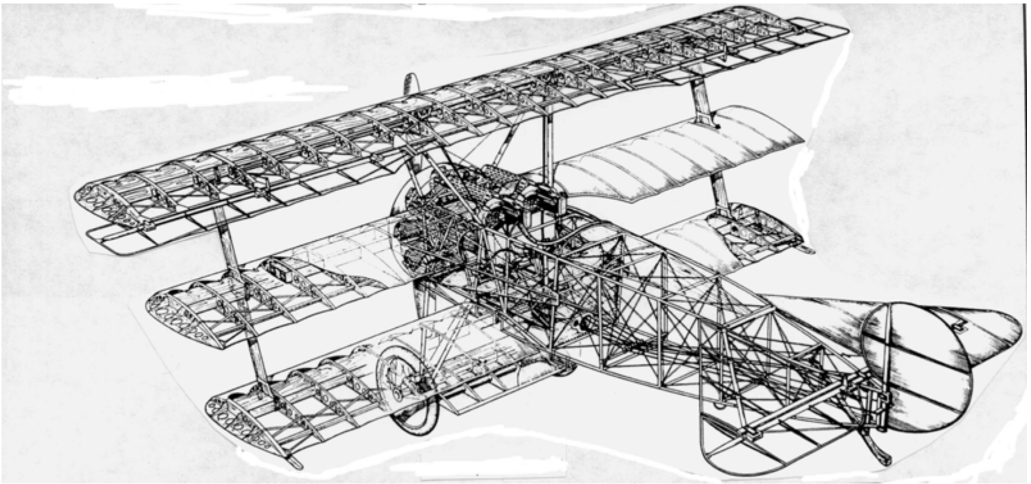
- **1909 : Louis Bleriot - monoplane and fuselage**





Evolution of Aircraft Structures

- **1914-1918 - WWI: Metallic structures and thicker wings**



- **1930s : Civil Aviation - (semi)monocoque**

Douglas DC-3

Evolution of Aircraft Structures

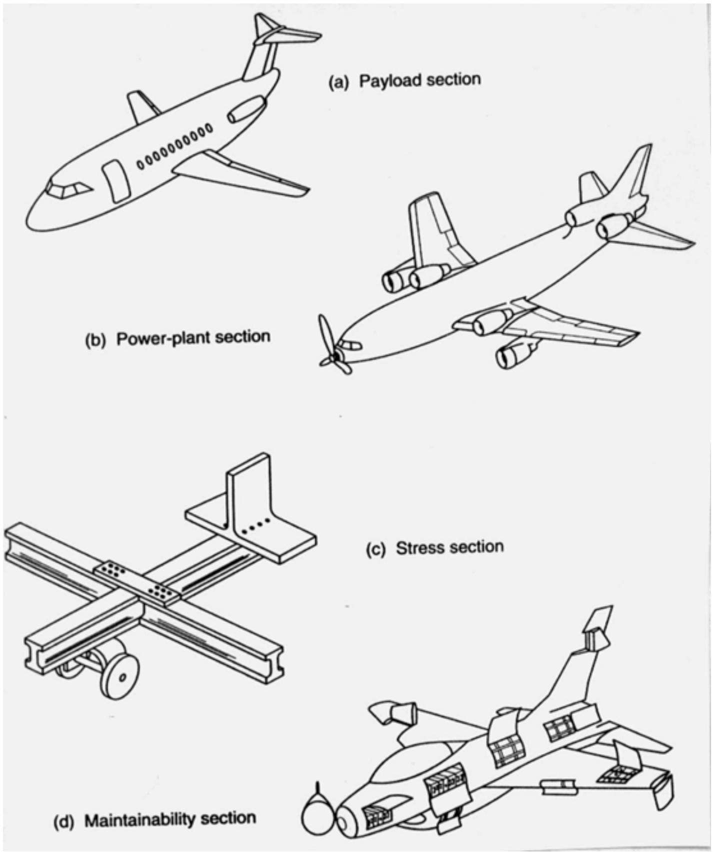
- **1940-1945 - WWII: First jets**

- **1950s to now: Advanced materials**

Titanium for hypersonic flight (X-15)

Key Issues

- **Aircraft design involves many requirements**
  - Payload
  - Power-plant
  - Structure
  - Maintainability
  - Electronics
  - Etc
- **KEY ISSUE: performance *vs.* weight**
  - Materials with high specific properties (i.e., property/density)
  - Low safety factors
- **Key questions**
  - What is the optimum structure to sustain aerodynamic loads?
  - What materials to select for various components?

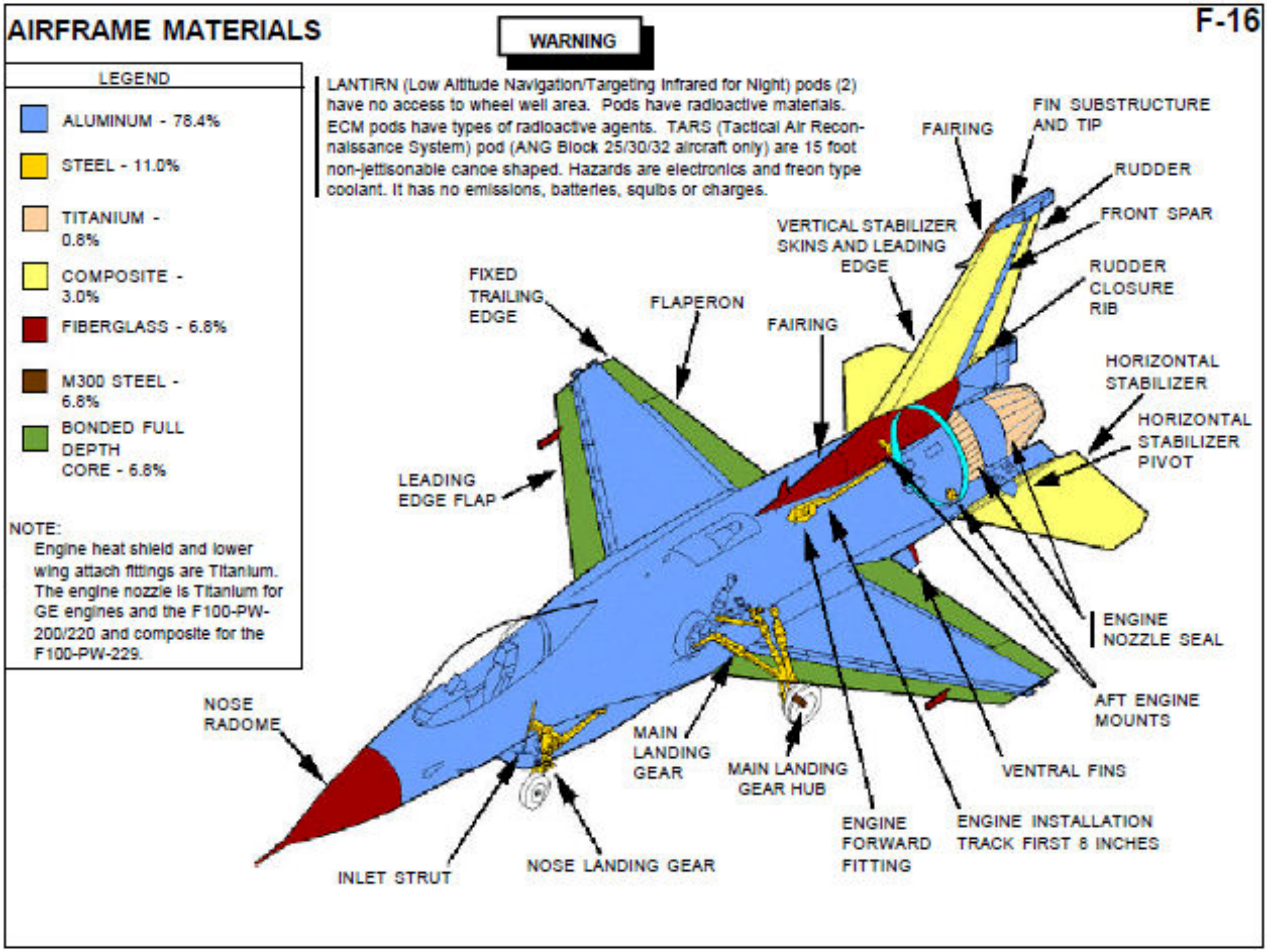


Weight required for performance equivalent to 100 lb of Aluminum

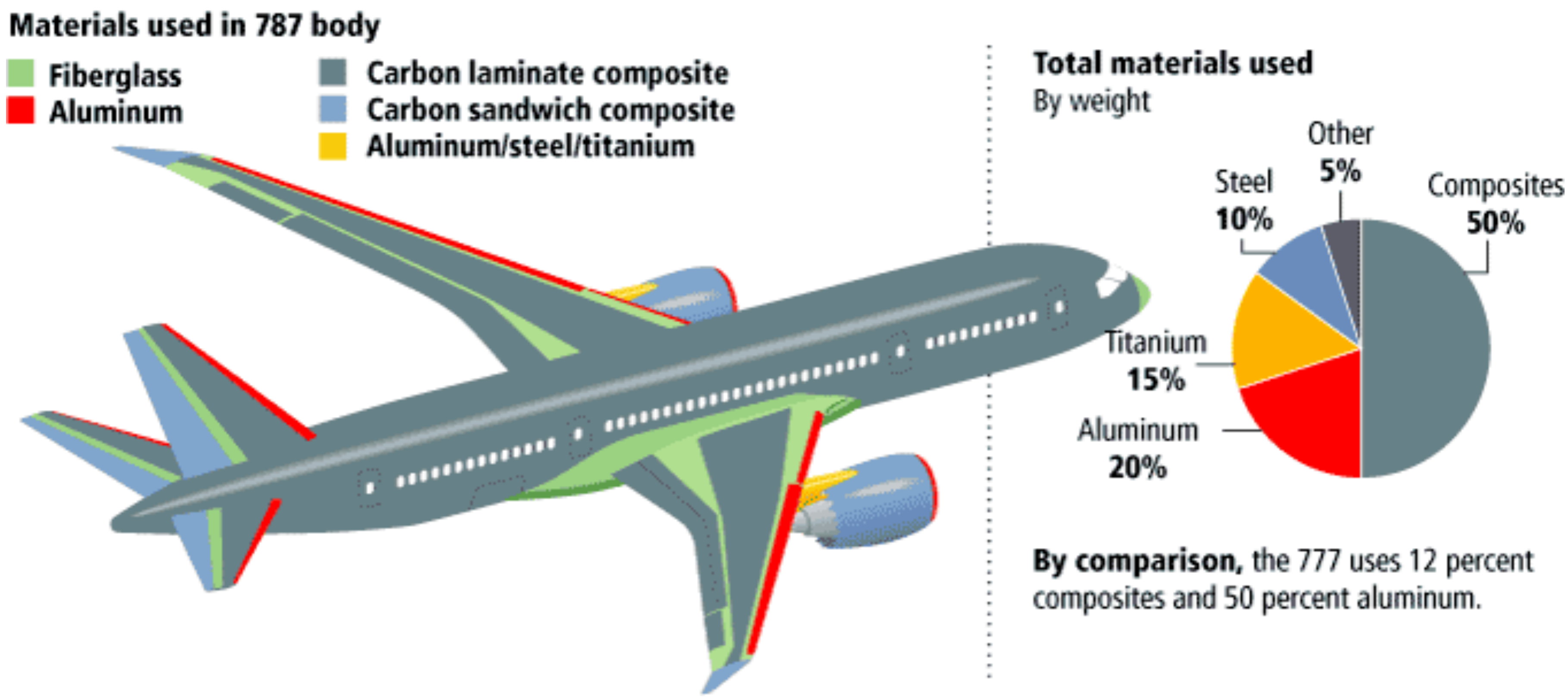
Material	Stiffness	Strength
Carbon fiber / Epoxy	30	30
Boron fiber / Epoxy	25	20
Glass fiber / Epoxy	85	15
Titanium	110	70
Steel	120	120

Aircraft (and spacecraft…) are among the most complex man-made structures

Materials Utilization



Materials Evolution

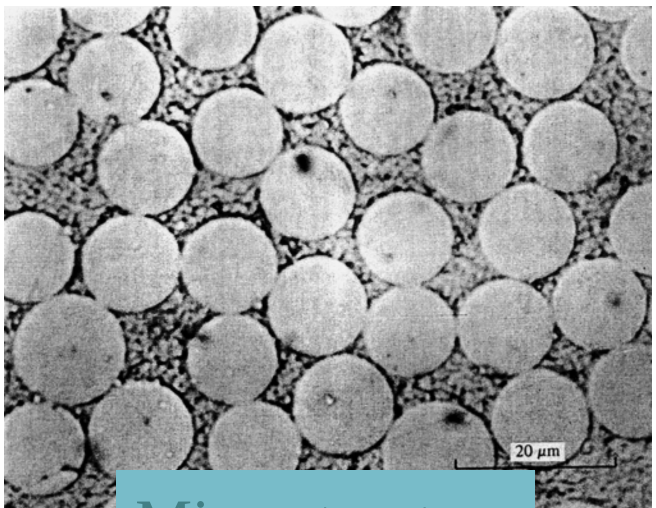


The Use of Composites

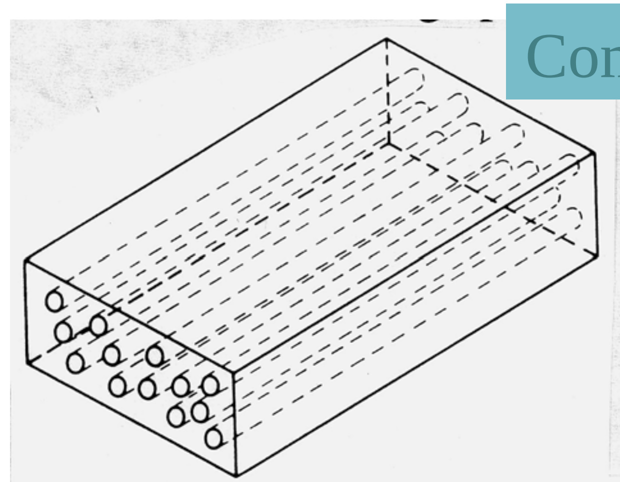
Basic idea: combine two or more materials to make a better one

Key advantage: anisotropy offers more flexibility in design

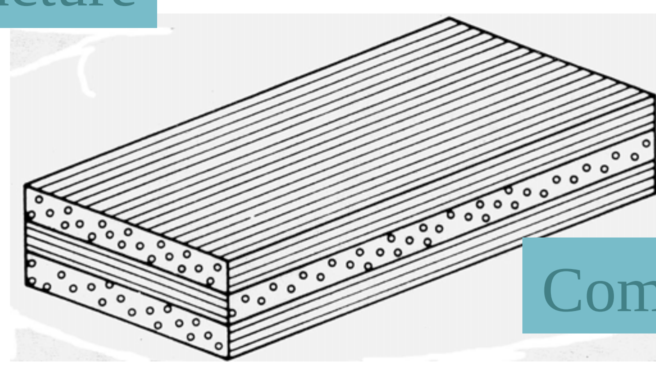
Example: *fiber-reinforced composites*



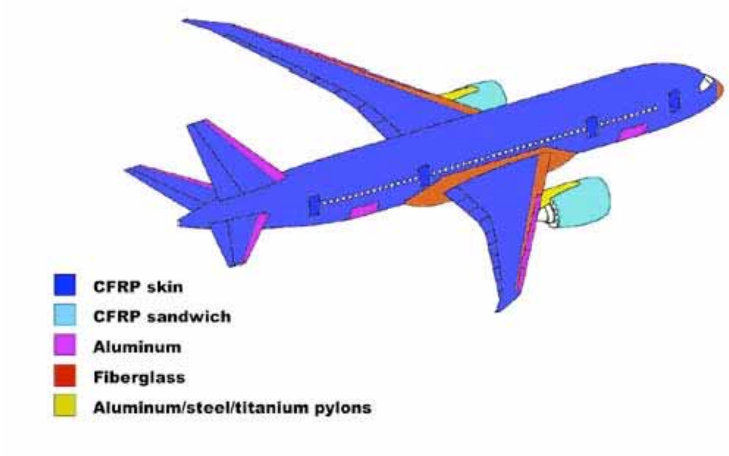
Microstructure



Composite layer



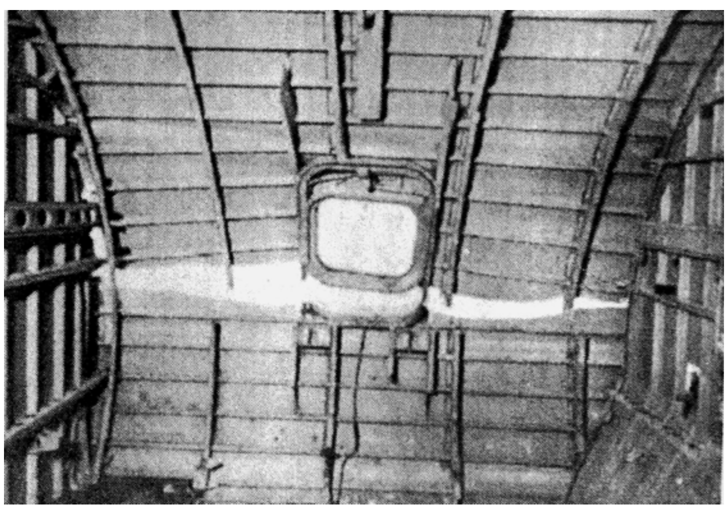
Composite laminate



- **Boeing 787**
  - Composite: 50%
  - Aluminum: 20%
  - Titanium: 15%
  - Steel: 10%
- **Composites in other airliners** (weight %)
  - Boeing 777: 12%
  - Airbus A380: 25%
  - F18 E/F Hornet: 18%
  - F22: 20%
  - F35 Joint Strike Fighter: 35%
- **Advantages for Boeing 787**
  - Less corrosion (allows for more humidity)
  - Lighter (allows for better range and/or fuel efficiency)
  - Less parts (19:1 ratio compared to Al sheets with fasteners)
  - Less maintenance

When things go wrong: Aircraft accidents

Comet aircraft (1952)

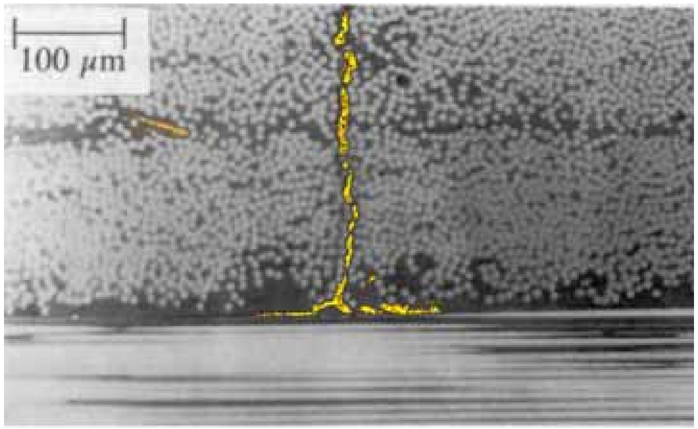


Old design

New design

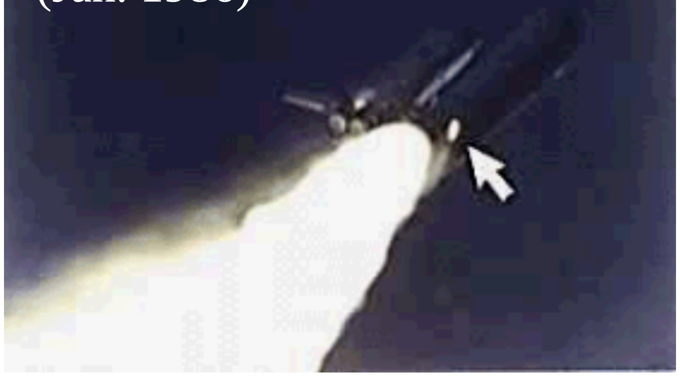
Aircraft Accidents: "Material Failures"

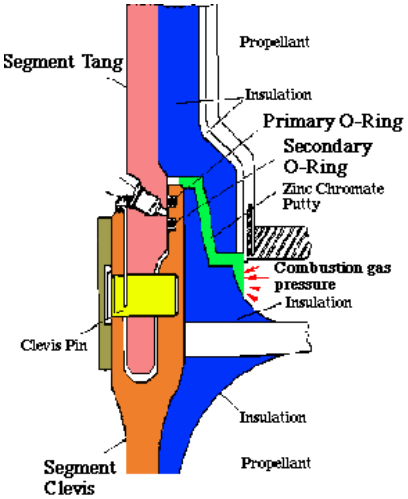
Fatigue: Aloha Airlines 243 (April 1988)



Internal cracks in composite

Ductile *vs.* brittle: Challenger (Jan. 1986)

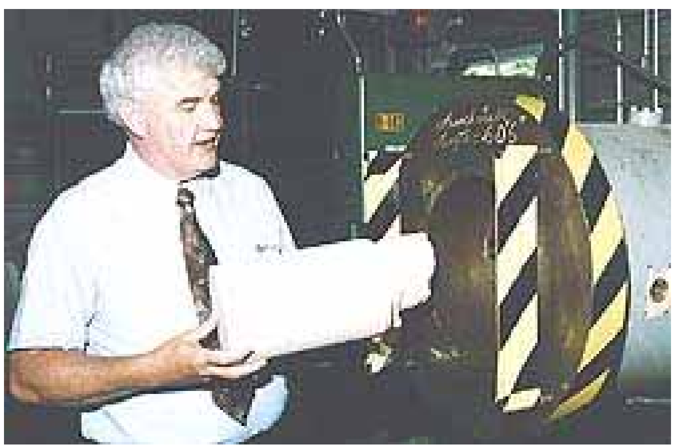




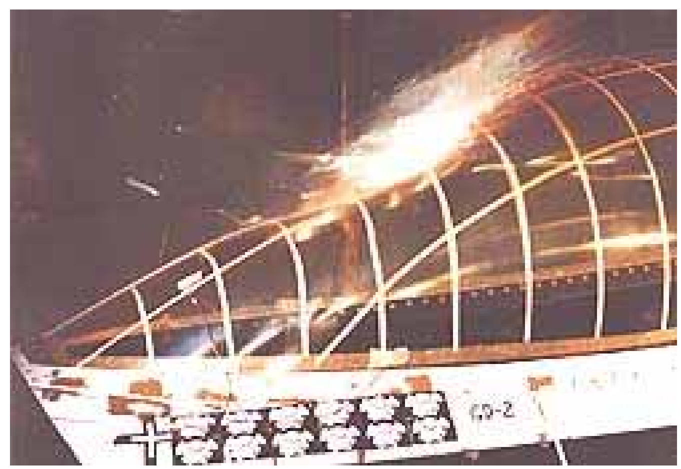
Other Accident Scenarios

Explosions: TWA flight 800 (1996)

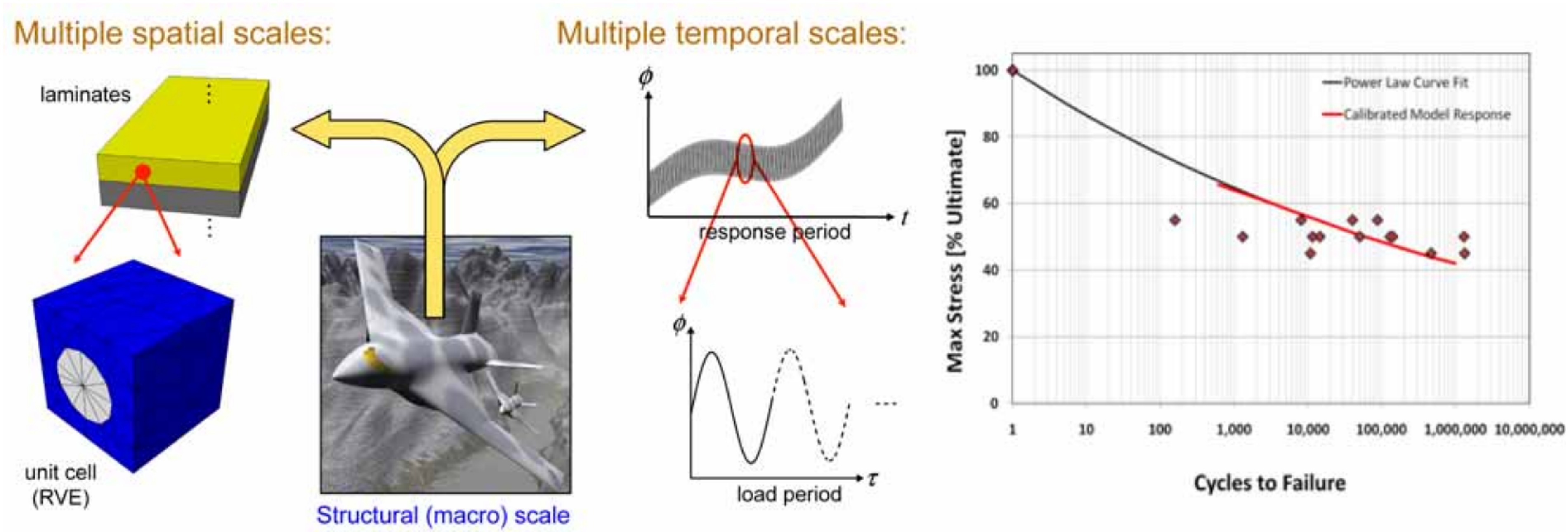
American Airlines Flight 587 (2001): Delamination of the composite vertical tail



Bird impact test on F-16 canopy



Structural Analysis is Challenging



Courtesy, Calgar Oskay, Vanderbilt U.

Structural Analysis is Multidisciplinary

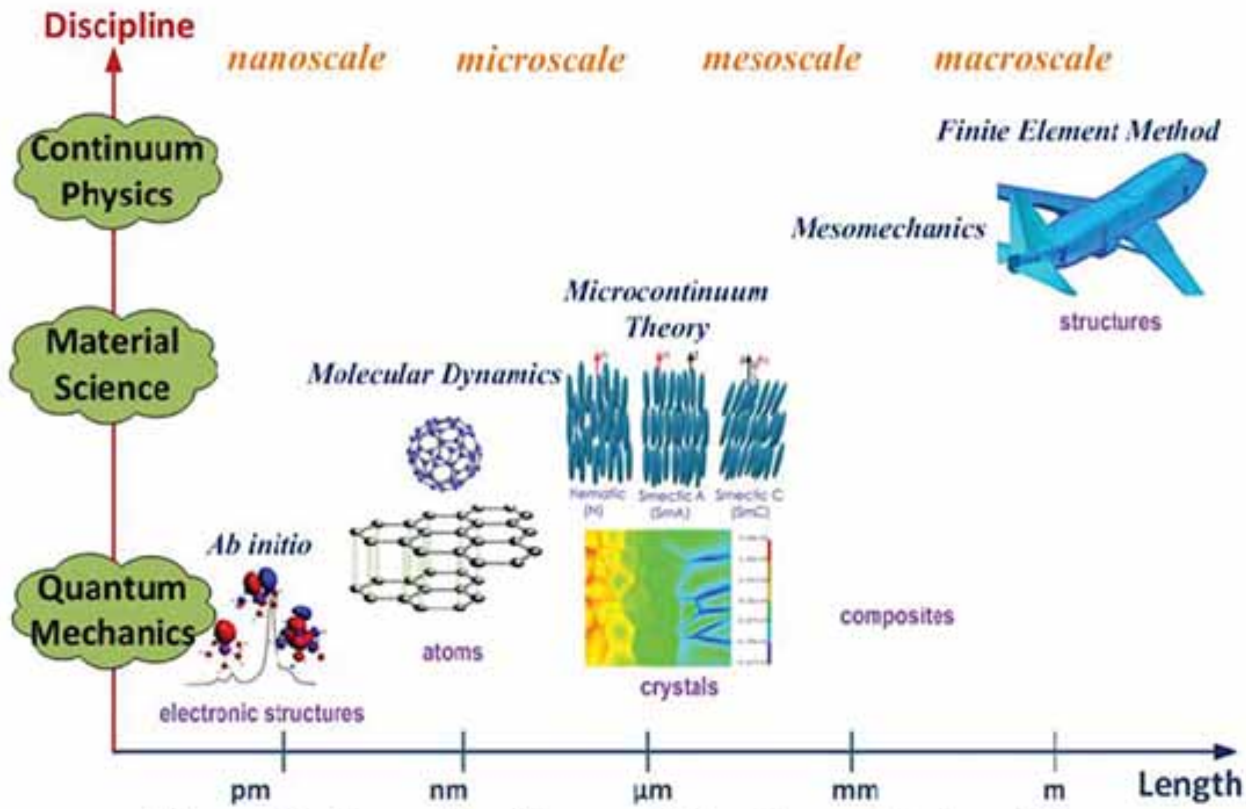
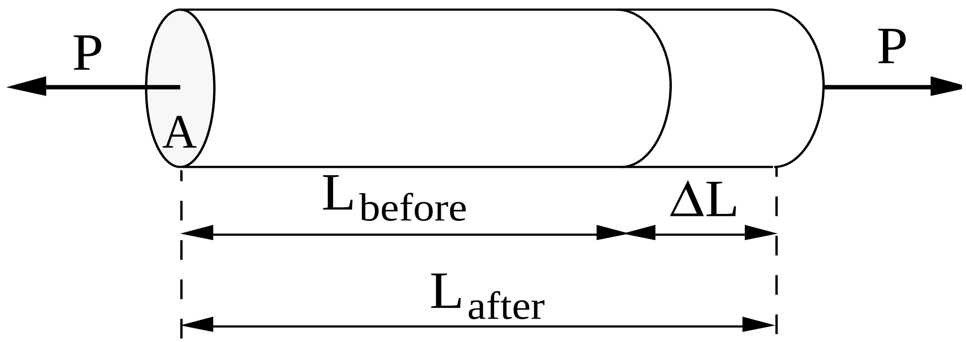


Figure 11. Examples of sequential or hierarchical modeling.

Courtesy, James Lee, George Washington U.

Course Objectives

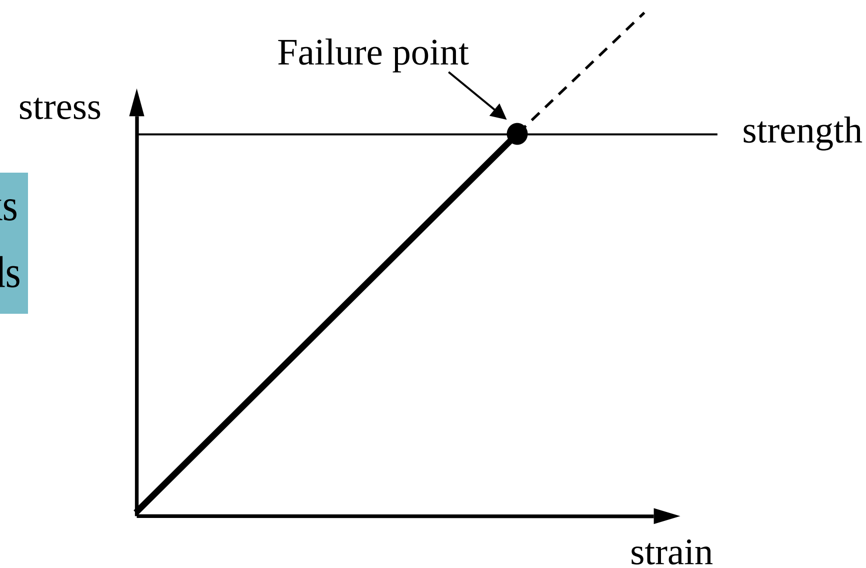
- Key objectives
  - To understand how structures/materials fail
  - To predict when a structure/material will fail
  - To prevent a structure/material from failing (catastrophically)



- Analytical tool: theory of elasticity
  - Kinetics: analysis of stress
  - Kinematics: analysis of strains
  - Conservation laws: equilibrium
- "1-D prelude"

$$\textbf{stress} = \sigma = \frac{P}{A} \quad \begin{cases} >0 & \text{tension} \\ <0 & \text{compression} \end{cases}$$

$$\textbf{strain} = \varepsilon = \frac{\Delta L}{L_{before}} = \frac{L_{after} - L_{before}}{L_{before}} \quad \begin{cases} <0 & \text{shrinks} \\ >0 & \text{expands} \end{cases}$$



- Question: How to expand to 3-D?

Course Outline

1. Mathematical preliminaries (1*)
   - 1.1 Review of vector theory
   - 1.2 Indicial notation
   - 1.3 Tensor theory
2. Kinetics: Theory of stresses (3)
   - 2.1 Stress tensor
   - 2.2 Equilibrium equations
   - 2.3 Principal stresses
3. Kinematics: Theory of strain (2)
   - 3.1 Definition of strain
   - 3.2 Physical interpretation
   - 3.3 Compatibility
   - 3.4 Summary of stress and strain
4. Material behavior (4)
   - 4.1 Uniaxial response - Tensile test
   - 4.2 Generalized Hooke's law
   - 4.3 Isotropic solids
   - 4.4 Viscoelastic materials
5. **Formulations and solution strategies (5)**
   - 5.1 Formulations
   - 5.2 Solution strategies
6. **Extension, bending and torsion of cylindrical components (9)**
   - 6.1 Extension
   - 6.2 Bending
   - 6.3 Torsion
7. **Failure and fatigue**
   - 7.1 Failure criteria
   - 7.2 Yield surfaces
   - 7.3 Fatigue
8. **2-D plane stress/plane strain problems**
   - 8.1 Plane strain (7)
   - 8.2 Plane stress (7)
   - 8.3 Solutions (8)

*** Numbers in parentheses refer to chapters in "Elasticity: Theory, Applications and Numerics" by M. H. Sadd**

A Global Industry, A Global Career…..