Fuselage Design 101:

Basic Terms and Concepts

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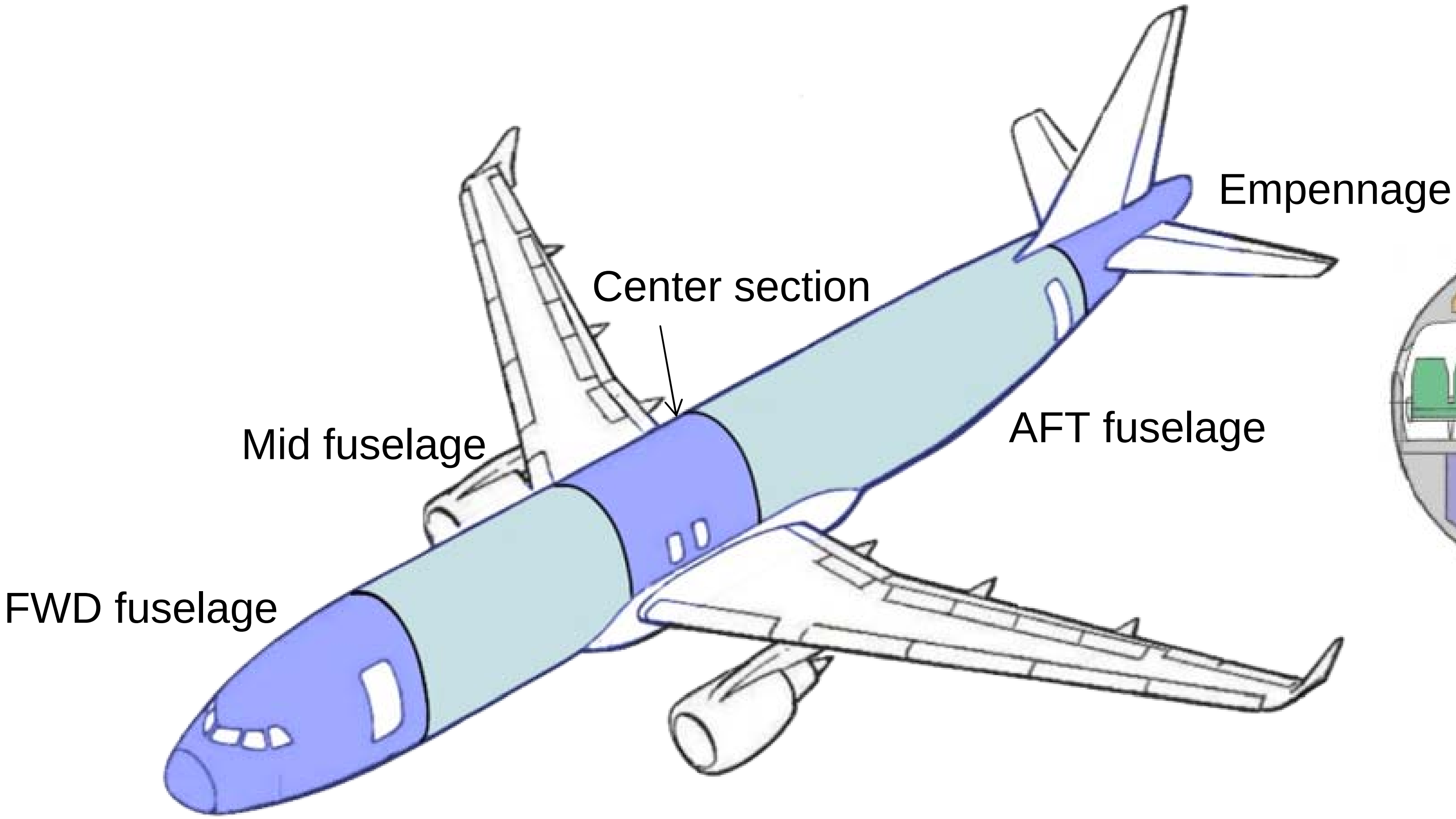
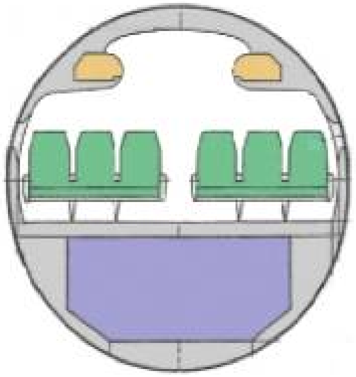
Outline

- What is a fuselage?
- Primary loads
- Construction techniques
- Parts
- Materials
- Mechanical Fasteners
- Section splices
- Cutouts: windows and doors
- Airframe Design: Terminology, History, Criteria
- Substantiation: Building block approach
- Evolution of Fuselage Design / Structural Concepts

Fuselage: What is it?

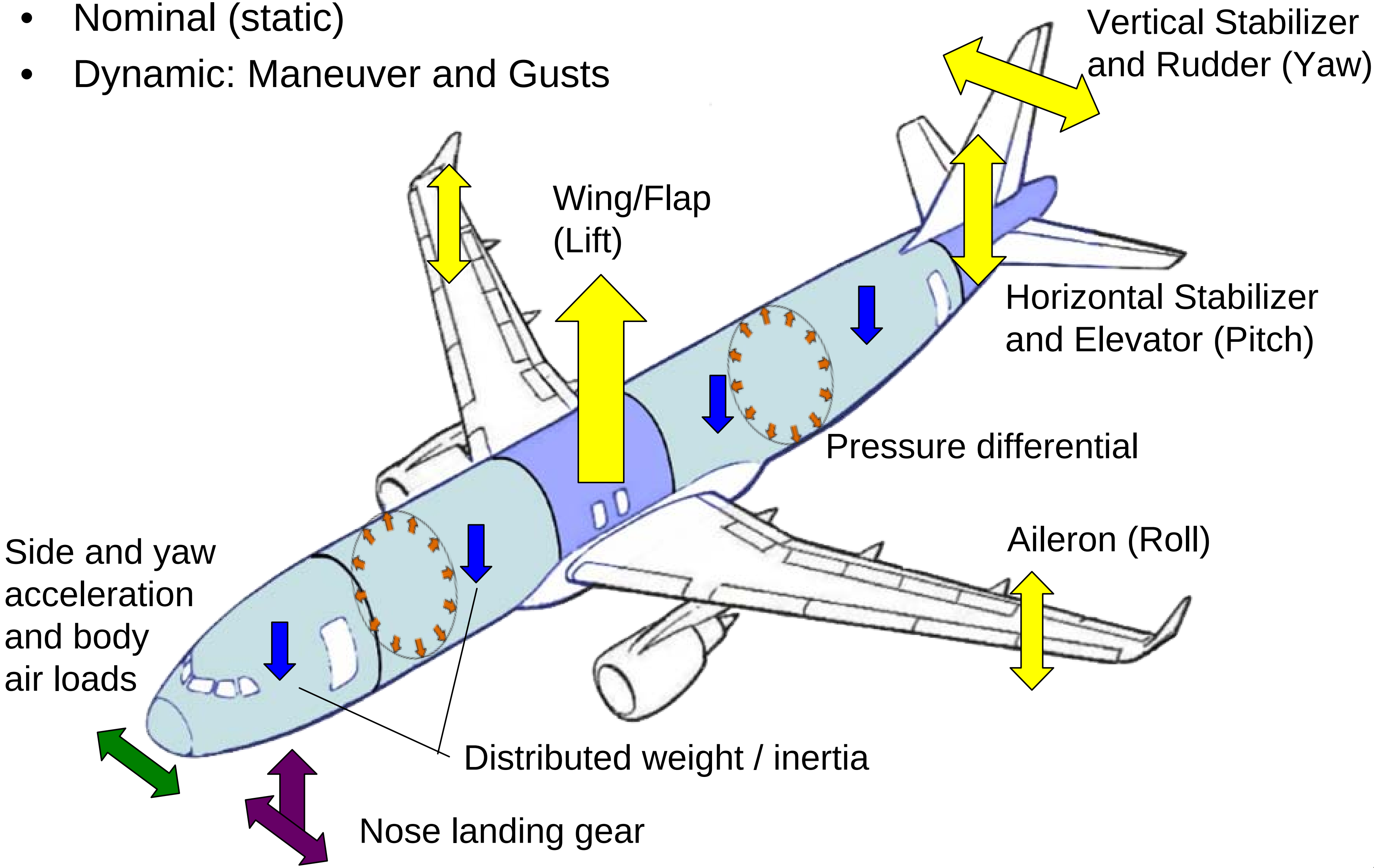
- Fuselage is based on French word fuseler, which means "to streamline”
- Passenger/cargo volume connecting all major aircraft parts:
- Pressurized for passenger comfort
- Optimize / compromise: maximize volume, access, minimize weight, drag



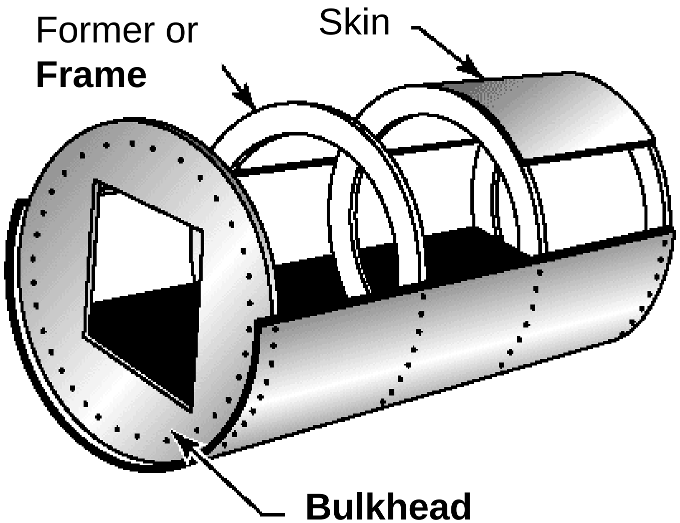


Fuselage Primary Loads

- Nominal (static)
- Dynamic: Maneuver and Gusts

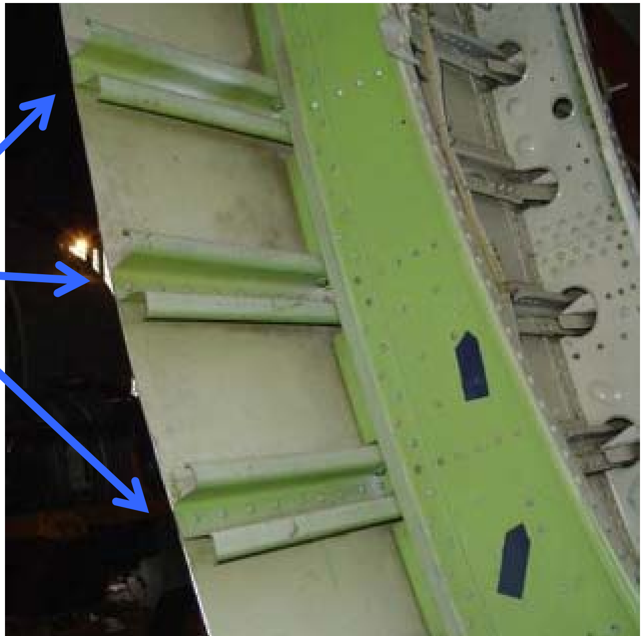


Fuselage Construction



- **Monocoque**, meaning 'single shell' in French, is a construction technique that utilizes the external skin to support some or most of the load (structural skin, stressed skin, unibody)

- **Semi-monocoque:** skin is stiffened by longitudinal elements (stiffeners, stringers, longerons)
  - **Stringers (6-10 in. spacing)**
    - increases skin stability
    - carry fuselage bending
    - provide multiple load paths for fail-safe design
  - **Frames** (~ 20 in. spacing)



Semi-monocoque Construction Parts

Fail-safe tear strap
- Al or Ti strap bonded, spot-welded, or riveted to skin

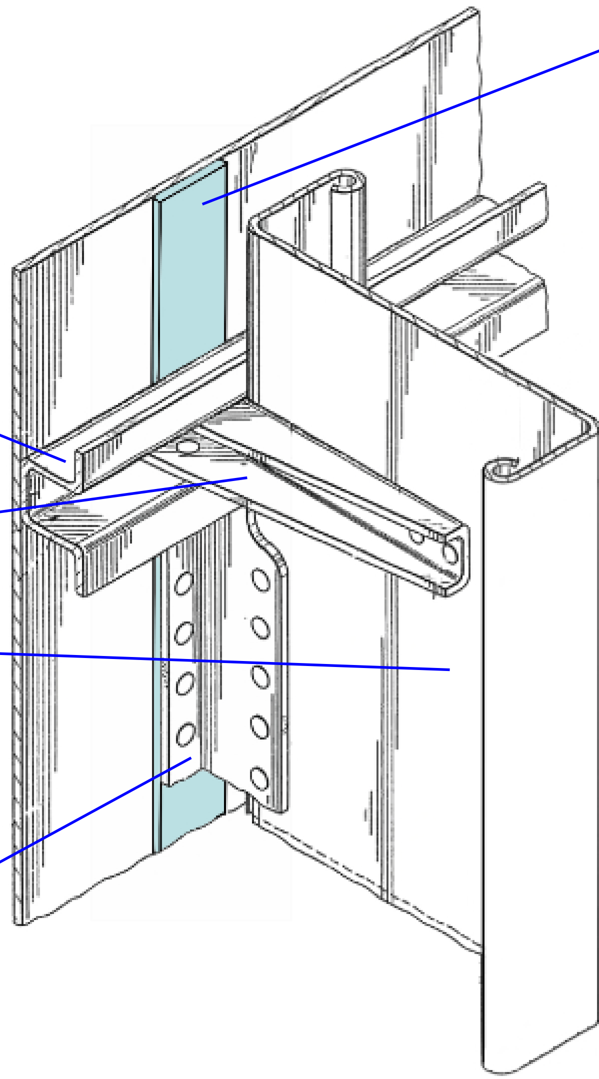
OR
- Waffle pattern doubler bonded to skin under stringers and frames

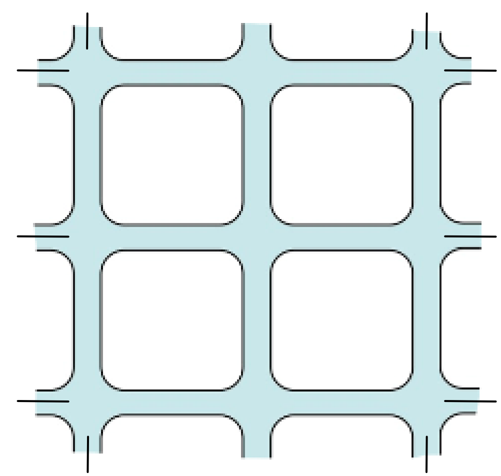
Stringer

Stringer clip

Frame
(floating, mousehole or shear tied)

Shear tie





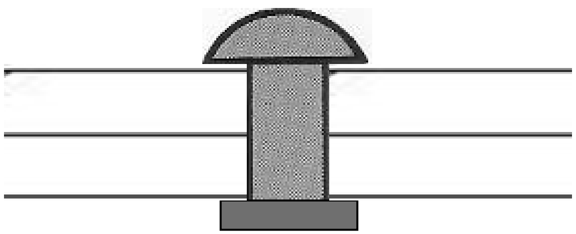
Materials

- Requirements:
  - Structural:
    - Skin carries cabin pressure (tension) and shear loads
    - Longitudinal stringers carry the longitudinal tension and compression loads
    - Circumferential frames maintain the fuselage shape and redistribute loads into the skin, and bulkheads carry concentrated loads.
  - Material:
    - Strength, Young's modulus, fatigue initiation, fatigue crack growth, fracture toughness and corrosion are all important, but fracture toughness is often the limiting design consideration

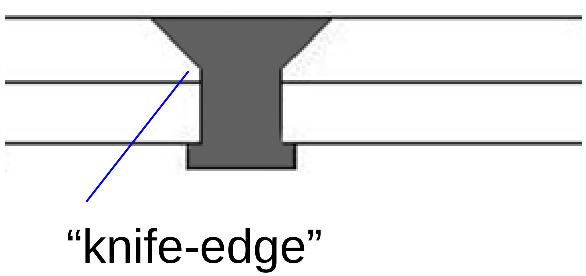
- Common material choices:
  - Al 2024-T3: Fuselage skin and other high strength tension applications - Best fracture toughness, slow crack growth rate, good fatigue life
  - Al 7075-T6: Frame and stringers – higher strength than 2024, lower fracture toughness; avoid fatigue critical tension applications
  - Ti: fail-safe tear strap; higher strength than Al, but expensive

Mechanical Fasteners

- **Rivets**
  - Low cost, permanent fasteners
  - **Button head**



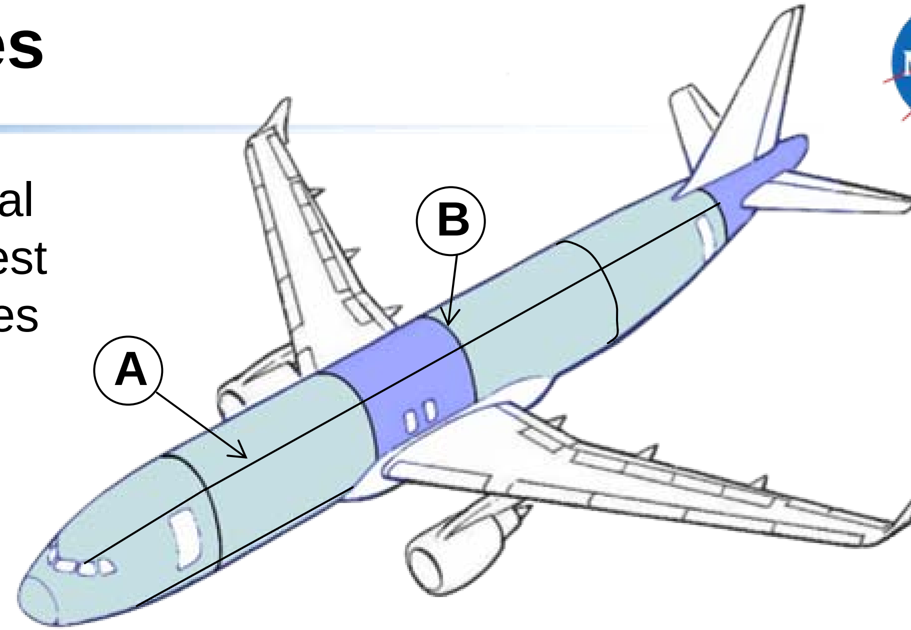
  - **Flush-head**
    - Aerodynamic efficiency
    - Inadequate head clearance



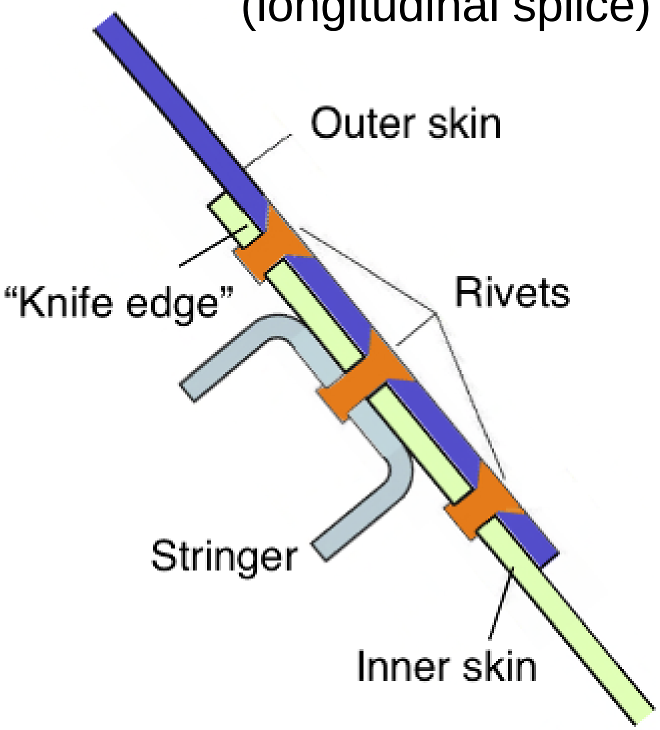
- **Threaded Collar Fastener**
  - High clamp up, one sided

Typical Fuselage Splices

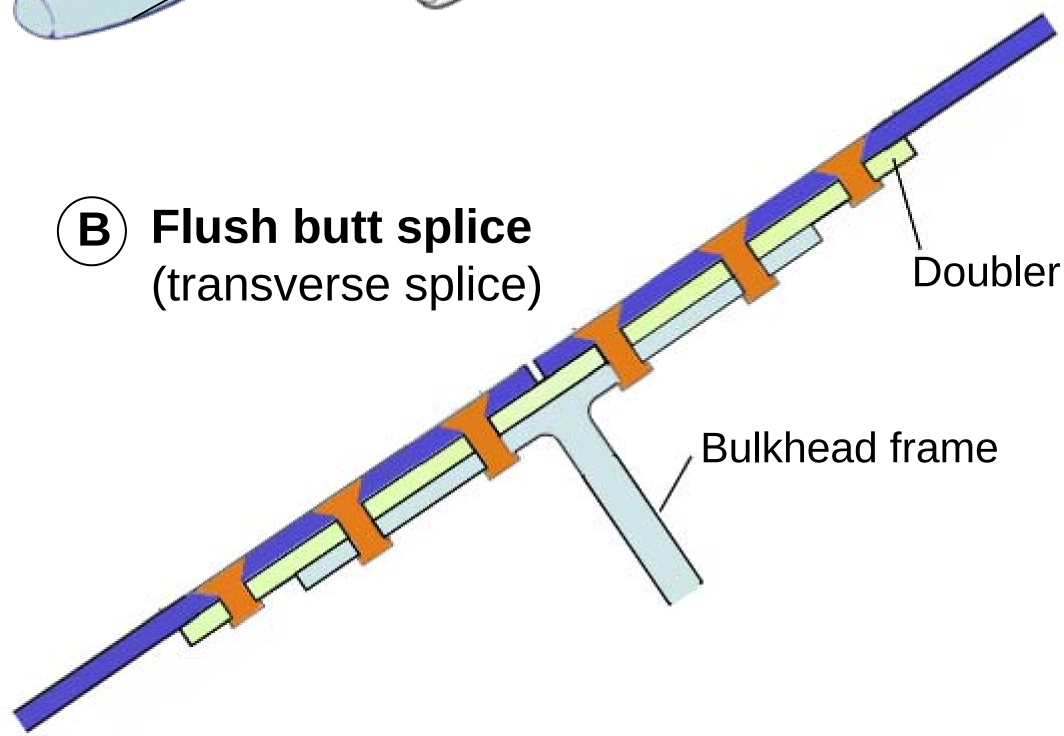
- Most efficient structure has minimal number of joints and splices; largest panels possible, limited by mil sizes and manufacturing



Ⓐ **Single lap splice**
(longitudinal splice)



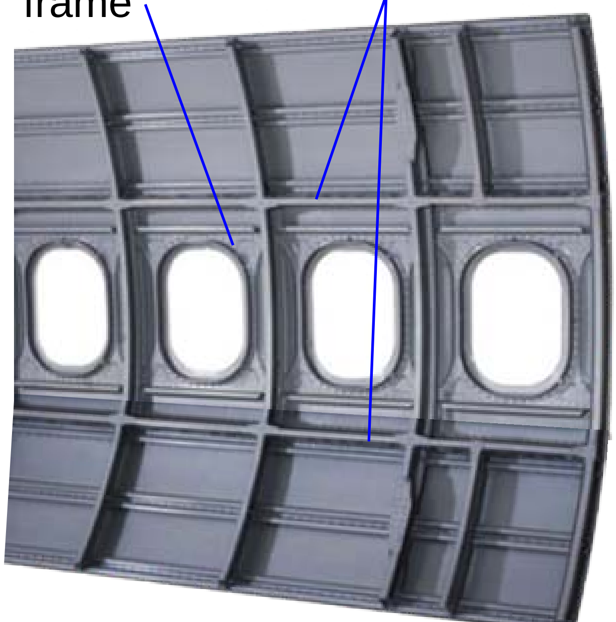
Ⓑ **Flush butt splice**
(transverse splice)



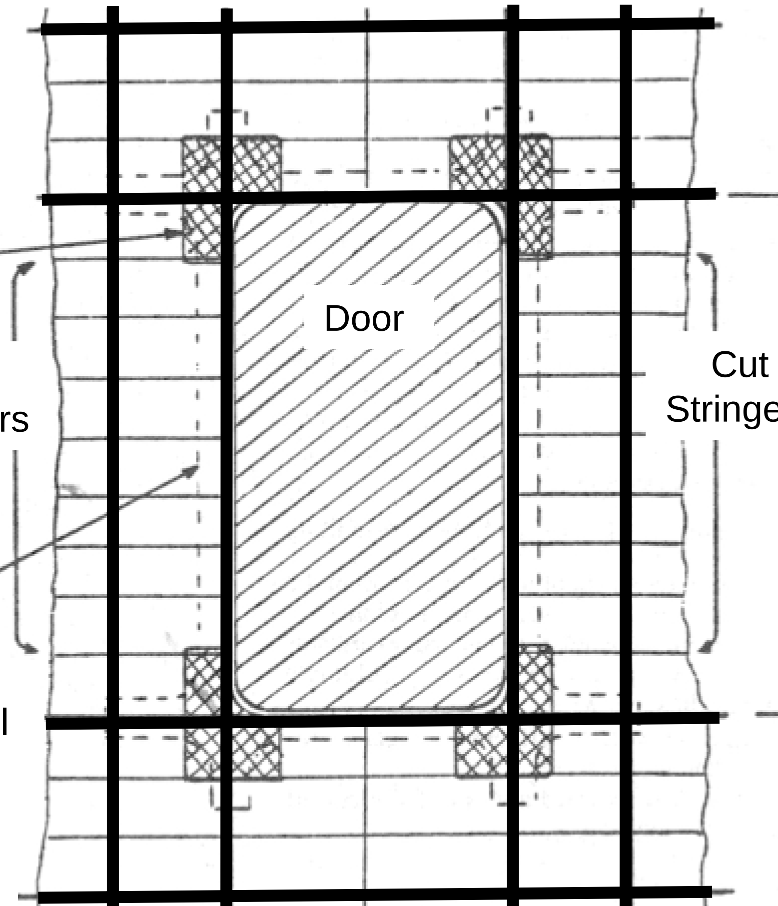
Cutouts

- Hole in load-bearing skin – stronger surrounding structure must provide alternate load path
- Rounded corners reduce stress concentrations

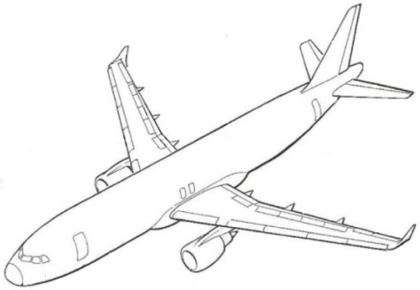
Passenger Cabin Windows



Cargo/Passenger Doors

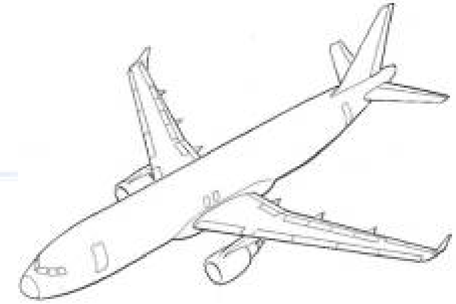


Aircraft Design: Load Factors



- **Nominal loads**are for straight and level flight, lift = weight
- **Load factor**: multiplying factor that defines total load in terms of weight
  - Maximum maneuvering load factor (2 to 3 for transport aircraft)
  - Gust load factors: atmospheric disturbances, turbulence
- **Limit loads:** the maximum loads anticipated on the aircraft during its life
- **Ultimate load** = Limit load X Factor of safety (typically 1.5)
  - Factor of safety provides reserve strength for
    - Approximations in design
    - Variability in materials, fabrication, inspection
    - Reserve for emergency flight conditions or extreme gust conditions

Airframe Design History



1930 – 1940: Commercial development of metal aircraft for public transport, designed for static ultimate strength

1940 – 1950s: WWII technology provided higher material static strength without corresponding increase in fatigue strength; introduced strength and fatigue design

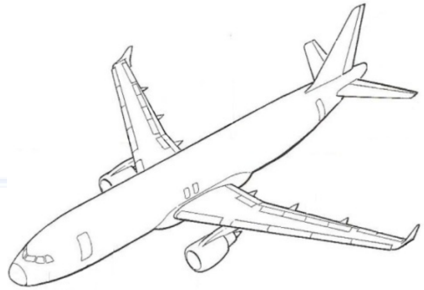
1960 – 1990: Safety from fatigue alone recognized as inadequate; developed

- **fail-safe** : adequate safety after some degree of damage
- **damage tolerant** : sustain defects safely until repair can be effected - inspection frequency

Design Objectives:

- structural efficiency (light, stiff, strong)
- viability: manufacturing, maintenance
- maximum safety margin
- ‘reasonable’ life based on economic obsolescence

Modern Airframe Design Criteria



Static strength of undamaged structure
•Support ultimate loads without complete failure for 3 seconds
•Deformation at limit loads may not interfere with safe operation

Fatigue crack initiation
•Fail-safe structures meet customer service life requirements
•Safe life components remain crack free in service

Residual static strength of damaged structure
•Fail-safe structures support 80-100% of limit loads without catastrophic failure
•Single member failure in redundant structures and significant partial failure in monolithic structures

Crack growth life of damaged structure
•Fail-safe structures: inspection frequency set based upon crack growth rate to minimize risk of catastrophic failure
•Safe-life: inspection frequency and replacement time such that probability of failure by fatigue cracking is extremely remote

Structural Development and Substantiation

Building Block Approach:

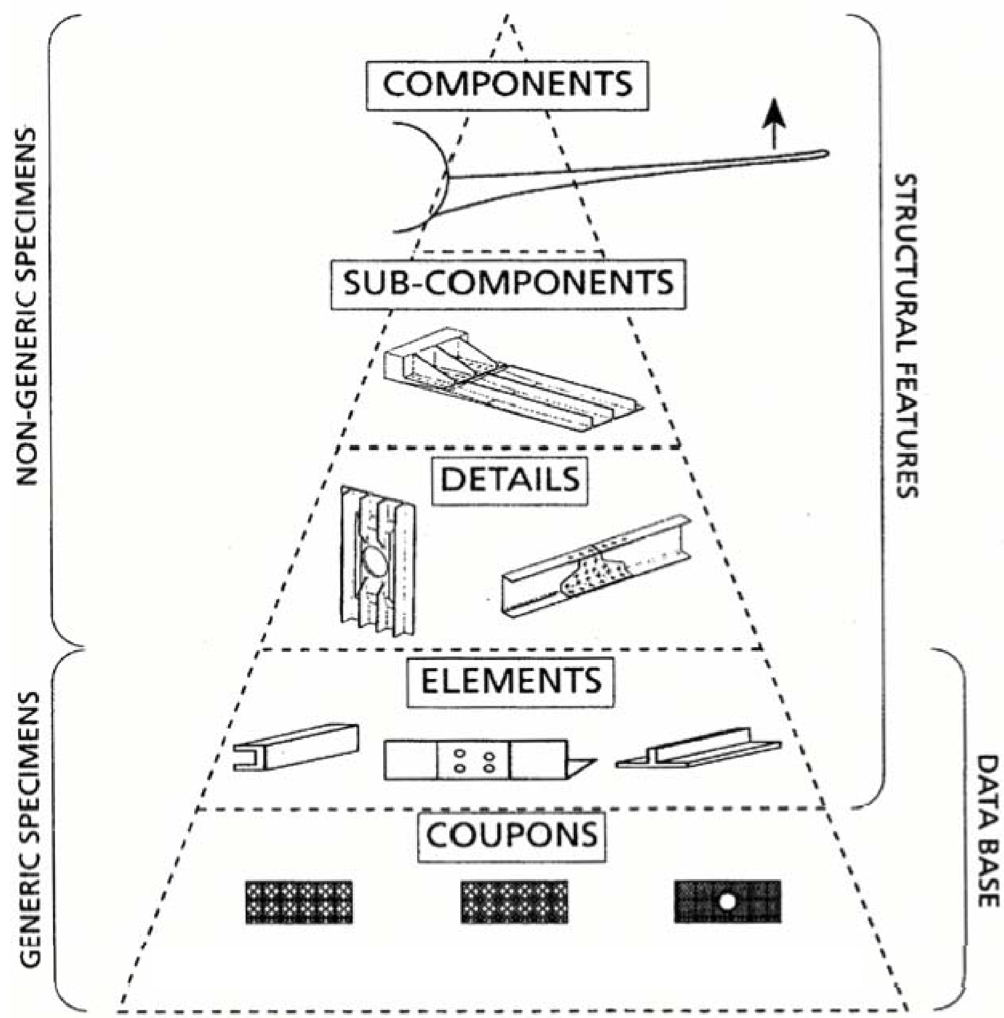
Engineering, supported by analysis, and validated by tests from coupons to full-scale components

Structural Vertification

Manufacturing process development and scale-up

Design concepts and analysis development

Material properties



Evolution of Fuselage Design / Structural Concepts

- Decades of incremental refinement of details, yet same basic structural concept

B707 (1958)

B737-800 (1998)

Bombardier Cseries Development (2009)

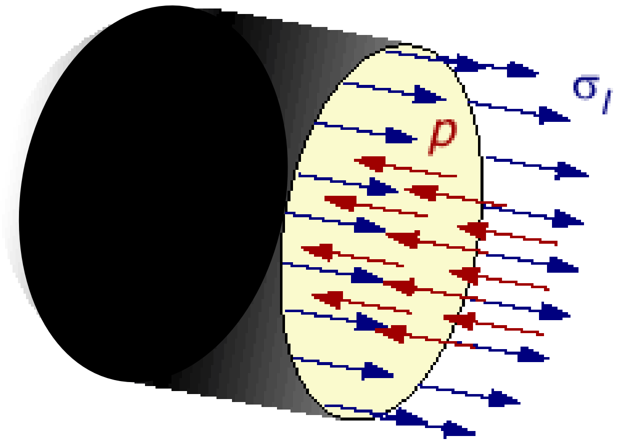
- Composite Fuselage Concepts
  - New materials
  - Fabrication / assembly
  - Different failure modes

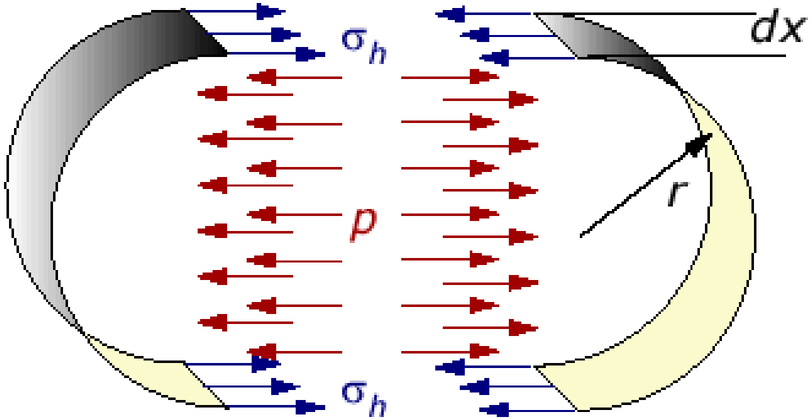
A350 Development (2009)

BWB Development, X-48B (2007)

BACK-UP SLIDES

Skin Stress in Pressurized Semi-monocoque Structure





Unstiffened shell

$\sigma_l * t * 2\pi r = p * \pi r^2$

$\rightarrow \sigma_l = pr / 2t$

Shell with Stringers: $A_{st} = A_{sk}$

$\rightarrow \sigma_l \sim pr / 4t = 0.25 * pr / t$

Unstiffened shell

$2 * \sigma_h * t * dx = p * 2r * dx$

$\rightarrow \sigma_h = pr / t$

Shell with Frames: $A_F = A_{sk}$

$\rightarrow \sigma_h \sim 0.8 * pr / t$

Material Property Testing

- Manufactures are responsible for developing / validating material properties, and also validate full-scale structure performance
- May leverage material database if verify current materials are ‘in family’
  - Sources:
    - Company-developed database
    - Material-Supplier database
    - Metallic Material Properties Development and Standardization (MMPDS) Handbook (replaced MIL-HDBK-5)
    - NASGRO Material Properties Database:
      - NASGRO 4.0 database contains material properties for fatigue crack growth and fracture for 476 different metallic materials, including 3000 sets of fatigue crack growth data, 6000 fracture toughness data points, and statistically derived crack growth equations for all 476 materials
- Properties measured using standard test techniques, for example American Society for Testing and Materials (ASTM) standards