Aircraft Structures

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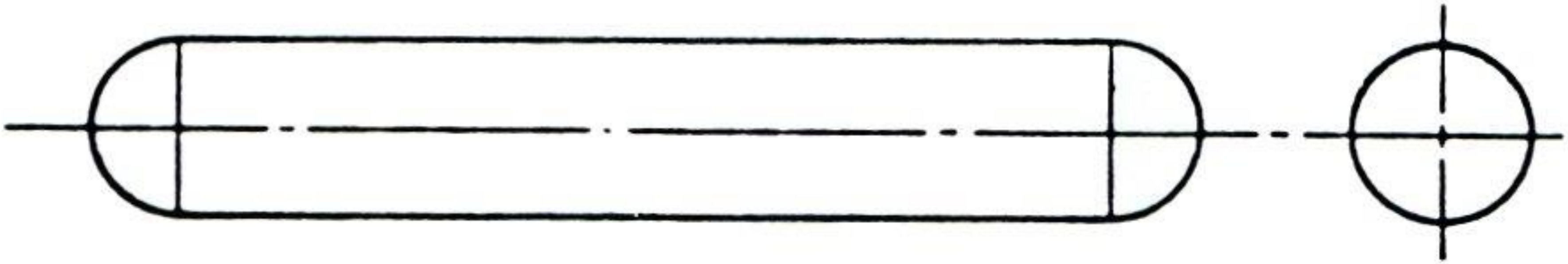
Section A8

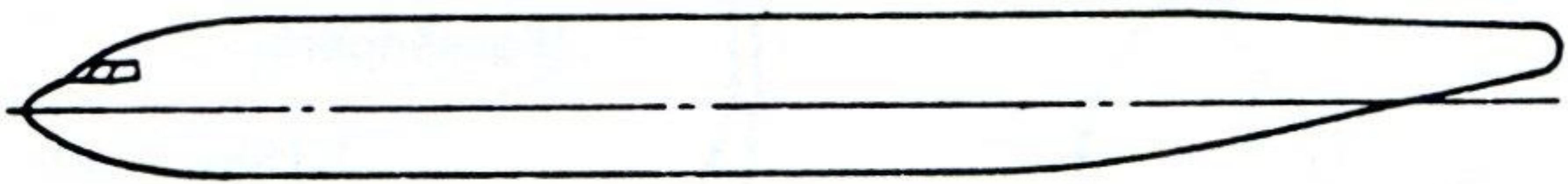
Analysis of fuselages

Fuselage requirements

- Pressure

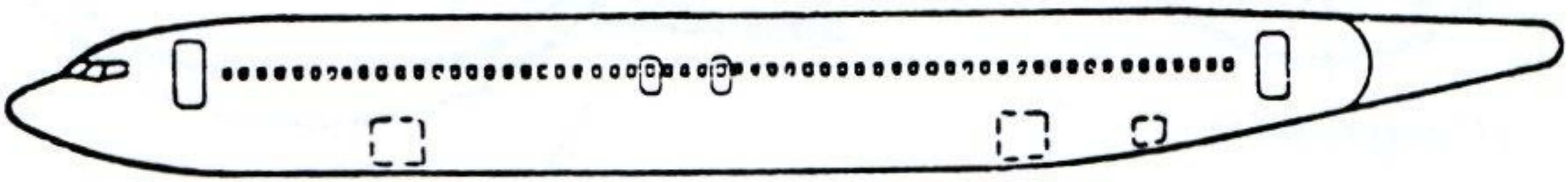


- Aerodynamics

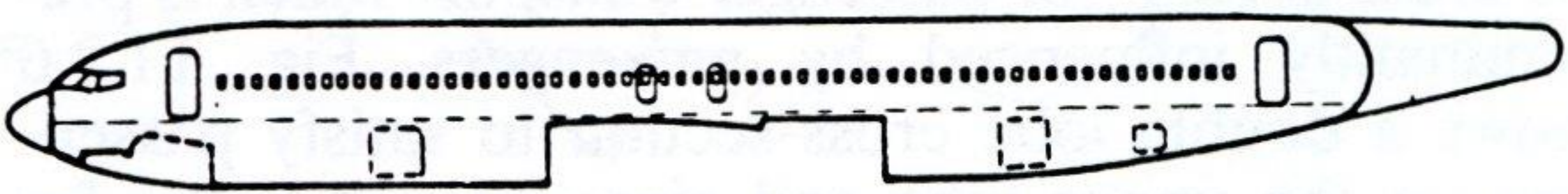


Fuselage requirements

- Access/comfort



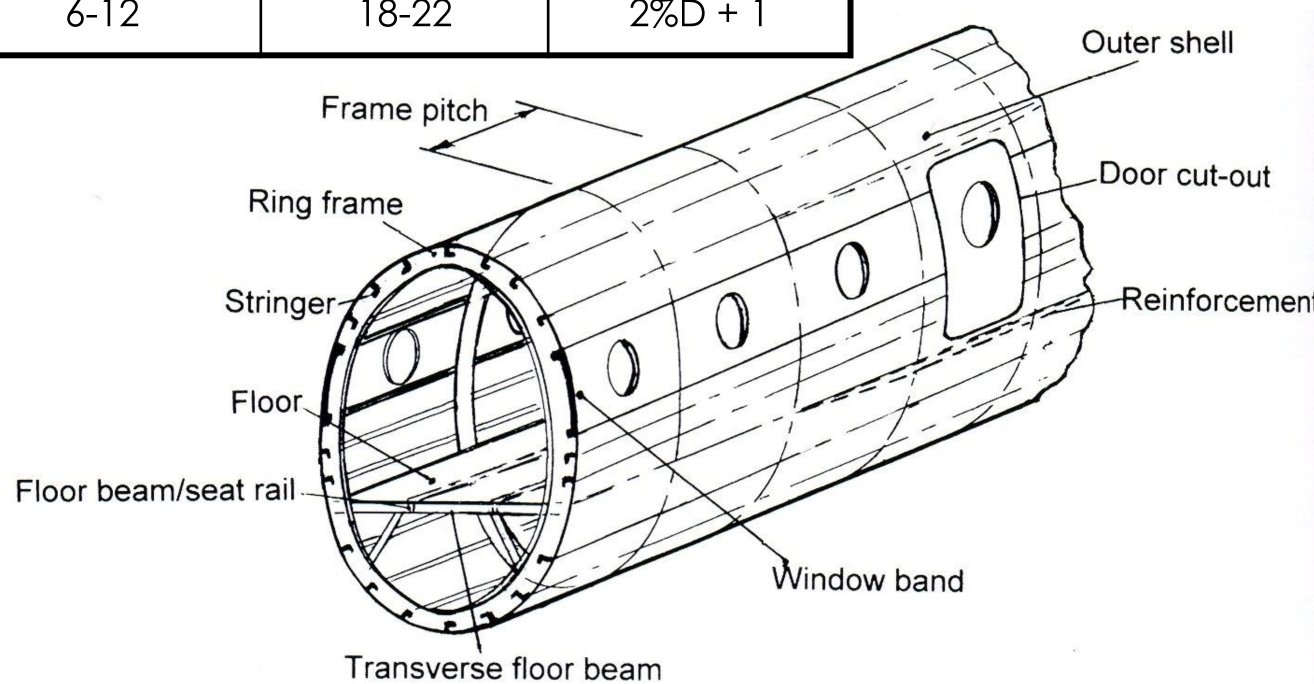
- Structural integration



Semi-monocoque

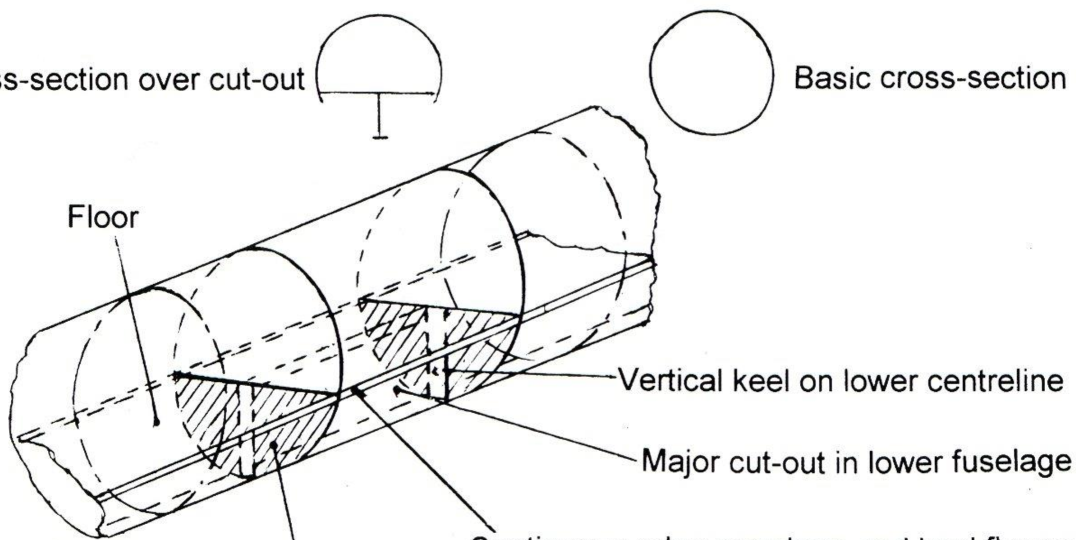
➢Classical ring/stringer layout

(inches)	Stringer pitch	Frame pitch	Frame depth
Small commercial	10-15	24-30	1.5
Fighter/trainer	8-12	15-20	2
Large transport	6-12	18-22	2%D + 1



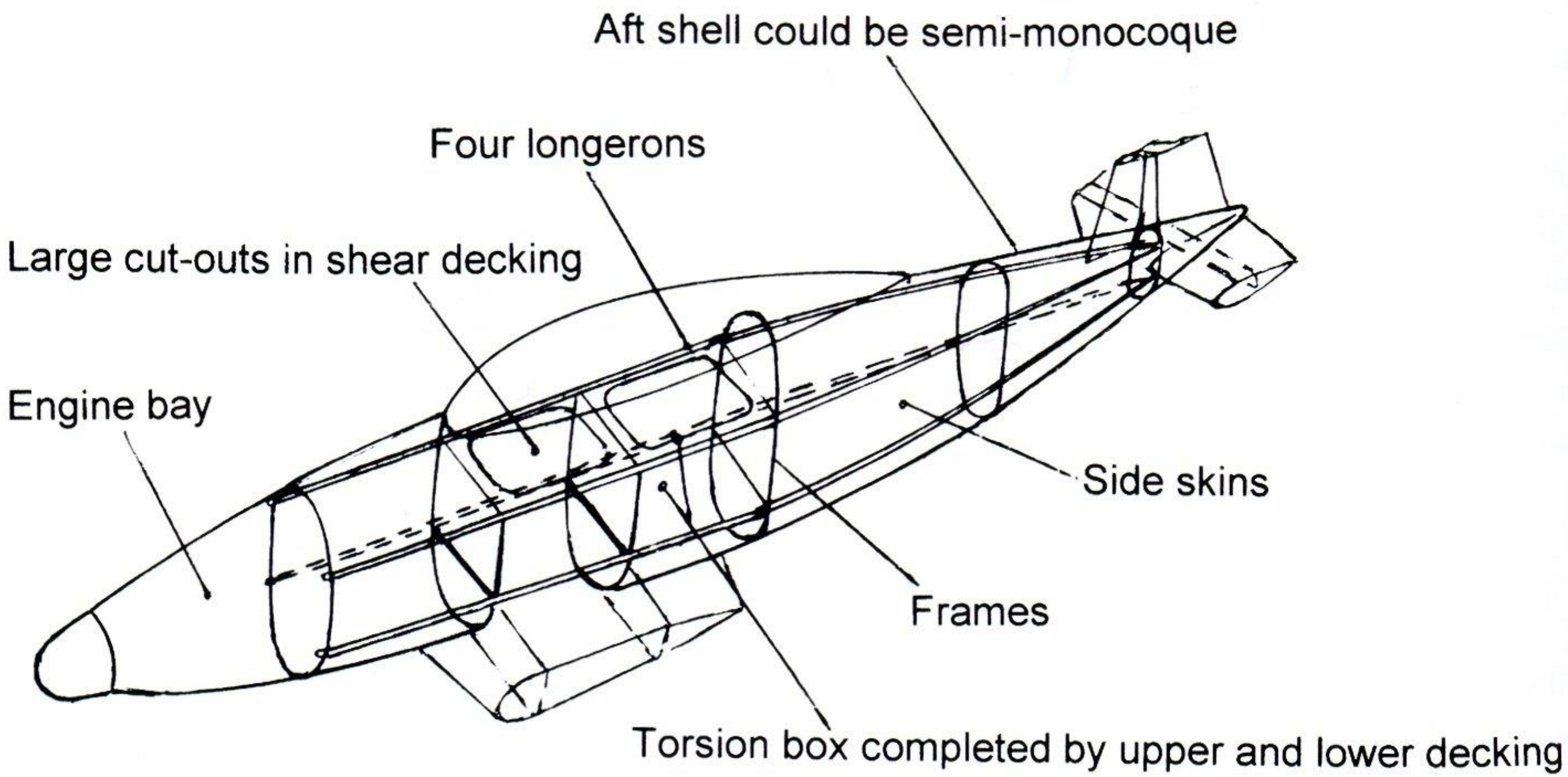
Cutouts

- Windows (& doors)
  - Window doubles (heavy stringers)
- Large cutouts
  - Pressure sealing
  - Load carry-on
  - Keel concept

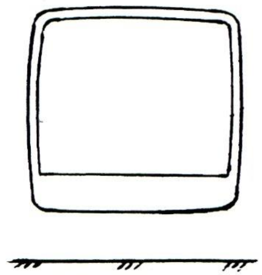


Discrete boom-longeron

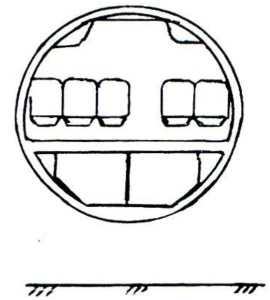
- Use heavy longerons
- For low loading, numerous cutouts



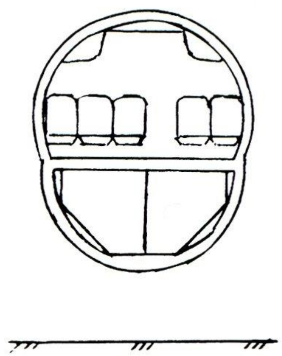
Cross-section types



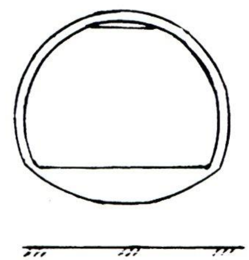
(a) Unpressurized, basically rectangular



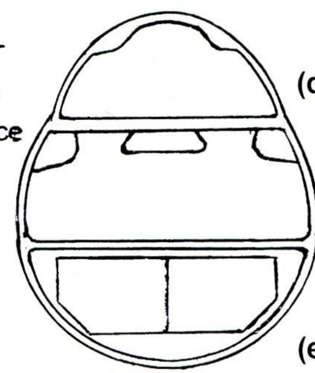
(b) Ideal circular shape



(c) Two-arc cross-section, increased below floor space



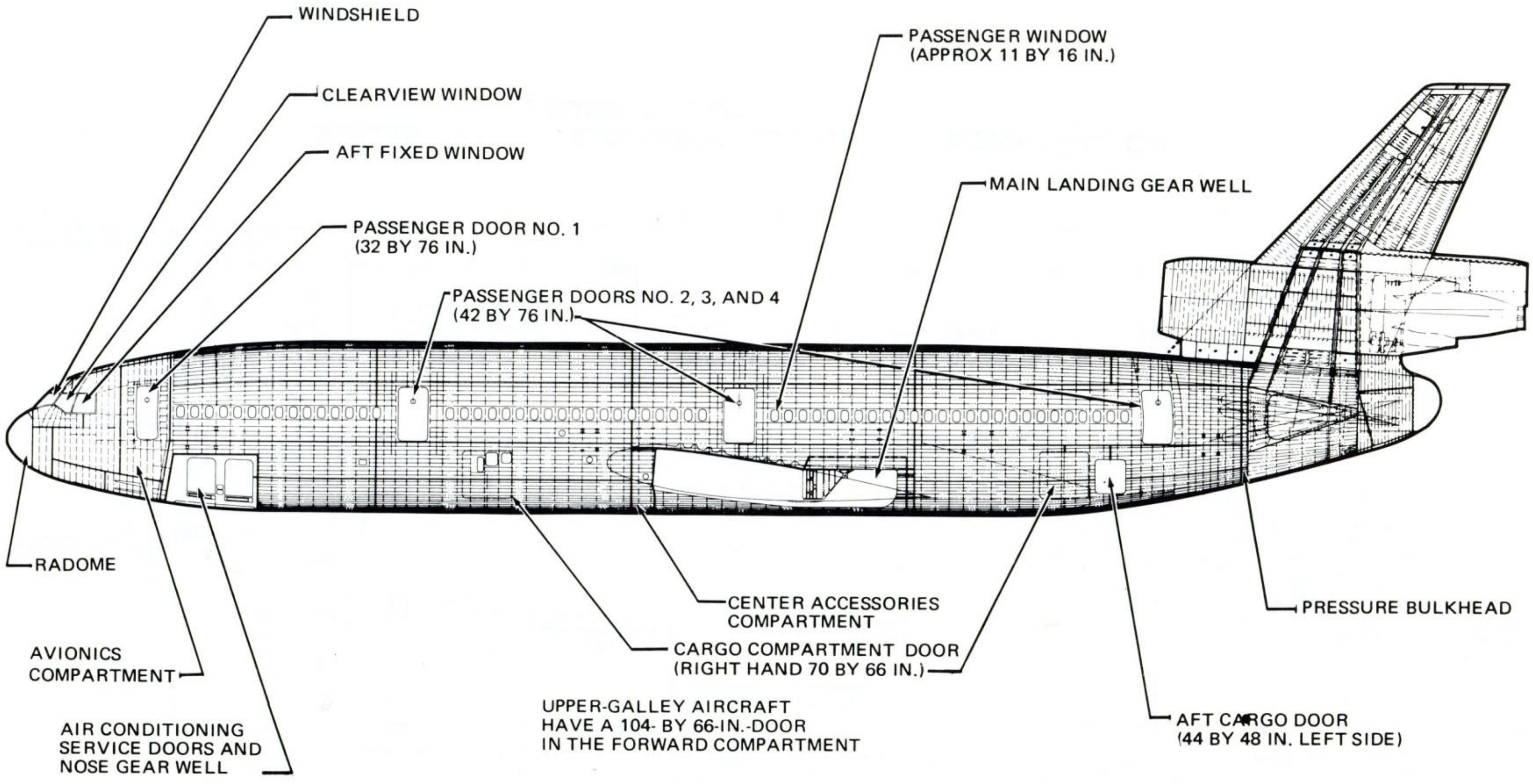
(d) Two-arc cross-section, floor line close to ground



(e) Three-arc cross-section

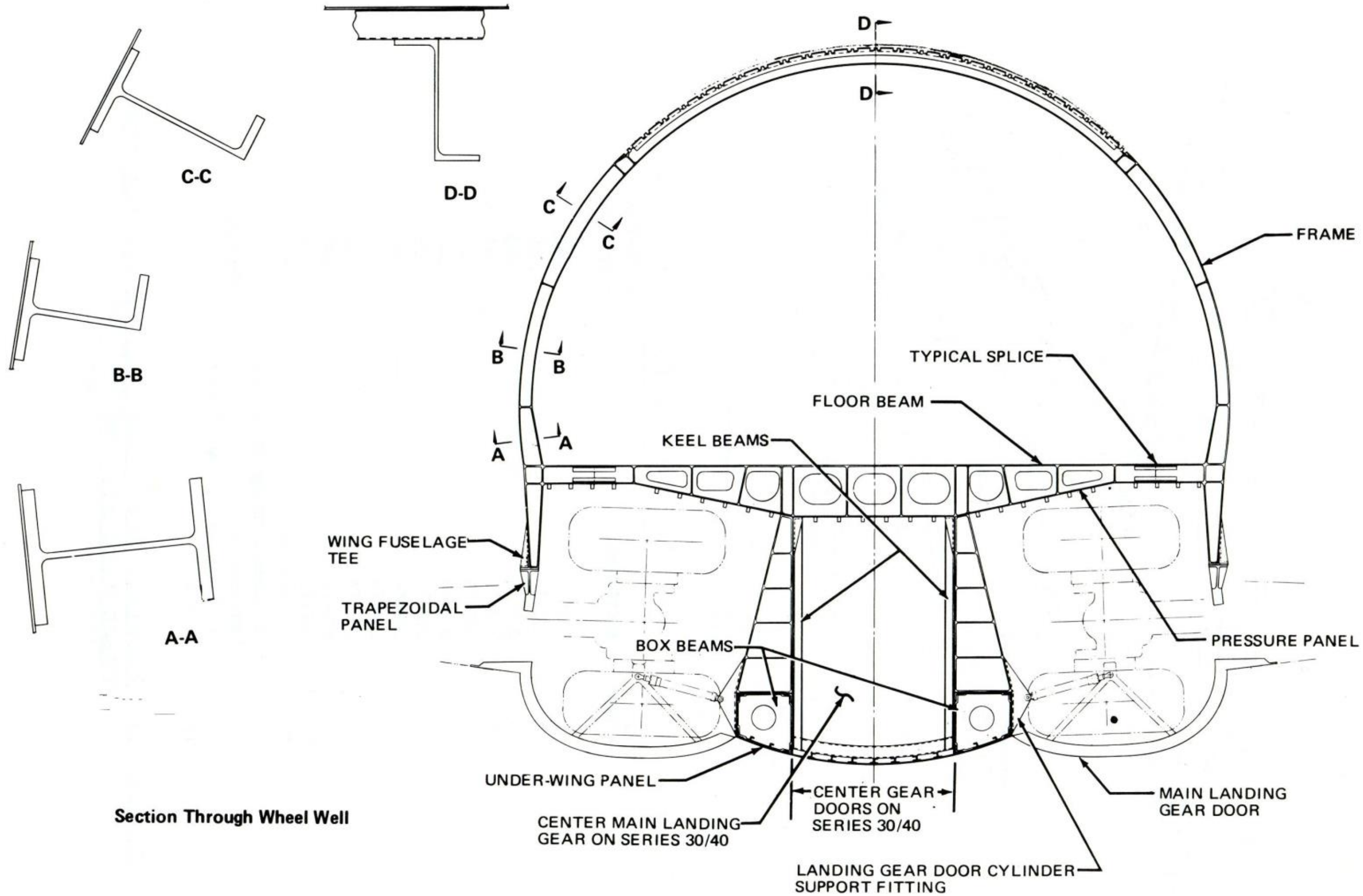
Fuselage examples

- DC-10



Fusélage examples

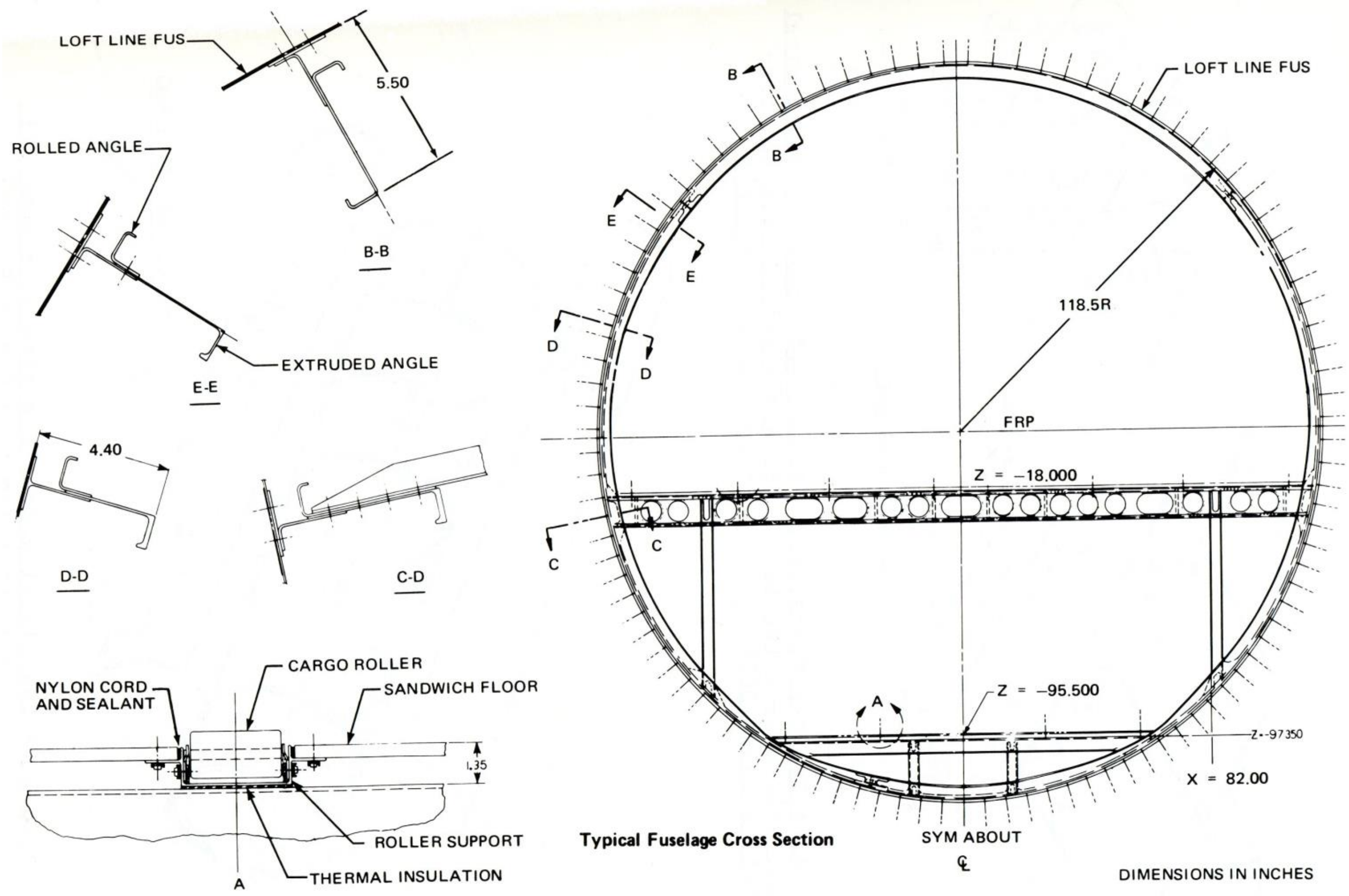
- DC-10



Section Through Wheel Well

Fusselage examples

- DC-10



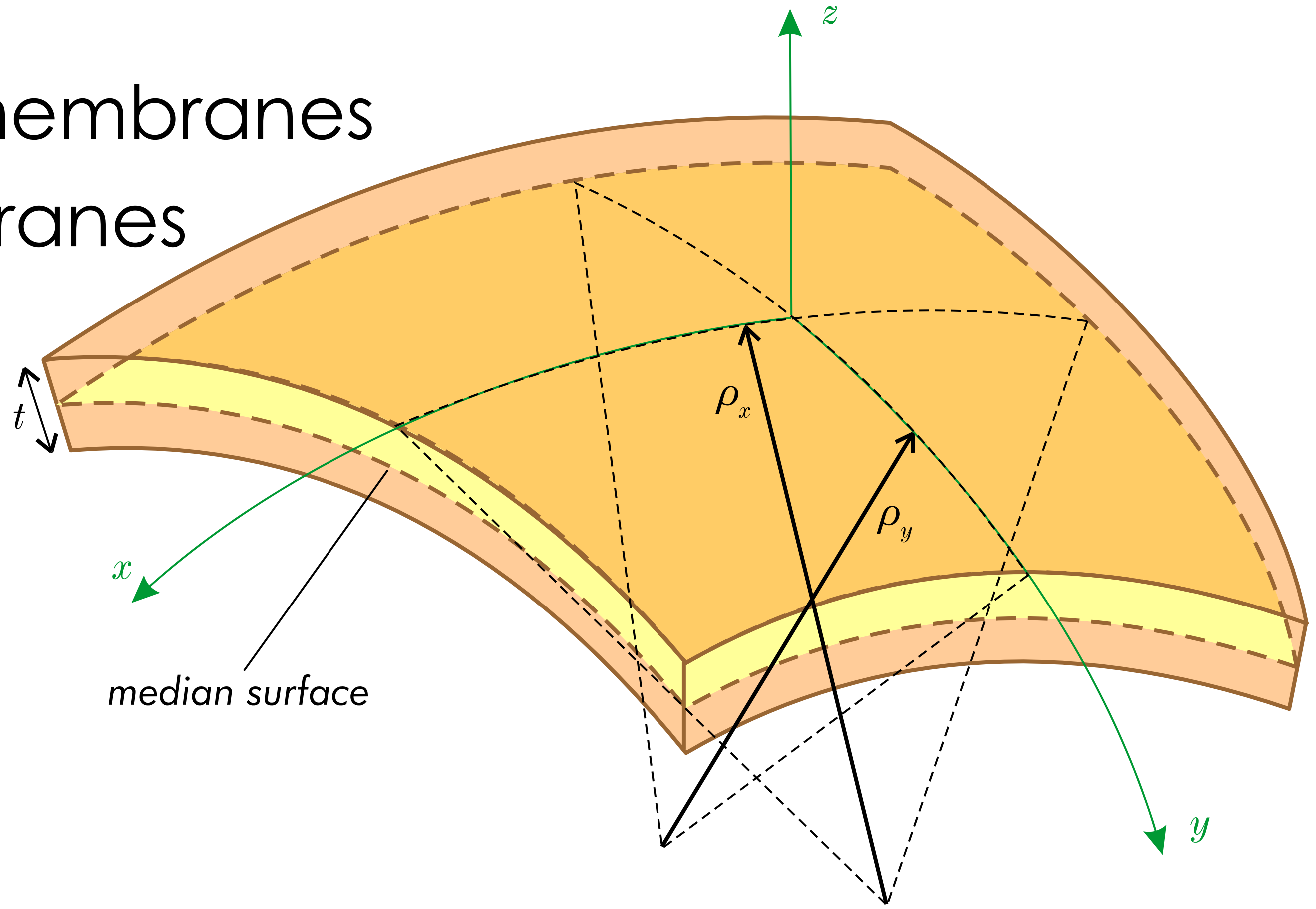
Typical Fuselage Cross Section

Analysis of shells

Aug. 4, 2009
An 18m (59ft)-long fuselage demonstrator was assembled in Hamburg and is close to the final design of the A350 fuselage, as it will be used for certification of the design principle.

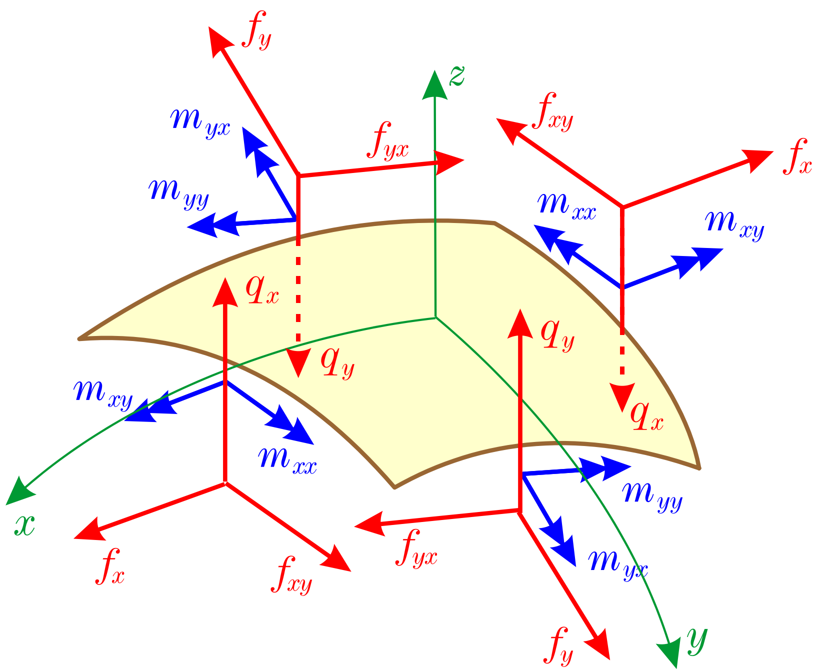
Shells

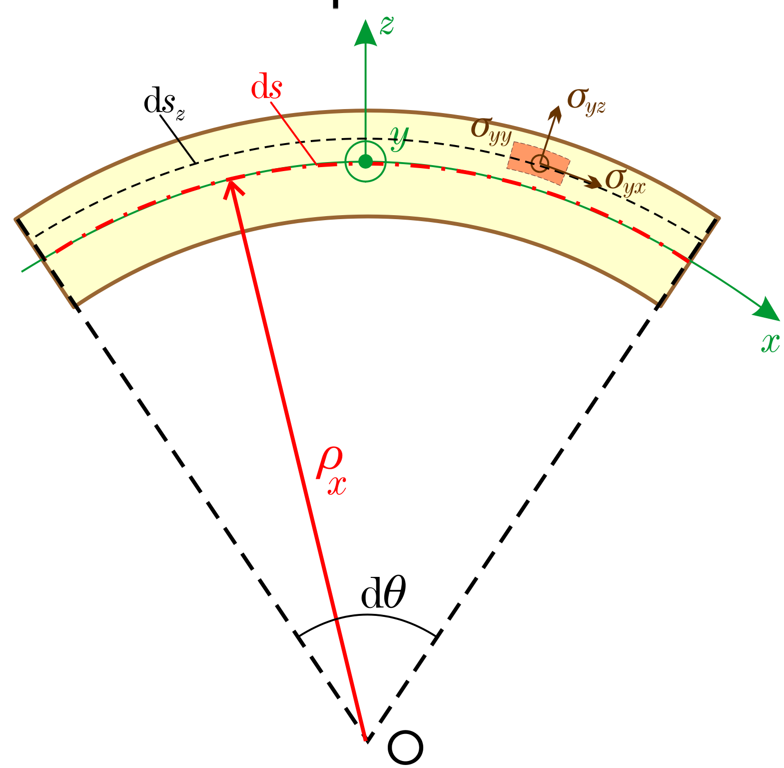
- Curved surfaces even without loads
  - Shells
  - Shell-membranes
  - Membranes



Internal resultants

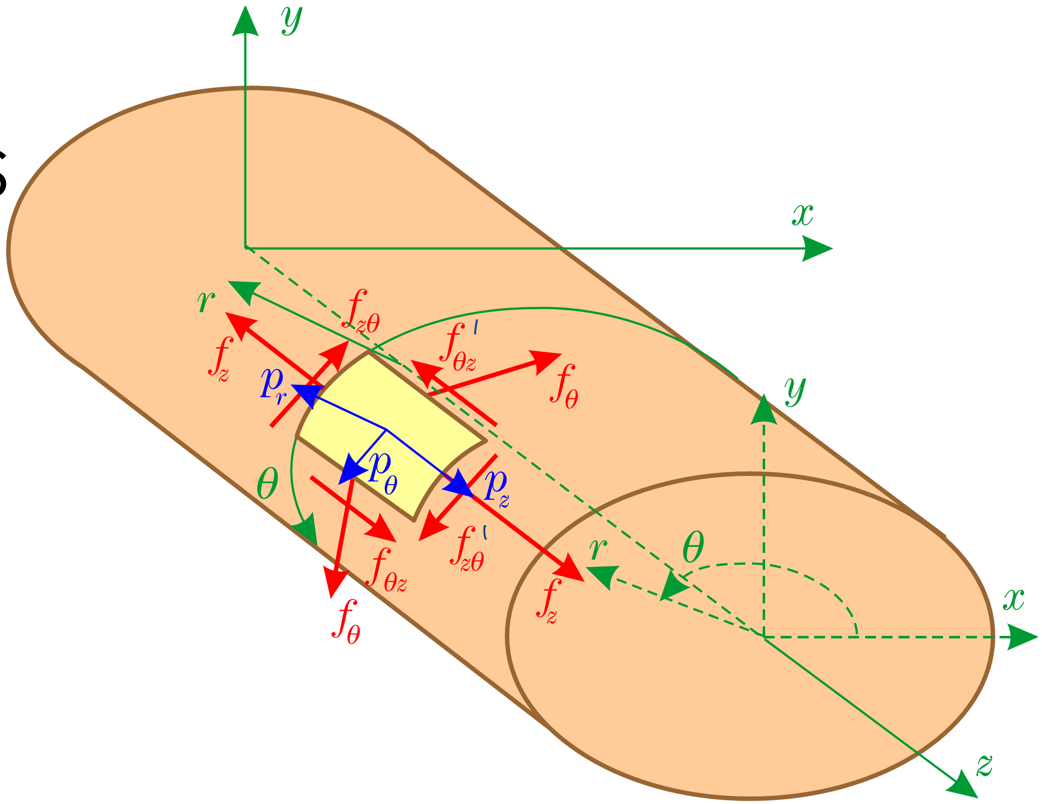
- Stress-based convention (as plates)
- Internal resultants are not « reciprocal »
  - True only under thin shell assumption

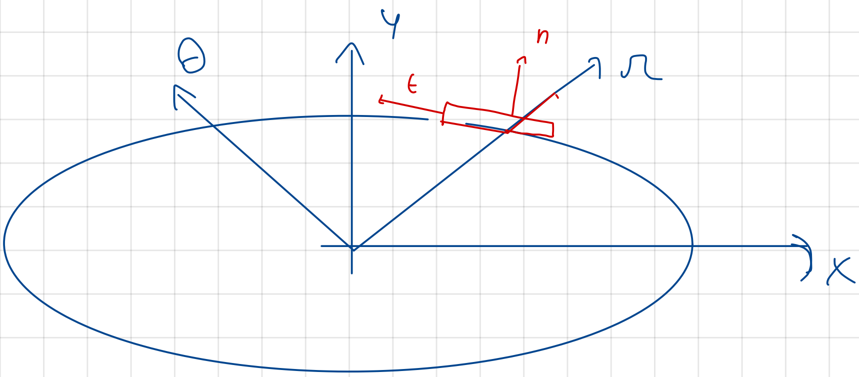




Cylindrical shells

- Equilibrium equations
- Stresses
- Strains
- Displacements





1) $f'_z \rho \, d\theta - f_z \rho \, d\theta + f'_{\theta z} \, dz - f_{\theta z} \, dz + p_z \, dz \, \rho \, d\theta = 0$

↓ Taylor

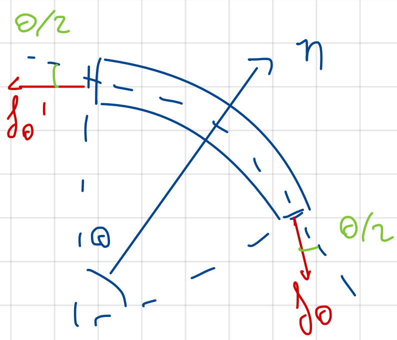
$$\left(f_z + \frac{\partial f_z}{\partial z} dz\right) \rho \, d\theta - f_z \rho \, d\theta + \left(f_{\theta z} + \frac{\partial f_{\theta z}}{\partial \theta} d\theta\right) dz - f_{\theta z} \, dz + p_z \rho \, dz \, d\theta = 0$$

$$\boxed{\frac{\partial f_z}{\partial z} + \frac{\partial f_{\theta z}}{\partial \theta} \cdot \frac{1}{\rho} = -p_z}$$

2) $f'_\theta \, dz - f_\theta \, dz + (f'_{z\theta} - f_{z\theta}) \rho \, d\theta + p_\theta \rho \, dz \, d\theta = 0$

$$\Longleftrightarrow \frac{\partial f_\theta}{\partial \theta} d\theta \, dz + \frac{\partial f_{z\theta}}{\partial z} dz \, \rho \, d\theta + p_\theta \, dz \, d\theta = 0$$

$$\Longleftrightarrow \boxed{\frac{1}{\rho} \frac{\partial f_\theta}{\partial \theta} + \frac{\partial f_{z\theta}}{\partial z} = -p_\theta} \quad (2)$$



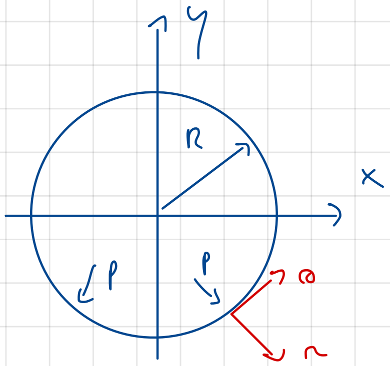
$$(f'_\theta + f_\theta) \, d\theta \, \sin\left(\frac{d\theta}{2}\right) - p_r \rho \, d\theta \, dz = 0$$

$$\Big(\underbrace{\cancel{\frac{\partial f_\theta}{\partial \theta}} d\theta}_{=0 \text{ (small)}} + 2 f_\theta\Big) \frac{\cancel{dz}\,\cancel{d\theta}}{2} - p_r \rho \, \cancel{d\theta}\,\cancel{dz} = 0$$

projection in the n-direction is the same twice

$$\Longrightarrow \boxed{f_\theta = p_r \cdot \rho} \quad (3)$$

Cylindrical shell



$$f_\theta = pR \Rightarrow \sigma_{\theta\theta} = \frac{f_\theta}{t} = \frac{pR}{t}$$

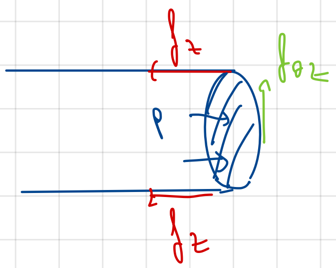
(2) : $\underbrace{\frac{1}{R}\frac{\partial f_\theta}{\partial \theta}}_{=0} + \frac{\partial f_{z\theta}}{\partial z} = 0 \Rightarrow f_{z\theta} = cte = 0$ (at the edge stress resultant = 0)

$\hookrightarrow f_{\theta z} = 0$

$$\frac{\partial f_z}{\partial z} + \underbrace{\frac{\partial f_{\theta z}}{\partial \theta}}_{=0} \cdot \frac{1}{R} = 0$$

(thin wall)

$\hookrightarrow f_z = cte = \frac{pR}{2} \rightarrow \sigma_{zz} = \frac{p.R}{2t}$



$$f_z \cdot 2\cancel{\pi}\cancel{R} = p \cdot \cancel{\pi} \cdot R^{\cancel{2}}$$

$$f_z = \frac{p.R}{2}$$

$$\begin{pmatrix} \varepsilon_{\theta\theta} \\ \varepsilon_{zz} \end{pmatrix} = \frac{1}{E}\begin{pmatrix} 1 & -\nu \\ -\nu & 1 \end{pmatrix}\begin{pmatrix} \sigma_{\theta\theta} \\ \sigma_{zz} \end{pmatrix}$$

$$\varepsilon_{\theta\theta} = \frac{\sigma_{\theta\theta}}{E} - \frac{\nu\,\sigma_{zz}}{E} = \frac{p.R}{t.E} - \frac{\nu.pR}{2tE} = (2-\nu).\frac{pR}{2tE}$$

$$\varepsilon_{zz} = -\nu.\frac{\sigma_{\theta\theta}}{E} + \frac{\sigma_{zz}}{E} = -\frac{\nu.p.R}{tE} + \frac{p.R}{2tE} = (1-2\nu)\frac{p.R}{2tE}$$

Cylindrical shell (circular crossection)

$$\frac{\partial u_z}{\partial z} = \varepsilon_{zz} \Rightarrow u_z = (1-2\nu)\,\frac{p \cdot R}{2tE} \cdot z$$

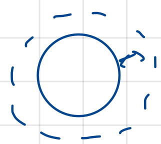
$$\frac{1}{R} \cdot \frac{\partial u_\theta}{\partial \theta} + \frac{u_R}{R} = \varepsilon_{\theta\theta} \qquad u_R = R\,\varepsilon_{\theta\theta} = (2-\nu)\,\frac{p \cdot R^2}{2tE}$$

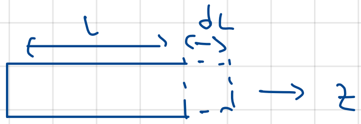
$$\underbrace{\frac{\partial u_\theta}{\partial z}}_{=0} + \frac{u_R}{R}\,\frac{\partial u_z}{\partial \theta} = \underbrace{\varepsilon_{\theta z}}_{=0}$$

because the pressurized cabin will only inflate

it can't twist

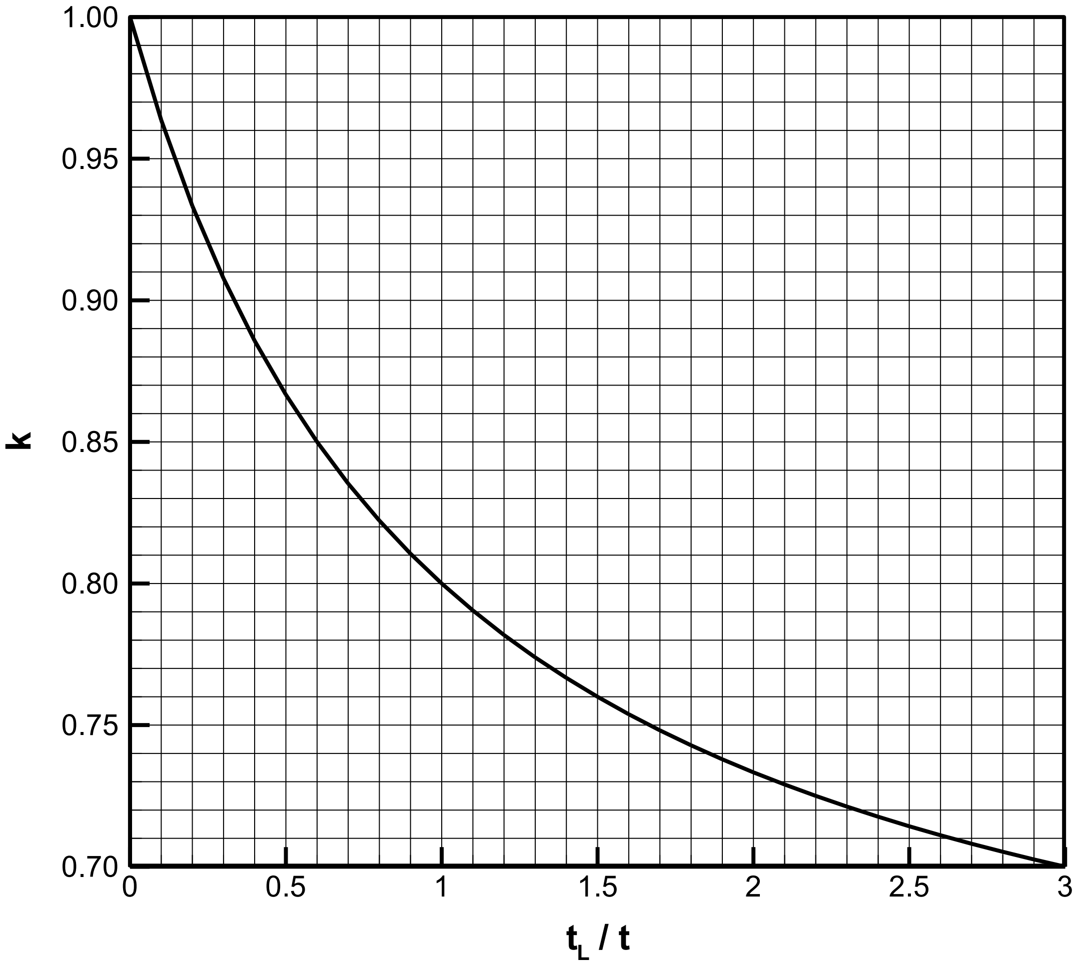
$\sigma_{\theta z}$ was 0





Application to fuselages

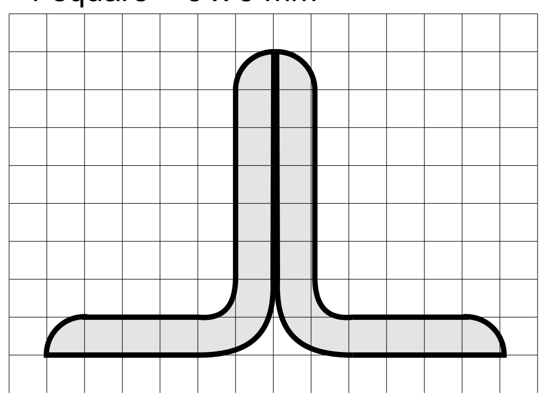
- Flügge approach
  - Rings
  - Stringers
  - Skin



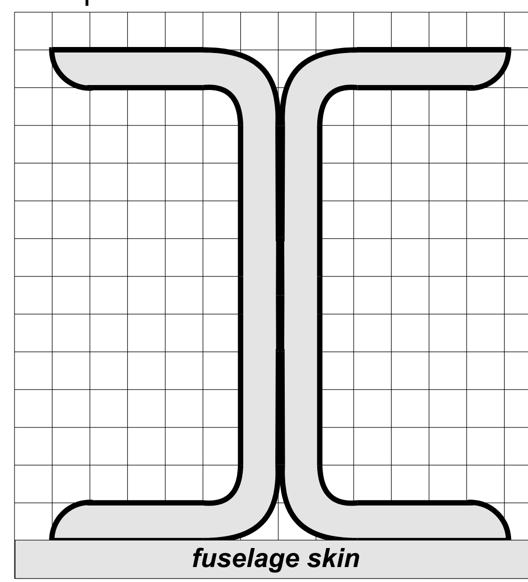
Exercise

- Consider an ERJ fuselage geometry
  - 37 000 ft ISA with 8000 ft cabin altitude
    - FL 370: δ = 0.2138; FL 80: δ = 0.7428
  - Cylindrical, 238 cm diameter, fuselage
    - Stringers as shown, every 20°
    - rings as shown, 50 cm pitch
    - Skin 5 mm

This figure is to scale
1 square = 5 x 5 mm

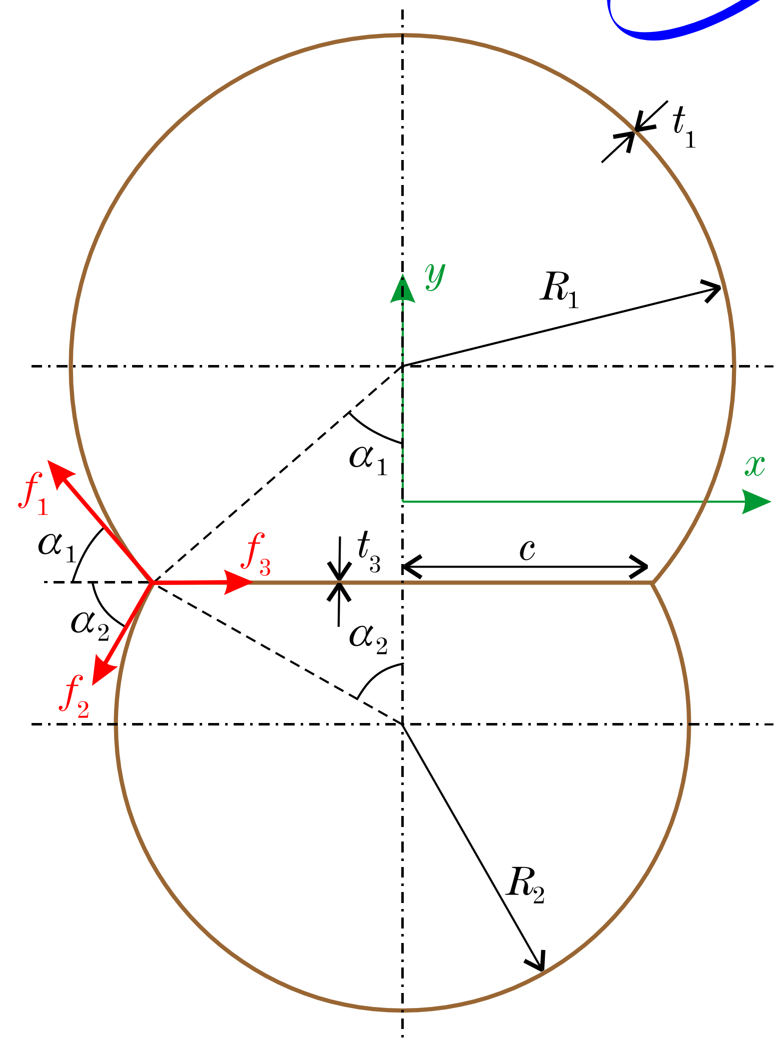


Ring section is to scale
1 square = 5 x 5 mm

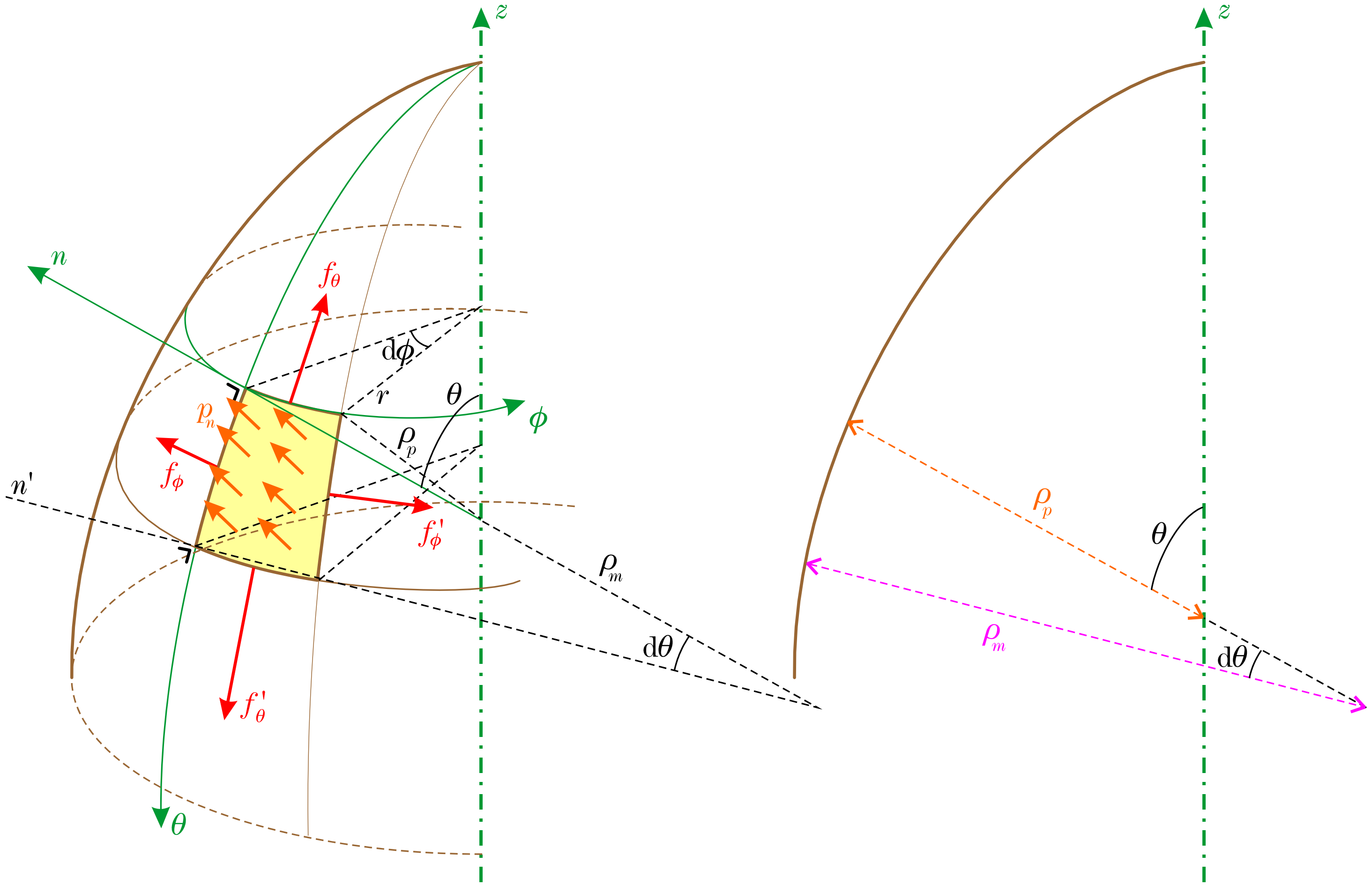


Double fuselage case

- The running weight is independent of fuselage geometry for given total enclosed area

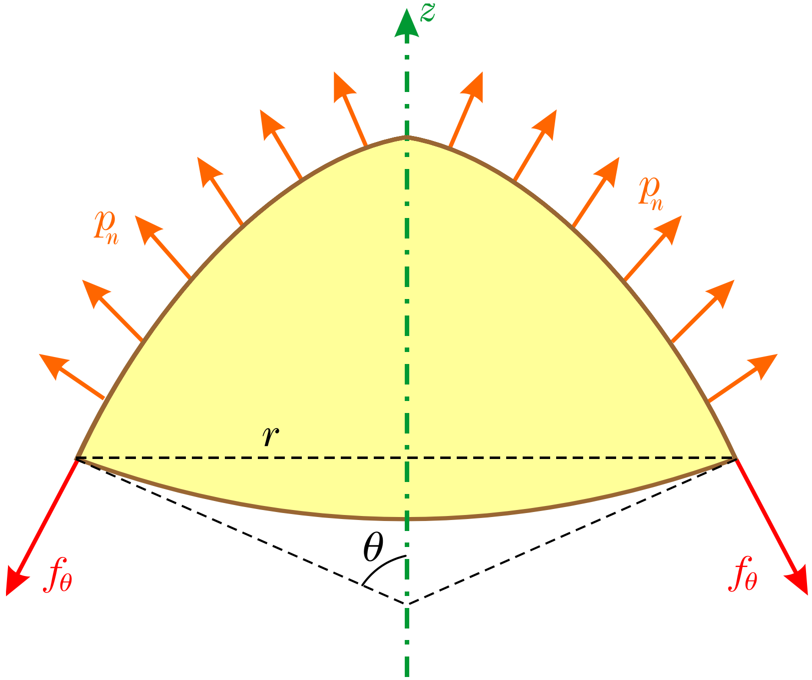


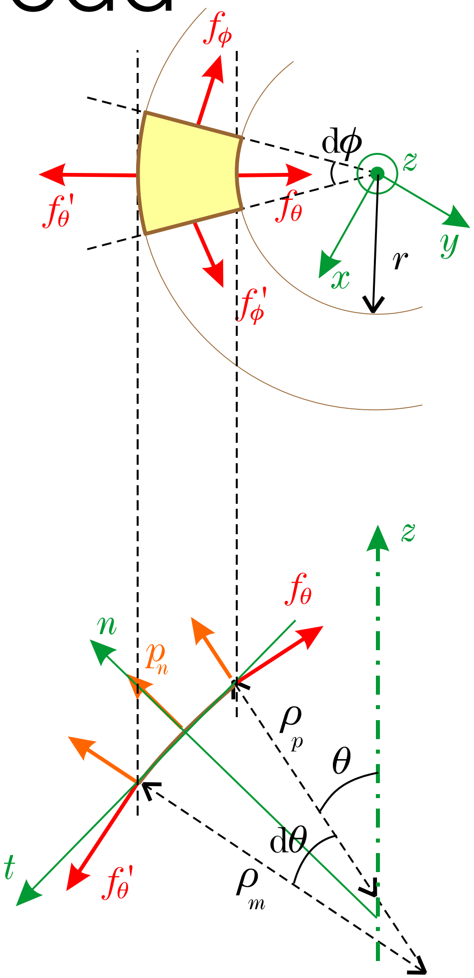
Axisymmetric shells



Axisymmetric shells

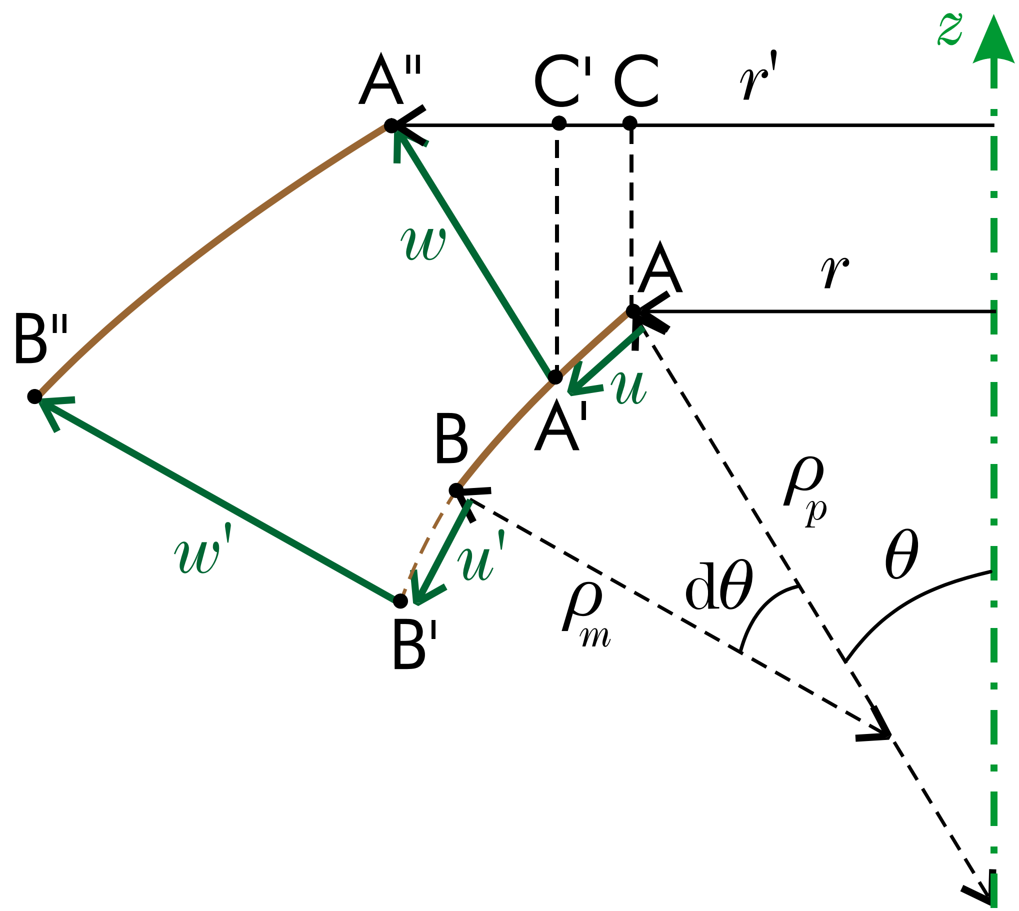
➢ Equilibrium under pressure load





Axisymmetric shells

➢ Strains and displacements

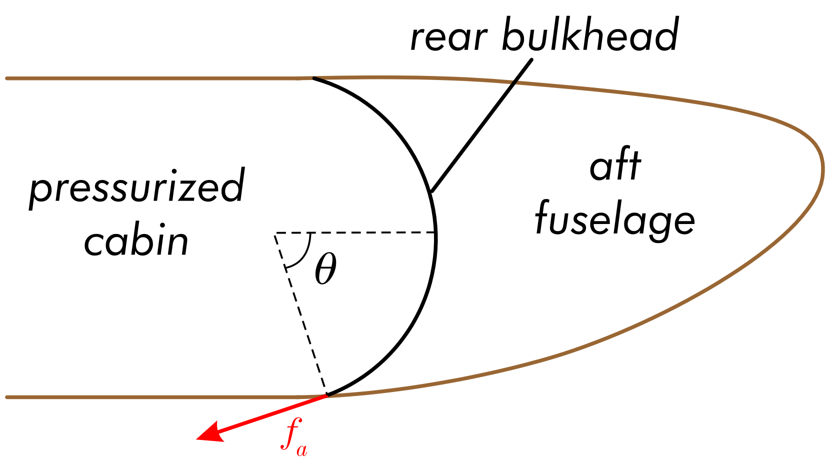


Exercise

- Consider an ERJ fuselage geometry
  - 37 000 ft ISA with 8000 ft cabin altitude
    - FL 370: $\delta = 0.2138$; FL 80: $\delta = 0.7428$
  - Cylindrical, 238 cm diameter, fuselage
- Determine the shell thickness for the pressure bulkhead considering the use of a spherical bulkhead

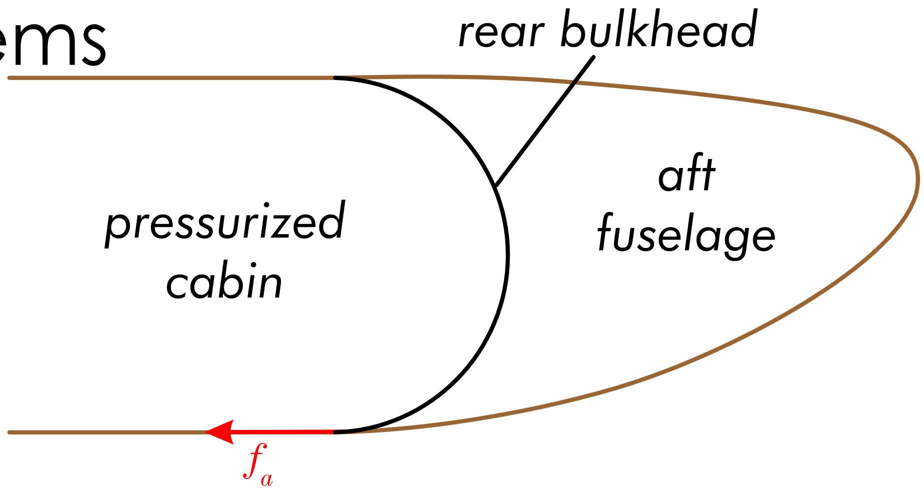
Bulkhead troubles

- Spherical caps
  - non-axial meridional forces (shear forces and bending in the cylinder)
  - Discontinuity in hoop stresses, strains and displacements
  - Compressive stresses if radius/depth is high



Bulkhead troubles

- Hemispherical caps
  - Discontinuity in hoop stresses (factor 2!)
    - Large discontinuity in displacements (shear and moments in the joint)
    - Requires reinforcing ring
  - May pose manufacturing/assembly problems



Exercise

- Investigate the previous phenomena using the ERJ results previously obtained for the cylinder and bulkhead cases