MS Excel spreadsheet for “Wing Box sizing tool – worked example”

Also:

- ✓ Q & A running throughout the session (Join at *menti.com* & use code ***18 66 63 12***)
- ✓ Brief comments on questions asked on “*Ed Discussion*”

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Timeline

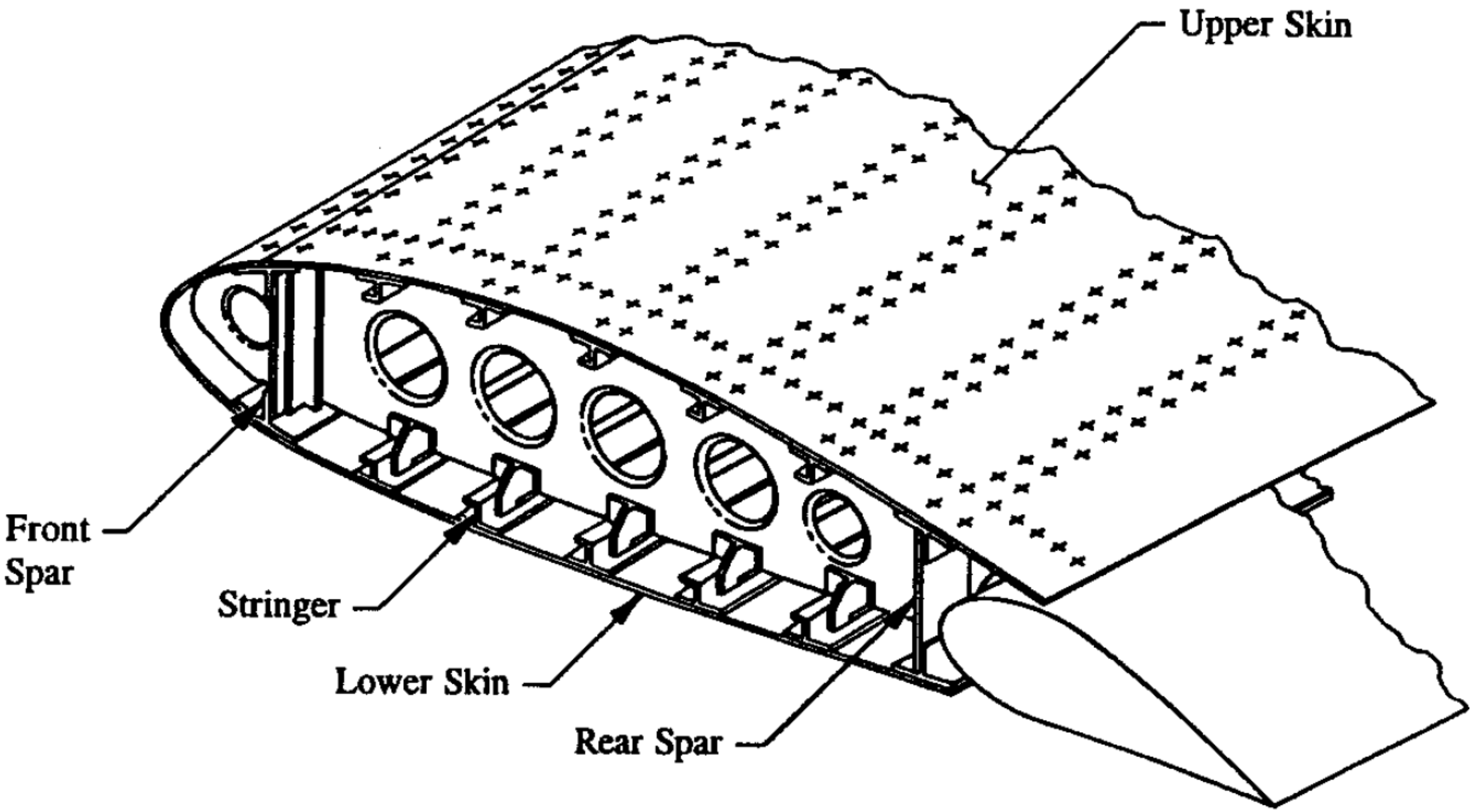
Design Sessions
Introduction to Airframes
Civil Airframes
Military Airframes

Design Sessions	
Workshop 1: Loads & Fatigue	**Workshop 2: Lifting Surface Design**
Types of loading	**Wing structural layout**
Symmetric Manoeuvre Loads	*General Aviation Wings*
Asymmetric Loads	*Commercial Aircraft Wings*
Analysis of Lifting Surfaces	*Design Options*
Analysis of Fuselages	
Loading action work example	**Design of Members**
	Instability of compression covers - Flat plates
Fatigue - Introduction	*Instability of compression covers - Curved plates*
Design Methodology	*Skin-stringer panels - Introduction*
Designing for Fatigue	*Skin-stringer panels - Buckling & catchpole diagram*
Fatigue Life	*Skin-stringer panels - FARRAR efficiency*
Safety Factors	*Spar Design*
Miner's Rule & Failure Curves	*Rib Design*
Examples	
	Worked Example

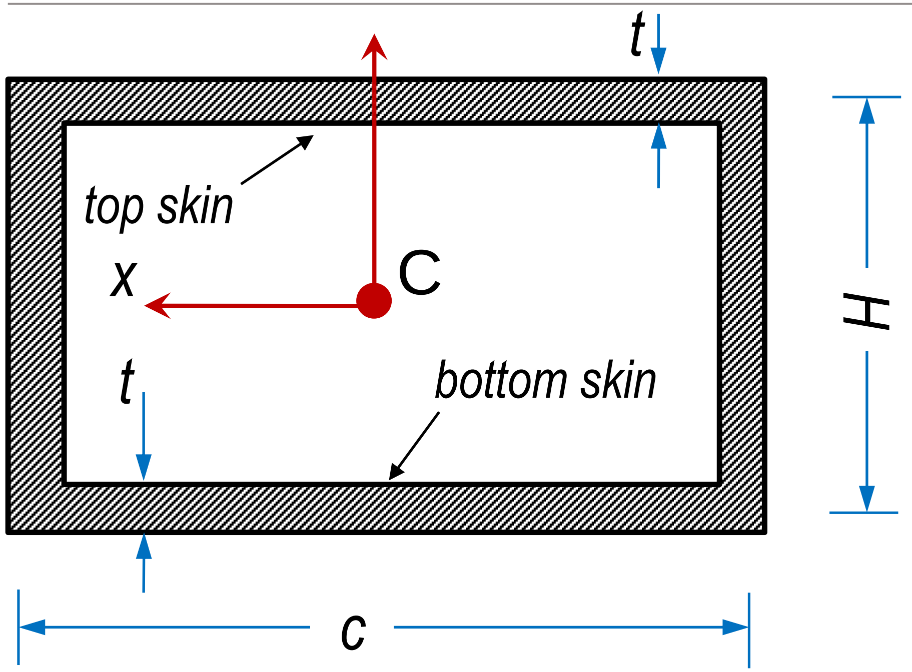
Design Sessions	
Workshop 3: Fuselage Design	**Workshop 4: Secondary Structure & Composite Design**
Introduction to tubular fuselage structures	**Secondary Structure**
Fuselage stressed-skin design	*Cutouts*
Design of light frames	*Joints & Fittings*
Design of heavy frames	*Engine Mounts*
Fuselage design tool	**Composite Component Design**
	Introduction to Composites
	Composite structures
	Composite Material Handbook
	Composite Airframes
	Composite Design - Part 1
	Composite Design - Part 2
	Buckling of composites
	Sandwich panels
	Worked example

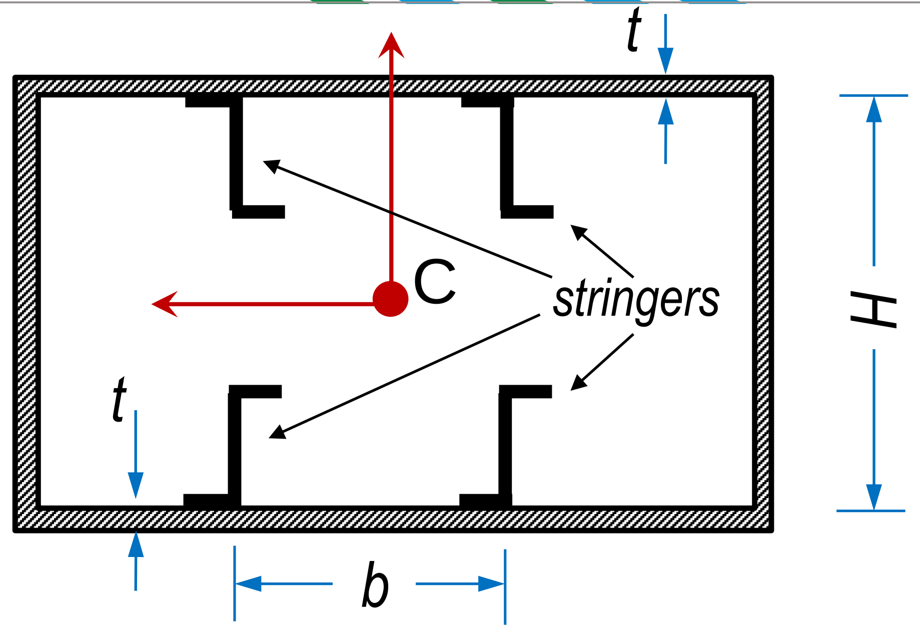
We are HERE

Typical multi-spar wing arrangement



Skin





Without *stringers:*

- ✓ *top & bottom skin carry bending moment Mx*
- ✓ *top skin in tension & bottom skin in compression*
- ✓ *ETB applies with* ***skin thickness t***, ***box width c***, *and box height H*
- ✓ *Global (Euler) buckling is considered*

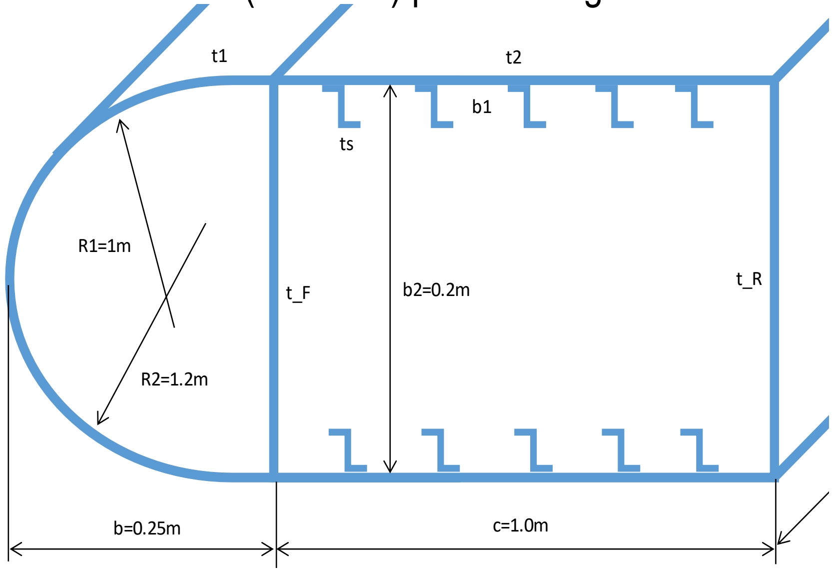
With *stringers (A_s: cross-sectional area of each stringer):*

- ✓ *top & bottom skin* ***AND stringers*** *carry bending moment Mx*
- ✓ *top skin/stringers in tension & bottom skin/stringers in compression*
- ✓ *panel of width w defined as part of skin between stringers*
- ✓ *stringers smeared onto skin-> skin effective thickness t_{eff}:* $t_{eff} = t + \left(\frac{A_s}{b}\right)$
- ✓ *ETB applies with* ***effective thickness t_{eff}***, ***panel width c***, *box height H*
- ✓ *Global (Euler) buckling is considered*
- ✓ *Local buckling modes are considered*

Skin *(without stringers)*

At wing station examined:
(pitch-up M positive: top skin in compression & bottom skin in tension)

- *M*: bending moment
- b_2: wing box height
- *c*: *wing box width*
- *t*: skin thickness (can be different for top & bottom skin)
- *n*: number of panels *(skin strips between stringers)*
- b_1: *panel width*
- *F*: axial load due to bending moment M
- *N*: axial load (due to M) per unit length



Optimum design: buckling and yielding occur simultaneously

Width considered: *wing box width c*

Axial Load due to M: $F = \left(\frac{M}{b_2}\right)$

Axial Load (due to M) per unit length: $N = \left(\frac{F}{c}\right) = \left(\frac{M}{c\, b_2}\right)$

Axial stress (due to M): $\sigma = \left(\frac{F}{A}\right) = \left(\frac{M}{b_2\, c\, t}\right) = \left(\frac{N}{t}\right)$

Critical global buckling stress: $\sigma_{crit,gb} = 3.62\, E \left(\frac{t}{c}\right)^2$

Best material efficiency: $\sigma_{crit,gb} = \sigma$

Skin thickness required *(no stringers)*:

$$3.62\, E \left(\frac{t}{c}\right)^2 = \left(\frac{N}{t}\right) \rightarrow t = \sqrt[3]{\left(\frac{N\, c}{3.62\, E}\right)} = \sqrt[3]{\left(\frac{M\, \epsilon}{\epsilon\, b_2\, 3.62\, E}\right)} = \sqrt[3]{\left(\frac{M}{3.62\, E\, b_2}\right)}$$

Skin *(with stringers)*

At wing station examined:

- *M*: bending moment
- b_2: wing box height
- *c*: *wing box width*
- *t*: skin thickness (can be different for top & bottom skin)
- *n*: number of panels (skin strips between stringers)
- b_1: *panel width*
- F_{ax}: axial load due to bending moment M
- *N*: axial load (due to M) per unit length

pitch-up M positive: top skin in compression & bottom skin in tension

Panel width: $b_1 = \left(\frac{c}{n}\right)$

Panel Effective Thickness $t_{eff} = t + \left(\frac{A_s}{b}\right)$

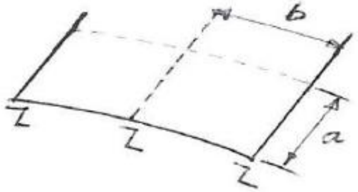
Axial Load due to M: $F = \left(\frac{M}{b_2}\right)$

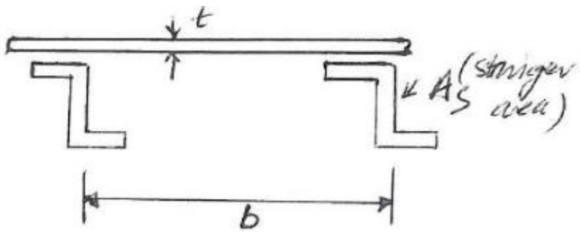
Axial Load (due to M) per unit length: $N = \left(\frac{F}{c}\right) = \left(\frac{M}{c\ b_2}\right)$

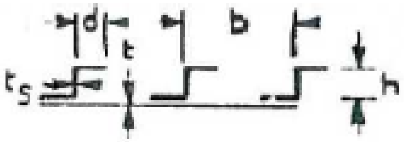
Axial stress (due to M): $\sigma = \left(\frac{F}{A}\right) = \left(\frac{M}{b_2\ c\ t_{eff}}\right) = \left(\frac{N}{t_{eff}}\right)$

Critical global buckling stress: $\sigma_{crit,gb} = 3.62\ E \left(\frac{t_{eff}}{c}\right)^2$

Best material efficiency: $\sigma_{crit,gb} = \sigma = \sigma_{localbuckl}$







First estimation of skin thickness (with stringers): $3.62\ E \left(\frac{t_{eff}}{b}\right)^2 = \left(\frac{N}{t_{eff}}\right) \rightarrow t_{eff} = \sqrt[3]{\left(\frac{N\ b}{3.62\ E}\right)} = \sqrt[3]{\left(\frac{M\ \mathbf{b_1}}{c\ b_2\ 3.62\ E}\right)}$

!! Apply Farrar approach !!

Farrar coefficient for optimum design

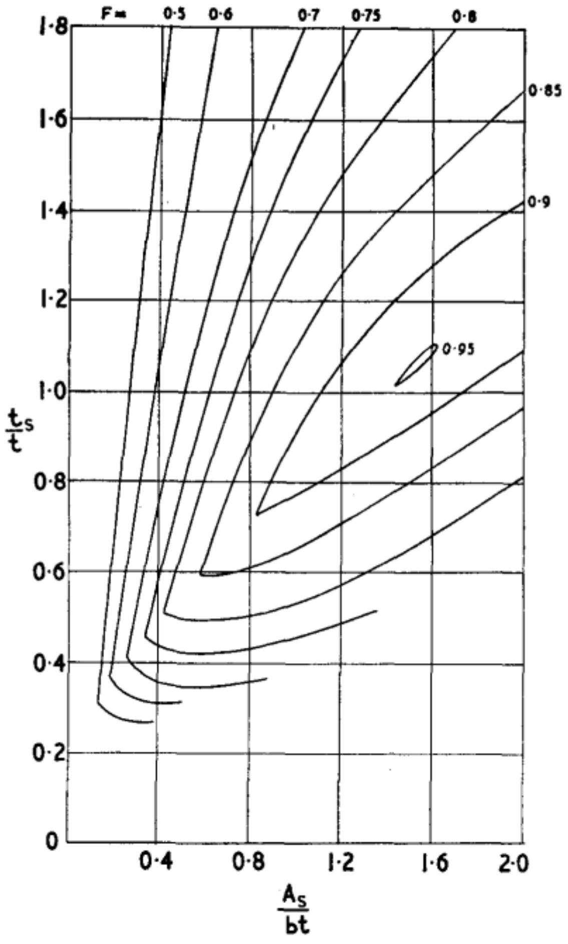


Fig.2.

Contours of $f\sqrt{\frac{L}{PE_T}}$ for Z-section stringers where initial buckling coincides with failure.

P …. compressive end load carried per inch width of skin-stringer combination
L …. rib or frame spacing.
T …. thickness of skin with same cross sectional area as skin- stringer combination
E …. compression Young's modulus of skin-stringer material.
E_T … tangent modulus of skin-stringer material.
f …. mean stress realised by skin and stringers at failure *(Note: f=P/T)*
F…. Farrar coefficient

- ✓ *For a given geometry, calculate the ratios A_s/bt and t_s/t*
- ✓ *From the graph, read the associated value F for the Farrar coefficient*
- ✓ *Use Eq.(1) to estimate the mean stress by skin and stringer at failure*

$$f = F\sqrt{P\frac{E_T}{L}}$$

THE DESIGN OF COMPRESSION STRUCTURES FOR MINIMUM WEIGHT
D. J. FARRAR, M.A., A.F.R.Ae.S
Paper received March 1949.
Mr. Farrar is Assistant Chief Designer, Aircraft Division, Bristol Aeroplane Co. Ltd.