ARO 357L Fuselage Bending Lab

References

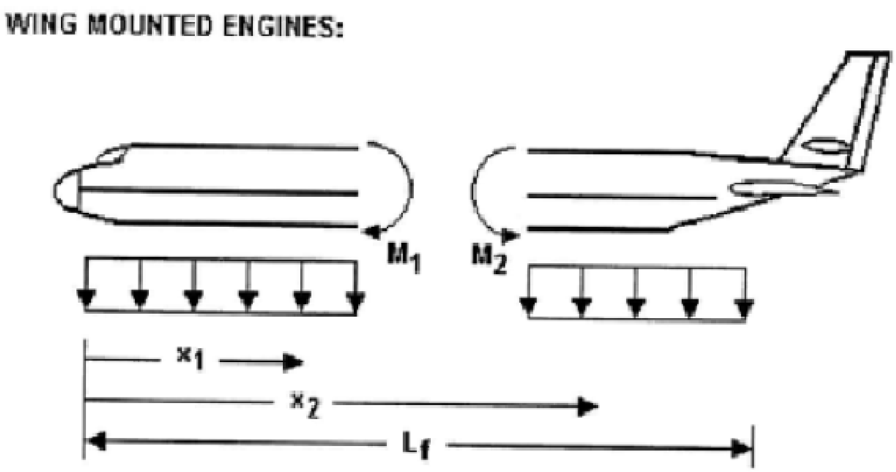
1. **Bruhn, Analysis & Design of Flight Vehicle Structures**
2. **Flügge, Stress Problems in Pressurized Cabins**

Objective

Use simple beam theory to calculate the longitudinal stringer and skin stresses in an aircraft fuselage due to a 5.5g down gust load case (due to aircraft pull up) and a cabin pressure Δp=7.2psi (~30,000 ft altitude).

Analysis

Consider an aircraft fuselage structure being designed to support a 1g distributed fuselage load w_f=100 lbs/in. The bending moment due to this distributed load forward of the wing (for wing mounted engines) can be computed as follows:



Installation Forward of Wing 1/4 Chord: $M_1 = \frac{W_f\, x_1^2}{2 L_f}$

$$w_f = \frac{W_f}{L_f}$$

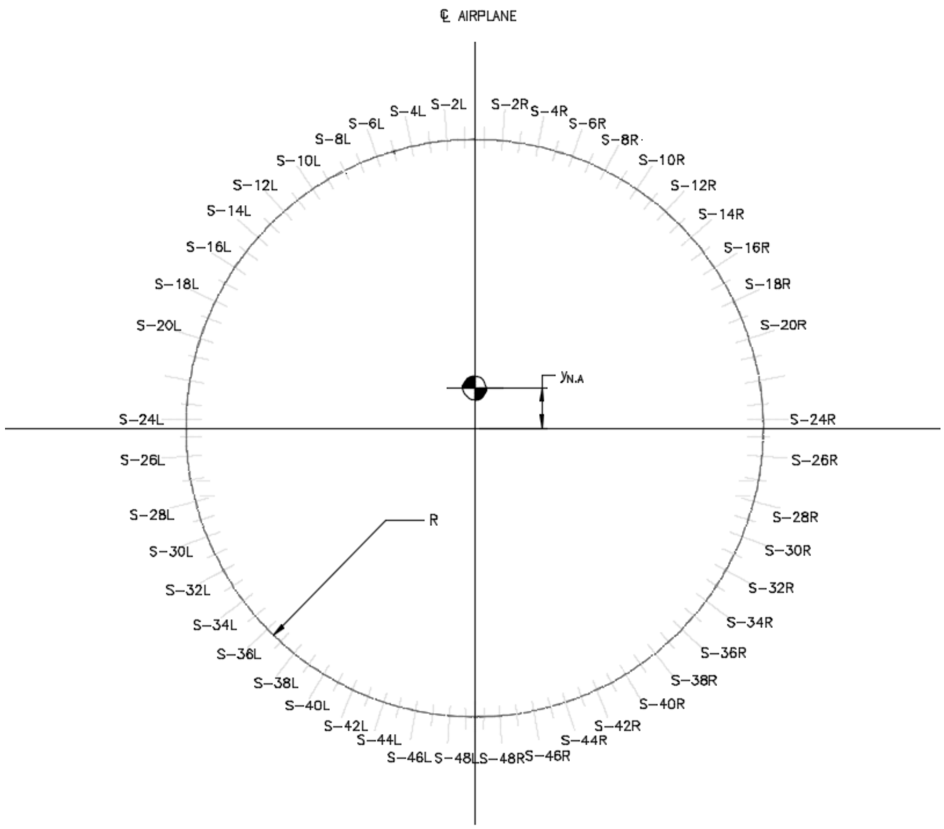
$$M_1 = \frac{w_f \times x_1^2}{2}$$

Note that L_f is the distance between the forward pressure bulkhead and the aft pressure bulkhead. W_f is the fuselage weight, which includes cargo capacity and interiors as well as structure weight.

The forward pressure bulkhead is assumed to be located at STA 120. The aft pressure bulkhead is assumed at STA 2100. The STA is measured from the aircraft at a location forward of the nose. When using the value x_1 in the above equation, remember it is being measured from the location of the forward bulkhead. Each station number is already in "inches" and will be used as is.

The fuselage cross section is assumed to remain constant and circular. The stringer arrangement will look like the below figure. Note that not all stringer IDs are shown. However, there are 49 stringers per side, which we will assume to be equally spaced every Φ=3.6 degrees. Note that the first stringer (at the top) on either the Left or Right side is not located at the centerline but at our assumed 3.6 degrees.

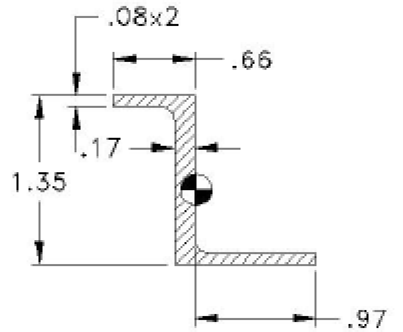
The stringers will be spaced approximately 7.6 inches based on the assumed 3.6 degrees.



R=122 inches (Fuselage radius)

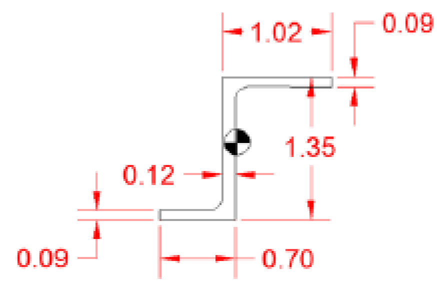
b_s= 7.6 inches (Stringer spacing)

For this exercise, we will assume stringers 1 through 3 on either side have the following cross section **$\underline{A_{str}}$** as well as 47 through 49.



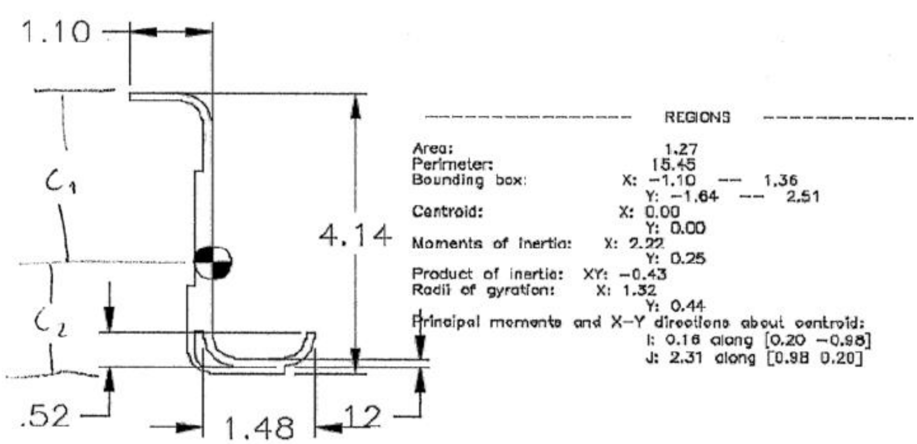
Area: 0.35
Perimeter: 5.86

All other stringers are assumed to have the following cross section



Area: 0.3014
Perimeter: 5.7970

In this exercise all frames will have the cross section shown below with an area **$\underline{A_{fr} = 1.27in^2}$.**



We will calculate the stringer and skin stresses at two STA locations. STA 846 and STA 866. This aircraft is assumed to have constant frame spacing of 20 inches. Each skin panel is therefore 20 inches in length by 7.6" wide (slightly curved due to geometry). Use a skin thickness of 0.1 inches at stringers 1 through 3, and 47 through 49. Everywhere else use a thickness of 0.063 inches.

1) Calculate the bending moment at STA 846 and STA 866 using the equation in page 1.
2) Calculate the axial stress on the skin and stringer based on pressure and the reference provided. Calculate it for the different skin thicknesses and stringer areas provided.

   This is one simple way to calculate loads on stringers and skin due to pressure under certain cases when FEA or other proprietary information is not available. Note that it is conservative to just calculate the stress on the skin in the standard form f= Pr/2t and assume the stringer carries the same load.

3) Calculate the second moment of area of the fuselage cross section and the location of the neutral axis then compute the stresses on the skin and stringer using the equations provided below and the previous moments developed. Do this for both moments (At STA 846 and STA 866).

   Use the table in the next page as a guide. Note that we only need to do one half since this cross section is symmetric.

   The effective skin area is a function of the stress levels in the skin and stringer and compressive strength of the panels (in this case the bottom half is in compression while the upper half is in tension). Since this is an iterative process (not enough time for us to do more) we will just assume an effective width equal to 30 x t_{skin} (standard in preliminary design) for the side in compression. Feel free to use a method like in Bruhn Chapter A20 for the effective width.

   The area of the skin is either $A_{skin} = b_s \times t_{skin}$ in the upper half or $A_{skin} = 30 \times t_{skin}^2$ in the bottom half of the fuselage. The value b_s is the stringer spacing of 7.6 inches calculated before.

   The location of each stringer in this arrangement and neutral axis of the section can be obtained as follows:

$$\mathrm{y} = R\sin\left[(90 + i \times \emptyset) \times \frac{\pi}{180}\right]$$

$$\bar{\mathrm{y}} = \frac{\sum yA_{tot}}{\sum A_{tot}}$$

$$\mathrm{I} = 2 \times \sum A_{tot}y^2 - 2 \text{ x } \bar{y}^2 \sum \mathrm{A}_{tot}$$

   The value of 2 accounts for the other half

   Bending for the fuselage at 5.5gs is:

$$\mathrm{f}_{b,5.5g} = 5.5 \times \mathrm{M}\,(y - \bar{y})/\mathrm{I})$$

   Longitudinal stress on the stringer due to pressure is equal to f_L, which is computed from page 5 of the NACA reference provided.

   Longitudinal stress on the skin due to pressure is equal to f_x, which is computed from page 5 of the NACA reference provided.

   The resultant stress on the skin and stringer are:

$$f_{str} = f_{b,5.5g} + f_L$$

$$f_{skin} = f_{b,5.5g} + f_x$$

									STA 866	STA 846			STA 866		STA 846	
	[in]	[in^2]	[in]	[in]	[in^2]	[in^2]	[in^3]	in	psi	psi	psi	psi	psi	psi	psi	psi
Stringer No. [i]	y	A_{str}	t_{skin}	*b_s	A_{skin}	A_{tot}	$y \times A_{tot}$	$(y-\bar{y})$	$f_{b5.5g}$	$f_{b5.5g}$	f_L	f_x	f_{str}	f_{skin}	f_{str}	f_{skin}
1																
2																
3																
…																
48																
49																
Σ																

$\bar{y}$	=		in
I	=		In^4

*Remember to use 30t for bs in all skin panels in the bottom half of the fuselage.

4) Assume the stringer and skin are made of 2024-T3 material and compute a margin of safety at each stringer location. Use F_{tu} for the side in tension and use $F_{cc} = 0.9F_{cy}$ (Crippling strength for Zee sections) for the stringers and skin in the side of compression. For 5 Extra credit points assume the stringers are attached with countersunk rivets to the skin. Select the appropriate fastener spacing to avoid inter-rivet buckling. Do this for each stringer location.
5) For more E.C. (+30 points) feel free to calculate the shear flow and shear stresses on the cross section. You can use the VQ/I method or the ΔP method. Reference Bruhn Chapter A20.
6) Include a cover page, a small summary section with objective etc. and show the margins of safety at each stringer/skin location. Submit this along with your spreadsheet.

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Table 3.2.4.0(b$_1$). Design Mechanical and Physical Properties of 2024 Aluminum Alloy Sheet and Plate

Specification	AMS 4037 and AMS-QQ-A-250/4[a]					AMS 4269 and AMS-QQ-A-250/4[a]		
Form	Sheet					Sheet		Plate
Temper	T3					T361		
Thickness, in.	0.008-0.009	0.010-0.128		0.129 - 0.249		0.020-0.062	0.063-0.249	0.250-0.500
Basis	S	A	B	A	B	S	S	S
Mechanical Properties:								
F_{tu}, ksi:								
L	64	64	65	64	66	68	69	67
LT	63	63	64	63	65	67	68	66
F_{ty}, ksi:								
L	47	47	48	47	48	56	56	54
LT	42	42	43	42	43	50	51	49
F_{cy}, ksi:								
L	39	39	40	39	40	47	48	46
LT	45	45	46	45	46	53	54	52
F_{su}[b], ksi	39	39	40	40	41	42	42	41
F_{bru}[b,c], ksi:								
(e/D = 1.5)	104	104	106	106	107	111	112	109
(e/D = 2.0)	129	129	131	131	133	137	139	135
F_{bry}[b,c], ksi:								
(e/D = 1.5)	73	73	75	73	75	82	84	81
(e/D = 2.0)	88	88	90	88	90	97	99	96
e, percent (S-Basis):								
LT	10	[d]	...	[d]	...	8	9	9[e]
E, 10^3 ksi	10.5							10.7
E_c, 10^3 ksi	10.7							10.9
G, 10^3 ksi	4.0							4.0
μ	0.33							0.33
Physical Properties:								
ω, lb/in.^{3}	0.100							
C, K, and α	See Figure 3.2.4.0							

Last Revised: Apr 2014, MMPDS-09, Item 03-17.

a Mechanical properties were established under MIL-QQ-A-250/4.

b Grain direction unknown.

c Bearing values are "dry pin" values per Section 1.4.7.1. See Table 3.1.2.1.1.

d See Table 3.2.4.0(c).

e 10% for 0.500 inch.