Airframe Design and Construction

Fuselage Ultimate bending strength

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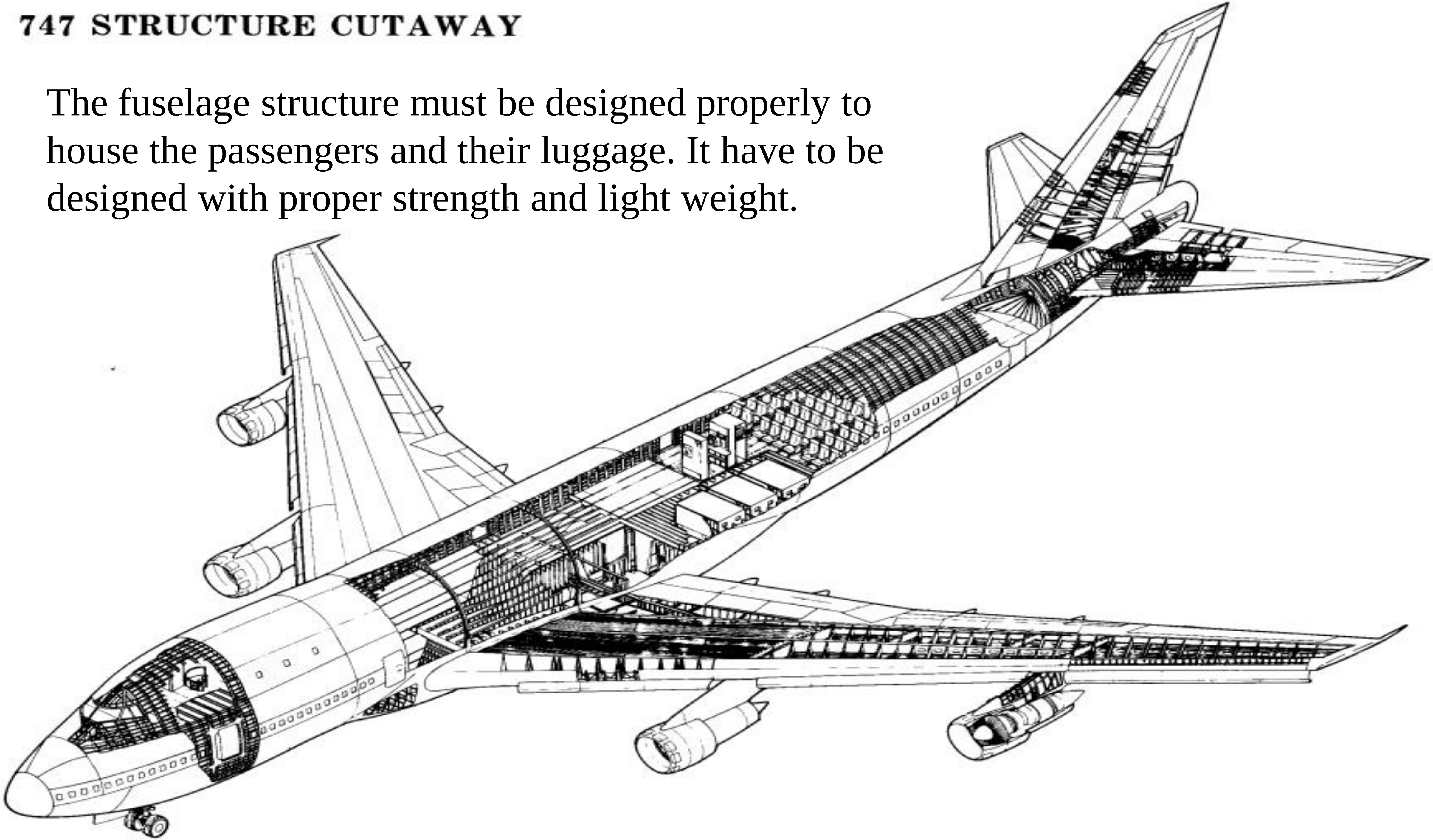
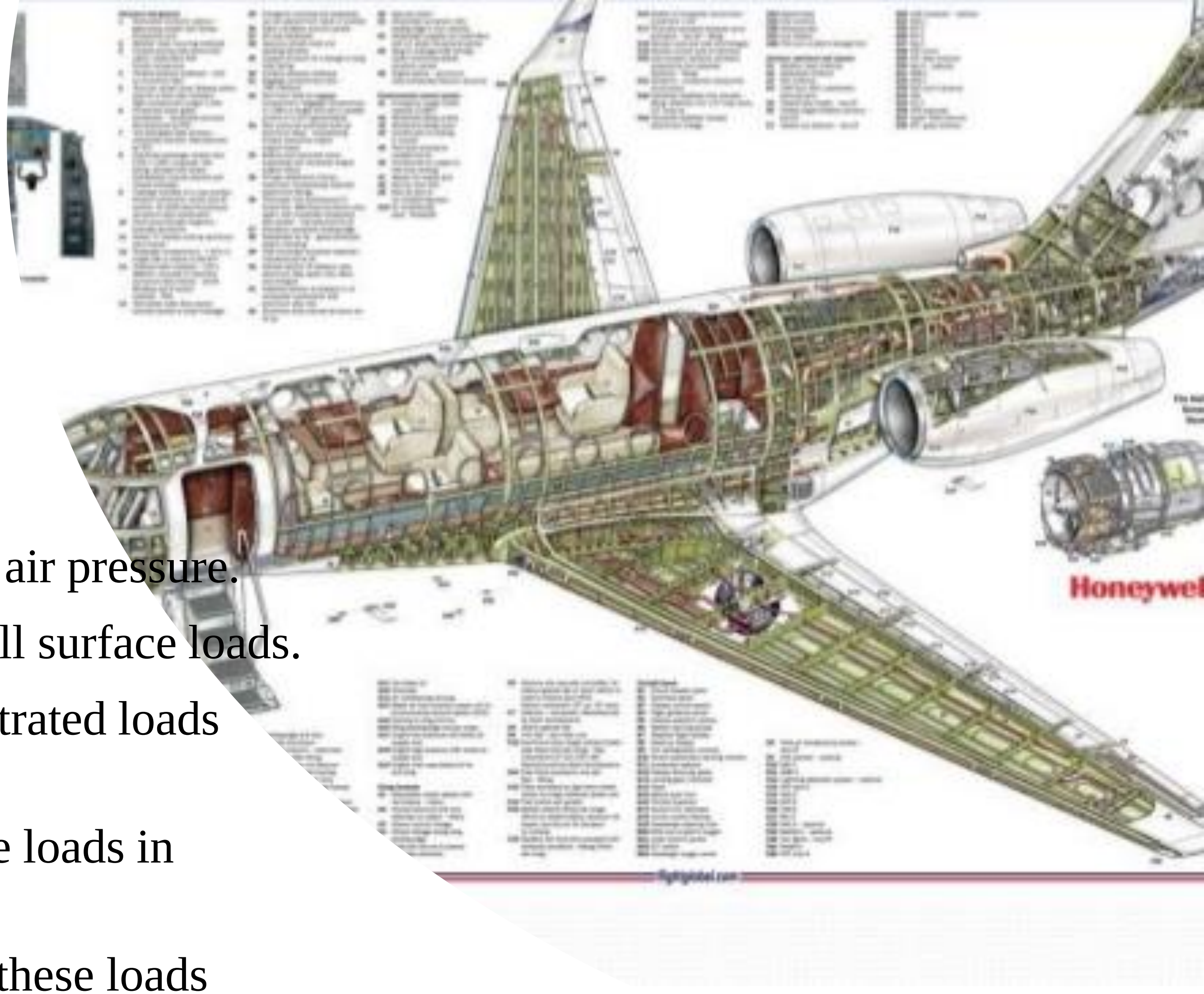
747 STRUCTURE CUTAWAY

The fuselage structure must be designed properly to house the passengers and their luggage. It have to be designed with proper strength and light weight.



Fuselage loads

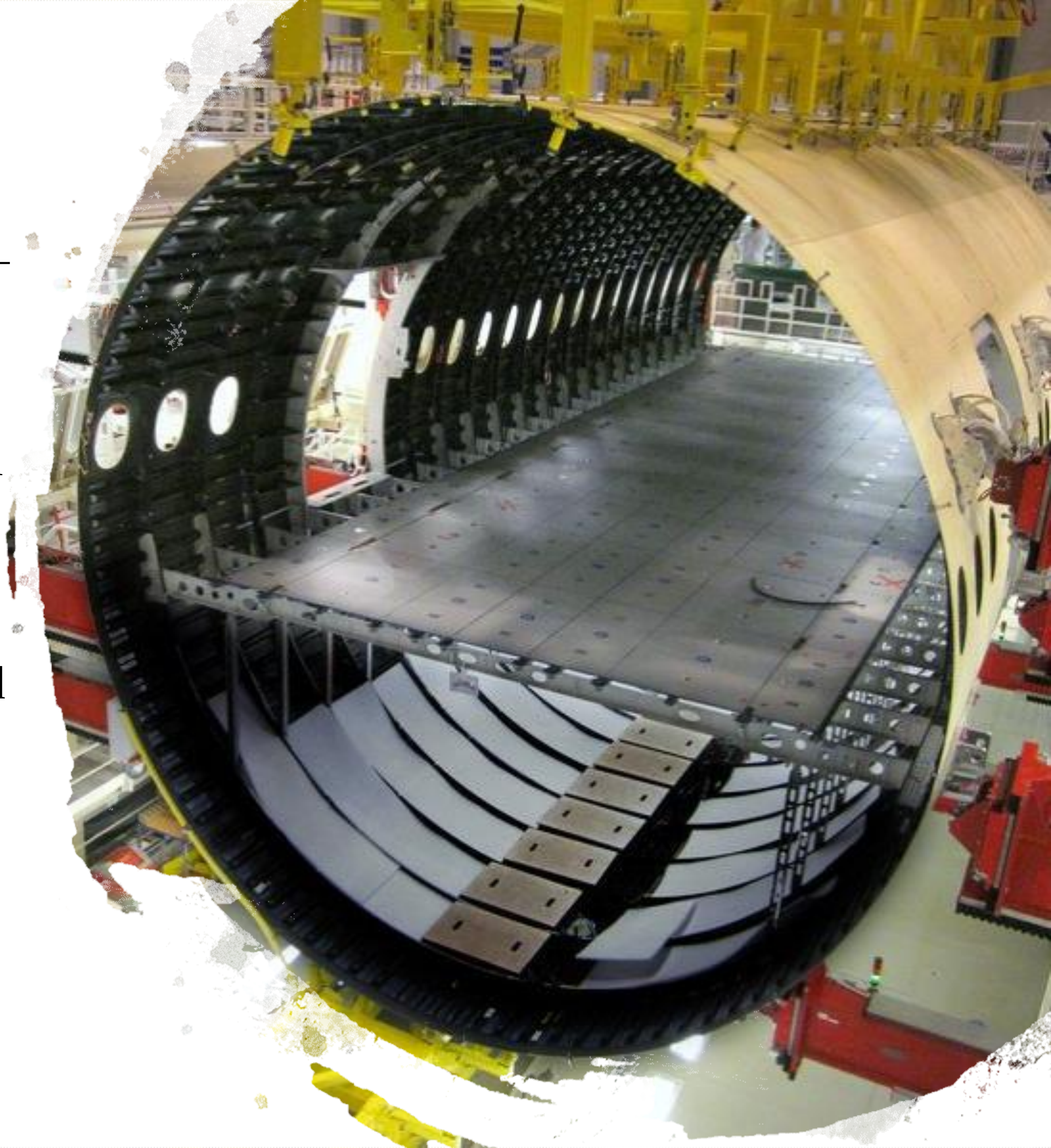


- The wing is subject to large distributed loads due to air pressure.
- However, the fuselage is subjected to relatively small surface loads.
- The fuselage is subjected to large amount of concentrated loads such as the wing reactions, the landing gear loads.
- The fuselage must be designed to withstand all these loads in addition to the internal pressure.
- It is found that the best efficient shape to handle all these loads effectively is the circular cross-section.

Fuselage Structure

The fuselage structure is usually

- a single cell thin walled tube with many transverse frames or rings, and longitudinal stringers .
- provides combined elements which can handle concentrated and distributed applied loads efficiently and safely.
- simply is a beam structure subjected to bending, torsional, and axial forces.
- has many cutouts and discontinuity.



Fuselage structure analysis

- Given fuselage structure and determine the *ultimate bending strength*.

- Given loads and determine the *maximum stresses* applied to the fuselage structure.

- Given loads and determine the *shear flow distribution.*

Ultimate bending strength - Example

The figure shows a circular fuselage cross-section. The stringers are arranged symmetrically w.r.t. the fuselage center point. Three stringers are used as illustrated in the Figure. The material is aluminum 2024.

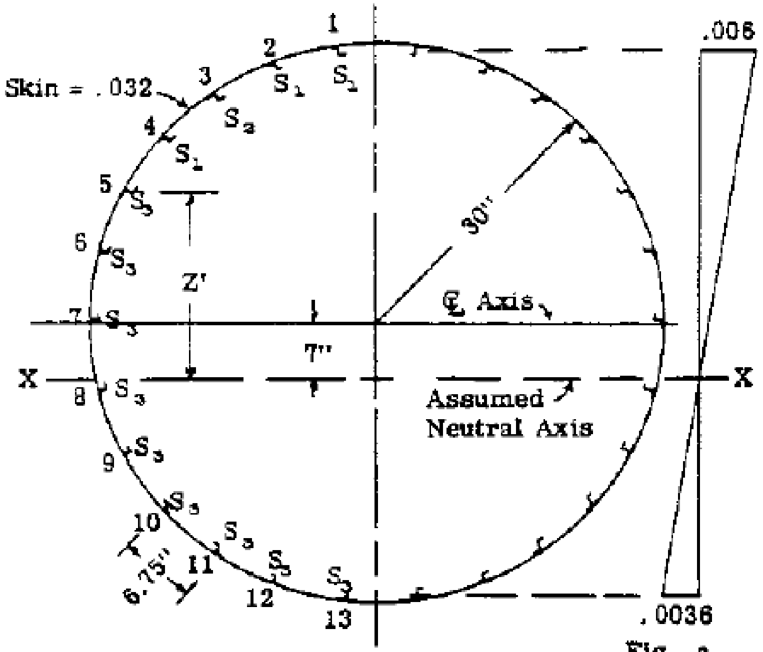
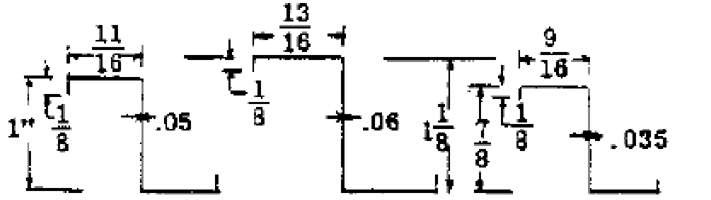
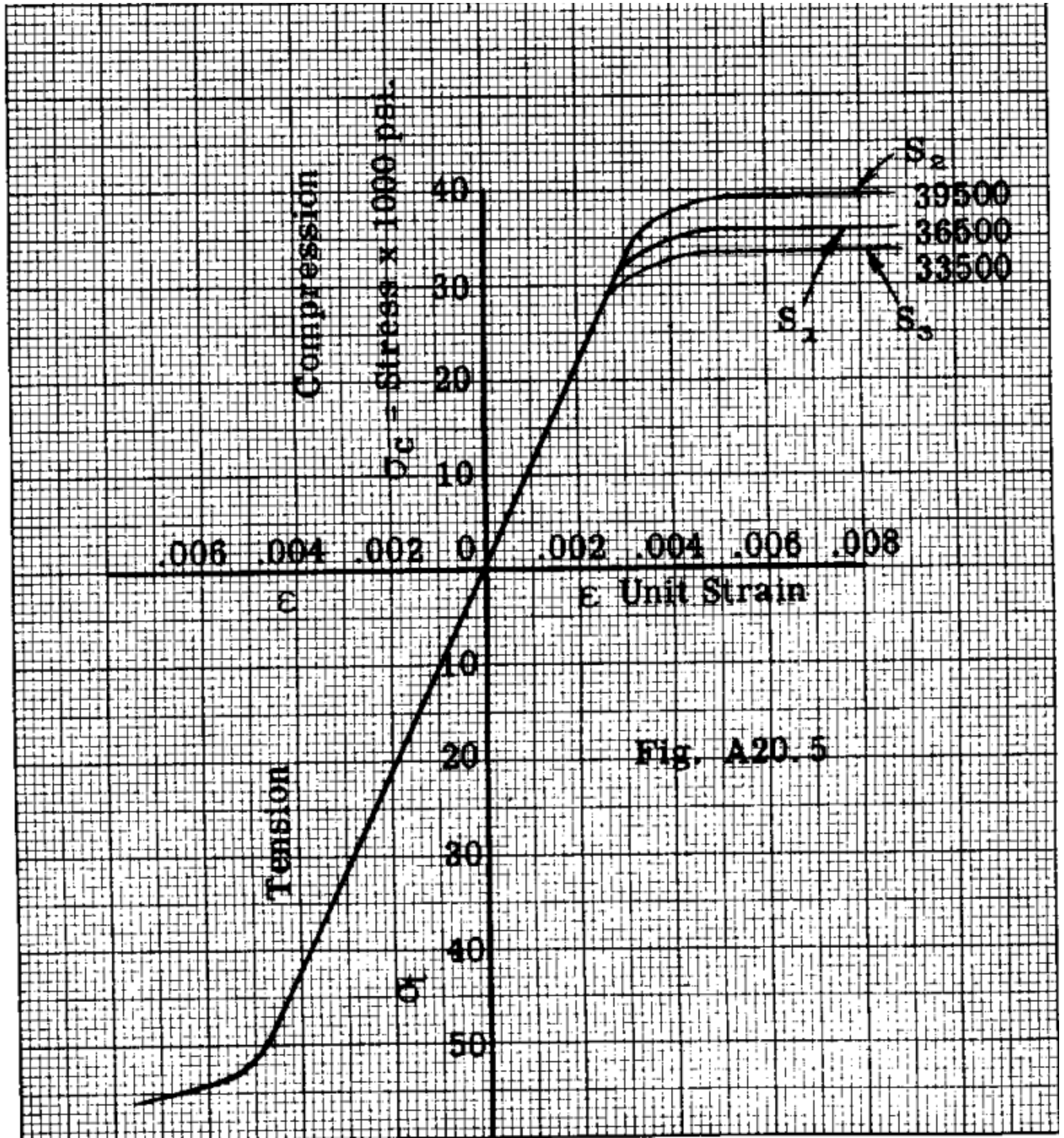


Fig. a Strain Diagram



Ultimate bending strength - Example

Given the stringers' stress-strain curve, determine the fuselage ultimate bending strength?



Ultimate bending strength - Example

Solution strategy

- The fuselage is under bending moment which results in compression in the upper portion and tension in the lower portion.
- The location of the centroid in unknown and subsequently the location of the neutral axis.
- Due to symmetry about the z-axis, only half of the fuselage can be considered in the present calculations.
- Neglect the buckled skin effect.
- We will use the beam stress formula which is based on linear stress variation

$$\sigma_b = -\frac{M_x\, z}{I_x}$$

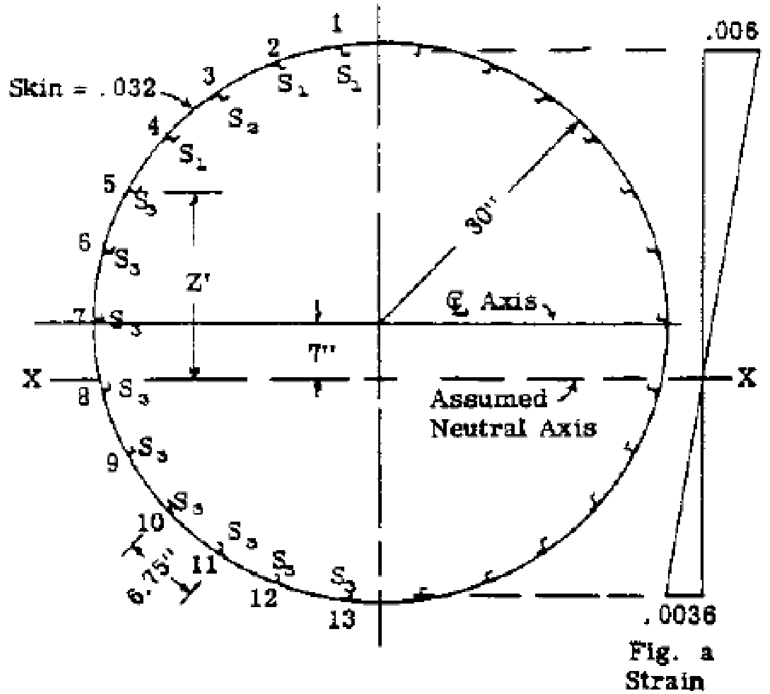


Fig. A20.3

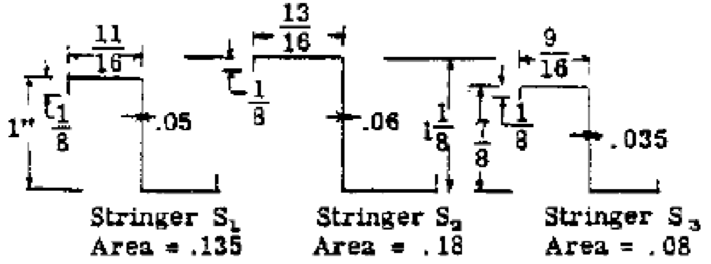


Fig. A20.4

Ultimate bending strength - Example

Solution process

1. List the stringer number, stringer type, and stringer area.

Stringer		Stringer Area
no.	Type	$A_{st}\ [in^2]$
1	S1	0.135
2	S1	0.135
3	S2	0.18
4	S1	0.135
5	S3	0.08
6	S3	0.08
7	S3	0.08
8	S3	0.08
9	S3	0.08
10	S3	0.08
11	S3	0.08
12	S3	0.08
13	S3	0.08

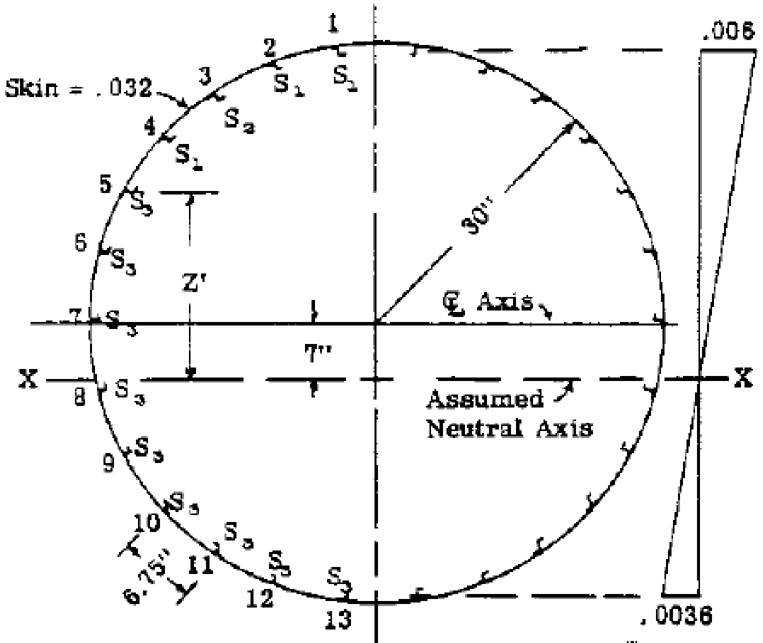


Fig. A20.3

Fig. a Strain Diagram

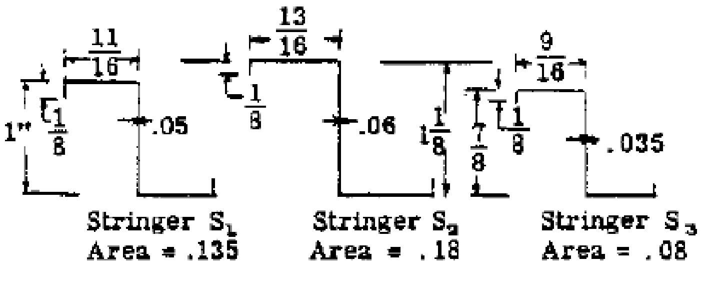


Fig. A20.4

Ultimate bending strength - Example

<u>Solution process</u>

2. Stringers initial position

Angle	Radius	Initial Centroid
θ[*rad*]	R [*in*]	Z' [*in*]
1.69163	29.484	36.269
1.93329	29.484	34.568
2.17495	29.4215	31.2134
2.41661	29.484	26.5515
2.65827	29.5465	20.7309
2.89993	29.5465	14.0709
3.14159	29.5465	7
3.38325	29.5465	-0.0709
3.62491	29.5465	-6.7309
3.86658	29.5465	-12.593
4.10824	29.5465	-17.316
4.3499	29.5465	-20.626
4.59156	29.5465	-22.331

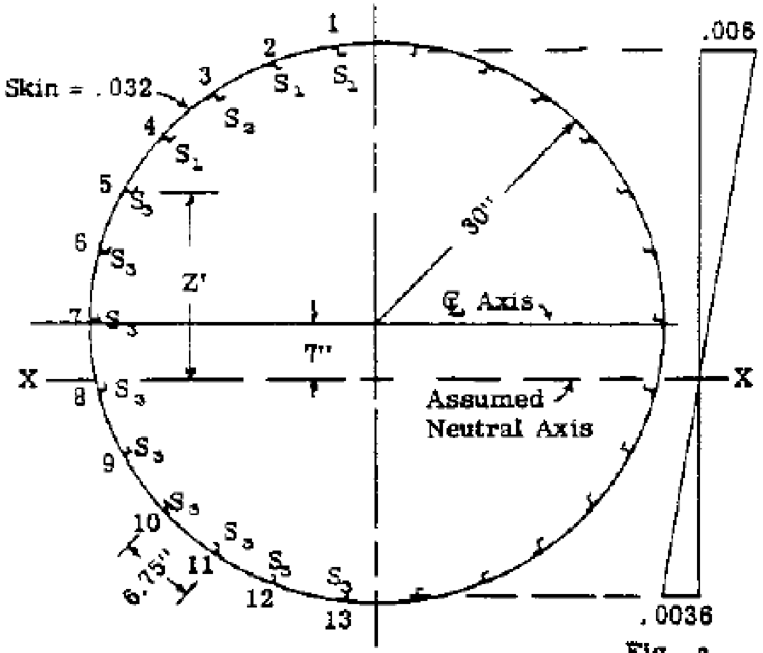


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Fig. a Strain Diagram

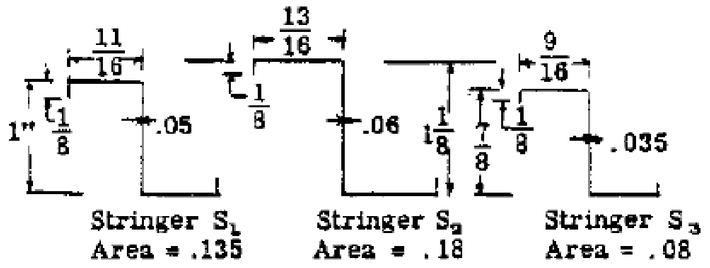

Fig. A20.4

Ultimate bending strength - Example

<u>Solution process</u>

2. Effective width and effective area

- Assume linear stress.
- All skin areas in the tension side are effective.

$$w_{eff} = 1.9t\sqrt{\frac{E}{\sigma_{st}}}$$

Linear stress	effective Area	Total area
σlinear [psi]	A_{eff} $[in^2]$	A_{tot} $[in^2]$
-36500	0.03268	0.16768
-34788.16	0.03348	0.16848
-31412.2	0.03523	0.21523
-26720.6	0.0382	0.1732
-20862.96	0.04323	0.12323
-14160.55	0.05247	0.13247
-7044.578	0.0744	0.1544
71.392043	0.108	0.188
6773.8078	0.216	0.296
12673.149	0.216	0.296
17426.568	0.216	0.296
20757.813	0.216	0.296
22473.283	0.216	0.296

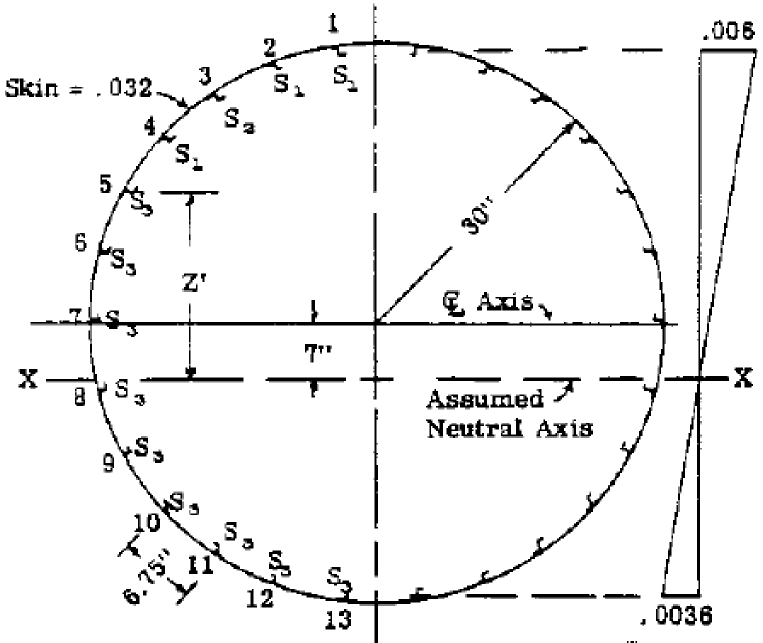

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Fig. a Strain Diagram

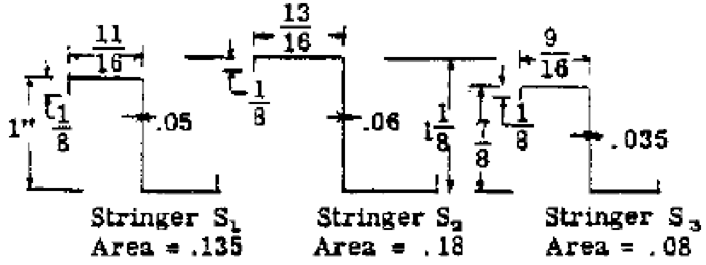


Fig. A20.4

Ultimate bending strength - Example

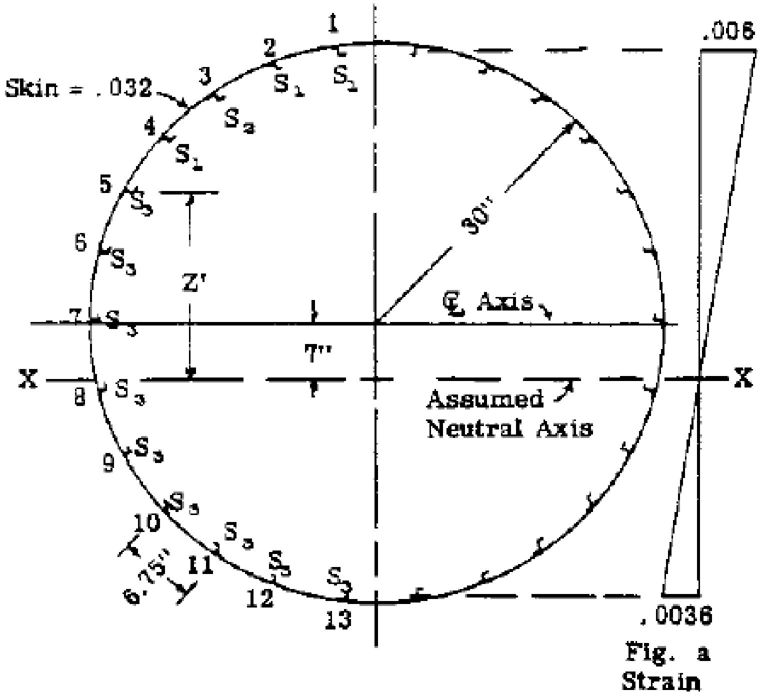
Solution process

3. Nonlinear stress correction

- Correct the linear stress assumption based on the linear strain distribution.
- The true stresses are calculated from the given stress strain relations.

$$K_{eff} = \frac{\sigma_{true}}{\sigma_{linear}}$$

linear strain	True stress	Effective correction factor	Corrected Effective Area
ε_{linear}	σ_{true} [psi]	K_{eff}	A_{corr}
-0.006	-36500	1	0.1677
-0.005719	-36500	1.0492	0.1768
-0.005164	-39100	1.2447	0.2679
-0.004392	-36000	1.34727	0.2333
-0.003430	-31500	1.50985	0.1861
-0.002328	-24000	1.6948	0.2245
-0.001158	-12500	1.774	0.2740
0.000012	0	1	0.1880
0.001114	10000	1.476	0.4370
0.002083	20500	1.617	0.4788
0.002865	30000	1.721	0.5096
0.003412	35000	1.686	0.4991
0.003694	38000	1.69	0.5005
			4.1432



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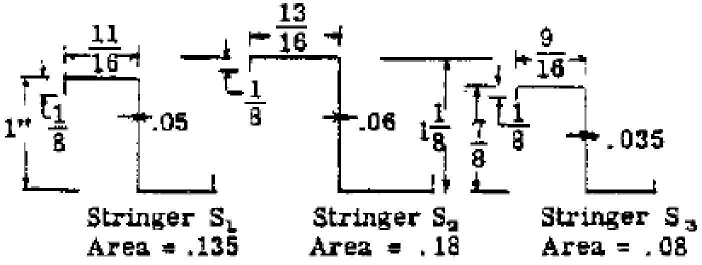


Fig. A20.4

Ultimate bending strength - Example

Solution process

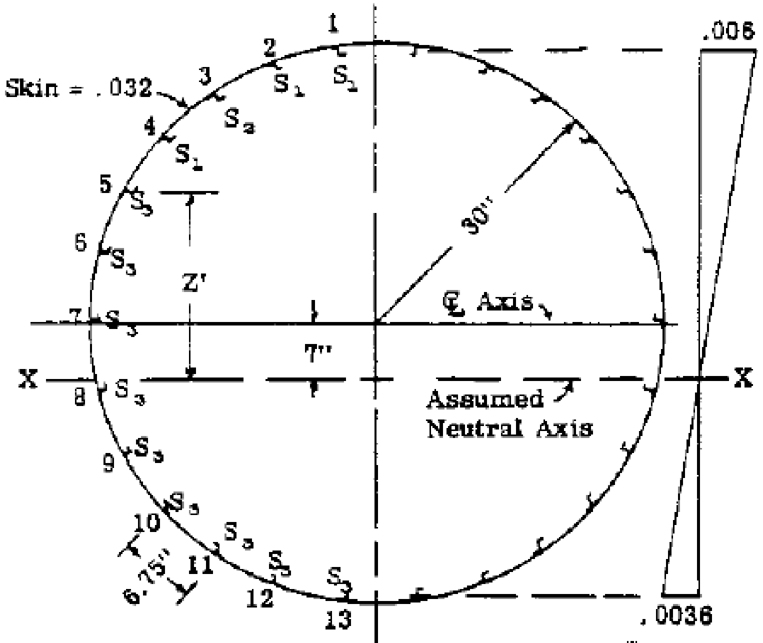
4. First moment of area, centroid, and second moment of area.

$$\bar{Z} = \frac{\sum A_{corr} Z'}{\sum A_{corr}} = \frac{-3.59}{4.143} = -0.87\ in$$

$$Z = Z' - \bar{Z}$$

$$I_{xx} = 2 \sum A_{corr} Z^2 = 3405\ in^4$$

First moment of area	Centroid	Second moment of area
$A_{corr} Z'$	Z	$A_{corr} Z^2$
6.08171	37.1367	231.258
6.11052	35.4357	221.966
8.36227	32.0811	275.728
6.1957	27.4192	175.433
3.85718	21.5986	86.7966
3.15922	14.9386	50.1046
1.91773	7.86768	16.9583
-0.0133	0.79674	0.11934
-2.9413	-5.8633	15.0224
-6.0296	-11.725	65.8275
-8.8238	-16.449	137.867
-10.294	-19.759	194.849
-11.177	-21.463	230.572
-3.5949		1702.5



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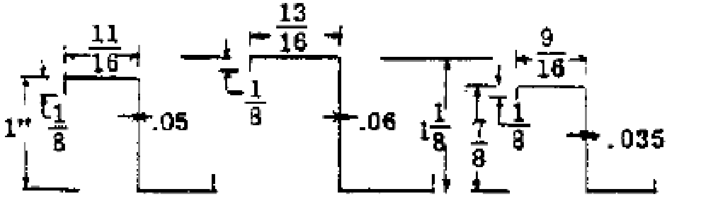


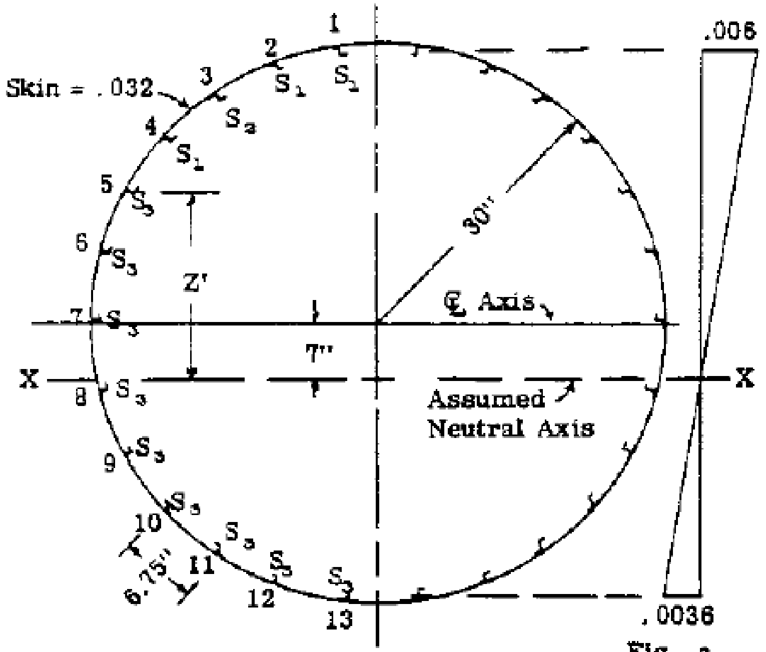
Fig. A20.4

Ultimate bending strength - Example

Solution process

5. Fuselage ultimate bending strength.

$$M_x = -\frac{\sigma_b I_x}{z} = \frac{36500 * 3405}{37.1367} = 3.335 \text{ E6 Ib.in}$$



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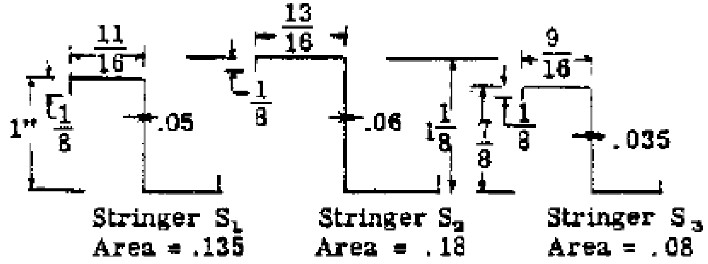
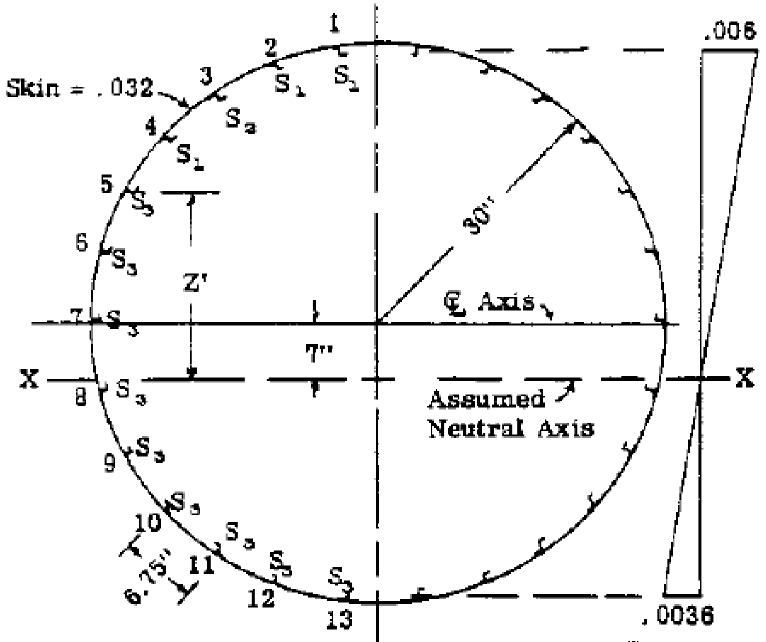


Fig. A20.4

Ultimate bending strength - Example

Comments

- Although the arm of stringer 3 is smaller than that of stringer 1, stringer 3 carries more stresses than stringer 1 and 2.
- The stress distribution is assumed to be linear, since the bending stress equation is based on linear stress analysis.
- The ultimate bending strength is a property to the structure which is independent to the applied loads.



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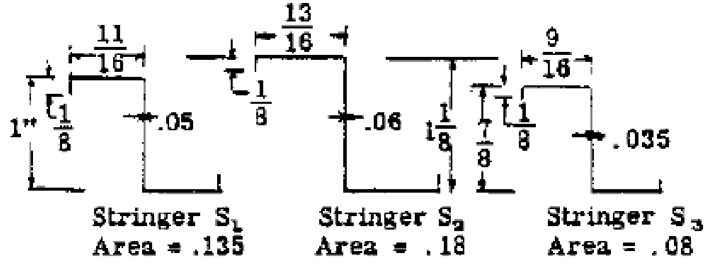

Fig. A20.4

Ultimate bending strength - Example

Comments

- The nonlinear stress effect is important

What will happen if the nonlinear stress effect was not considered?