



AEE 461 Design of Aircraft Structures

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Lecture #6

Axial and Bending Members – cont'd

General Discussion of Fuselage Frame Design:

In aircraft design, frames are primarily used to support or reinforce the shell of the fuselage while simultaneously supporting or distributing many different types of flight and ground conditions under load. Among the most important of these load types are the following:

1. Surface airloads,
2. Landing gear reactions,
3. Wing pivot reactions,
4. Floor beam reactions.

Fuselage frames are designed to resist these loads while still maintaining the general design shape or configuration of the fuselage shell.

Example 2-4:

The internal loads acting at designated node points around the fuselage frame structure of Fig. 2-22 were obtained from a finite-element computer model analysis of that structure. After a careful review of all flight and landing conditions around this frame, the following locations were found to have critical loading combinations:

<i>Critical Section</i>	<i>P [lb]</i>	<i>V [lb]</i>	<i>M [in-lb]</i>
@Node 32	8000	2000	10000
@Node 29	-9500	1000	-11000
@Node 25	-4500	4000	-3700

Calculate the stresses for the cross-sections shown in Fig. 2-22 with applied loads given above.

2.5 Axial and Bending Stresses of Beams that Bend in One Plane

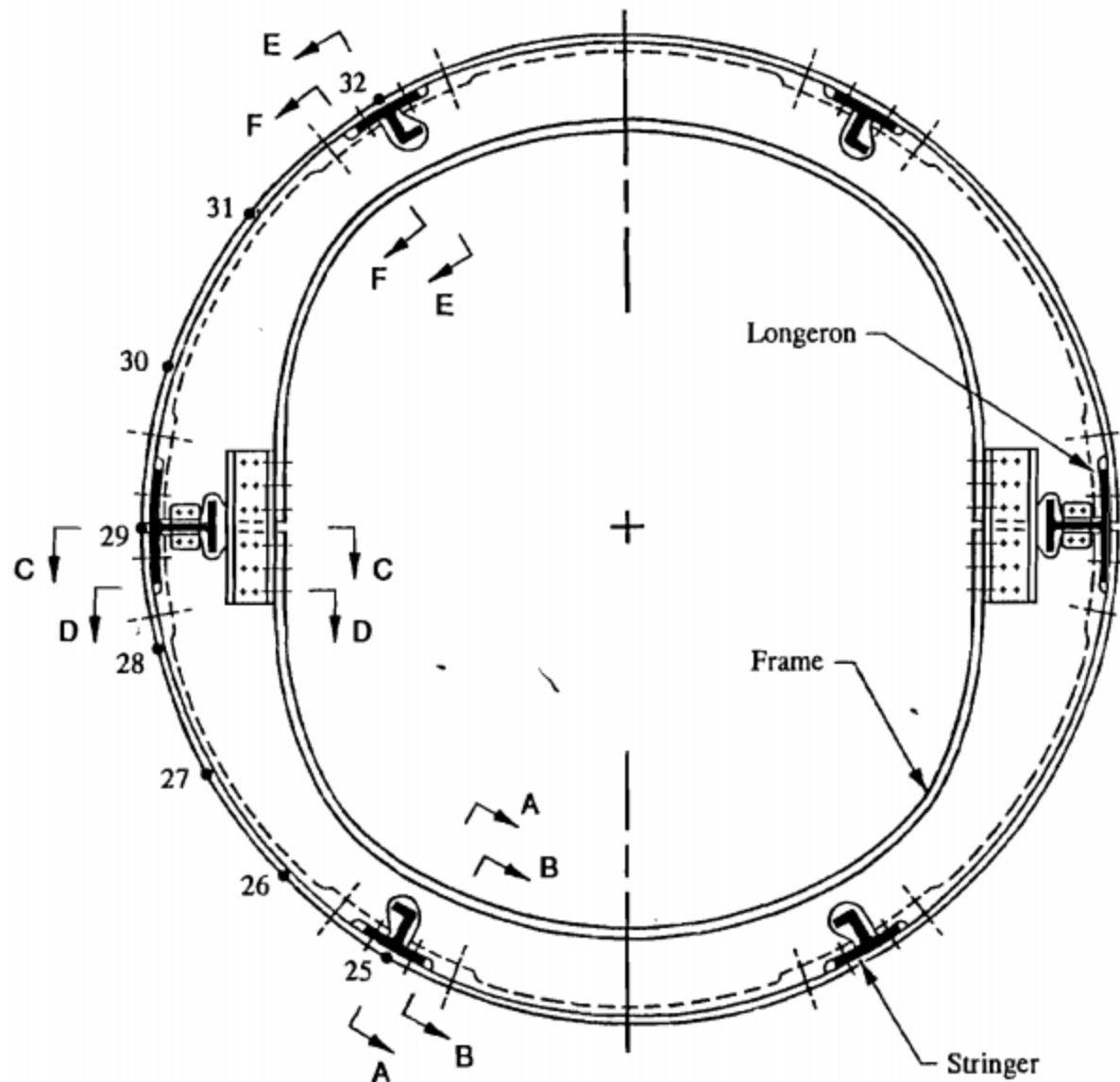
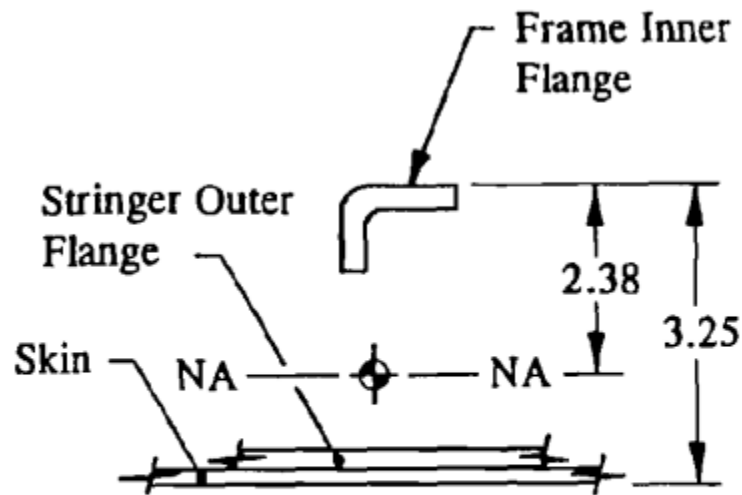


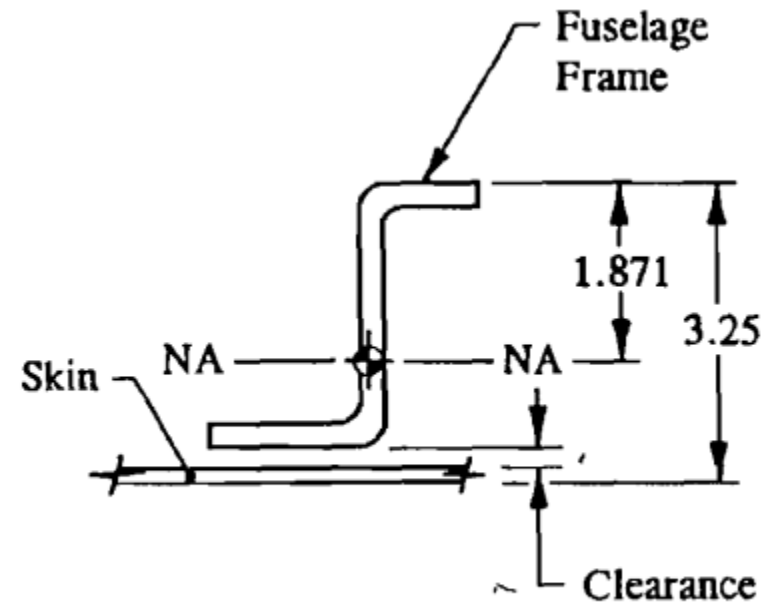
FIGURE 2-22 Designated node points around a fuselage frame structure.

2.5 Axial and Bending Stresses of Beams that Bend in One Plane

Fuselage frame effective cross-sectional areas:



SECTION **A-A** Node 25

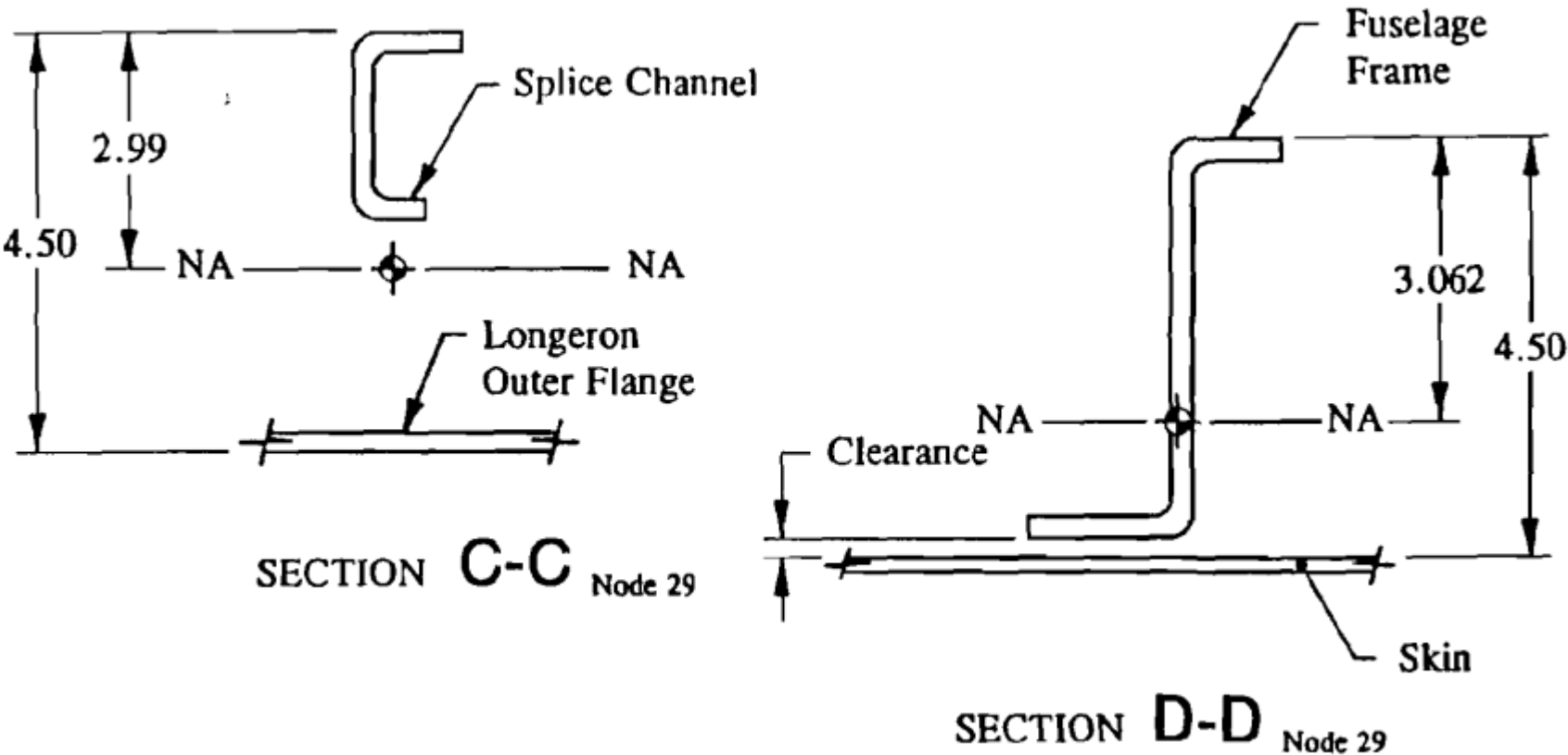


SECTION **B-B** Node 25

Section	Area A [in²]	Moment of Inertia I_{na} [in⁴]
A-A	.529	.830
B-B	.388	.601

2.5 Axial and Bending Stresses of Beams that Bend in One Plane

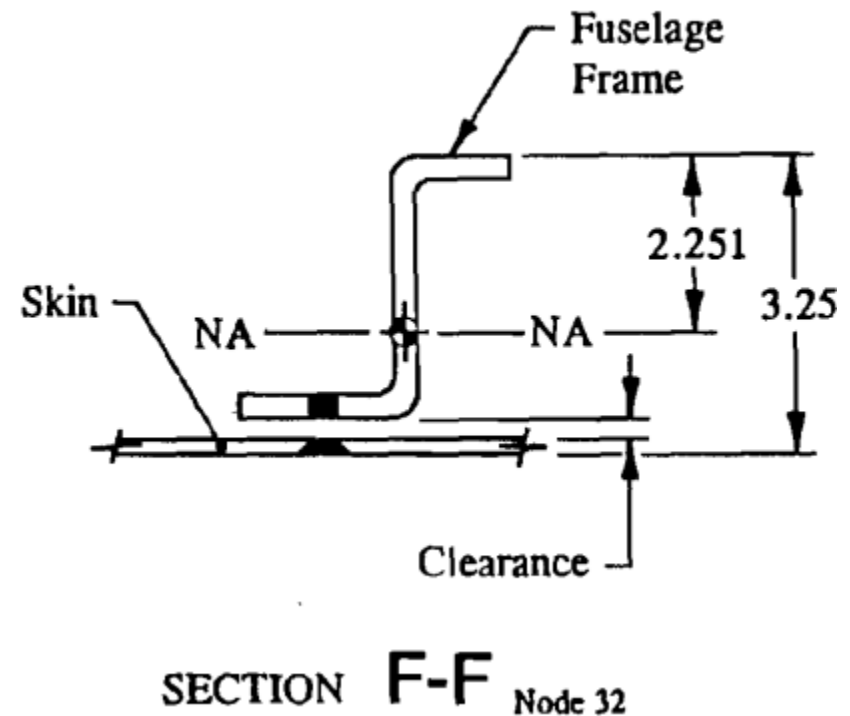
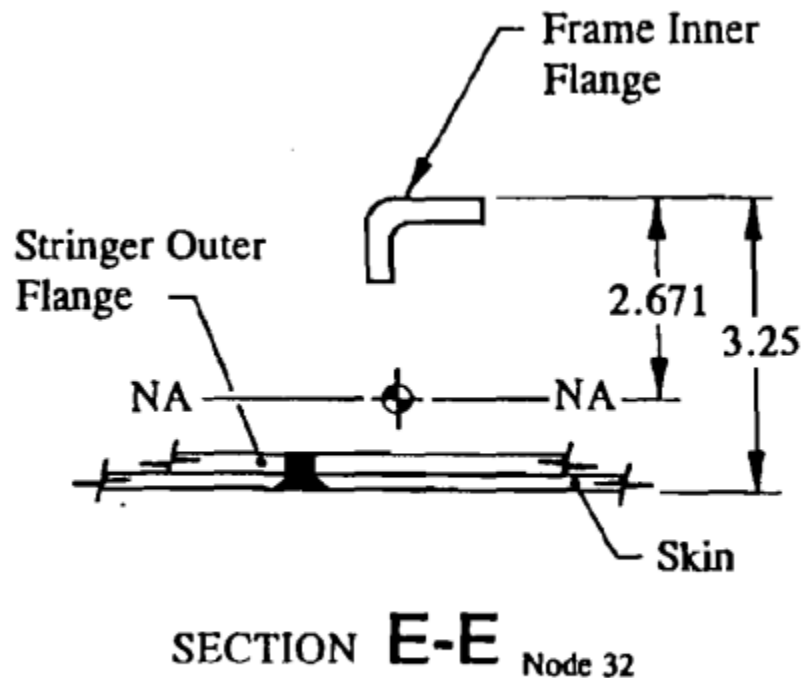
Fuselage frame effective cross-sectional areas:



<i>Section</i>	<i>Area A [in²]</i>	<i>Moment of Inertia I_{na} [in⁴]</i>
C-C	.863	2.575
D-D	.650	1.740

2.5 Axial and Bending Stresses of Beams that Bend in One Plane

Fuselage frame effective cross-sectional areas:

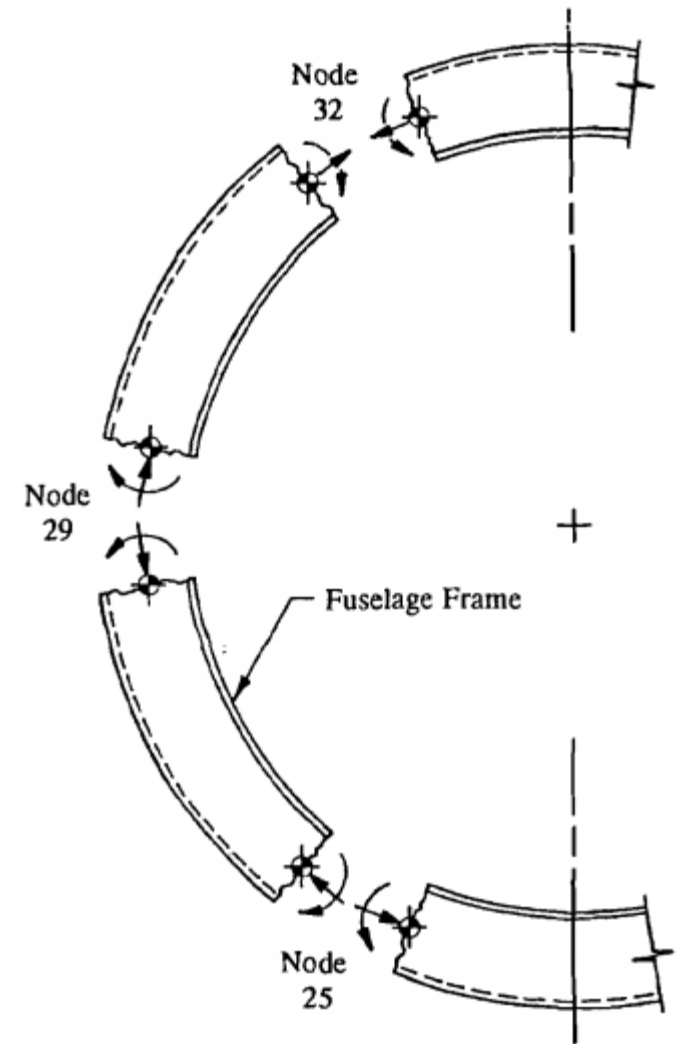


Section	Area A [in²]	Moment of Inertia I_{na} [in⁴]
E-E	.829	.955
F-F	.538	.795

2.5 Axial and Bending Stresses of Beams that Bend in One Plane

Solution:

1. P is a compression load
if its value is positive (negative).
2. P is a tension load
if its value is negative (positive).
3. M produces compression on the skin side and
tension on the inner frame cap side
if its value is positive (negative).
4. M produces tension on the skin side and
compression on the inner frame cap side
if its value is negative (positive).



Solution - cont'd:

SECTION A-A (Node 25)

Inner Flange:

$$f_t = -\frac{4500}{0.529} + \frac{3700(2.38)}{0.830} = 2103 \text{ psi}$$

Skin:

$$f_c = -\frac{4500}{0.529} - \frac{3700(3.25-2.38)}{0.830} = -12385 \text{ psi}$$

SECTION B-B (Node 25)

Inner Flange:

$$f_t = -\frac{4500}{0.388} + \frac{3700(1.871)}{0.601} = -79 \text{ psi}$$

Skin:

$$f_c = -\frac{4500}{0.388} - \frac{3700(3.25-1.871)}{0.601} = -20088 \text{ psi}$$

Solution - cont'd:

SECTION C-C (Node 29)

Inner Flange:

$$f_t = -\frac{9500}{0.863} + \frac{11000(2.99)}{2.575} = 1765 \text{ psi}$$

Skin:

$$f_c = -\frac{9500}{0.863} - \frac{11000(4.50-2.99)}{2.575} = -17459 \text{ psi}$$

SECTION D-D (Node 29)

Inner Flange:

$$f_t = -\frac{9500}{0.650} + \frac{11000(3.062)}{1.740} = 4742 \text{ psi}$$

Skin:

$$f_c = -\frac{9500}{0.650} - \frac{11000(4.50-3.062)}{1.740} = -23706 \text{ psi}$$

Solution - cont'd:

SECTION E-E (Node 32)

Inner Flange:

$$f_c = + \frac{8000}{0.829} - \frac{10000(2.671)}{0.955} = -18318 \text{ psi}$$

Skin:

$$f_t = + \frac{8000}{0.829} + \frac{10000(3.25-2.671)}{0.955} = 15713 \text{ psi}$$

SECTION F-F (Node 32)

Inner Flange:

$$f_c = + \frac{8000}{0.538} - \frac{10000(2.251)}{0.795} = -13445 \text{ psi}$$

Skin:

$$f_t = + \frac{8000}{0.538} + \frac{10000(3.25-2.251)}{0.795} = 27436 \text{ psi}$$

It is the subject of this section to evaluate the member forces that are carried by the element areas that make up the cross-sectional area of a beam. Mathematically, this is accomplished by multiplying the average stress level of an element by its corresponding element area.

$$P = fA$$

where f = average stress level of an element area (if present, include both axial and bending stresses)

A = element area.

This equation is by definition a derivative of the basic equation for normal or axial stresses ($f_n = \pm P/A$).

2.6 Member Forces

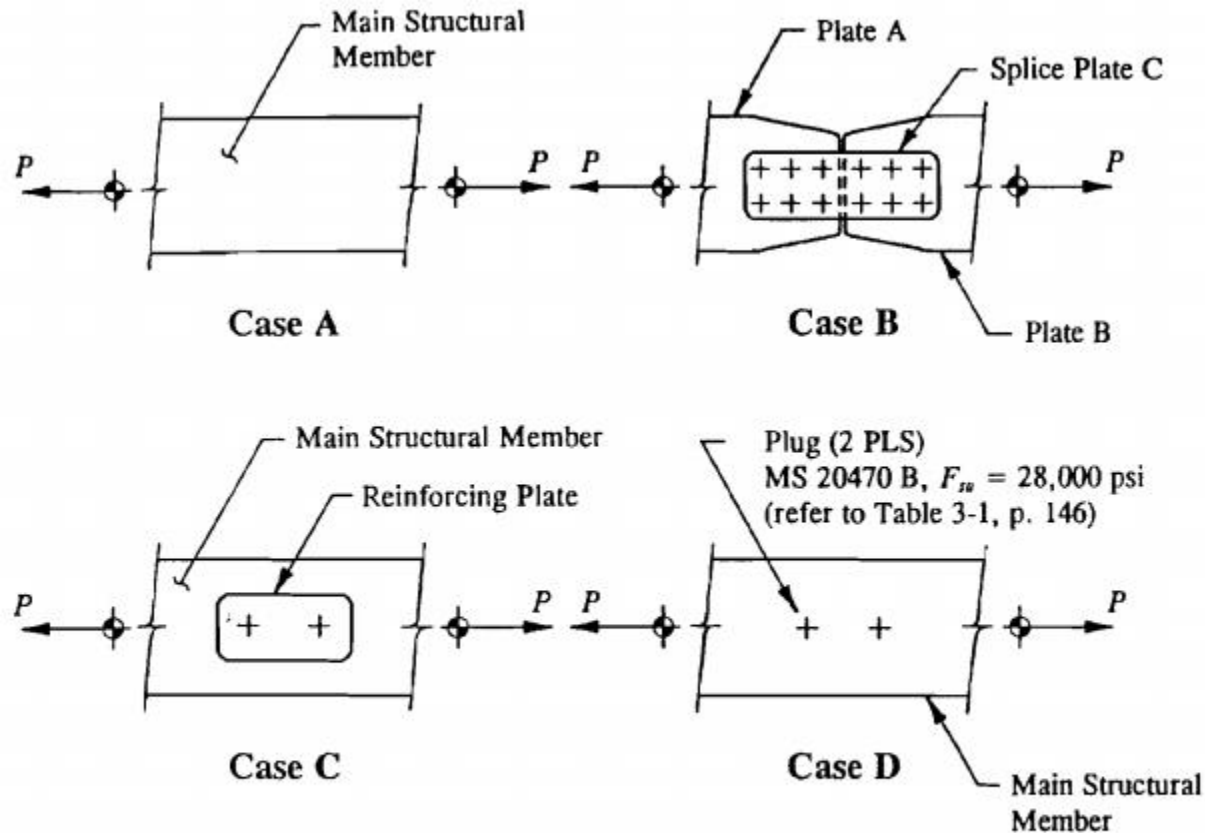
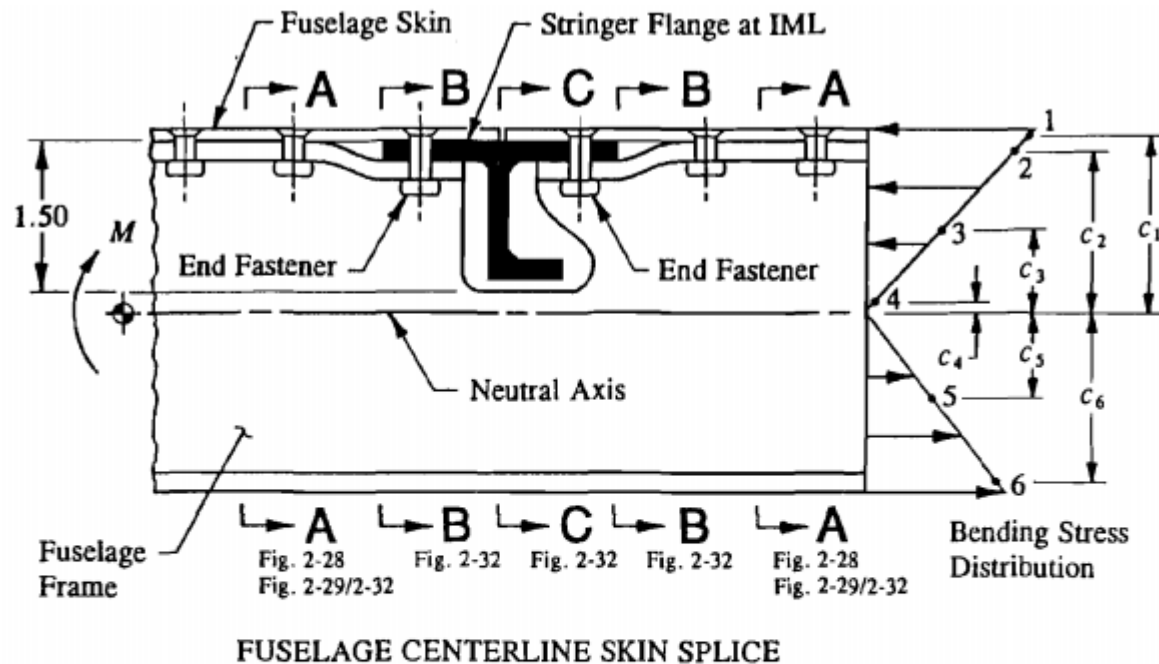


FIGURE 2-26 Diagrams are used to show concepts and theory of load transfers through various joints.

Consider the plates diagrammed in Fig. 2-26. If the plate member of Case A is cut into two parts, some type of splicing member would be needed to transfer the force P from one plate to the other. This is accomplished as shown in Case B, where the transfer of force from plate A to plate B is achieved through each group of fasteners of splice plate C. Or, to say it another way, the load P that the plates carried before they were cut must now be transferred by each group of fasteners of plates A and B across the discontinuity through splice plate C.

The two main points of this discussion are summarized below:

1. Continuous members across a splice-joint provide a continuous load path to sustain their internal forces across the joint.
2. Discontinuous members across a splice-joint must transfer their internal forces through other structural members that can provide a continuous load path across the joint.



LOADS: $M = 3,000$ in-lb (compression skin side)

$P = 0$

$V = 0.$

MATERIAL: Aluminum 2024-T3 Clad

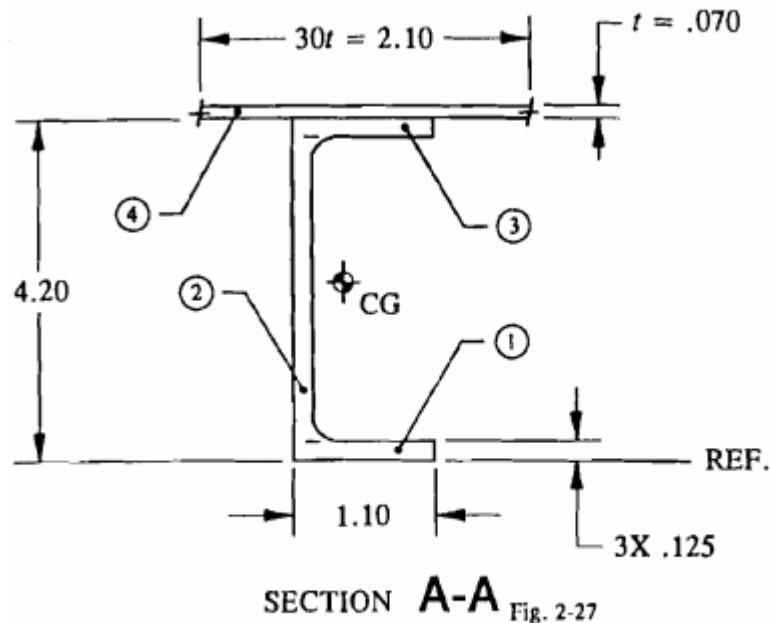
2024 Aluminum Alloy (Extrusion).

FIGURE 2-27 Stringer cutout in pure bending.

Now, with the benefit of these discussions, the stringer cutout arrangement depicted in Fig. 2-27 will be analyzed in pure bending.

The transfer of internal member forces across the joint of the stringer cutout are easily seen by directly relating each structural member to the simple splice-joint concepts depicted earlier in this section. The internal forces that are carried by the skin, outer frame flange, and part of the web that was cut away must now transfer across the joint through the end fasteners of the stringer flange. The stringer flange, in effect, provides a continuous load path for these members. All members that are discontinuous at a splice-joint must transfer their internal forces through other members that can provide a continuous load path across the joint. If the load each member carried before it was cut away can be found, one can then logically reason out the internal member forces that must transfer through the end fasteners of the stringer flange.

2.6 Member Forces



$$Y_{cg} = \frac{\Sigma Ay}{\Sigma A} = \frac{2.238}{0.915} = 2.446 \text{ in.}$$

$$I_{cg} = \Sigma I_0 + \Sigma Ay^2 - Y_{cg}(\Sigma Ay)$$

$$I_{cg} = 0.642 + 7.167 - 2.446(2.238)$$

$$I_{cg} = 2.335 \text{ in}^4$$

$$Y_{na} = Y_{cg} = 2.446 \text{ in.}$$

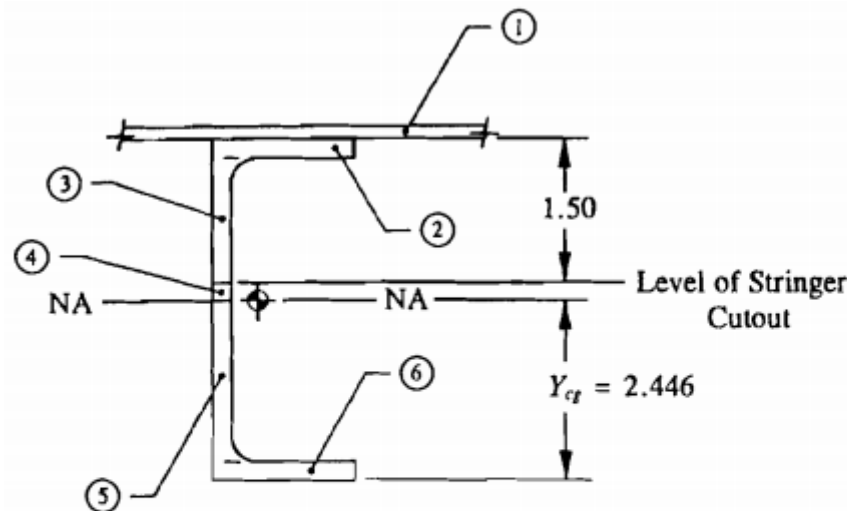
$$I_{na} = I_{cg} = 2.335 \text{ in}^4.$$

FIGURE 2-28 Fuselage frame cross-sectional area. All fillet radii neglected.

Element	b	h	y	A	Ay	Ay ²	I ₀
1	1.100	0.125	0.062	0.137	0.009	0.001	0.000
2	0.125	3.950	2.100	0.494	1.037	2.177	0.642
3	1.100	0.125	4.137	0.137	0.569	2.353	0.000
4	2.100	0.070	4.235	0.147	0.623	2.636	0.000
Total				0.915	2.238	7.167	0.642

2.6 Member Forces

Now, refer to Section A-A of Fig. 2-29. The element areas in this figure are chosen as a function of the internal member forces desired for our particular splice-joint configuration. To find the internal member forces of these element areas, use will be made of Eq. 2-10, where the average bending stress across each element of the section is multiplied by its corresponding element area. This can be done most conveniently in tabular form, as shown in next page.



SECTION A-A Fig. 2-27

FIGURE 2-29 Fuselage frame element areas used to determine internal member forces.

2.6 Member Forces

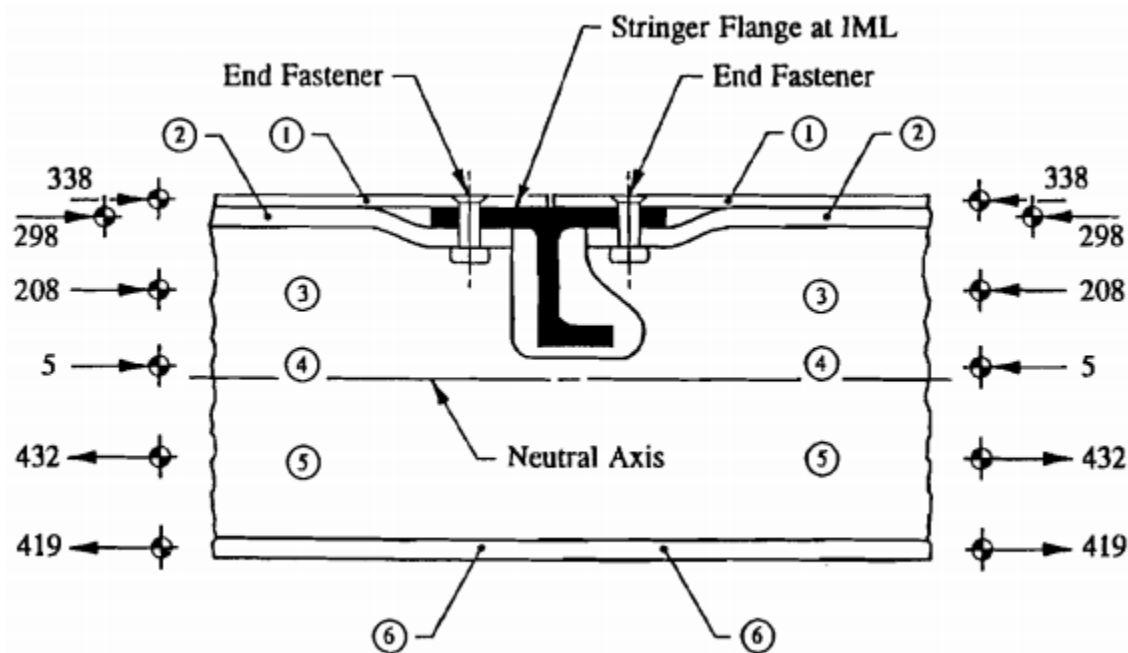
<i>Element</i>	<i>Member</i>	<i>b</i>	<i>h</i>	<i>A</i>	<i>c</i>	<i>F*</i>	<i>P**</i>
1	skin	2.100	0.070	0.147	1.789	-2.299	-338
2	outer flange	1.100	0.125	0.137	1.691	-2.173	-298
3	portion of web (cutout)	0.125	1.375	0.172	0.941	-1.209	-208
4	web above the n.a.	0.125	0.254	0.032	0.127	-163	-5
5	web below the n.a.	0.125	2.321	0.290	1.160	1.490	432
6	inner flange	1.100	0.125	0.137	2.383	3.062	419

$$* \quad f = f_b = \pm Mc/I_{na}$$

$$** \quad P = fA$$

2.6 Member Forces

The ideas of this section may now be fully utilized here most efficiently in describing the transfer of these forces across the stringer cutout. These ideas, as they relate to the internal forces which are carried by members that can provide continuous load paths across the joint, will show that elements #4, #5, and #6 will not necessarily transfer their internal member forces to other structural members of the joint. Instead, these members will sustain their loads and thereby maintain a fairly constant stress level across the joint.



By taking an intelligent and logical approach to the analysis of discontinuous members, it can be reasoned out that the loads of elements #1, #2, and #3 must transfer through the end fasteners of the stringer flange. Also, it is interesting to note that the load carried by element #3 could conceivably redistribute (disperse) some of its load to the inner frame cap side of the fuselage frame. The percentage of redistribution will depend upon the magnitude of the inner frame stresses. If the inner frame stresses are high, very little additional load would be expected to actually redistribute to the inner frame cap (elements #4, #5, and #6). In problems where the inner frame cap stresses are relatively low, the engineer must decide, hopefully, conservatively, how much of this load will actually distribute to the inner frame cap. Realistically, however, only a strain-gauge survey of this joint during flight or structural testing will accurately establish the actual load distribution. Keeping this point in mind then, the most direct approach to a conservative stress analysis solution of the end fasteners would be to completely force the entire load of element #3 or 208 lb through each end fastener.

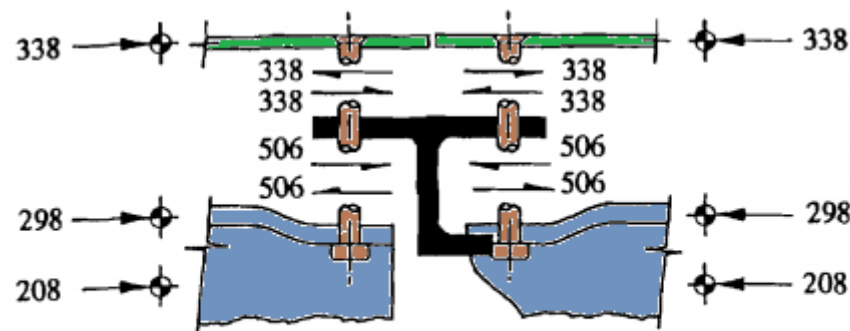


FIGURE 2-31 Transfer of shear forces across the frame cutout.

The ideas of this section may now be fully utilized here most efficiently in describing the transfer of these forces across the stringer cutout. These ideas, as they relate to the internal forces which are carried by members that can provide continuous load paths across the joint, will show that elements #4, #5, and #6 will not necessarily transfer their internal member forces to other structural members of the joint. Instead, these members will sustain their loads and thereby maintain a fairly constant stress level across the joint.

2.6 Member Forces

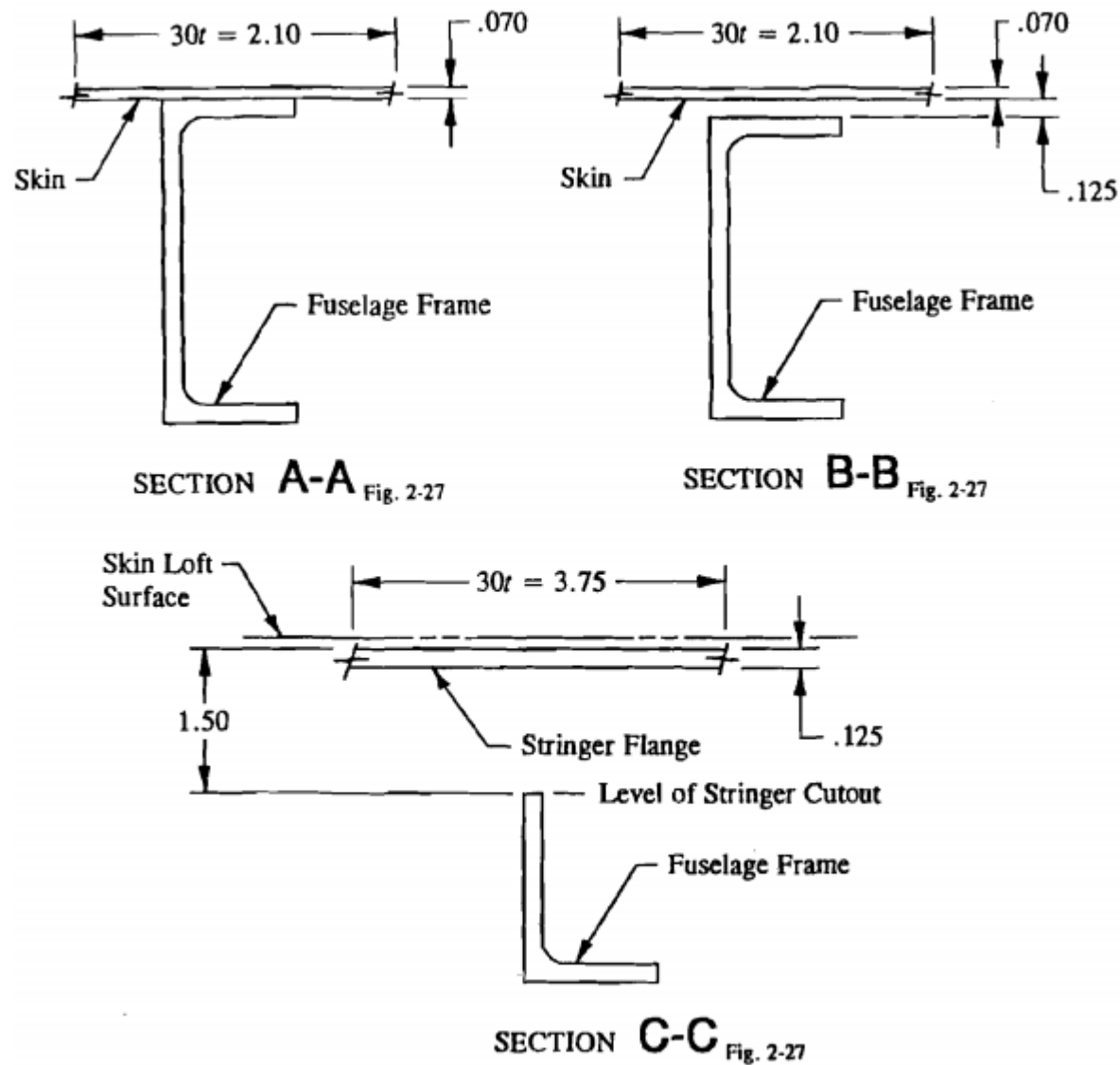


FIGURE 2-32 Fuselage frame cross-sectional areas (refer to Fig. 2-27).

All members offering effective means of load transfer, or providing the most direct load paths across the splice-joint, are used in the calculation of basic section properties. As a brief review of those principles here, conventional stress analysis methods require a complete investigation of the basic frame structure at Sections A-A, B-B, and C-c. These sections are shown in Fig. 2-32. Note, in particular, that the stringer flange (Fig. 2-30) provides an effective load path for the frame outer cap. For this reason, this member becomes part of the effective cross-sectional area of Section C-C. After the section properties of these sections are calculated, the extreme fiber stresses are computed using the flexure formula.