Lunar Landing Research Vehicle

STRUCTURAL ANALYSIS HANDBOOK

REPORT NO. 7161-954001

1 APRIL 1964

MANUFACTURED

BY

BELL AEROSYSTEMS COMPANY
DIVISION OF BELL AEROSPACE CORPORATION-A textron COMPANY

FOR NATIONAL AERONAUTIC AND SPACE ADMINISTRATION
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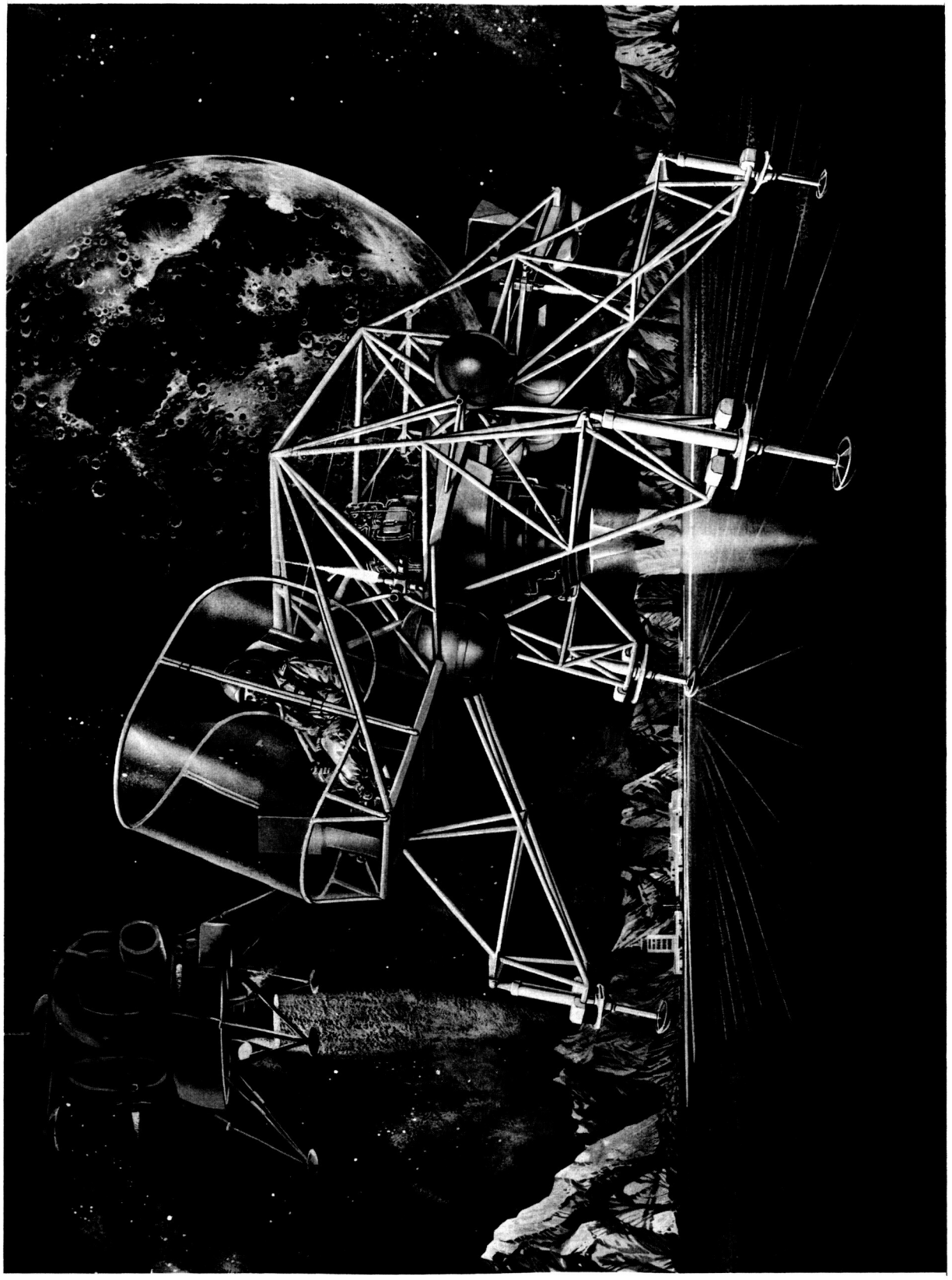

Lunar Landing Research Vehicle

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SECTION 1
STRUCTURAL DESIGN CRITERIA

This section defines the design conditions for the airframe. Limit velocities are given for flight and landing. Load factors are established for landing, flight, and handling conditions. Possible off-design landing conditions are suggested. Specific loads are defined for unique portions of the airframe.

The structural design criteria defines the operating environment for which the LLRV is designed. Three general operating regimes are considered: flight, landing, and handling. In the flight regime the design velocities are 60 feet per second horizontal or 100 feet per second vertical. However, the only portions of the airframe critical for airloads are the windscreen and the parachute attachment, so design loads in the flight regime are produced by engine thrust. The design loads on the major portion of the airframe are produced by the landing conditions, and these are discussed first in the following portions of the criteria.

In all design landing conditions it is assumed that the landing surface is a concrete runway and the vehicle is in a level attitude. One basic combination of landing parameters is 6 feet per second vertical velocity, 3 feet per second horizontal velocity, with engine thrust locked parallel to the vehicle vertical centerline equal to 2/3 the vehicle weight. At 3400 pounds vehicle weight, with one leg forward and infinite coefficient of friction, this becomes condition number one for the design of the landing gear shock strut metering pin.

Since the above condition requires that the shock strut on the leading leg absorb more than 25% of the vehicle kinetic energy, the four struts acting together in a level landing, with no horizontal velocity, are capable of absorbing the energy of a 10 ft/sec vertical landing. This becomes condition number two for the design of the metering pin.

The above two conditions and combinations of the two conditions are listed in Table 1.1.

It should be noted that landings can be made at other than design conditions if specific requirements are reduced. Some of the more significant exceptions are listed:

(1) No limit is necessary on horizontal velocity if the coefficient of friction between the landing feet and the runway is 0.5 or less.

(2) With engine in the local vertical mode, and zero horizontal velocity, the vehicle can be landed on the runway in tilted attitudes up to 5° with engine thrust equal to 2/3 vehicle weight and zero vertical velocity at initial impact.

(3) With the engine in the local vertical mode, and zero horizontal velocity, the vehicle can be landed on the runway at any tilted attitude up to 40° with engine thrust equal to vehicle weight and up to 4 ft/sec vertical velocity at initial impact.

(4) On rough terrain with diagonally opposite feet contacting the ground simultaneously, and the vehicle in level attitude, landings can be made at a vertical velocity of 6 ft/sec with engine thrust equal to 2/3 vehicle weight.

(5) With the engine in the local vertical mode, and engine thrust equal to vehicle weight, the vehicle can be set down on rough terrain or slopes up to 40°, when initial contact is made with zero horizontal velocity and 4 ft/sec vertical velocity.

In all conditions where the engine thrust is 2/3 vehicle weight the maximum permissable limit shock strut reaction is 2260 pounds. At greater values of thrust the strut reaction would be less.

The rubber mounts, which react the landing gear lateral loads, are designed to permit the landing foot to deflect 6.75 inches sideways when one foot arrests the 3400 lb vehicle moving at the design horizontal velocity of 3 ft/sec. This results in a 1700 pound lateral load at the bottom of the foot. The corresponding vertical load is calculated by making the line of action of the resultant of the lateral and vertical loads pass thru the center of gravity. A smaller vertical load would result in an overturning condition. A greater vertical load would be less critical for the leg structure.

Four basic analysis conditions are displayed in Figure 1.1: vertical 4 leg landing, vertical two diagonal leg landing, one leg side drift landing, and two leg side drift landing.

All the combinations of critical parameters for the flight conditions are shown in Table 1.2. Not shown in the table are the jet engine pitch and roll actuator loads which are superimposed on any condition. Either actuator can have a load of +3400 pounds, 0, or -3400 pounds except that in the extreme travel positions (40° tilt) the actuator load is only applied in a direction to return the engine to neutral.

An additional airload condition, not indicated in the table, is deployment of the recovery parachute. The maximum limit parachute load is 2500 pounds applied to any one bridle in any direction in which it is possible for one bridle only to be loaded.

Handling conditions are shown in Table 1.3. These have been made less severe than the flight or landing conditions. It is assumed that when the vehicle is transported it will be mounted on the trailer on the vehicle landing gear. It should be noted that the airframe truss members are not designed to bear the weight of a man standing on any member.

Two design weight configurations are used in the structural design and analysis: 3400 pounds and 2600 pounds. These are considered to be maximum and minimum landing weight respectively. The 3400 pound weight represents a vehicle that has consumed some fuel in taking off and maneuvering into position to land. It is assumed that normal landings will be made after appreciable time in flight. Any landings made after flights of short duration, with a vehicle weight greater than 3400 pounds, must be done at less than design velocities. The 2600 pound weight represents a vehicle with some equipment offloaded and most of the fuel consumed. The maximum weight of 3400 pounds is used to establish the design ground reactions based on the conditions listed in Table 1.1. These design ground reactions are critical for the landing gear, legs, and portions of the center body structure. To take advantage of this strength at the lighter vehicle weight (which will exist for most landings) the same design ground reactions are used for the 2600 pound vehicle to determine the design load factors for the portions of the structure which are critical for inertia loadings. These higher load factors for the 2600 pound weight are also listed in Table 1.1.

Additional load factors to those listed are applied to special portions of the vehicle. In order to insure that the fuel tanks will remain with the airframe in a crash which is severe enough to collapse the leg structure, the tank mounts are designed for a vertical limit load factor of 8.5. For a similar reason the seat support structure is designed for a limit load factor of 13.33 applied in any direction between vertical and 20° from vertical. Other design conditions for the seat support are shown in Figure 1.2.

Design ultimate loads for the airframe are 1.5 times limit loads.

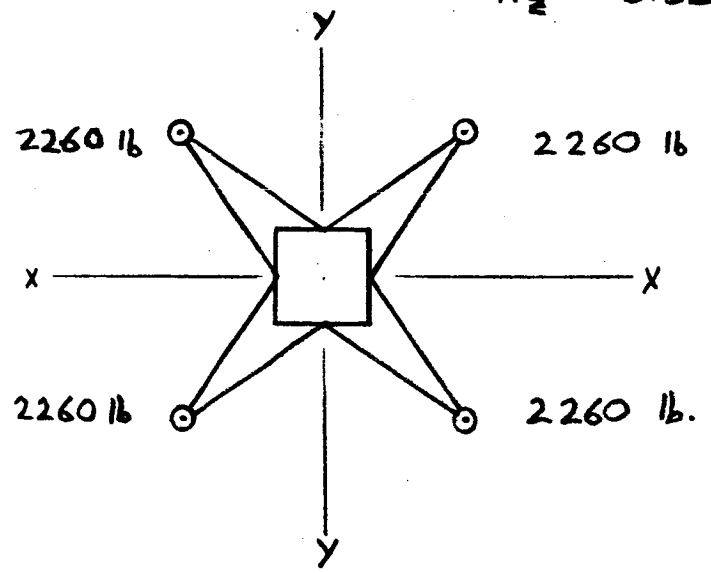
TABLE 1.1

LANDING CONDITIONS

CONDITION	VERTICAL					SIDE DRIFT			
LEGS	FOUR LEG			TWO LEG		ONE LEG		TWO LEG	
WEIGHT	3400	2600	2600	3400	2600	3400	2600	3400	2600
LIFT	2267	1733	4000	2267	1733	2267	1733	2267	1733
VELOCITY									
VERTICAL	10	10	10	6	6	6	6	6	6
HORIZONTAL	—	—	—	—	—	3	3.4	3	3.4
STRUT LOAD									
VERTICAL	2260	2260	1690	2260	2260	1260	1260	1260	1260
LONGITUDINAL	—	—	—	—	—	1200	1200	1200	1200
LATERAL	—	—	—	—	—	1200	1200	—	—
LOAD FACTOR									
n_z	3.33	4.14	4.14	2.00	2.40	1.04	1.15	1.41	1.64
n_x	—	—	—	—	—	.35	.46	.71	.92
n_y	—	—	—	—	—	.35	.46	—	—

FOUR LEG VERTICAL LANDING (V_s = 10 ft/sec)

n_z = 3.33



TWO LEG VERTICAL LANDING (V_s = 6 ft/sec)

n_z = 2.00

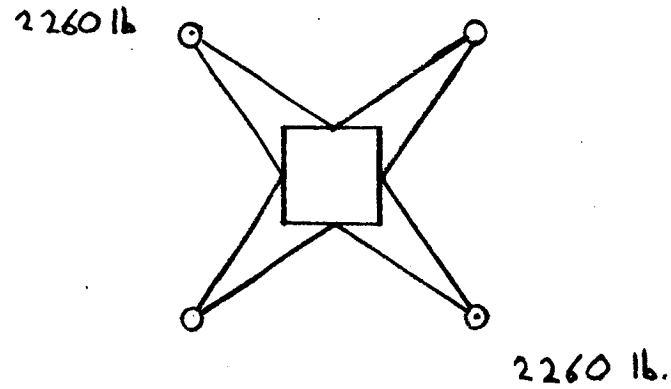
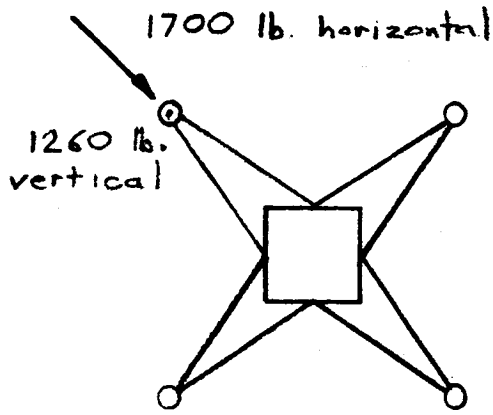


Figure 1.1. Airframe Design Load Conditions (Sheet 1 of 2)

ONE LEG SIDE DRIFT LANDING (V_d = 3 ft/sec)

n_x = .50



TWO LEG SIDE DRIFT LANDING (V_d = 3 ft/sec)

n_x = .71

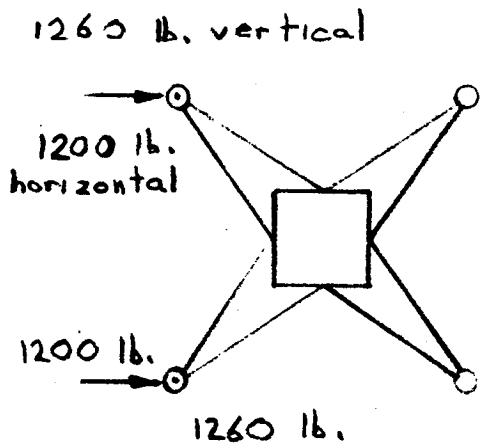


Figure 1.1. Airframe Design Load Conditions (Sheet 2 of 2)

TABLE 1.2

FLIGHT CONDITIONS

VEHICLE WEIGHT	ENGINE THRUST		ENGINE TILT		LIMIT LOAD FACTOR		
	JET	ROCKET	PITCH	ROLL	n_z	n_x	n_y
3400	4200	0	0	0	1.23	—	—
			±40°	0	.95	±.80	—
			0	±40°	.95	—	±.80
			±40°	±40°	.73	±.65	±.80
3400	4200	4000	0	0	2.40	—	—
			±40°	0	2.12	±.80	—
			0	±40°	2.12	—	±.80
			±40°	±40°	1.91	±.65	±.80
3400	0	4000	0	0	1.18	—	—
			±40°	0	1.18	—	—
			0	±40°	1.18	—	—
			±40°	±40°	1.18	—	—
2600	4200	0	0	0	1.61	—	—
			±40°	0	1.24	±1.04	—
			0	±40°	1.24	—	±1.04
			±40°	±40°	.96	±.80	±1.04
2600	4200	4000	0	0	3.16	—	—
			±40°	0	2.78	±1.04	—
			0	±40°	2.78	—	±1.04
			±40°	±40°	2.49	±.80	±1.04
2600	0	4000	0	0	1.54	—	—
			±40°	0	1.54	—	—
			0	±40°	1.54	—	—
			±40°	±40°	1.54	—	—

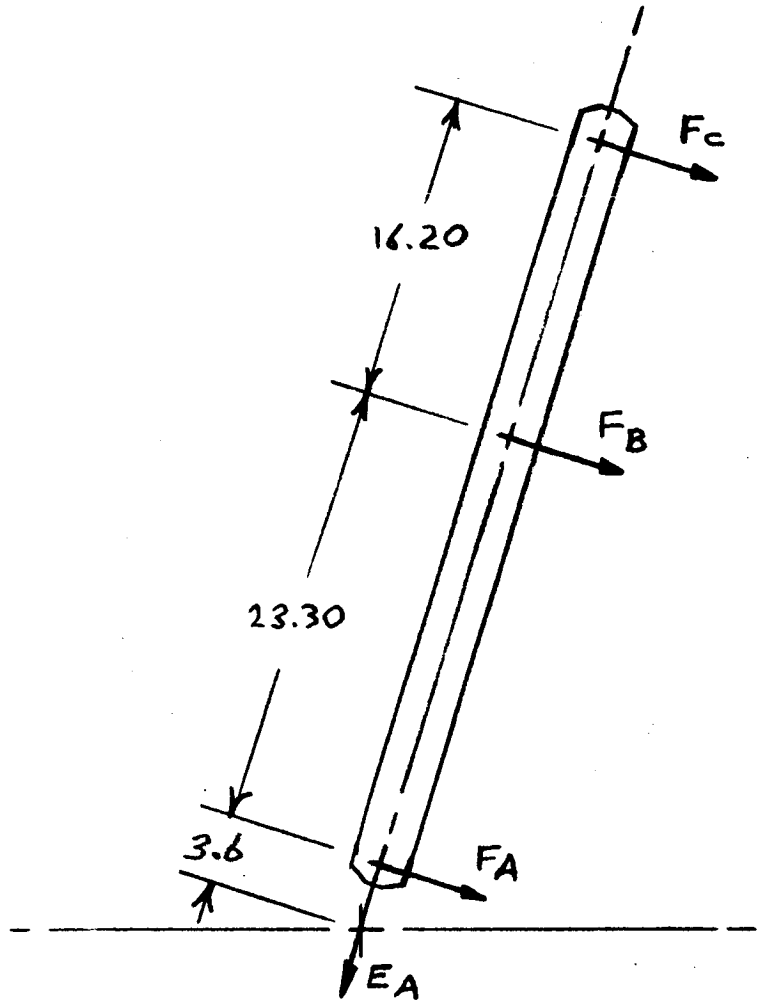
TABLE 1.3

HANDLING CONDITIONS

CONDITION	WEIGHT	LOAD FACTORS		ENGINE THRUST	
		VERTICAL	HORIZONTAL	JET	ROCKET
TOWING	3400	2.0	.71	—	—
HOISTING	3400	2.0	0	—	—
JACKING	3400	1.5	0	—	—
TIEDOWN	3400 to 2600	1.0	*	4200	4000

* ENGINE MAY BE TILTED ON GIMBALS TO THE LIMIT OF THE ACTUATORS IF GUY WIRES ARE ATTACHED AT EACH TIE DOWN FITTING ON THE VEHICLE LEGS TO REACT THE LATERAL COMPONENT OF THRUST. WITHOUT GUY WIRES THE TIE DOWN LINKS ARE SUFFICIENT FOR VERTICAL LOADS ONLY.

THE LOADS SHOWN ARE EACH SEAT RAIL ACTING ON THE SEAT SUPPORT STRUCTURE.

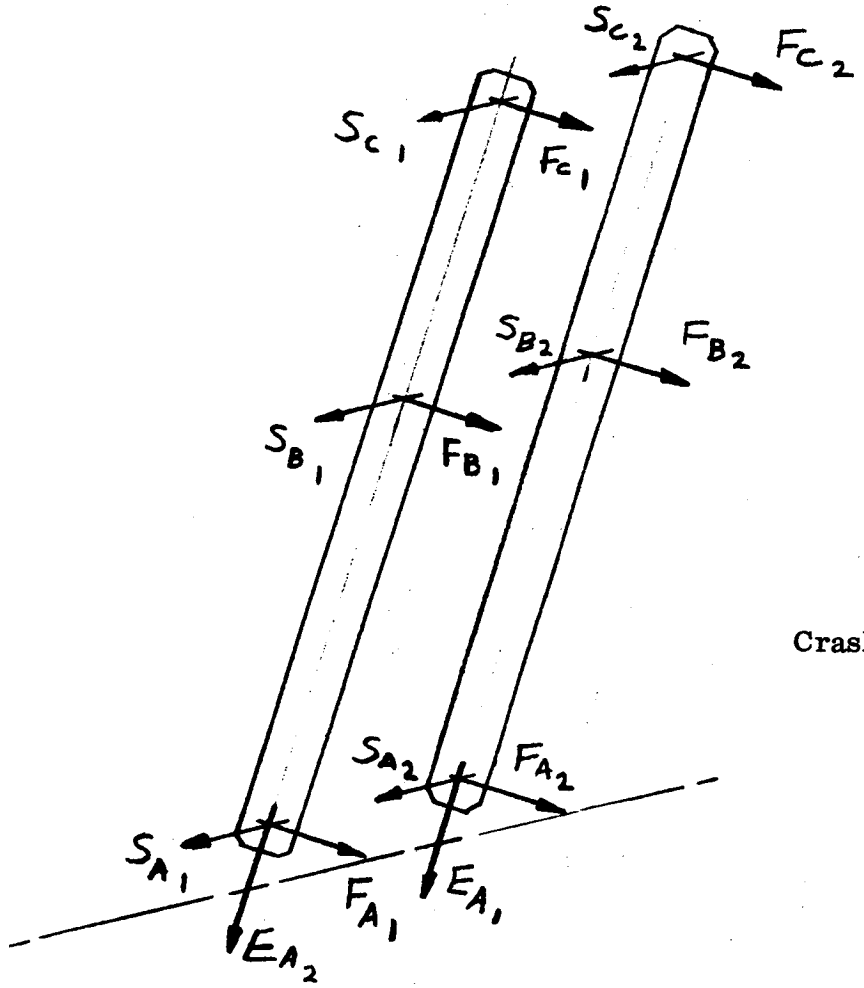


Ejection Loads

CONDITION	E_A	F_A	F_B	F_C
EJECTION (2A)	4083	2805	-2860	+55
EJECTION (2B)	4083	1335	2030	-3365

Figure 1.2. Seat Support Structure Loads (Sheet 1 of 2)

THE LOADS SHOWN ARE ACTING ON THE STRUCTURE



Crash Loads

Condition	Vertical	Side		Fwd	Aft
Rail	Each	1	2	Each	Each
F_C	774	1527	-83	940	-1513
S_C	0	-145	-145	0	0
F_B	1253	6139	-3781	235	2124
S_B	0	1007	1007	0	0
F_A	-1152	-1794	-358	-1329	1160
S_A	0	163	163	0	0
E_A	2875	2687	2687	2995	2400

Figure 1.2. Seat Support Structure Loads (Sheet 2 of 2)

SECTION 2

COCKPIT SECTION

The primary structure of the cockpit consists of a platform supported by truss members attached to the center body at four points. The main members of the platform are two longitudinal side rails and several transverse beams under the floor. Weight items are supported by the beams which are supported by the side rails. The side rails beam the loads to the truss members. Design loads result from inertia conditions, control forces, and seat ejection. Pitching moments from the seat are not applied to the cockpit structure but are applied to a separate seat support structure.

2.1. LOAD FACTORS

LOAD	LANDING CONDS.				FREE FLIGHT CONDS.				
	1	2	3	4	5	6a	6b	7a	7b
N_x	—	—	0.46	0.92	—	1.04	1.04	0.80	0.80
				OR		OR	OR		
N_y	—	—	0.46	0.92	—	1.04	1.04	1.04	1.04
N_z	4.14	4.14	1.15	1.64	3.16	1.24	2.78	0.96	2.49

NOTE: ALL FACTORS SHOWN ARE LIMIT. SEE CRITERIA SECT. FOR LOAD FACTOR DEVELOPMENT. IN FREE FLIGHT CONDITION, LOADS 6 & 7 ARE SUBDIVIDED INTO a & b LISTINGS. THESE SUBDIVISIONS INDICATE EITHER,

a. ROCKET ENGINES INOPERATIVE

OR,

b. ROCKET ENGINES OPERATIVE

2.2. PRINCIPAL COCKPIT ITEMS: WEIGHTS & LOCATIONS

ITEM		WEIGHT (lbs.)	CENTROID COORDS.		
NO.	DESCRIPT.		X	Y	Z
1	PILOT, SEAT, & BRACE	320	122.0	200.0	213.5
2*	PEDESTAL	60	89.3	196.5	210.0
3	CONSOLE	25	112.0	182.0	197.0
4	OXYGEN BOTTLE	9.3	119.0	213.0	194.8
5	PEDAL ASSEMBLY	5	89.3	200.0	195.5
6	STICK	1.5	105.0	200.0	197.0
7	WINDSHIELD	41.5	102.4	200.0	223.0

* PEDESTAL PROVIDED & INSTALLED BY N.A.S.A

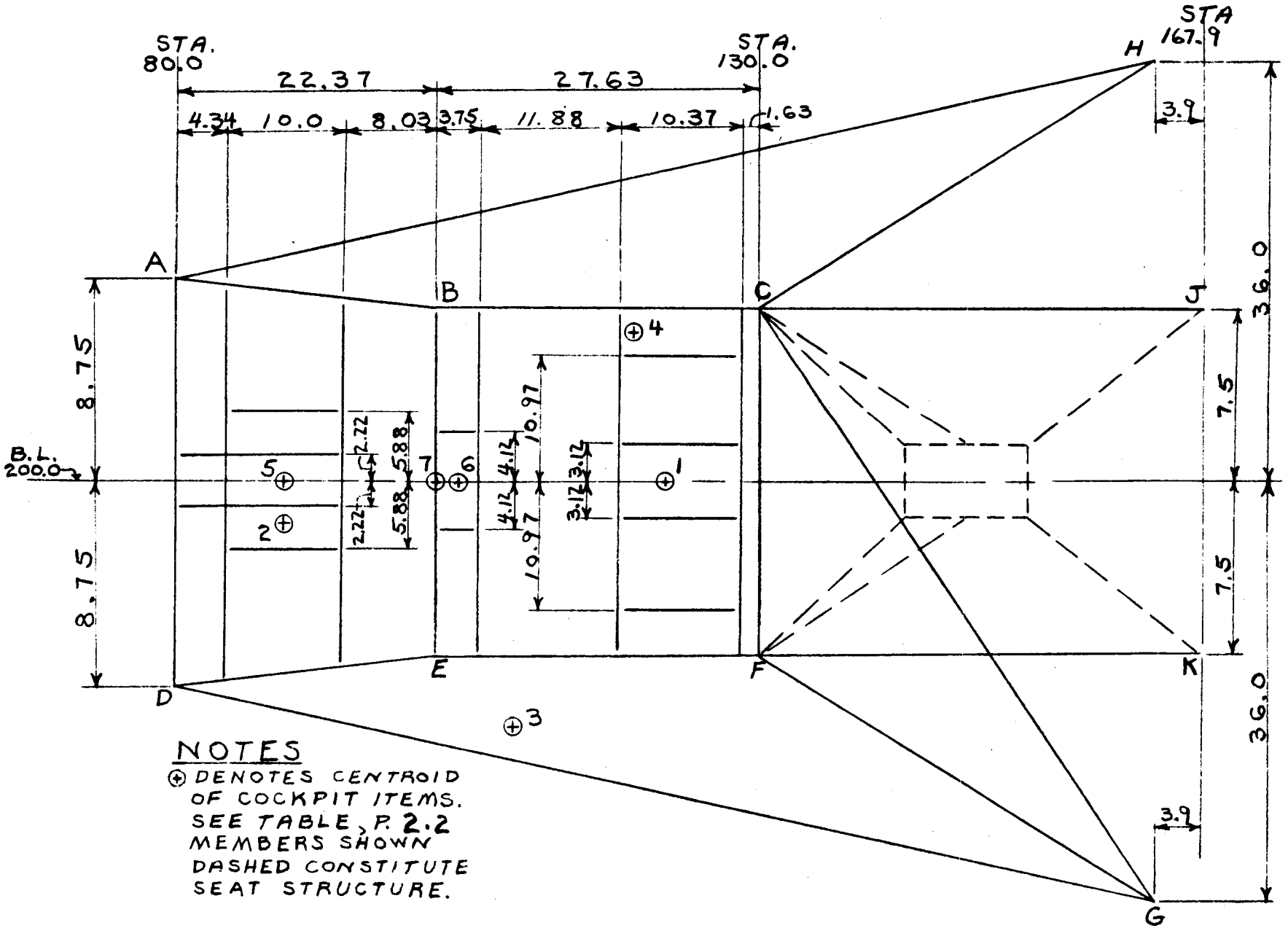


Figure 2.1. Cockpit Structure Plan View

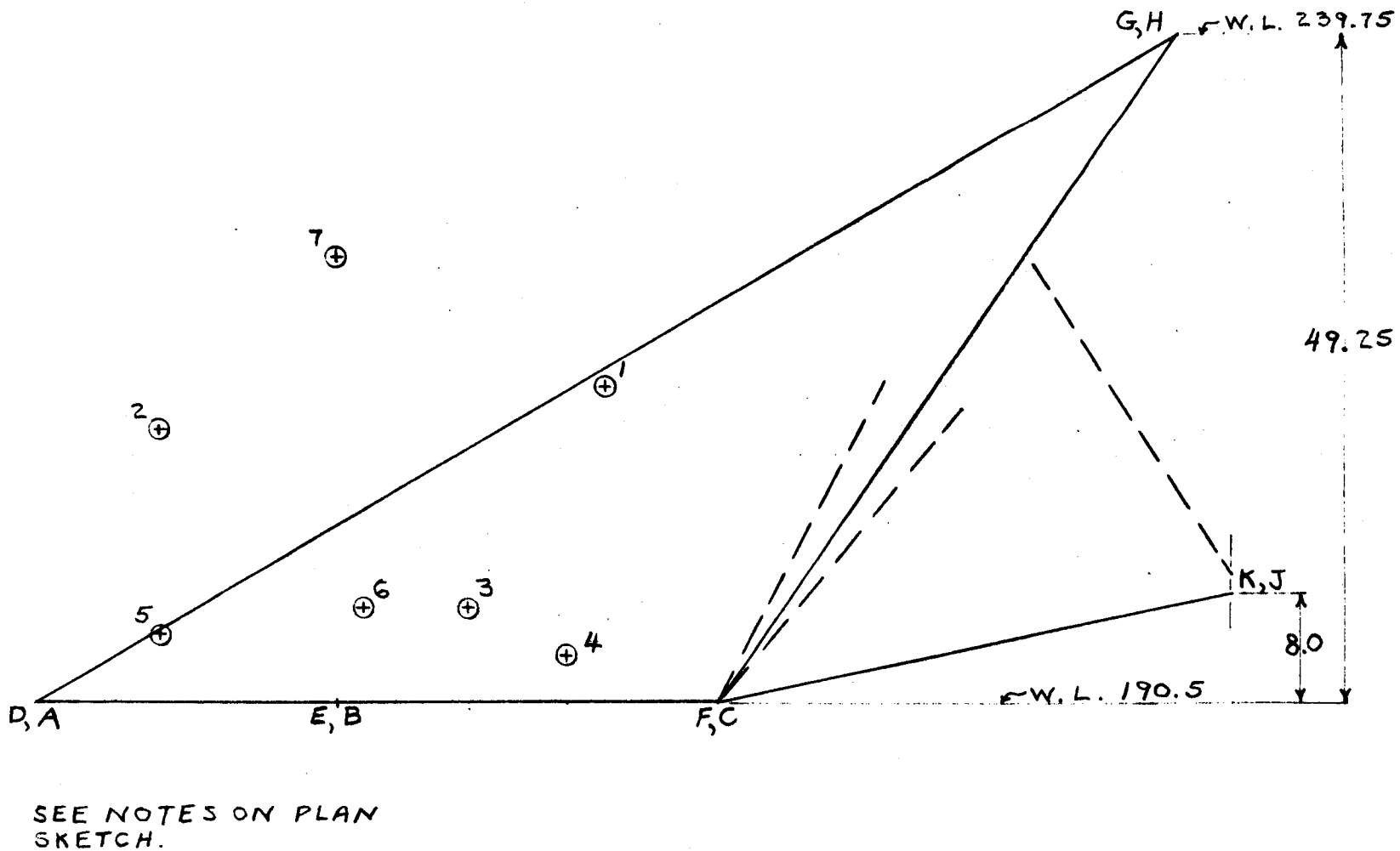


Figure 2.2. Cockpit Structure Elevation

2.3. COCKPIT FLOOR BEAMS

(MATERIAL IS 2024-T4 THROUGHOUT)

BEAMS @ STA 80.0 & STA 118.0 ARE NOMINALLY LOADED AND SERVE AS POINTS OF TERMINATION FOR SHEAR TRANSFER MEMBERS.

BEAMS @ STA. 84.34 & 94.34

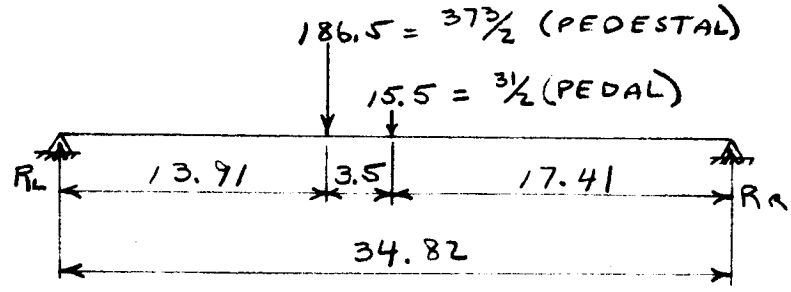
CONDITION 1 OR 2 CRITICAL

$N_z = 4.14 \times 1.5 = 6.21$ ULT.

PEDESTAL LOAD $= 6.21 \times 60 = 373^{\#}$

PEDAL LOAD $= 6.21 \times 5 = 31^{\#}$

BEAM SPAN @ STA. 84.34 LONGER THAN BEAM SPAN @ STA. 94.34. SINCE LOADS ARE EQUAL FOR TWO BEAMS, ANALYZE LONGER MEMBER.



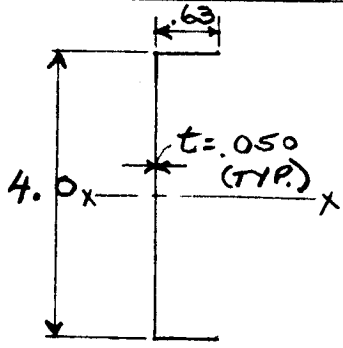
$\Sigma M_{R_R} = 0$

$$15.5(17.41) + 186.5(20.91) - 34.82 R_L = 0$$

$$R_L = \frac{270 + 3900}{34.82} = 120^{\#}$$

$$M_{max} = 120 \times 13.91 = 1670 \text{ IN. } \#$$

BEAM SECT.



$$I_{x-x} = \frac{.63 \times (4)^3}{12} - \frac{.58 \times (3.9)^3}{12}$$

$$= 0.491 \text{ IN}^4$$

$$f_b = \frac{Mc}{I} = \frac{1670\,(2.0)}{0.491} = 6800 \text{ PSI}$$

M.S. = HIGH

BEAMS @ STA. 84.34 & 94.34 (CONT.)

CHECK M.S. FOR 20 g VERTICAL CONDITION

$$M_{max.} = \frac{20}{6.21}(1670) = 5380 \text{ IN.\#}$$

$$f_b = \frac{Mc}{I} = \frac{5380\,(2.0)}{0.491} = 21900 \text{ PSI.}$$

$$\text{FLANGE } b/t = \frac{0.63}{0.05} = 12.6$$

$$f_{bcr} = 22000 \text{ PSI (REF. B.S.M., FIG. 80.04.2-3)}$$

$$M.S. = \frac{1}{\frac{21900}{22000}} - 1 = .005$$

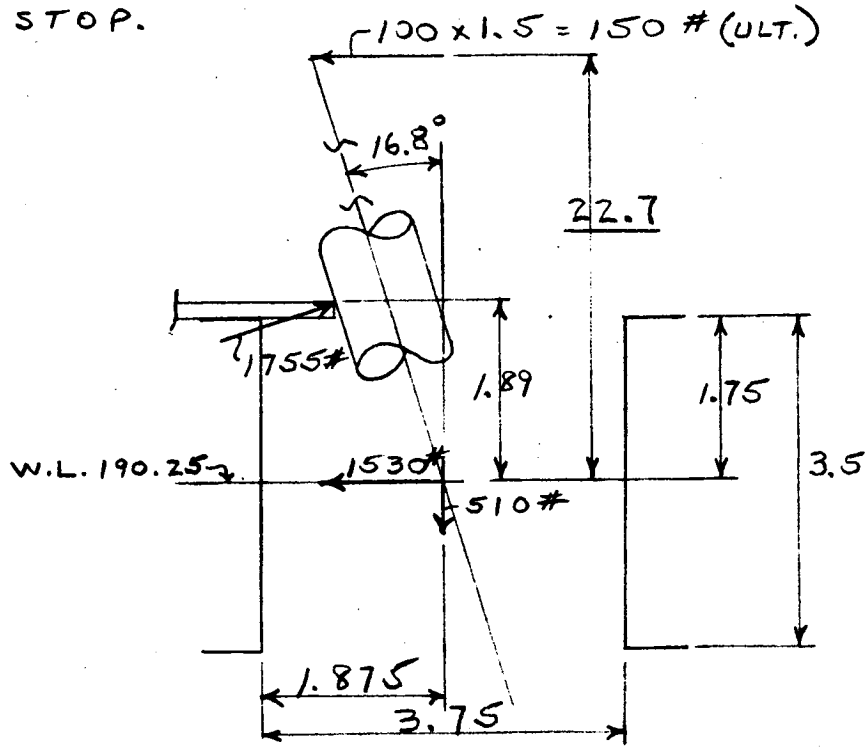
BEAMS @ STA. 102.37 & 106.12

CRITICAL LOAD FOR THESE MEMBERS DEVELOPS FROM PILOT STICK EFFORT.

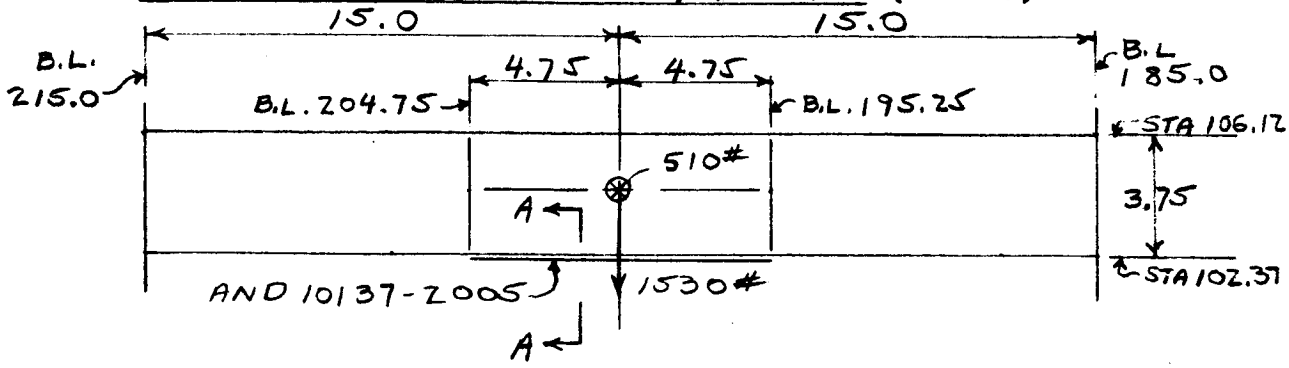
STICK LOADS:

FORE & AFT = 100# } LIMIT
SIDE = 67#

BEAMS TAKE MAX. LOAD WHEN STICK HITS STOP.



BEAMS @ STA. 102.37 & 106.12 (CONT.)

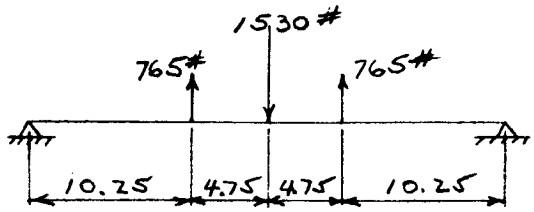


510# LOAD DIVIDES BETWEEN STAS. 102.37 & 106.12. LOAD IS BEAMED TO LONGITUDINAL MEMBERS @ B.L.'s 185.0 & 215.0.

DUE TO BEARING FITS, 1530# THRUST LOAD MUST ENTER STRUCTURE @ STA. 102.37. LOAD IS SHEARED INTO FLOOR PLATE BETWEEN B.L.'s 195.25 & 204.75.

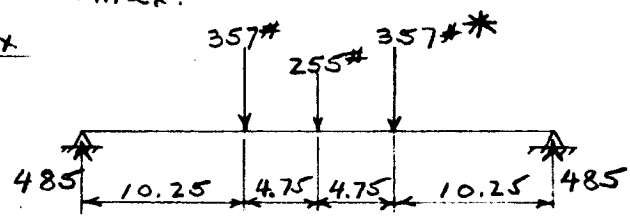
ANALYZE BEAM @ STA. 102.37 FOR ULT. FWD. LOAD

M_{z-z}



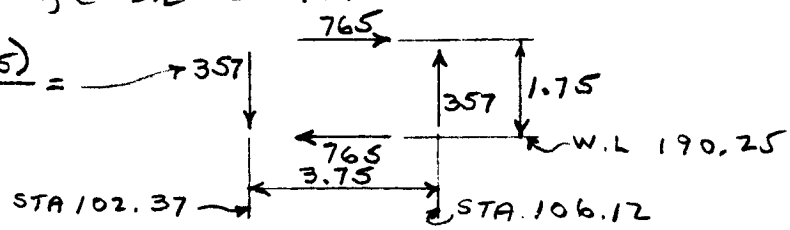
$M_{z-z\,max.} = 765 \times 4.75 = 3640$ IN.#

M_{x-x}



* LOAD IS HALF OF COUPLE CREATED WHEN 1530# LOAD IS ASSUMED REACTED BY FLOOR PLATE SHEAR @ B.L.'s 195.25 & 204.75. i.e., @ B.L 204.75:

$$\frac{765\,(1.75)}{3.75} = 357$$

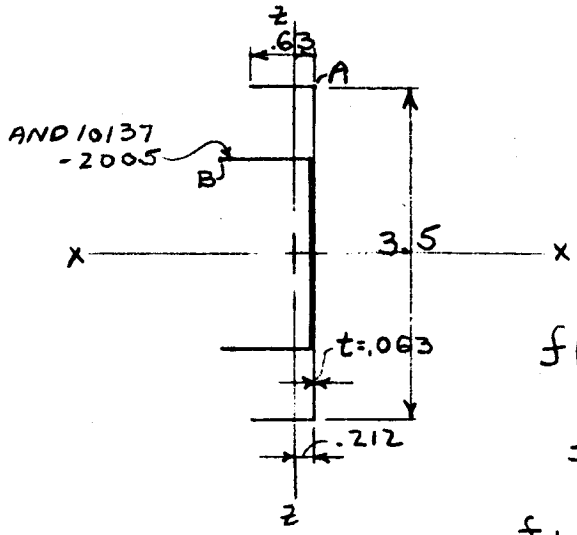


BEAMS @ STA. 102.37 & 106.12 (CONT.)

$M_{x-x\,max} = 485 \times 10.25 + 128 \times 4.75$

$= 4970 + 608 = 5578$ IN.#

BEAM SECT.



$I_{x-x} = .715\ IN^4$

$I_{z-z} = .054\ IN^4$

$f_{b_{x-x}} = \frac{Mc}{I} = \frac{5578(1.75)}{.715}$

$f_{b_{x-x}} = 13650$ PSI

$f_{b_{z-z}} = \frac{Mc}{I} = \frac{3640(.212)}{.054}$

$f_{b_{z-z}} = 14300$ PSI

COMBINED BENDING STRESS MAX. @ PT. A

$f_{b\,max} = 13650 + 14300 = 27950$ PSI.

FLANGE $b/t = \frac{.63}{.063} = 10$

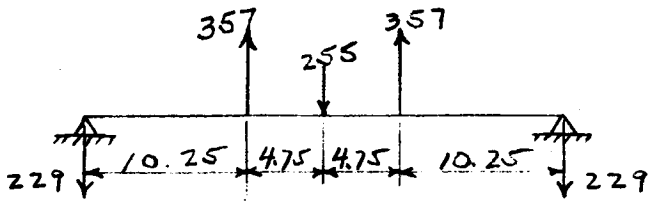
$f_{b\,cr} = 36000$ PSI (ACROSS ENTIRE FLANGE)

M.S. = HIGH

ANALYZE BEAM FOR ULT. AFT LOAD

$M_{z-z\,max} = 3640$ IN.# (SAME AS ABOVE)

M_{x-x}



$M_{x-x\,max} = 229 \times 10.25 = 2350$ IN.#

BEAMS @ STA. 102.37 & 106.12 (CONT.)

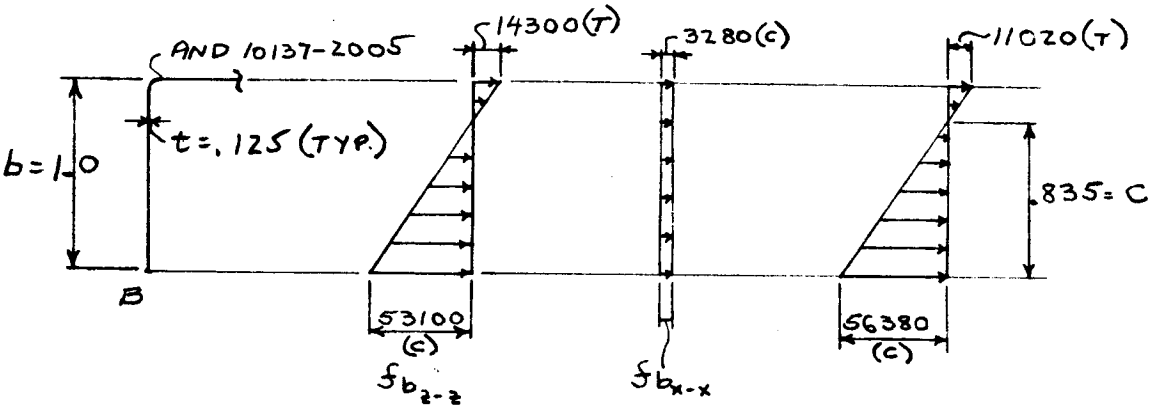
$$f_{b_{z-z}} = \frac{Mc}{I} = \frac{3640\,(.788)}{.054} = 53100 \text{ PSI}$$

$$f_{b_{x-x}} = \frac{Mc}{I} = \frac{2350\,(1.75)}{.715} = 5750 \text{ PSI}$$

COMBINED BENDING STRESS MAX. @ PT. B

$$f_{b_{x-x_B}} = \frac{1.0}{1.75}(5750) = 3280 \text{ PSI}$$

STRESS ACROSS FLANGE OF AND 10137-2005:



(REF. B.S.M., FIG. 120.02-6)

$$\alpha = b/c = \frac{1.0}{.835} = 1.2$$

$$K_b = 0.575$$

$$f_{b_{cr}} = \frac{K_b \pi^2 \eta E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2, \quad \eta = 1.0$$

$$f_{b_{cr}} = \frac{0.575\,\pi^2\,(10^7)}{10.92}\left(\frac{.125}{1.0}\right)^2$$

$$f_{b_{cr}} = 81300 \text{ PSI}$$

$$M.S. = \frac{81300}{56380} - 1.0 = 0.44$$

2.4. MEMBERS ABC & DEF (SEE FIG. 2.1.)

FOR ANALYSIS, ASSUME MEMBERS ARE STRAIGHT OVER ENTIRE L = 50 IN.

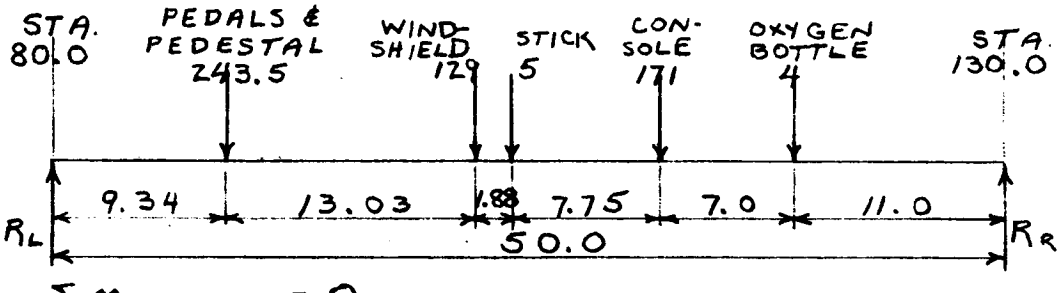
CONDITION 1 OR 2 CRITICAL

$N_z = 4.14 \times 1.5 = 6.21$ (ULT.)

BEAM COCKPIT ITEMS ② THRU ⑦ TO L. OR R. BEAM, ITEM ① CARRIED BY SEAT SUPPORT STRUCTURE.

ITEM	$N_z \times$ WT.	$R_{B.L.185.0}$	$R_{B.L.215.0}$
② PEDESTAL	373	228	145
③ CONSOLE	155	171	- 16
④ OXYGEN BOTTLE	58	4	54
⑤ PEDALS	31	15.5	15.5
⑥ STICK	10	5	5
⑦ WINDSHIELD	258	129	129

ANALYZE MEMBER DEF (B.L. 185.0) SINCE ALL LOADS ACT IN POSITIVE DIRECTION



$\Sigma M_{STA.130.0} = 0$

$$4(11) + 171(18) + 5(25.75) + 129(27.63) + 243.5(40.66) - 50 R_L = 0$$

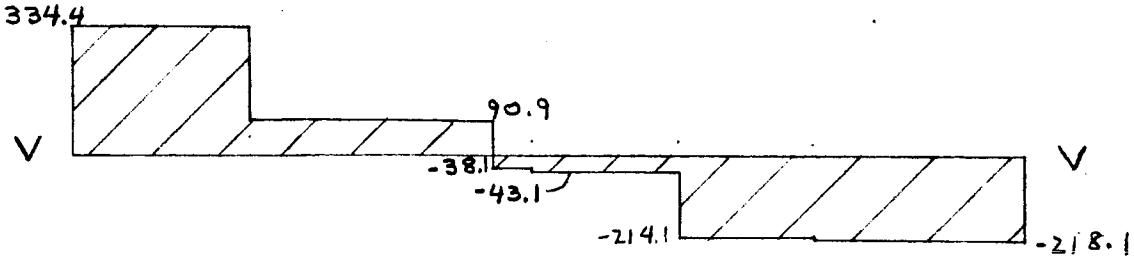
$$R_L = \frac{44 + 3080 + 129 + 3565 + 9900}{50}$$

$$R_L = 334.4 \#$$

MEMBERS ABC & DEF (CONT.)

$\Sigma F_z = 0$

$R_R = 218.1\#$



$M_{max} = 334.4(9.34) + 90.9(13.03)$

$= 3120 + 1180 = 4300$ IN.#

REACTION @ STA. 80.0 PROVIDED BY MEMBER AH.

DIRECTION COSINES OF AH

$= .84i + .223j + .498k$

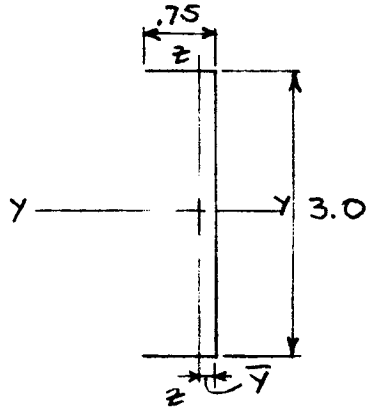
$AH = \frac{334.4}{.498} = 672\#$ (T)

∴ AXIAL FORCE IN ABC DUE TO TENSION IN AH

$= 672(.84) = 565\#$ (C)

ANALYZE MEMBER AS BEAM-COL.

BEAM SECT.



$I_{Y-Y} = 0.33\ IN^4$

$\bar{Y} = 0.108$ IN.

$I_{Z-Z} = .0104\ IN^4$

$r_{min} = \sqrt{\frac{I_{Z-Z}}{A}}$

$= \sqrt{\frac{.0104}{.276}} = 0.194$

$L/r = \frac{11.88}{.194} = 61.2$

$F_{co} = F_{cy}\left(1 + \frac{\sqrt{F_{cy}}}{1000}\right) = 36000\left(1 + \frac{\sqrt{36000}}{1000}\right)$

$F_{co} = 36000(1.189) = 42800$ PSI

MEMBERS ABC & DEF (CONT.)

TRANSITIONAL $L/\rho = 1.732\pi\sqrt{\frac{E}{F_{co}}}$

$= 83.2$ ∴ COL. IS SHORT

$$F_c = F_{co}\left[1 - 0.385\frac{(L/\rho)}{\pi\sqrt{E/F_{co}}}\right]$$

$$= 42800\left[1 - 0.385\left(\frac{61.2}{48}\right)\right]$$

$F_c = 21800$ PSI

FLANGE $b/t = \frac{.75}{.063} = 11.9$

$f_{b_{cr}} = 24500$ PSI

$$f_b = \frac{Mc}{I} = \frac{4300(1.5)}{0.33} = 19550 \text{ PSI}$$

$$f_c = P/A = \frac{565}{.276} = 2050 \text{ PSI}$$

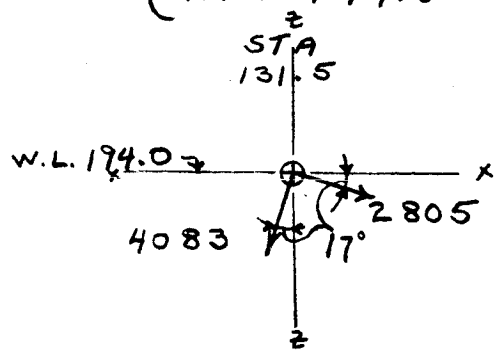
$$\frac{f_b}{f_{bcr}} + \frac{f_c}{F_c} = \frac{19550}{24500} + \frac{2050}{21800}$$

$$= .798 + .094 = 0.892$$

$$M.S. = \frac{1}{0.892} - 1 = 0.12$$

2.5. MEMBER CF

PILOT EJECTION CONDITION 2A CRITICAL LOADS INTRODUCED THROUGH SEAT RAILS @ $\begin{cases} \text{STA. } 131.5 \\ \text{B.L.'s } 197.0 \ \& \ 200.0 \\ \text{W.L. } 194.0 \end{cases}$



$F_x = 2805 \cos 17° - 4083 \sin 17°$

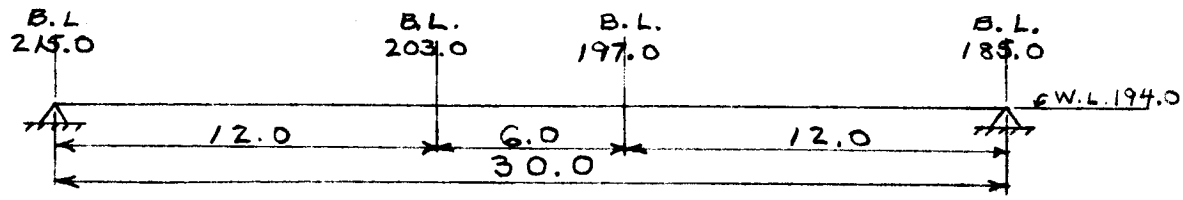
$= 2680 - 1190$

$F_x = 1490\#$

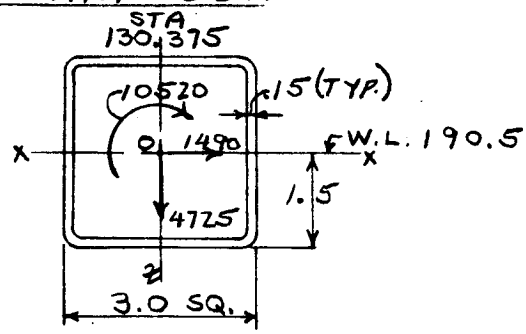
$F_z = 2805 \sin 17° + 4083 \cos 17°$

$= 820 + 3905$

$F_z = 4725\#$



BEAM SECT.



$I_{x-x} = I_{z-z} = \frac{(3)^4}{12} - \frac{(2.7)^4}{12}$

$= 2.33 \text{ IN}^4$

TRANSFER LOADS INDICATED ABOVE TO BEAM C.G.

$F_0 = 1490\,i - 4725\,k$

$r = 1.125\,i + 3.5\,k$

$M = r \times F = (1.125\,i + 3.5\,k) \times (1490\,i - 4725\,k)$

$M_0 = 5310\,j + 5210\,j = 10520\,j$

LOADS INDICATED ACT @ BEAM C.G. @ B.L.'S 197.0 & 203.0

MEMBER CF (CONT.)

1490# LOAD IN X DIRECTION DOES NOT CONTRIBUTE TO BENDING IN BEAM BUT IS SHEARED INTO FLOOR PLATE THROUGH ANGLES SPANNING LONGITUDINALLY BETWEEN MEMBER CF & BEAM @ STA. 118.0.

$R_{z\,B.L\,185.0} = R_{z\,B.L.\,215.0} = 4725\#$

$M_{z\text{-}z\,MAX.} = 4725\,(12.0) = 56700$ IN.#

$T = 10520$ IN.#

$q = \frac{T}{2A} + \frac{V}{2d}$

$A = (2.85)^2 = 8.12\ IN^2$

$d = 2.85$

$q = \frac{10520}{2(8.12)} + \frac{1490}{2(2.85)} = 648 + 262 = 910\#/IN$

$f_s = q/t = \frac{910}{.15} = 6070$ PSI

$f_b = \frac{Mc}{I} = \frac{56700\,(1.5)}{2.33} = 36500$ PSI

$b/t = \frac{2.85}{.15} = 19.0$

$f_{bcr} = f_{cy} = 40000$ PSI

$F_{st} = 39000$ PSI

$\left(\frac{f_s}{F_{st}}\right)^2 + \left(\frac{f_b}{f_{bcr}}\right)^2 \leq 1.0$

$\left(\frac{6070}{39000}\right)^2 + \left(\frac{36500}{40000}\right)^2 = .024 + .832 = 0.856$

$M.S. = \frac{1}{.856} - 1 = 0.17$

2.6 COCKPIT SUPPORT MEMBERS

(MATERIAL IS 6061-T6 THROUGHOUT)

CRITICAL LOAD FOR THESE MEMBERS DEVELOPS FROM PILOT EJECTION CONDITIONS AND CRASH CONDITIONS.

MEMBERS SHOWN DASHED IN FIGURE 2.1 AND FIGURE 2.2 ARE TO BE PROOF TESTED BY ACTUAL SEAT EJECTION BY NASA AND ARE NOT INCLUDED IN THIS ANALYSIS.

MEMBER	SIZE	LENGTH (IN.)	CRITICAL LOAD COND.	MAX. LOAD (ULT.)	ALLOW. LOAD
CH	1½ x .049	65	PILOT EJECT.	8170 T	9370
FG	1½ x .049	65	PILOT EJECT.	8170 T	9370
CJ	2 x .083	36	PILOT EJECT.	4350 C	13700
FK	2 x .083	36	PILOT EJECT.	4350 C	13700
CG	1¾ x .049	70.5	CRASH (L. OR R.)	1775 {C, T}	5190
AH	1½ x .035	74.3	CRASH DOWN	672 T	6770
DG	1½ x .035	74.3	CRASH DOWN	672 T	6770

SECTION 3
EQUIPMENT SECTION

The equipment support structure is adjustable to allow the center of gravity of the equipment to be positioned before each flight so as to achieve the proper balance of the entire vehicle. The adjustment is made possible by moving a large platform vertically on a supporting truss, and moving a small platform horizontally (longitudinal or lateral) on the large platform. Most of the equipment is mounted on the small platform. Indexing holes are provided on the small platform, to permit lateral movement, and on the large platform to permit longitudinal movement. The supporting truss is a composite of beams and axial loaded members. Indexing holes are provided in two vertical beams and two diagonal members to permit vertical movement of the large platform.

3.1. APPLIED LOADS

(FOR APPLICABLE LOAD FACTORS, SEE CRITERIA SECTION)

LOAD	LANDING CONDITION				FREE FLIGHT CONDITION				
	1	2	3	4	5	6a	6b	7a	7b
P_x	——	——	115	230	——	260	260	200	200
P_Y	——	——	115	230	——	260	260	260	260
P_z	1035	1035	288	410	790	310	695	238	614

NOTE: ALL LOADS ARE LIMIT

3.2. LOCATION OF LOADS

CASE I: (EQUIPMENT AT MAXIMUM AFT AND MINIMUM W.L. POSITION)

VERTICAL LOAD AT STATION 325 AND B.L. 203.25 OR BL 196.75
FORWARD LOAD AT W.L. 224 AND BL 203.25 OR BL 196.75
LATERAL LOAD AT WL 224 AND BL 203.25 OR BL 196.75

CASE II: (EQUIPMENT AT MAXIMUM FORWARD AND MAXIMUM W.L. POSITION.)

VERTICAL LOAD AT STATION 293 AND BL 203.25 OR BL 196.75
FORWARD LOAD AT W.L. 235 AND BL 203.25 OR BL 196.75
LATERAL LOAD AT W.L. 235 AND BL 203.25 OR BL 196.75

3.3. LOAD DISTRIBUTION

CASE I

$$P_{ZAL} = .534\,P_z + .556\,P_Y - .155\,P_x$$
$$P_{ZAR} = .344\,P_z - .556\,P_Y - .155\,P_x$$
$$P_{ZDL} = .074\,P_z + .078\,P_Y + .155\,P_x$$
$$P_{ZDR} = .050\,P_z - .078\,P_Y + .155\,P_x$$
$$P_{YDL} = .608\,P_Y \quad : \quad P_{YDR} = .392\,P_Y$$
$$P_{A'B'L} = 2.36\,P_{ZAL} \quad : \quad P_{A'B'R} = 2.36\,P_{ZAR}$$
$$P_{XDL} = .608\,P_x + 1.79\,P_Y + 2.04\,P_{ZAL}$$
$$P_{XDR} = .392\,P_x - 1.79\,P_Y + 2.04\,P_{ZAR}$$

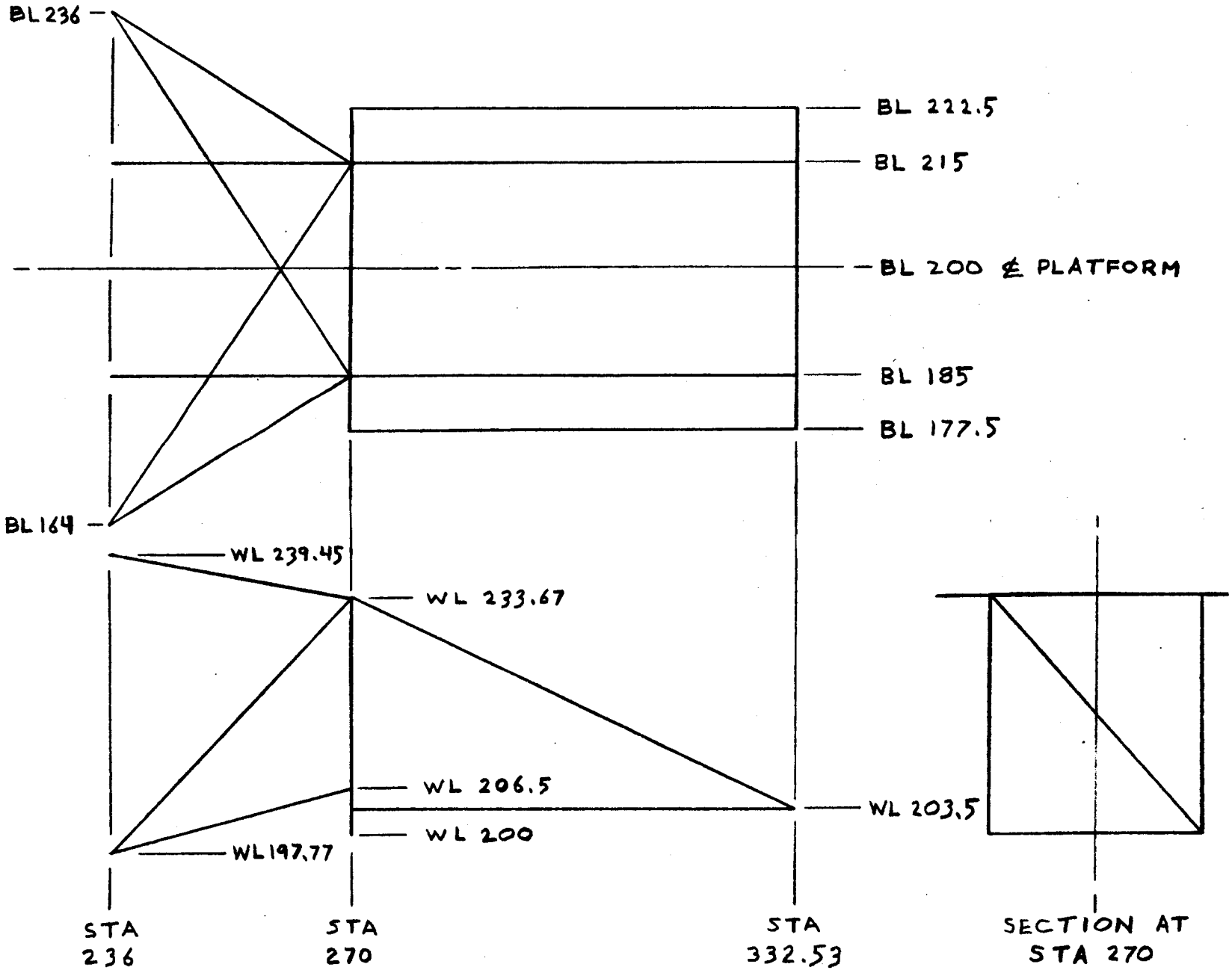


Figure 3.1. Equipment Section

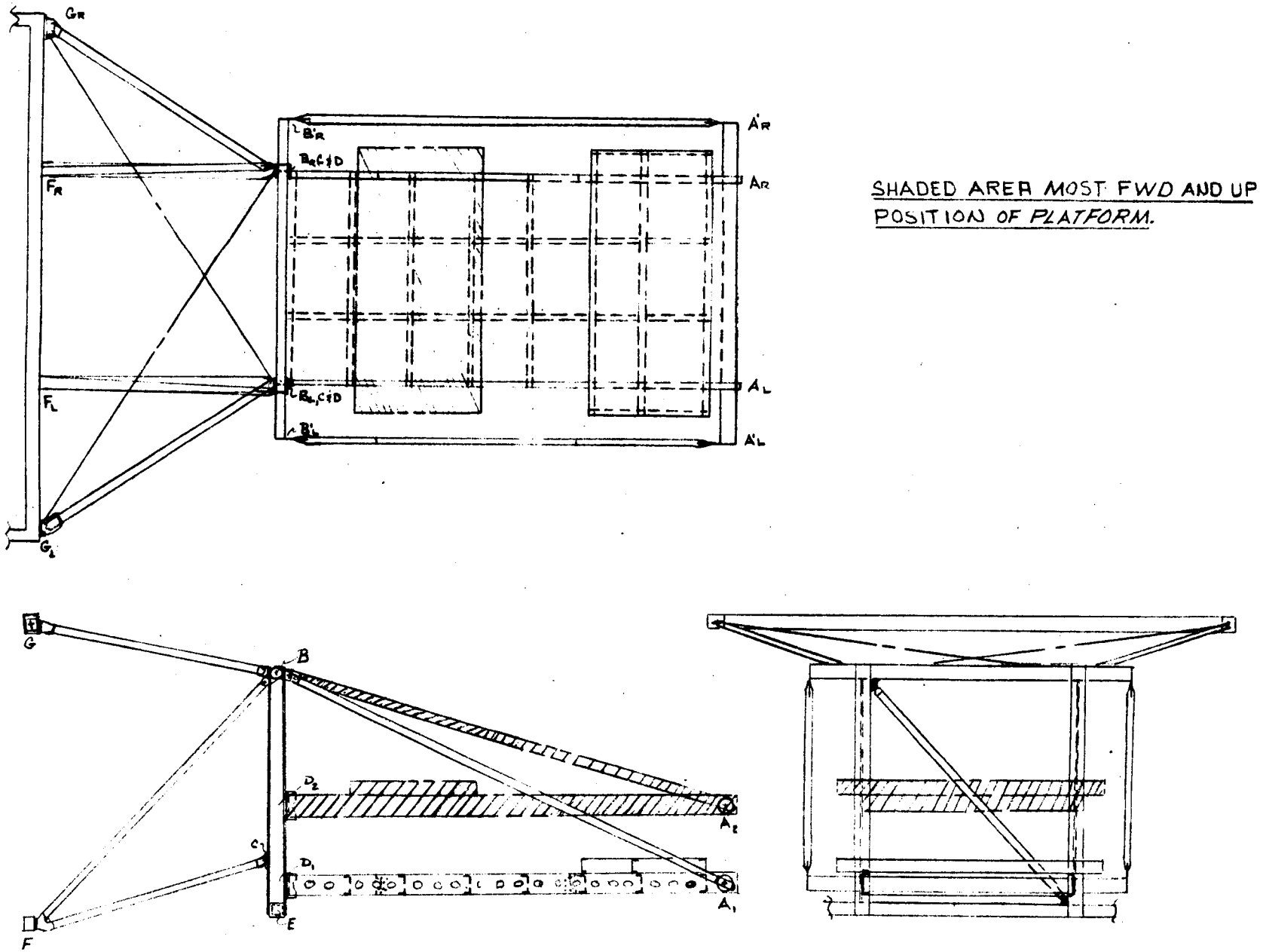


Figure 3.2. Equipment Section Platform Positions

LOAD DISTRIBUTION (CONT'D)

CASE II

$$P_{ZAL} = .216\,P_Z + .224\,P_Y - .155\,P_X$$

$$P_{ZAR} = .139\,P_Z - .224\,P_Y - .155\,P_X$$

$$P_{ZDL} = .392\,P_Z + .409\,P_Y + .155\,P_X$$

$$P_{ZDR} = .253\,P_Z - .409\,P_Y + .155\,P_X$$

$$P_{YDL} = .608\,P_Y \quad ; \quad P_{YDR} = .392\,P_Y$$

$$P_{A'B'L} = 3.56\,P_{AZL} \quad ; \quad P_{A'B'R} = 3.56\,P_{AZR}$$

$$P_{XDL} = .608\,P_X + .724\,P_Y + 3.41\,P_{ZAL}$$

$$P_{XDR} = .392\,P_X - .724\,P_Y + 3.41\,P_{ZAR}$$

PRELIMINARY ANALYSIS INDICATED CONDITIONS 2 (LANDING) AND 66 (FREE FLIGHT) ARE CRITICAL

LOAD	CASE I		CASE II	
	2	66	2	66
P_{ZAL}	552	476	224	168
P_{ZAR}	356	54	144	-1
P_{ZDL}	76	111	405	418
P_{ZDR}	51	55	262	110
P_{YL}	——	158	——	158
P_{YR}	——	102	——	102
$P_{A'B'L}$	1300	1120	800	600
$P_{A'B'R}$	840	127	514	-3
P_{XDL}	1125	1593	765	920
P_{XDR}	725	-253	491	-89

NOTE: ALL LOADS ARE LIMIT.

LOAD DISTRIBUTION (CONT'D)

FWD OF STATION 270.

CASE I

$P_{CF} = 1.143 P_{XD}$

$P_{BF} = .295 P_{AB} + 1.16 P_Y + 1.154 P_{ZD} - .356 P_{XD}$

$P_{BG} = .939 P_{AB} + .137 P_Y + .685 P_{ZD} - .117 P_{XD}$

$P_{B_LG_R} = 1.276 P_Y + .432 P_{ZD} + .598 P_{AB} - .074 P_{XD}$

$P_{EB} = 1.34 P_Y.$

CASE II

$P_{CF} = .726 P_{XD}$

$P_{BF} = .114 P_{AB} + .74 P_Y + 1.154 P_{ZD} - .281 P_{XD}$

$P_{BG} = .878 P_{AB} + .685 P_{ZD} - .114 P_Y - .332 P_{XD}$

$P_{B_LG_R} = 1.118 P_Y + .565 P_{AB} + .432 P_{ZD} - .21 P_{XD}$

$P_{EB} = .855 P_Y$

LOAD	CASE I		CASE II	
	2	66	2	66
P_{CFL}	1285	1820	555	670
P_{CFR}	825	-288	356	-65
P_{BFL}	72	73	344	411
P_{BFR}	49	308	222	227
P_{BGL}	1138	956	723	488
P_{BGR}	730	199	466	91
$P_{B_LG_R}$	786	802	465	503
P_{BRGL}	469	248	300	182
P_{EB}	——	348	——	222

NOTE: ALL LOADS ARE LIMIT.

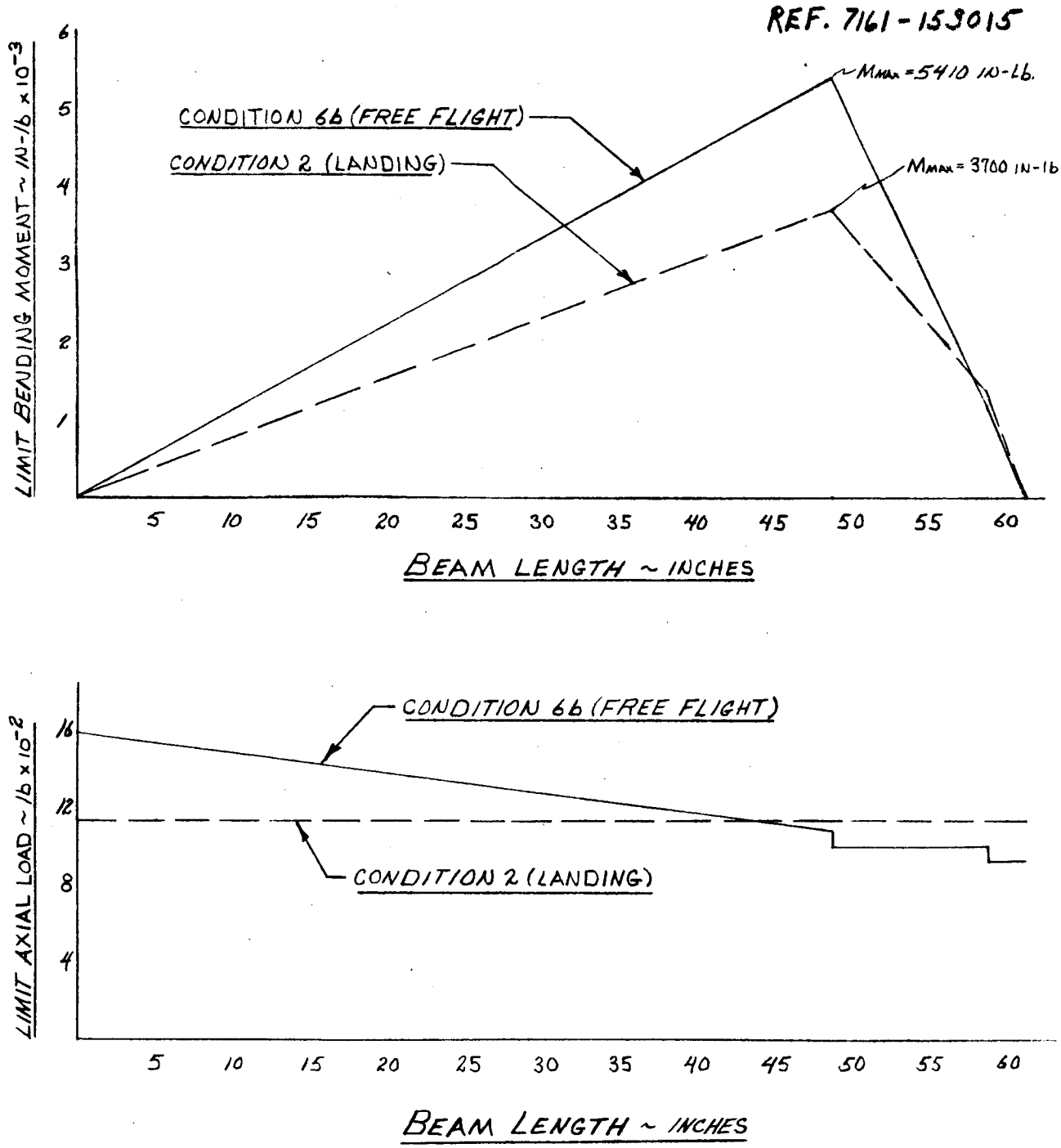


Figure 3.3. Horizontal Beam Member A-D Limit Bending Moment and Axial Load (Left Side Case I)

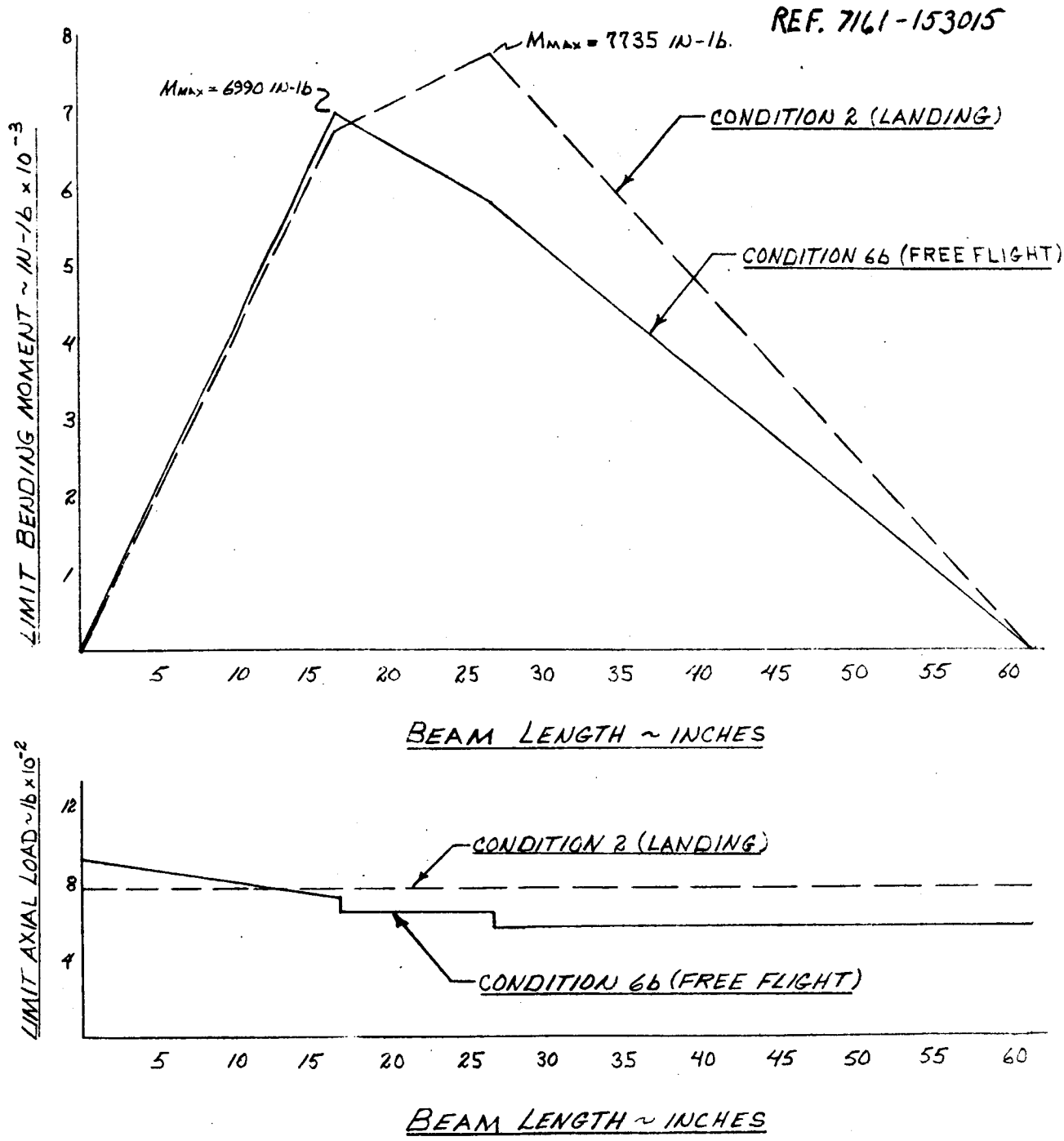


Figure 3.4. Horizontal Beam Member A-D Limit Bending Moment and Axial Load (Left Side Case II)

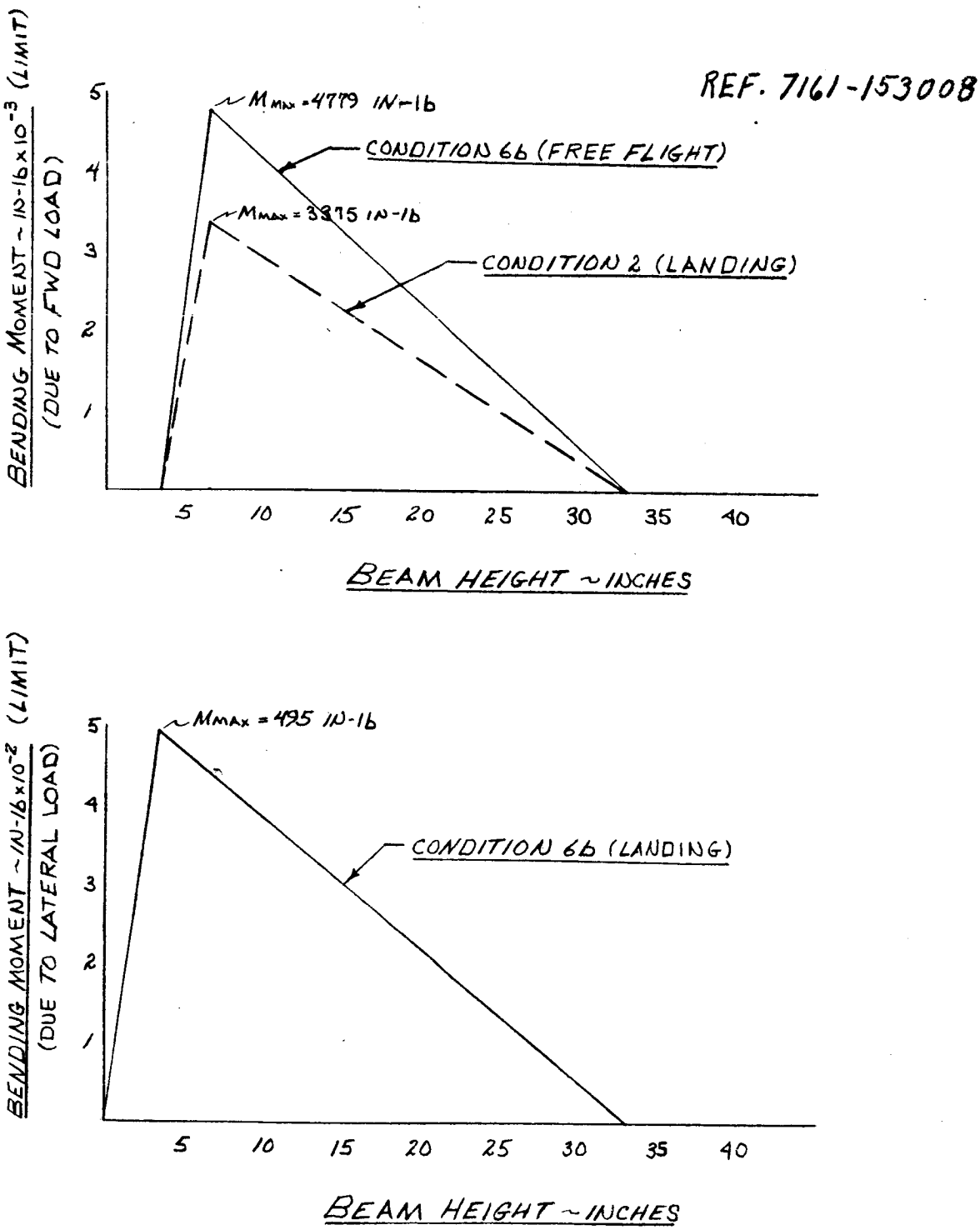


Figure 3.5. Vertical Beam Member BDE Limit Bending Moment (Left Side Case I)

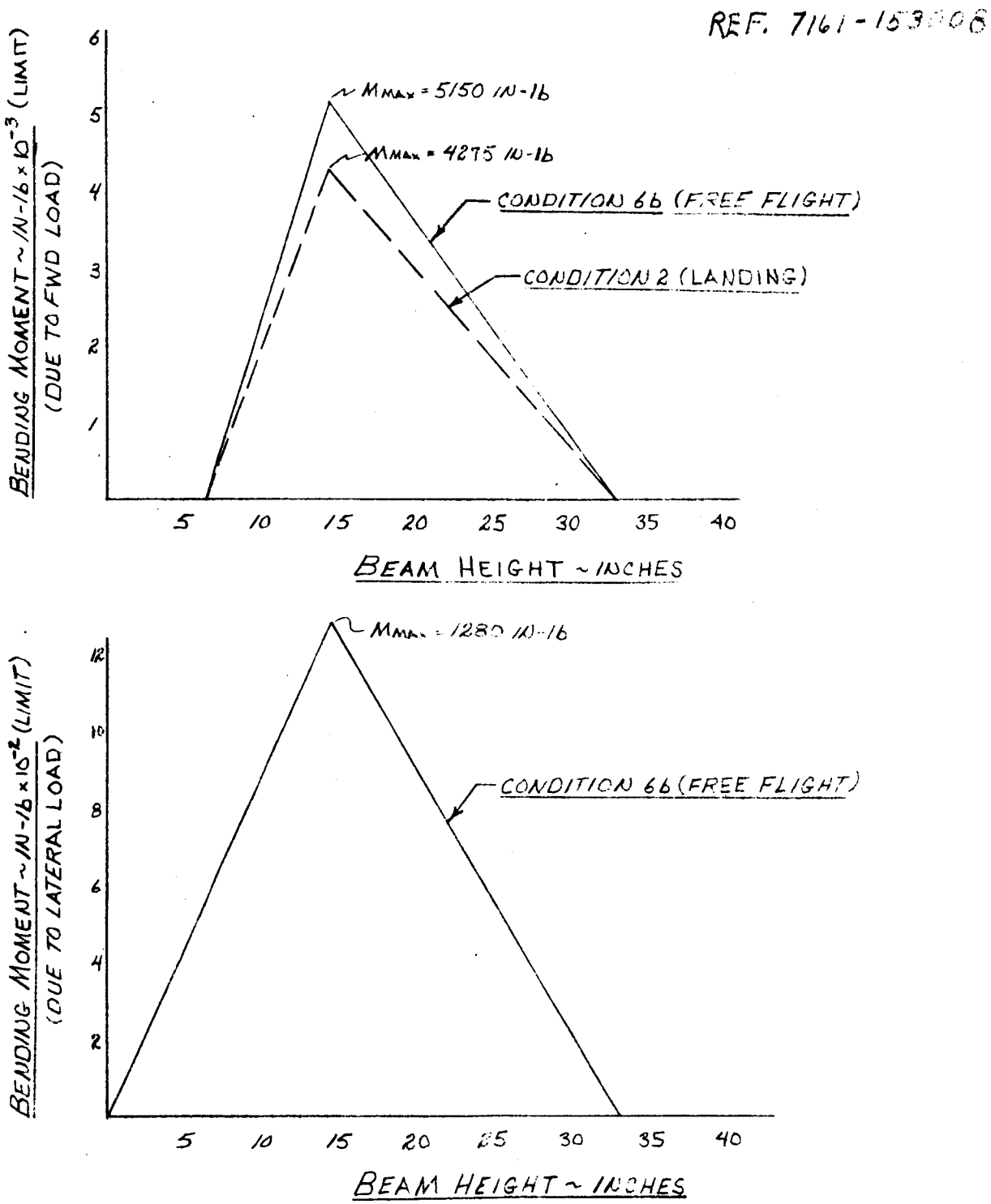


Figure 3.6. Vertical Beam Member BDE Limit Bending Moment (Left Side Case II)

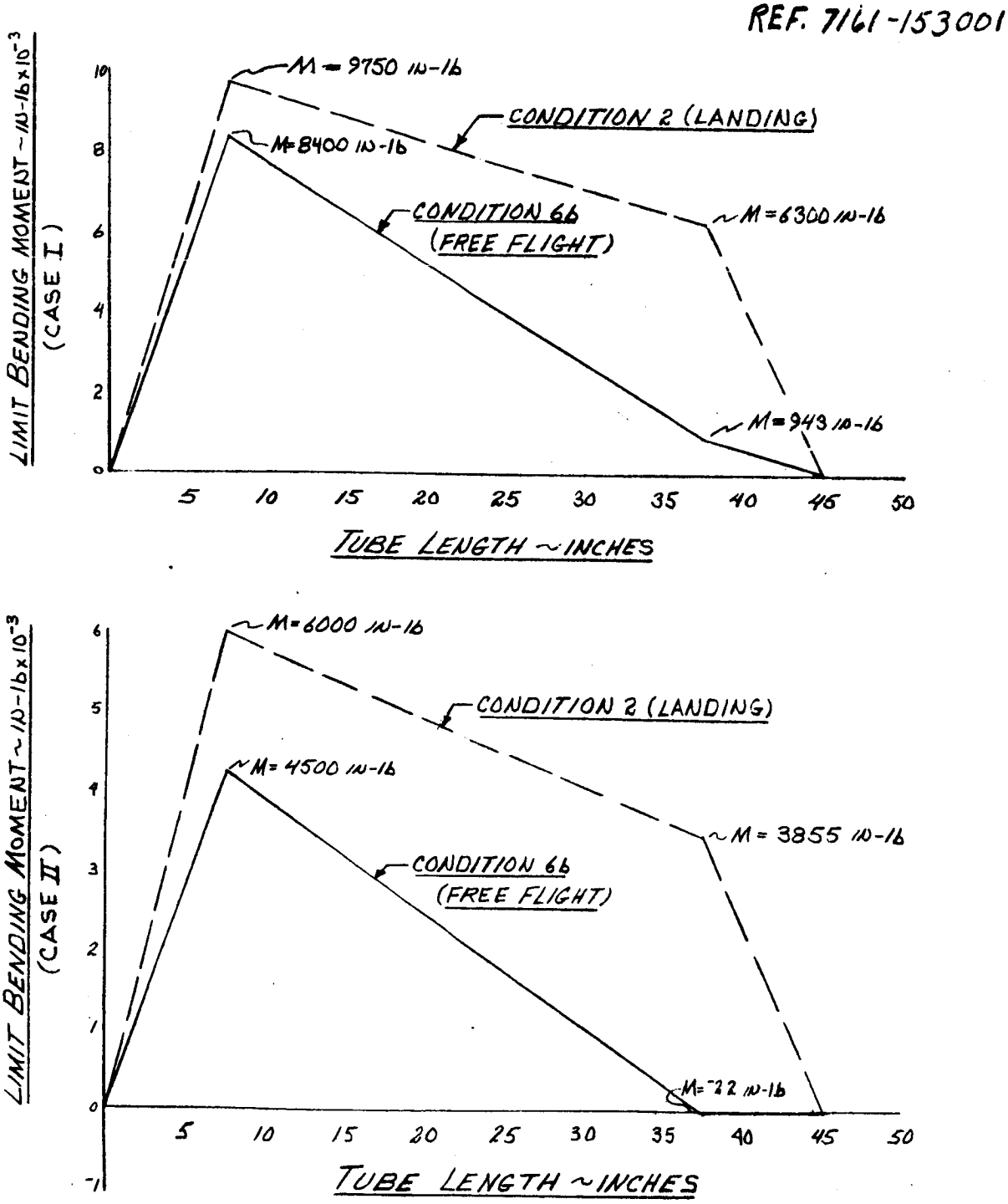
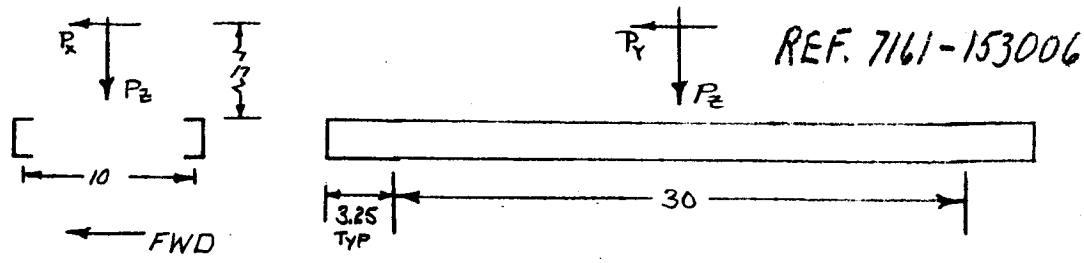


Figure 3.7. Upper Tube Station 270 Member $B_L B_R$ Limit Bending Moment



$$M_{max} = 3.75\,P_z + 12.75\,P_x + 4.25\,P_Y$$

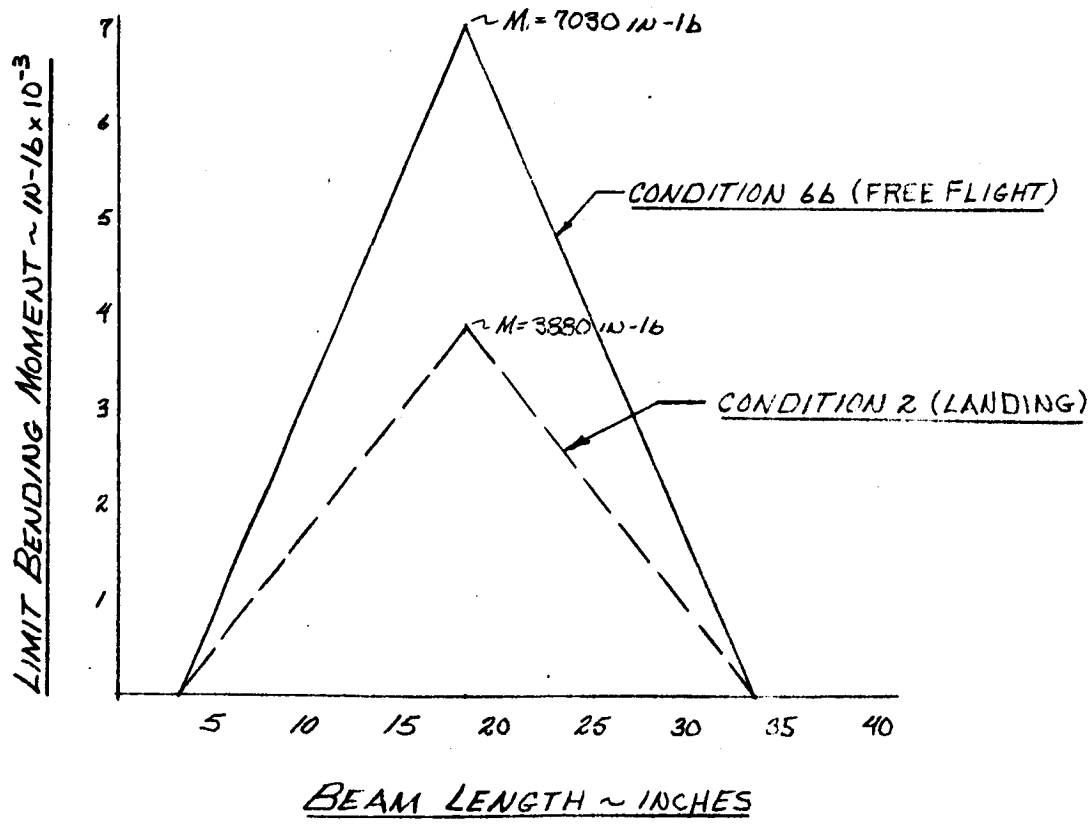
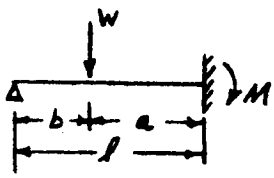


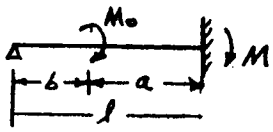
Figure 3.8. Lateral Beam - Moveable Platform Limit Bending Moment (Cases I and II)

SUPPORT STRUCTURE IS ASSUMED FIXED AT STATION 271.28 AND PINNED AT STATION 332.53.



	a	b	l	W
CASE I	53.72	7.53	61.25	$.608P_z + .604P_y$
CASE II	21.72	39.53	61.25	$.608P_z + .604P_y$

$$M = \frac{1}{2}W\left(\frac{a^3 + 2al^2 - 3a^2l}{l^2}\right)$$



$$M = \frac{1}{2}M_o\left(1 - 3\frac{b^2}{l^2}\right) \quad \text{WHERE } M_o = 9.5\,P_x$$

	CASE I		CASE II	
	2	6b	2	6b
M (IN-LB)	2265	3265	7280	6400

ALL MOMENTS ARE LIMIT.

BOLT LOAD = 7280 (1.3)/4(1.10) = 2150 LB

BENDING MOMENT.

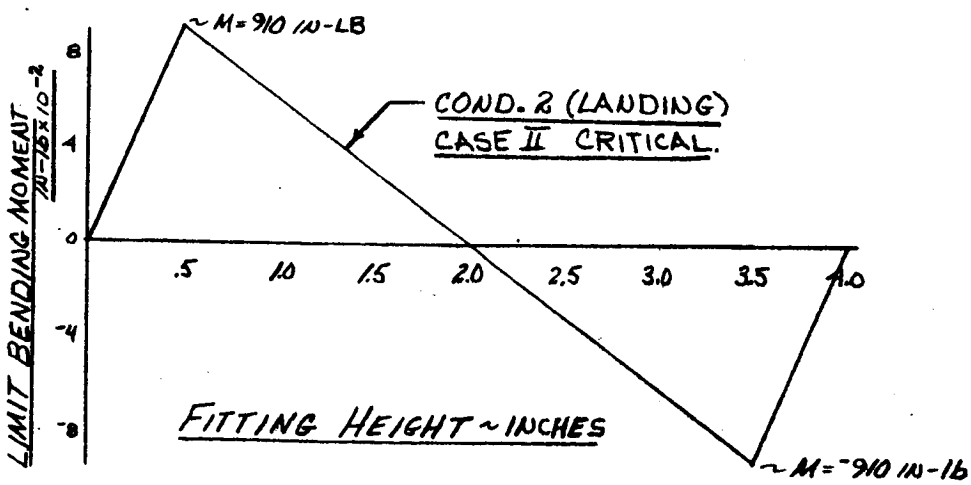
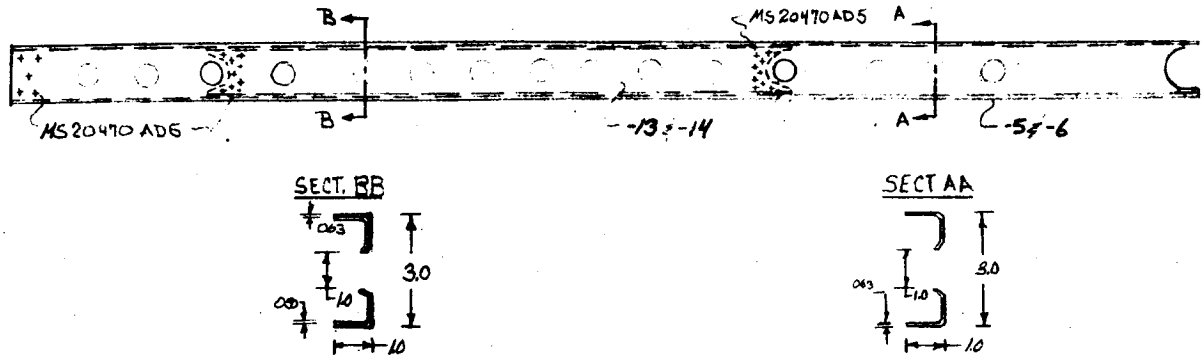


Figure 3.9. Fitting Loads

MAIN PLATFORM ASSEMBLY (7161-153015)



VERTICAL BEAM, AFT EQUIP. SECTION STA. 270 (7161-153008)

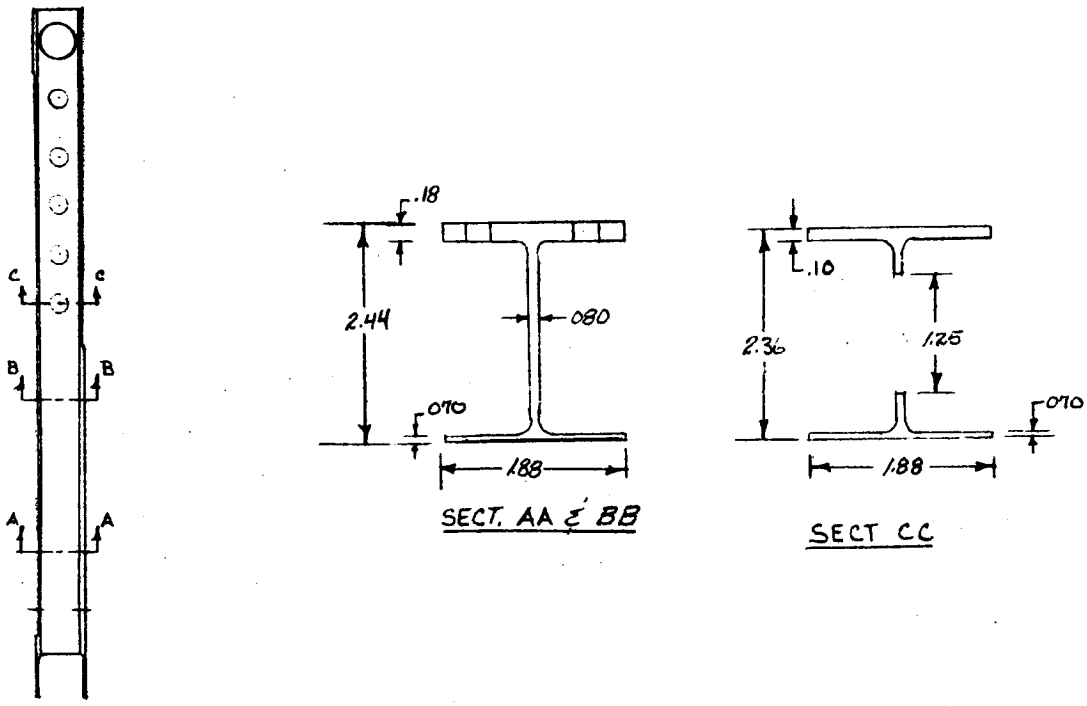


Figure 3.10. Critical Sections (Sheet 1 of 2)

FITTING - PLATFORM AFT EQUIP. SECTION (7161-153013)

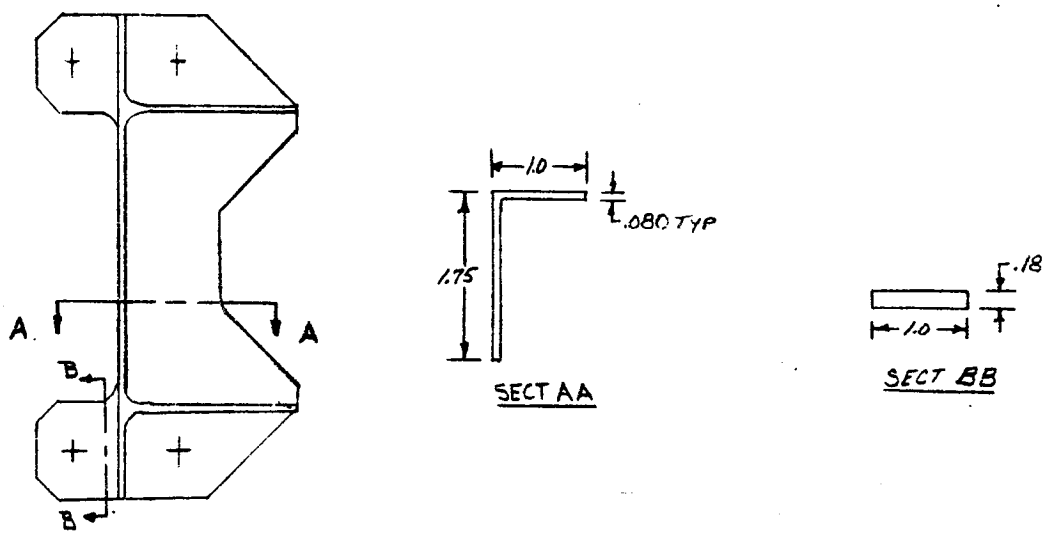


Figure 3.10. Critical Sections (Sheet 2 of 2)

SECTION 4
ENGINE MOUNT

The engine mount is a built-up sheet metal ring surrounding the engine just above the aft fan (the thrust axis is vertical). The cross-section of the ring is shaped so that the inner surface blends into the upper surface to form the inlet bellmouth for the aft fan. Fittings on the lower surface of the ring pick up two of the four mounting lugs on the aft fan case. When viewed from the top and measuring clockwise with 0° forward, the two fittings are at 135° and 315°. A steady rest at 0° extends from the case of the engine to the top of the ring. Fittings in the ring at 0° and 180° pick up roll bearings in the gimbal ring. The fitting at 0° also supports the steady rest and incorporates the crank arm for the roll actuator. The other end of the roll actuator is anchored to the gimbal ring.

The purpose of mount ring is to transmit loads from the vertical thrust engine to the gimbal ring. The engine mount ring is designated as part number 7161-421003-1, drawing number 7161-421003.

4.1. METHOD OF ANALYSIS

The analysis of the ring was performed on an IBM 7090 digital computer using the Bell Aerosystems general purpose structural analysis program. This program utilizes the matrix displacement method for the solution. Basic input data required is:

(1) Coordinates of all joints in a general structure coordinate system.

(2) Designation of type of element connecting the joints and element geometry.

(3) Type of material and temperature.

(4) Designation of load and restraint points.

(5) Loads.

From the input data the program evaluates the stiffness matrices for each element, transforms them into the structure coordinate system and assembles a stiffness matrix for the structure. This matrix is then inverted to give the flexibility matrix of the structure. Multiplication of the flexibility matrix by the load vector yields the deflections of the node points. Back substitution of the deflections into the element stiffness matrices yields the forces in the individual elements.

The ring was analyzed for the 19 basic loading conditions discussed in Section 4. From this information the member forces were combined by superposition to obtain the 92 in-flight conditions discussed in Section 5. During the combination assembly the member forces were scanned to obtain the maximum values in Table 8.2, Section 8.

4.2 GEOMETRY OF RING.

The geometry of the ring is shown in Figure 4.1. Load points are A, B, C. Loads are designated as D_1 through D_8. Reaction points are D, E, F. Reactions are designated R_1 through R_6.

4.3 BASIC LOADING CONDITIONS.

The basic loading conditions are subdivided into two groups.

(1) Landing Conditions

(2) In-Flight Conditions

Loading Information:

Vehicle Weight = 3400 lb

Engine Weight = 714 lb

Engine Thrust 4200 lb (Limit)
6300 lb (Ultimate ◄— Use

Rocket Thrust 4000 lb (Limit
6000 lb (Ultimate) ◄— Use

Minimum Structural Weight Associated with Rocket Thrust Condition is 2600 lb ◄— Use

Maximum Roll Angle = ±40°

Maximum Pitch Angle = ±54° (Subsequent to the beginning of the analysis this was changed to 40° - not here though!)

Minimum Rolling Moment (Associated with Maximum Roll Angle = ±15,100 in.-lb

Minimum Pitching Moment (Associated with Maximum Pitch Angle) = ±17,800 in.-lb.

Maximum Rolling Moment (Associated with Zero Roll Angle) = ±26,800 in.-lb

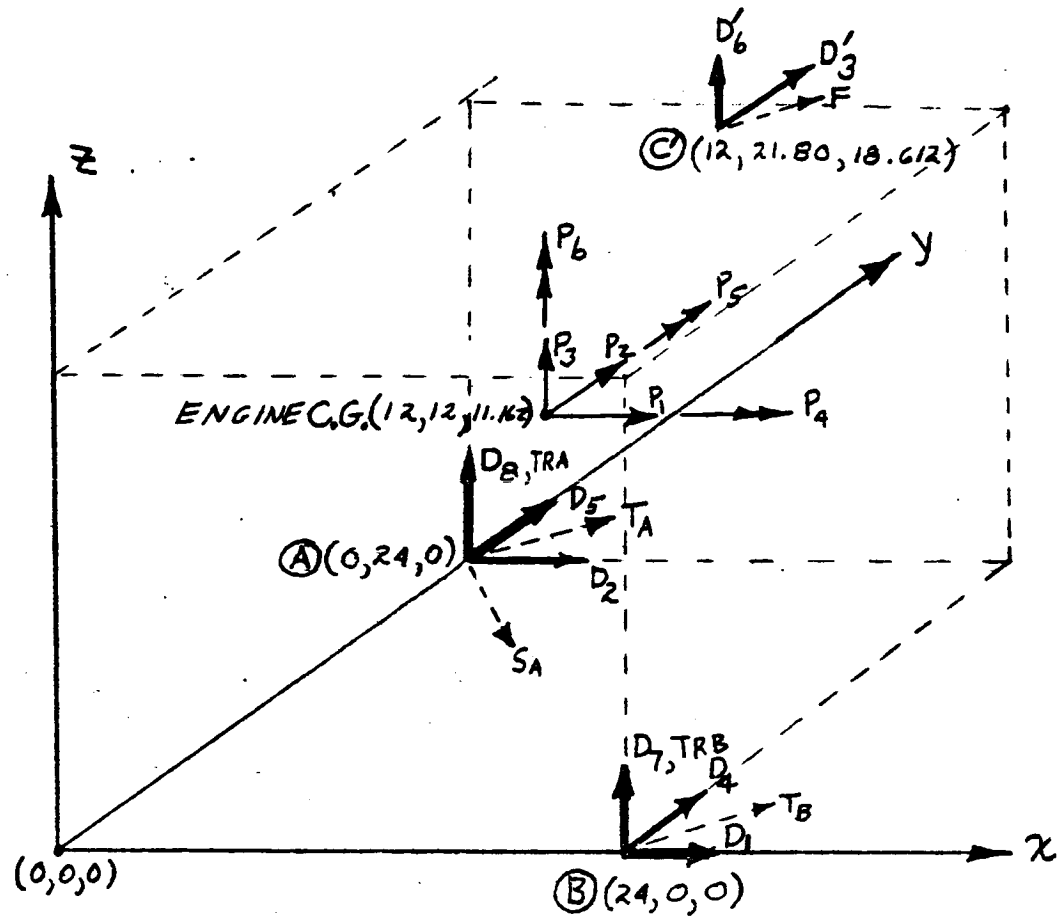
Maximum Pitching Moment (Associated with Zero Pitch Angle = ±29,700 in.-lb

Assume all loads are applied at the center of gravity of the engine. These loads are then transformed into loads applied to the ring at points A, B, and C.

TABLE 3.1

MARGINS OF SAFETY - EQUIPMENT SECTION

NAME	PART No.	SECT	SECTION PROPERTIES AREA	I_x or I_y	c	ρ	L/ρ	APPLIED (LIMIT) LOAD lb	MOMENT in-lb	STRESS PSI	COND. & CASE	ALLOWABLE LOAD lb	MOMENT in-lb	STRESS PSI	TYPE STRESS	M.S.
MAIN PLATFORM ASSEMBLY (LONGERON)	7161-153015	A-A	.244	.2906	1.5	—	—	1080	5410	32380	6b-I	—	—	50000	CRIPPLING	+.03
		B-B	.430	.5506	1.5	—	—	765	7735	22830	2-II	—	—	49100	"	+.49
MS 20470D AD5 RIVET (SPLICE AREA)			—	—	—	—	—	365	—	—	2-II	595	—	—	SHEAR	+.03
ATTACHMENT LONGERON (7161-153015) TO FITTING (7161-153013) 5 MS 20470AD5			—	—	—	—	—	1593	—	—	6-I	2975	—	—	SHEAR	+.24
ATTACHMENT LONGERON (7161-153015) TO FITTING (7161-153013) 5 MS 20470 B6			—	—	—	—	—	2426	—	—	2-II	4310	—	—	SHEAR	+.18
BEAM-ADJUSTABLE PLATFORM	7161-153006		.3438	.2250	1.00	—	—	—	7030	31200	6b	—	—	54000	CRIPPLING	+.15
DIAGONAL BRACE EQUIP. SECT. TUBE	7161-153016		.1611	.0432	.75	.518	121	1300	—	8050	2-I	—	—	42000	TENSION	HIGH
FITTING-PLATFORM AFT EQUIP. SECTION	7161-15013	A-A	.2136	.0174	.788	—	—	—	460	20900	2-II	—	—	45000	CRIPPLING	+.43
		B-B	.180	.00049	.09	—	—	—	182	35300	2-II	—	—	77000	BENDING	+.45
BOLT (NAS 654-6) ATTACHING FITTING (7161-153013) TO VERTICAL BEAM (7161-153008)			—	—	—	—	—	2150	—	—	2-II	4080	—	—	TENSION	+.26
VERTICAL BEAM, AFT EQUIP SECT.	7161-153008	A-A	.650	.6252 .1377	1.548 .94	— —	— —	— —	4779 445	11150 3040	6b-I	—	—	38000	CRIPPLING	+.79
		B-B	.650	.6252 .1377	.898 .94	— —	— —	— —	5150 1280	7140 8150	6b-II	—	—	45000	CRIPPLING	+.89
		C-C	.3196	.3354 .0936	.91 .94	— —	— —	— —	3700 920	10050 9250	6b-II	—	—	47000	CRIPPLING	+.62
TUBE (-27) EQUIP STRUCTURE INSTALLATION FWD	7161-153001		.4999	.230	1.00	.678	—	—	9750	—	2-I	—	15120	—	BENDING	+.035
TUBE ASSEMBLY - DIAGONAL AFT EQUIP SECT	7161-153005 (-2)		.1198	.0178	.5225	.385	103	348	—	—	6b-I	840	—	—	COLUMN	+.61
	WEB (-3)		—	.000012	—	.0144	44	348	—	—	6b-I	735	—	—	COLUMN	+.40
			—	—	—	—	—	348	—	—	6b-I	600	—	—	SHEAR-OUT	+.15
TUBE (-9) EQUIP STRUCTURE INSTALLATION FWD	7161-153001		.1336	.0247	.426	.429	109	411	—	—	6b-II	780	—	—	COLUMN	+.27



(ORIGIN OF COORDINATES NOT THE SAME AS FIG. 4.1)

$P_i \equiv$ LOADS APPLIED AT ENGINE C.G.
$TR \equiv$ THRUST
$T \equiv$ TANGENTIAL FORCE
$S \equiv$ NORMAL FORCE
$F \equiv$ AXIAL FORCE IN STEADY REST

$D_1 = 0.707\, T_B$
$D_2 = 0.707\, T_A + 0.707\, S_A$
$D_3 = D_3' = 0.9626\, F$
$D_4 = 0.707\, T_B$
$D_5 = 0.707\, T_A - 0.707\, S_A$
$D_6 = D_6' = -0.2708\, F$
$D_7 = TR_B$
$D_8 = TR_A$

Figure 4.2. Geometric Relationships Between Loads Applied at the Engine CG and Reactions from the Ring

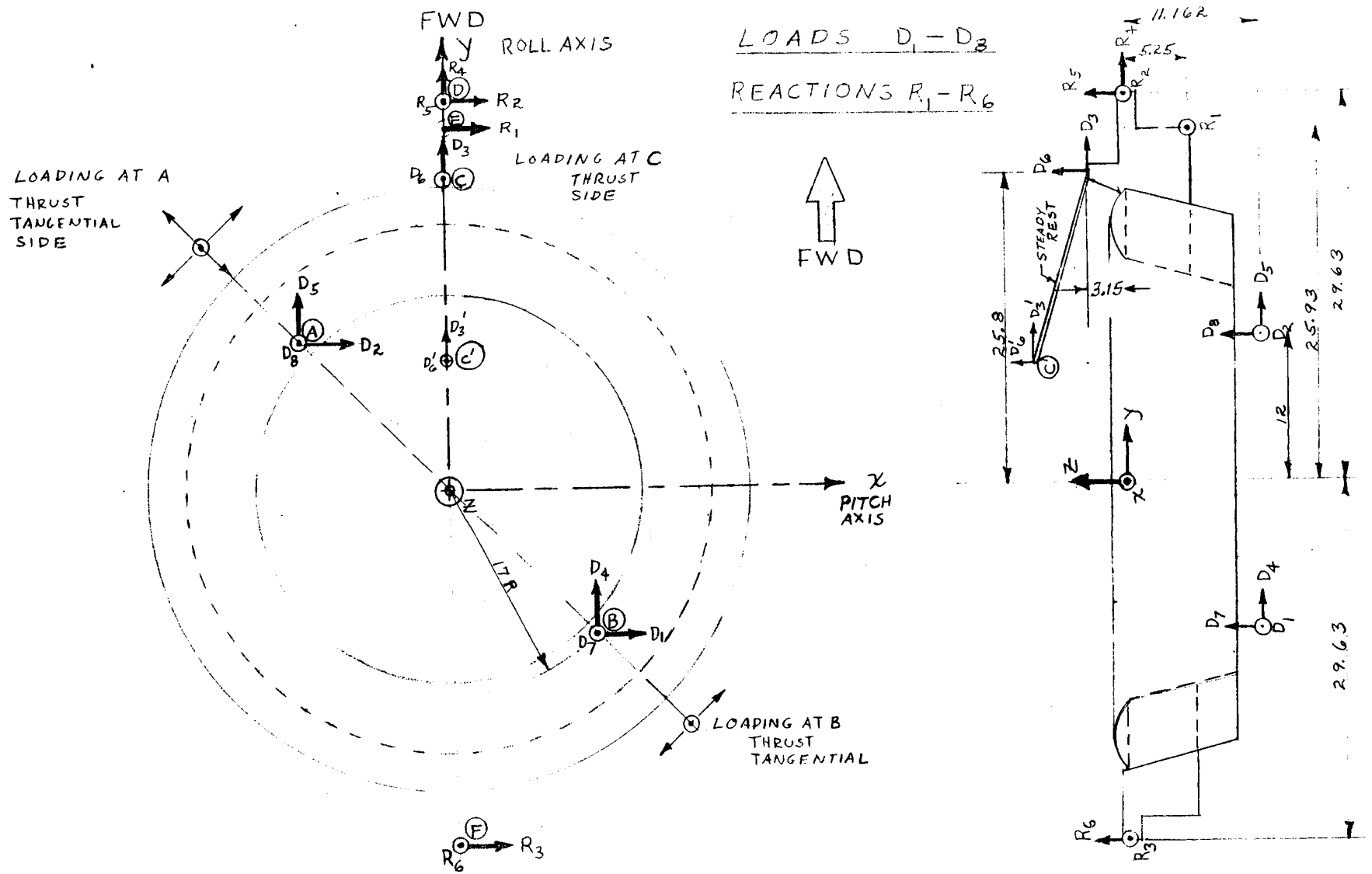


Figure 4.1. Ring Geometry – Location of Load and Restraint Points

SUMMING FORCES AND MOMENTS USING THE GEOMETRY OF FIG. 4.2 YIELDS:

$$\begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \end{bmatrix} + \begin{bmatrix} 0.7071 & 0.7071 & 0.7071 & 0 & 0 & 0 \\ 0.7071 & 0.7071 & -0.7071 & 0 & 0 & 0.9626 \\ 0 & 0 & 0 & 1.0 & 1.0 & -0.2708 \\ 7.8915 & 7.8915 & -7.8915 & 12.0 & -12.0 & -9.8252 \\ -7.8915 & -7.8915 & -7.8915 & 12.0 & -12.0 & 0 \\ -16.968 & 16.968 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} T_A \\ T_B \\ S_A \\ TR_A \\ TR_B \\ F \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

OR $[P] + [F][R] = [0]$ EQUILIBRIUM EQUATION

OR $[R] = -[F]^{-1}[P]$

INVERTING [F] WE HAVE:

$$\begin{bmatrix} T_A \\ T_B \\ S_A \\ TR_A \\ TR_B \\ F \end{bmatrix} = (-) \begin{bmatrix} 0.1689 & 0.1689 & 0.0000 & 0.0165 & -0.0165 & -0.0295 \\ 0.1689 & 0.1689 & 0.0000 & 0.0165 & -0.0165 & 0.0295 \\ 1.0764 & -0.3378 & 0.0000 & -0.0331 & 0.0331 & 0.0000 \\ 0.5385 & 0.0735 & 0.5000 & -0.0066 & 0.0482 & 0.0000 \\ -0.3915 & 0.0735 & 0.5000 & -0.0066 & -0.0351 & 0.0000 \\ 0.5426 & 0.5426 & 0.0000 & -0.0486 & 0.0486 & 0.0000 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \end{bmatrix}$$

NEXT DETERMINE THE P VECTORS FOR THE BASIC LOADING CONDITIONS.

4.4. LANDING LOAD CONDITIONS

(1.) ALL FOUR LEGS STRIKE GROUND SIMULTANEOUSLY.

LOAD FACTOR = 4.0

VEHICLE WEIGHT = 4(3400) = 13,600#

$$F = ma$$

$$a = \frac{F}{m} = \frac{13{,}600\#}{\frac{3400\#}{g}} = 4g$$

$$P_3 = ma = \frac{714\#}{g}(4g) = -2856\#$$ ← L.L.C. 1

(2.) IMPACT ON LEG (1) ONLY.

$F_z = 1890\#$

$F_i = 2550\#$ (DIRECTED INWARD IN XY PLANE)

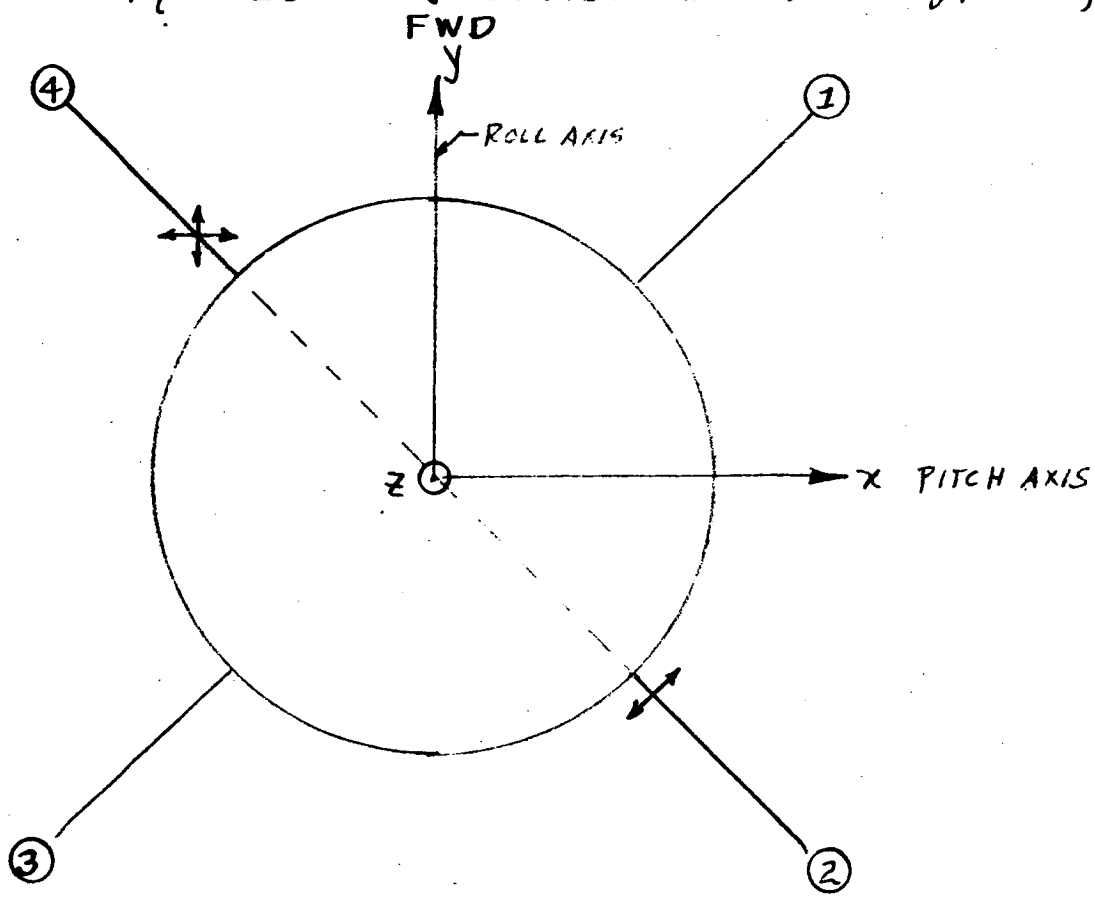


Figure 4.3. Leg Numbering

IMPACT ON LEG 1 ONLY (CONT.)

$$a_v = \frac{1890^{\#}}{3400^{\#}} g \quad \text{(UP)}$$

$$a_h = \frac{2550^{\#}}{3400^{\#}} g \quad \text{(INWARD)}$$

INERTIA FORCES

$$\left.\begin{aligned} P_3 &= -\frac{714^{\#}}{g}\left(\frac{1890^{\#}}{3400^{\#}} g\right) = -397^{\#} \\ P_1 &= (0.707)\left(\frac{714^{\#}}{g}\right)\left(\frac{2550^{\#}}{3400^{\#}} g\right) = 379^{\#} \\ P_2 &= (0.707)\left(\frac{714^{\#}}{g}\right)\left(\frac{2550^{\#}}{3400^{\#}} g\right) = 379^{\#} \end{aligned}\right\} \longleftarrow \text{L.L.C. 2}$$

(3.) IMPACT ON LEG (2) ONLY

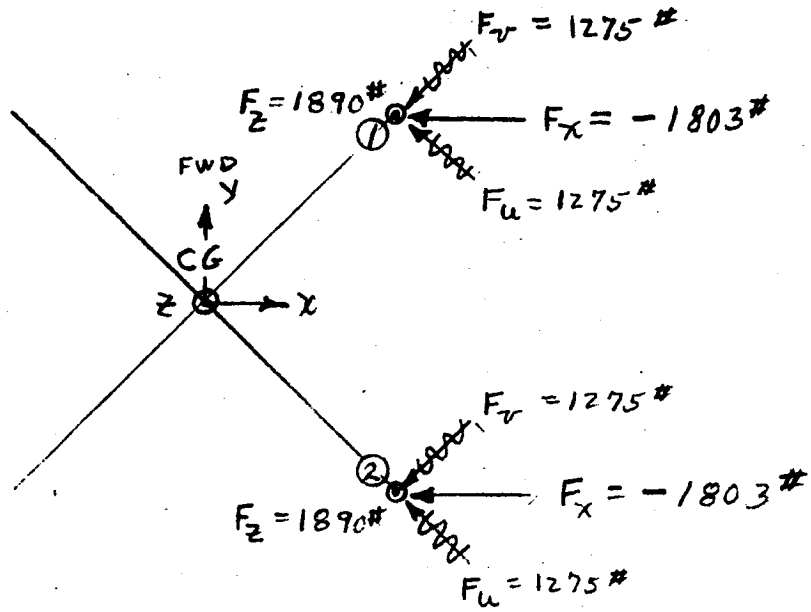
$$\left.\begin{aligned} P_3 &= -397^{\#} \\ P_1 &= 379^{\#} \\ P_2 &= -379^{\#} \end{aligned}\right\} \longleftarrow \text{L.L.C. 3}$$

IMPACT ON (3) & (4) YIELDS (1) & (2) RESPECTIVELY WITH SIGN CHANGE FOR P_1 & P_2

(4.) IMPACT ON LEGS ① & ② ONLY

$F_z = 1890^{\#}$

$F_u = F_v = = 1275^{\#}$



$$a_v = \frac{1890^{\#} + 1890^{\#}}{3400^{\#}} g = \frac{3780^{\#}}{3400^{\#}} g$$

$$a_h = \frac{-1803^{\#} - 1803^{\#}}{3400^{\#}} g = -\frac{3606}{3400} g$$

$$\left.\begin{aligned} P_3 &= -\frac{714^{\#}}{g}\left(\frac{3780^{\#}}{3400^{\#}} g\right) = -794^{\#} \\ P_1 &= -\frac{714^{\#}}{g}\left(-\frac{3606}{3400} g\right) = 756^{\#} \\ P_2 &= 0 \end{aligned}\right\} \longleftarrow \text{L.L.C 4}$$

(5.) IMPACT ON LEGS. ② & ③ ONLY.

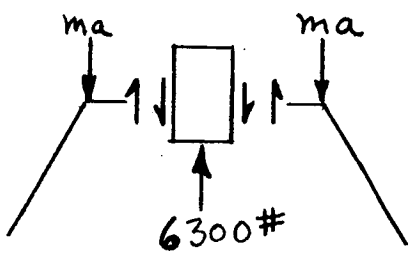
BY INSPECTION OF CASE(4.):

$$\left.\begin{aligned} P_3 &= -794^{\#} \\ P_1 &= 0 \\ P_2 &= -756^{\#} \end{aligned}\right\} \longleftarrow \text{L.L.C. 5}$$

IMPACT ON ③ & ④ REPRESENTS ① & ② WITH $(-P_1)$
IMPACT ON ④ & ① REPRESENTS ② & ③ WITH $(-P_2)$

4.5. INFLIGHT LOAD CONDITIONS

(1.) ENGINE AT FULL THRUST – ROCKETS INOPERATIVE – ATTITUDE AND MOVEMENT VERTICAL.

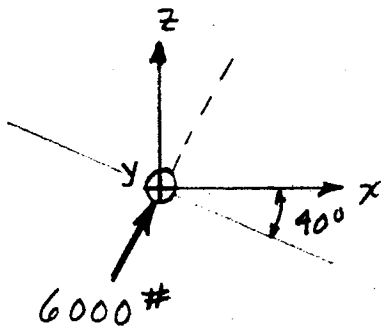


WEIGHT OF STRUCTURE IS CAUSING LOADS AT ENGINE MOUNTS

$$P_3 = \frac{3400^{\#} - 714^{\#}}{g}\left(\frac{6300^{\#}}{3400^{\#}}\, g\right)$$

$$\left.\begin{aligned} P_3 &= 4980^{\#} \\ P_1 &= 0 \\ P_2 &= 0 \end{aligned}\right\} \longleftarrow \text{I.F.L.C 1}$$

(2.) MAXIMUM ROLL ANGLE IS + 40°

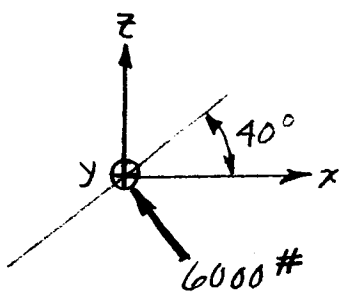


USE MINIMUM VEHICLE WEIGHT OF 2600# FOR MAXIMUM ACCELERATION.

$$a = \frac{6000\#}{2600\#} g = 2.31g$$

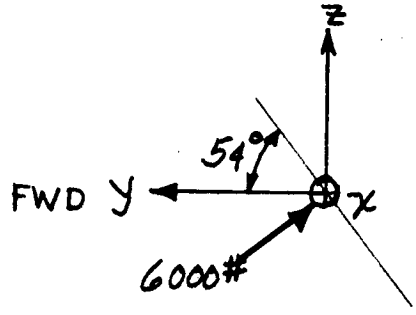
$$\left.\begin{aligned} P_1 &= -\frac{714\#}{g}(2.31g)\sin 40^\circ = -1058\# \\ P_3 &= -\frac{714\#}{g}(2.31g)\cos 40^\circ = -1262\# \\ P_2 &= 0 \end{aligned}\right\} \longleftarrow \text{I.F.L.C.2}$$

(3.) MAXIMUM ROLL ANGLE IS − 40°



$$\left.\begin{aligned} P_1 &= +1058\# \\ P_2 &= 0 \\ P_3 &= -1262\# \end{aligned}\right\} \longleftarrow \text{I.F.L.C.3}$$

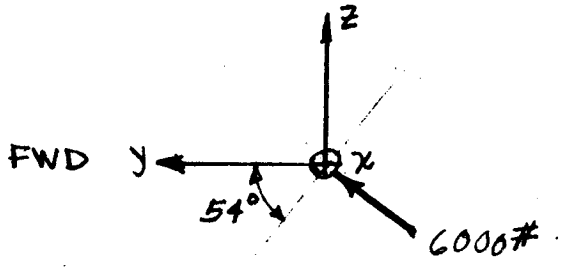
(4.) MAXIMUM PITCH ANGLE IS $+54°$



$a = 2.31g$ AS FOR I.F.L.C. 2

$$\left.\begin{aligned} P_1 &= 0 \\ P_2 &= \frac{714^{\#}}{g}(2.31g)\sin 54° = 1332^{\#} \\ P_3 &= -\frac{714^{\#}}{g}(2.31g)\cos 54° = -968^{\#} \end{aligned}\right\} \bigstar \quad \text{I.F.L.C 4}$$

(5.) MAXIMUM PITCH ANGLE IS $-54°$



$$\left.\begin{aligned} P_1 &= 0 \\ P_2 &= -1332^{\#} \\ P_3 &= -968^{\#} \end{aligned}\right\} \bigstar \quad \text{I.F.L.C. 5}$$

★ THROUGHOUT THE ANALYSIS A VALUE OF $P_2 = 1212^{\#}$ WAS USED FOR I.F.L.C. 4 AND 5. THIS INTRODUCED AN ERROR OF APPROXIMATELY 8% IN ALL REACTIONS AND ELEMENT STRESSES FOR THESE TWO BASIC LOADING CONDITIONS. SUBSEQUENT TO THIS ANALYSIS THE MAXIMUM PITCH ANGLE WAS REDUCED TO $\pm 40°$. THIS WILL REDUCE THE VALUE OF P_2. IT ALSO INCREASES THE VALUE OF P_3 BUT THE MAXIMUM VALUE OF P_3 FOR PITCH ANGLE OF ZERO IS INVESTIGATED. A CHECK OF TABLE 4.3 SHOWS THAT IN <u>NO CASE</u> IS THE MAXIMUM LOAD FOR A PARTICULAR TYPE OF ELEMENT ONE WHICH INVOLVES

LOAD CONDITIONS 4 AND 5. THE ONLY COMPONENT AFFECTED IS THE STEADY REST LINK. THE DESIGN LOAD FOR THE LINK WAS ±2858#. USING THE CORRECT VALUE OF $P_2 = 1332$# RESULTS IN A LOAD OF ±2898#. THE INCREASE IS 40# OR 1.4%. IF THE RESTRICTED PITCH ANGLE OF 40° IS USED THE RESULTING LOAD IS 2750#, A DECREASE OF 88# OR 3.1%. ON THE BASIS OF THE FOREGOING DISCUSSION IT WAS DECIDED THAT A REVISED ANALYSIS WAS UNNECESSARY. CONSEQUENTLY THE ANALYSIS REPRESENTED HERE WAS MADE USING P_2 FOR I.F.L.C. 4 & 5 OF 1212#.

(6.) POSITIVE ROLLING MOMENT ASSOCIATED WITH RESTORATION FROM FULL NEGATIVE ROLL. (−40°)

$$P_5 = +15{,}100 \text{ in\#}$$

(7.) NEGATIVE ROLLING MOMENT ASSOCIATED WITH RESTORATION FROM FULL POSITIVE ROLL (+40°)

$$P_5 = -15{,}100 \text{ in\#}$$

(8.) POSITIVE PITCHING MOMENT ASSOCIATED WITH RESTORATION FROM FULL NEGATIVE PITCH (−54°)

$$P_4 = +17{,}800 \text{ in\#}$$

(9.) NEGATIVE PITCHING MOMENT ASSOCIATED WITH RESTORATION FROM FULL POSITIVE PITCH (+54°)

$$P_4 = -17{,}800 \text{ in\#}$$

(10.) ENGINE THRUST = 0
ROCKET THRUST = 6000#
NEUTRAL ATTITUDE.

$$P_3 = -\frac{714^{\#}}{g}(2.31g) = -1650^{\#}$$

NOTE:
IN-FLIGHT LOAD CONDITIONS 11-14 ARE ALL ASSOCIATED WITH NEUTRAL ATTITUDE WITH REGARD TO THEIR RESPECTIVE AXES AND ARE MAXIMUM VALUES.

(11.) POSITIVE ROLL MOMENT.

$$P_5 = 26{,}800 \text{ in-}^{\#}$$

(12.) NEGATIVE ROLL MOMENT.

$$P_5 = -26{,}800 \text{ in-}^{\#}$$

(13.) POSITIVE PITCHING MOMENT.

$$P_4 = 29{,}700 \text{ in-}^{\#}$$

(14.) NEGATIVE PITCHING MOMENT.

$$P_4 = -29{,}700 \text{ in-}^{\#}$$

4.6. SUMMARY OF LOAD VECTORS

LOADS APPLIED TO THE CENTER OF GRAVITY OF THE ENGINE.

LANDING LOAD CONDITIONS.

	1	2	3	4	5
P_1		379#	379#	756#	
P_2		379#	−379#		−756#
P_3	−2856#	−397#	−397#	−794#	−794#
P_4					
P_5					
P_6					

IN-FLIGHT LOAD CONDITIONS

	1	2	3	4	5	6	7
P_1		−1058#	1058#				
P_2				1212#	−1212#		
P_3	4980#	−1262#	−1262#	−968#	−968#		
P_4							
P_5						15,100 in#	−15,100 in#
P_6							

	8	9	10	11	12	13	14
P_1							
P_2							
P_3			−1650#				
P_4	17,800 in#	−17,800 in#				29,700 in#	−29,700 in#
P_5				26,800 in#	−26,800 in#		
P_6							

THE REACTION INFLUENCE COEFFICIENT MATRIX ($[F]^{-1}$ p.4.5) WAS POST MULTIPLIED BY EACH OF THE ENGINE C. G. LOAD VECTORS TO GET THE REACTIONS FROM THE RING TO THE ENGINE. THESE REACTIONS WERE MULTIPLIED BY (−1) TO CONVERT THEM TO LOADS APPLIED TO THE RING. THESE LOADS WERE THEN TRANSFORMED INTO THE STRUCTURE COORDINATE SYSTEM BY THE RELATIONSHIPS EXPRESSED WITH FIG. 4.2. THE RESULTING LOADS APPLIED TO THE RING AND THE REACTIONS FROM THE GIMBAL RING TO THE ENGINE RING ARE SUMMARIZED IN TABLE 4.1.

4.7. COMBINATIONS OF IN-FLIGHT LOAD CONDITIONS

THE POSSIBLE COMBINATIONS OF IN-FLIGHT CONDITIONS WHICH CAN OCCUR ARE SUMMARIZED IN TABLE 4.2.

TABLE 4.1

BASIC LOAD CONDITIONS

	LANDING LOAD CONDITIONS					IN-FLIGHT LOAD CONDITIONS													
LOADS	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14
D_1	0	90	0	90	-90	0	-126	126	146	-146	-177	177	208	-208	0	-314	314	347	-347
D_2	0	288	379	666	90	0	-932	932	-146	146	177	-177	-208	208	0	314	-314	-347	347
D_3	0	396	0	396	-396	0	-554	554	635	-635	707	-707	-833	833	0	1255	-1255	-1390	1390
D_4	0	90	0	90	-90	0	-126	126	146	-146	-177	177	208	-208	0	-314	314	347	-347
D_5	0	-107	-379	-485	-271	0	680	-680	437	-437	-530	530	624	-624	0	-941	941	1041	-1041
D_6	0	-111	0	-111	111	0	156	-156	-179	179	-199	199	234	-234	0	-353	353	391	-391
D_7	-1428	-319	-375	-693	-452	2490	-216	-1046	-395	-573	-530	530	-117	117	-825	-941	941	-195	195
D_8	-1428	33	-22	10	-452	2490	-1202	60	-395	-573	728	-728	-117	117	-825	1292	-1292	-195	195
REACTIONS																			
R_1	0	-19	-19	-41	0	0	54	222	0	0	2875	-2875	0	0	0	5103	-5103	0	0
R_2	0	-171	-171	-340	0	0	479	-737	0	0	-2695	2695	0	0	0	-4784	4784	0	0
R_3	0	-188	-188	-375	0	0	525	-543	0	0	-179	179	0	0	0	-318	318	0	0
R_4	0	-379	379	-1	757	0	0	0	-1217	1217	0	0	1	-1	0	0	0	2	-2
R_5	1428	198	200	398	398	-2490	629	549	480	488	3	-3	-304	304	825	5	-5	-507	507
R_6	1428	197	197	395	394	-2490	633	593	488	480	-2	2	303	-303	825	-4	4	506	-506

TABLE 4.2

IN-FLIGHT LOAD COMBINATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	●	●												
2	●		●											
3	●			●										
4	●				●									
5	●										●			
6	●											●		
7	●												●	
8	●													●
9	●	●		●										
10	●	●			●									
11	●	●					●							
12	●	●											●	
13	●	●												●
14	●	●		●			●							
15	●	●		●			●		●					
16	●	●		●					●					
17	●	●			●		●							
18	●	●			●		●	●						
19	●	●			●			●						
20	●	●					●						●	
21	●	●					●							●
22	●		●	●										
23	●		●		●									
24	●		●			●								
25	●		●										●	
26	●		●											●
27	●		●	●		●								
28	●		●	●					●					
29	●		●	●		●			●					
30	●		●		●	●								
31	●		●		●			●						
32	●		●		●	●		●						
33	●		●			●							●	
34	●		●			●								●
35	●										●			
36	●											●		
37	●								●					
38	●								●		●			
39	●								●			●		
40	●				●						●			

Form 0179

TABLE 4.2. (CONT)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
41	●				●							●		
42	●				●			●						
43	●				●			●			●			
44	●				●			●				●		
45	●										●		●	
46	●										●			●
47	●											●	●	
48	●											●		●
49		●		●										
50		●			●									
51		●					●							
52		●											●	
53		●												●
54		●		●			●							
55		●		●			●		●					
56		●		●					●					
57		●			●		●							
58		●			●		●	●						
59		●			●			●						
60		●					●						●	
61		●					●							●
62			●	●										
63			●		●									
64			●			●								
65			●										●	
66			●											●
67			●	●		●								
68			●	●					●					
69			●	●		●			●					
70			●		●	●								
71			●		●			●						
72			●		●	●		●						
73			●			●							●	
74			●			●								●
75											●			
76												●		
77									●					
78									●		●			
79									●			●		
80					●						●			

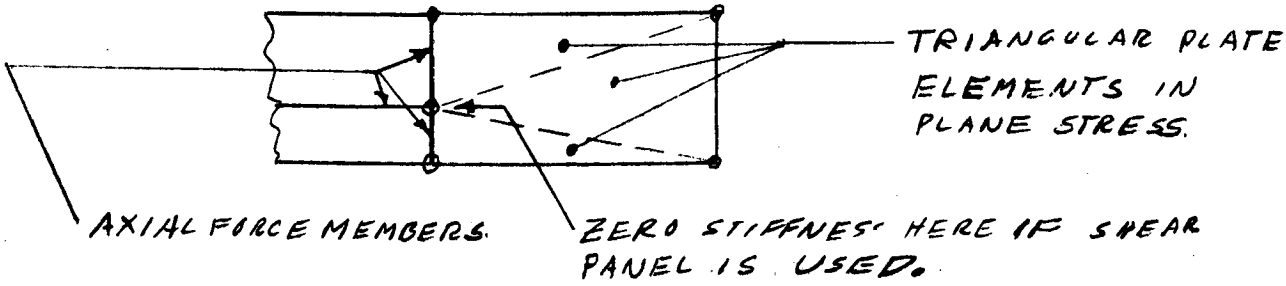
TABLE 4.2. (CONT)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
81					•							•		
82					•			•						
83					•			•			•			
84					•			•				•		
85										•	•			
86										•		•		
87										•			•	
88										•				•
89										•	•		•	
90										•	•			•
91										•		•	•	
92										•		•		•

4.8. IDEALIZATION OF STRUCTURE

FOR PURPOSES OF THE ANALYSIS THE RING WAS ASSUMED TO BE COMPOSED OF PIN CONNECTED AXIAL FORCE MEMBERS AND SHEAR PANELS. THE IDEALIZED CROSS SECTION IS SHOWN IN FIG. 4.4. FIG. 4.5 SHOWS A PLANFORM OF THE RING WITH THE NUMBERING OF THE NODE POINTS. SUPPORT FIXTURES ARE SIMULATED BY AXIAL FORCE MEMBERS AND SHEAR PANELS ALSO. THE ENGINE MOUNTS ARE SIMULATED BY AXIAL FORCE MEMBERS. THE CUTOUT SHOWN IN FIG. 4.5 WAS DELETED SUBSEQUENT TO THE ANALYSIS. SINCE REMOVAL OF THE CUTOUT TENDS TO REDUCE THE SEVERITY OF STRESS IN THAT VICINITY NO CHANGE WAS MADE IN THE ANALYSIS. MEMBERS IN THE REGION OF THE CUT OUT WHICH WERE HEAVILY LOADED WERE COMPARED WITH THEIR COUNTERPARTS IN THE REGION DIAMETRICALLY OPPOSED AND IN SOME CASES SLIGHT REDUCTIONS IN MEMBER LOADS WERE ASSUMED.

THE MATHEMATICAL ANALYSIS DOES NOT PERMIT THE USE OF SHEAR PANELS AT POINTS WHERE AN AXIAL FORCE MEMBER TERMINATES. FOR THIS REASON, TRIANGULAR PLATE ELEMENTS IN PLANE STRESS WERE USED AT THESE POINTS.



THE OUTPUT OF THE ANALYSIS PROGRAM FOR TRIANGLES IN PLANE STRESS IS σ_u, σ_v, τ_{uv} IN A LOCAL COORDINATE SYSTEM FOR THE ELEMENT. AN EVALUATION OF MAXIMUM SHEARING STRESS IN THE ELEMENT REQUIRES THE DETERMINATION OF THE PRINCIPAL STRESSES. INSTEAD OF THIS, THE MAXIMUM SHEAR STRESS IN A PANEL SIMULATED BY TRIANGULAR PLATE ELEMENTS WAS TAKEN AS THAT OF THE HIGHER STRESSED ADJACENT SHEAR PANEL.

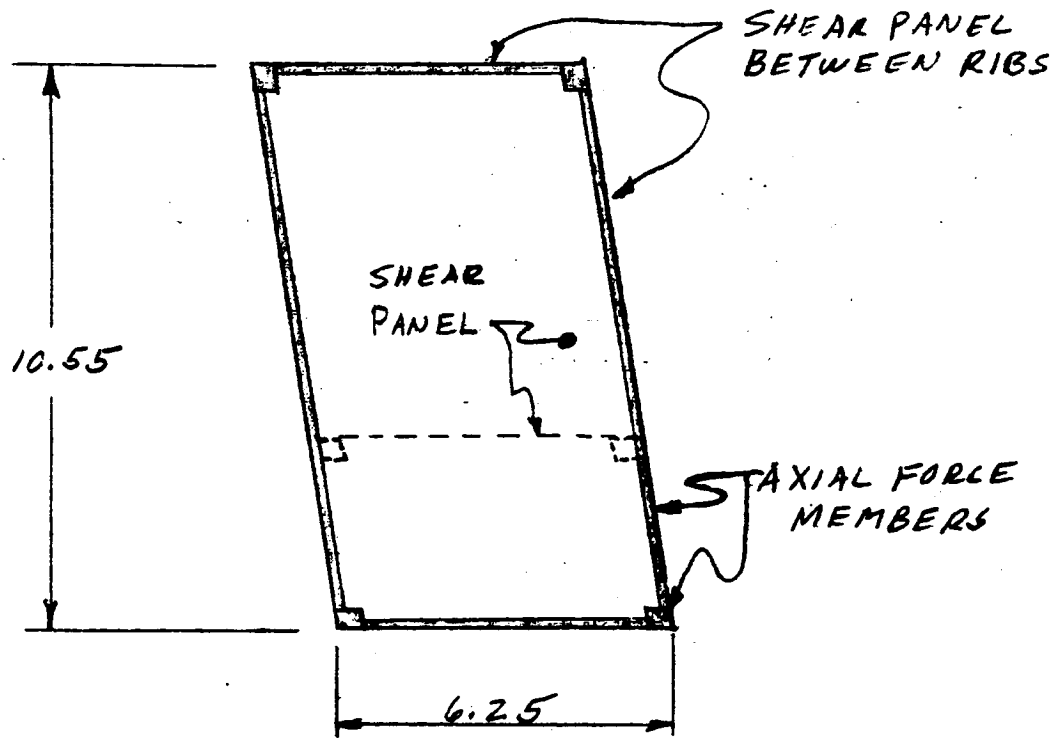
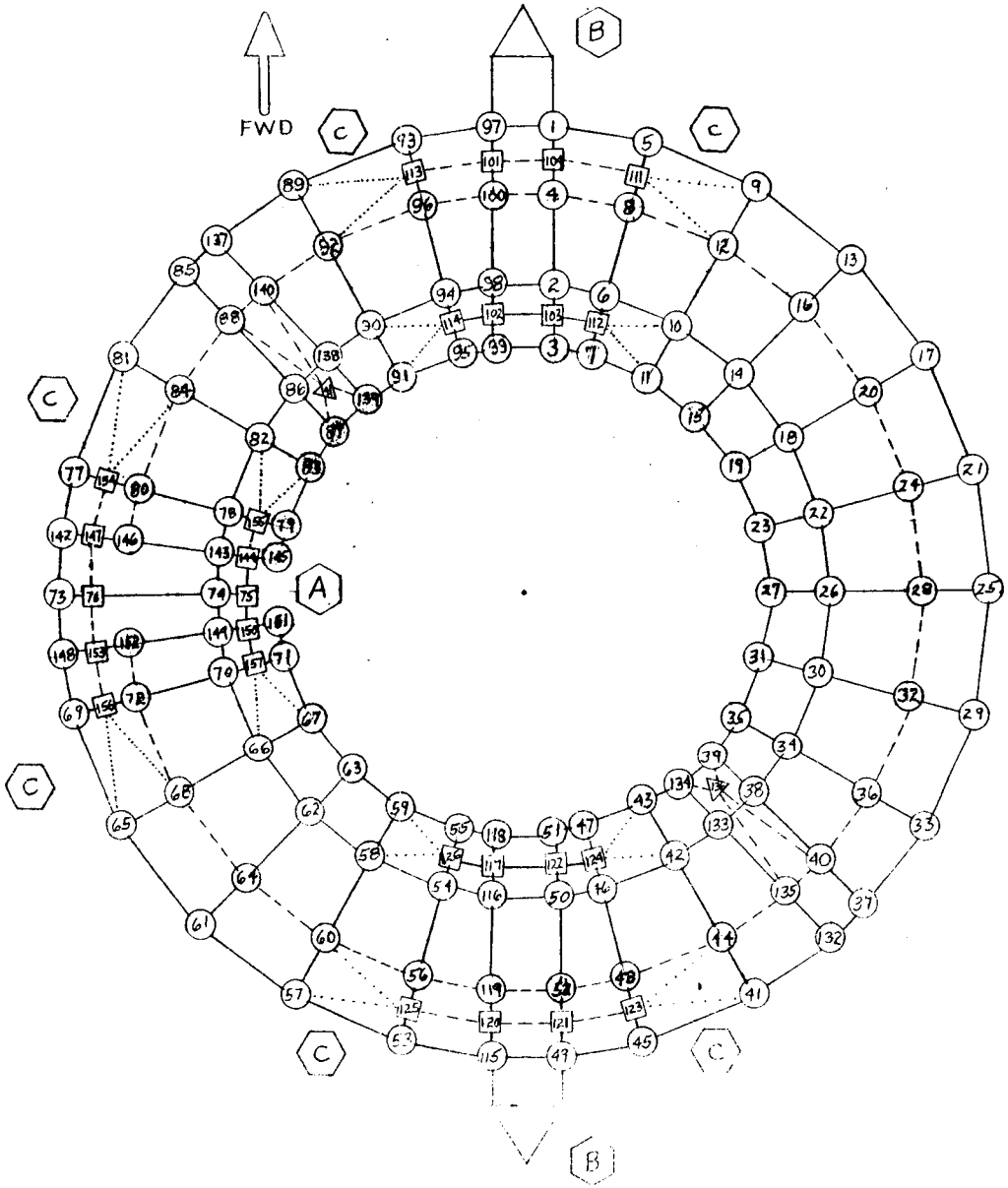
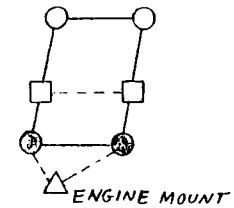


Figure 4.4. Idealized Cross Section



NOTES:

1. ELEVATION OF POINTS:



(A) CUTOUT DELETED IN FINAL DESIGN.

(B) NODE POINTS OF SIMULATED SUPPORT FIXTURES ARE OMITTED.

(C) TRIANGULAR PLATE ELEMENTS IN PLANE STRESS

Figure 4.5. Idealized Structure – Numbering of Node Points

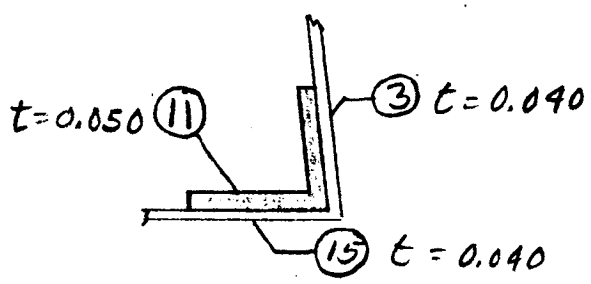
4.9. MAXIMUM ALLOWABLE ELEMENT LOADS

THE FOLLOWING ABBREVIATIONS ARE USED IN THIS SECTION:

BSM – BELL AEROSYSTEMS STRUCTURES MANUAL
MH5 – MILITARY HANDBOOK-5, STRENGTH OF METAL AIRCRAFT ELEMENTS.
ASH – ALCOA STRUCTURAL HANDBOOK – ALUMINUM COMPANY OF AMERICA.

4.9.1. PART 7161-421003-11 – LOWER INBOARD STRINGER

MAT'L - 2024-0, ASSUME 2024-T4
1X1 ANGLE



AREA = 0.172 in²

F_{tu} = 62 ksi
F_{ty} = 40 ksi
F_{cy} = 40 ksi

LOCAL BUCKLING – PROJECTING ELEMENT

$$t = t_{angle} + \frac{1}{2} t_{skin}$$

$$\frac{b}{t} = 14.3$$

BSM FIG. 80.04.2-5

$$\sigma_{cr} = 20 \text{ ksi}$$

COLUMN BUCKLING.

PROCEDURE FOR EVALUATING CRITICAL STRESS

$$P_{fa} = \sigma_a A_{fa}$$

$$P_{fb} = \sigma_b A_{fb}$$

$$P_{cr} = P_{fa} + P_{fb}$$

$$\bar{\sigma}_f = \frac{P_{cr}}{(A_{fa} + A_{fb})}$$

WHERE:

σ_i = MAX. AVERAGE FAILURE STRESS FOR FLANGE i

A_{fi} = AREA OF FLANGE i

P_{fi} = CRITICAL LOAD FOR ONE FLANGE

$\bar{\sigma}_f$ = MAX. AVERAGE FAILURE STRESS FOR SECTION.

σ_i IS EVALUATED FROM BSM FIG. 80.04.2-5

ENTER BSM FIG. 90.02.2-2 (JOHNSON PARABOLAS) WITH $\bar{\sigma}_f$ AND $\frac{L}{\rho\sqrt{c}}$. THIS GIVES σ_{cr} FOR COLUMN BUCKLING.

L = UNSUPPORTED LENGTH

ρ = LEAST RADIUS OF GYRATION

$\sqrt{c}$ = 1 FOR PINNED ENDS.

BSM FIG. 80.04.2-5.

$$\bar{\sigma}_f = 26 \text{ ksi}$$

BSM FIG. 90.02.2-2

$$\frac{L}{\rho} = \frac{4.75}{0.196} = 24.3$$

$$\sigma_{cr} = 25 \text{ ksi}$$

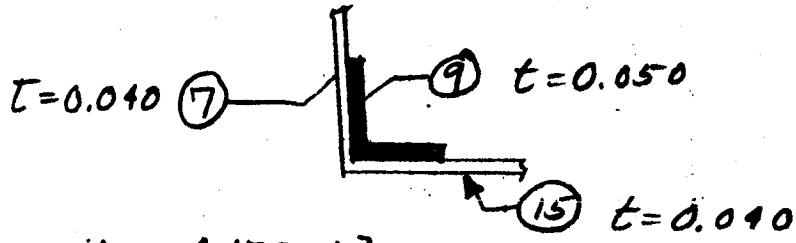
$$\boxed{P_{cr} = \sigma_{cr} A = 3440\#}$$

LIS. P_{cr} PART-II

4.9.2. PART 7161-421003-9 - LOWER OUTBOARD STRINGER.

MAT'L 2024-0, ASSUME 2024-T4

1x1 ANGLE



$A = 0.172 \text{ in}^2$

THIS IS THE SAME SECTION AS PART 11

COLUMN BUCKLING.

$$\frac{L}{\rho} = \frac{5.7}{0.196} = 29.1 \quad , \quad \bar{\sigma}_f = 26 \text{ ksi}$$

BSM FIG 90.02.2-2

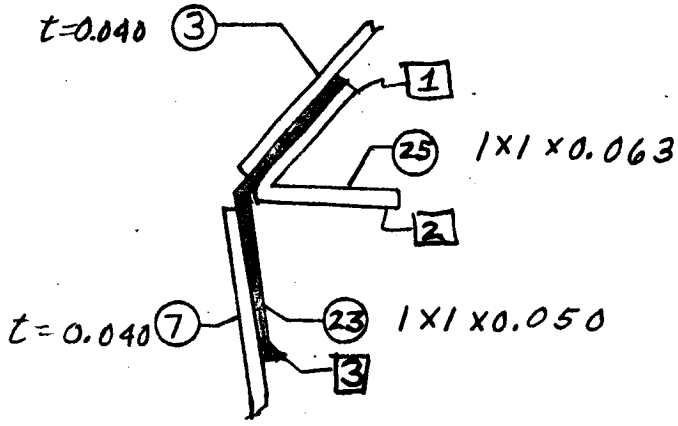
$$\sigma_{cr} = 24.5 \text{ ksi}$$

LOCAL BUCKLING CONTROLS

$$\boxed{P_{cr} = 3440\#}$$ L.O.S P_{cr}. PART 9

4.9.3. PARTS 7161-421003-25 } UPPER OUTBOARD
7161-421003-23 } STRINGER

MAT'L - 2024-0, ASSUME 2024-T4



AREA = 4(0.040) + 2(0.063) + 2(0.050)

A = 0.386 TOTAL

A = 0.306 USING $\frac{1}{2}$ SKINS

A = 0.226 ANGLES ONLY.

LOCAL BUCKLING-PROJECTING ELEMENT OF 25.

$$\frac{b}{t} = \frac{1}{0.063} = 15.9$$

BSM FIG 80.04.2-5

$\sigma_{cr} = 15.5$ KSI

COLUMN BUCKLING. BSM 80.04.2-5 (Neglect SKIN)

ELEMENT 1 $\frac{b}{t} = 8.85 \rightarrow \sigma_1 = 38$ KSI $\rightarrow P_1 = 4.29$K

2 $\frac{b}{t} = 15.9 \rightarrow \sigma_2 = 24$ KSI $\rightarrow P_2 = 1.51$K

3 $\frac{b}{t} = 20 \rightarrow \sigma_3 = 21$ KSI $\rightarrow P_3 = 1.05$K

P = 6.85K

$$\bar{\sigma}_f = \frac{6.85^K}{0.226} = 30.3 \text{ KSI}$$

BSM 90.02.2-2

$\frac{L}{\rho}$ CORRESPONDING TO σ_{cr} (LOCAL BUCKLING) OF 15.5 KSI:

$$\frac{L}{\rho} = 83$$

$$L = 83(0.199) = 16.5 \text{ in}$$

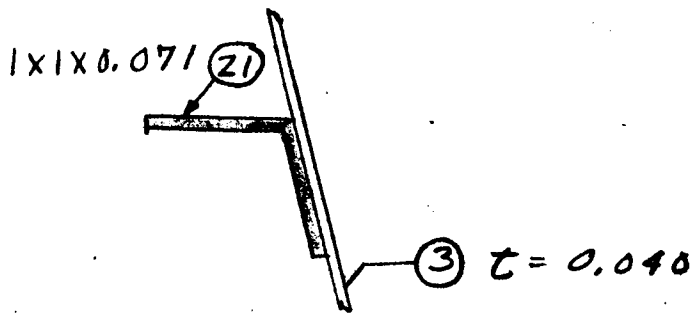
MAXIMUM ACTUAL LENGTH FOR THIS ELEMENT IS 6 in. ∴ LOCAL BUCKLING CONTROLS.

$$P_{cr} = 15.5 \text{ ksi}(0.306)$$

$$\boxed{P_{cr} = 4740\#}$$ ← U.O.S. P_{cr}. PART 23,25

4.9.4. PART 7161-921003-21 UPPER INBOARD STRINGER

MAT'L - 2024-0 ASSUME 2024-T4



AREA = $(0.071)(0.193) + 0.040(1) = 0.177$

A = 0.157 FOR ANGLE + ½ SKIN.

LOCAL BUCKLING - PROJECTING ELEMENT OF 21

$$\frac{b}{t} = \frac{1}{0.071} = 14.1$$

BSM FIG. 80.04.2-5

$$\sigma_{cr} = 20.1 \text{ ksi}$$

COLUMN BUCKLING.

$$\bar{\sigma}_f = 26 \text{ ksi}$$

BSM FIG. 90.02.2-2

$\frac{L}{\rho}$ FOR WHICH COLUMN BUCKLING EQUALS LOCAL BUCKLING.

$$\frac{L}{\rho} = 62$$

$$L = 62(0.1444) = 8.95 \text{ in}$$

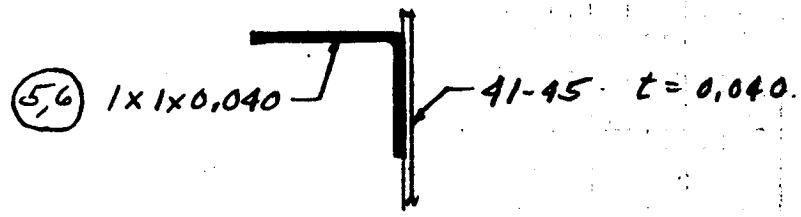
MAX. LENGTH IN RING IS 4 in. OK

LOCAL BUCKLING CONTROLS.

$$\boxed{P_{cr} = (20.1 \text{ ksi})(0.157) = 3160\#}$$ ← U.I.S. PART 21

4.9.5. PART 7161-421003-5,6 - AXIAL FORCE MEMBERS ON UPPER EDGE OF RIBS.

MAT'L: 2024-T3



AREA = $(1.96)(0.040) + \frac{1}{2}(0.040)(1)$

AREA = 0.098 ANGLE + $\frac{1}{2}$ RIB.

LOCAL BUCKLING - PROTECTING ELEMENT

$$\frac{b}{t} = \frac{1}{0.040} = 25$$

BSM FIG 80.04.2-4

$$\sigma_{cr} = 6.5 \text{ ksi}$$

COLUMN BUCKLING.

BSM FIG. 80.04.2-4.

$$\bar{\sigma}_f = 19.5$$

FROM BSM FIG. 90.02.2-1 - VALUE OF $\frac{L}{\rho}$ FOR WHICH σ_{cr} FOR COLUMN BUCKLING EQUALS σ_{cr} LOCAL BUCKLING IS:

$$\frac{L}{\rho} = 115$$

$$L = 0.20(115) = 23 \text{ in}$$

MAX. LENGTH IS 6 in. OK LOCAL BUCKLING CONTROLS

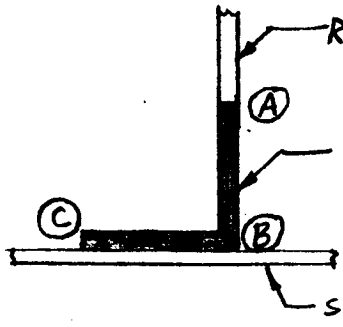
$$P_{cr} = (6.5 \text{ ksi})(0.098 \text{ in}^2)$$

$$\boxed{P_{cr} = 637 \text{ lbs}}$$

AXIAL FORCE MEMBERS ON RIBS
P_{cr} - 5,6

4.9.6. PART 7161-421003-41 THRU 45 - AXIAL FORCE MEMBERS ON RIB PERIMETER.

MAT'L: 2024-0 ASSUME 2024-T4



ASSUMED AXIAL FORCE MEMBER
0.75 X 0.75 X 0.040

$$A = (1.46)(0.040) + (0.75)\left(\frac{0.040}{2}\right)$$

$$A = 0.0733$$

LOCAL BUCKLING OF PROJECTING ELEMENT.

ASSUME C IS A FREE EDGE, B IS SIMPLY SUPPORTED - USE $\frac{1}{2}$ SKIN THICKNESS

$$\frac{b}{t} = \frac{0.75}{0.06} = 12.5$$

BSM FIG 80.04.2-5

$$\sigma_{cr} = 25 \text{ KSI}$$

COLUMN BUCKLING.

BSM FIG 80.04.2-5 $\qquad \frac{b}{t} = \frac{0.75}{0.040} = 18.75$

$$\bar{\sigma}_f = 22 \text{ KSI}$$

BSM FIG 90.02.2-2

HORIZONTAL LENGTH = 6.0 in

VERTICAL LENGTH = 10.5 in

HORIZONTAL. - $\frac{L}{\rho} = \frac{6}{0.142} = 41.2$

$$\sigma_{cr} = 20 \text{ KSI}$$

VERTICAL. $\frac{L}{\rho} = \frac{10.5}{0.142} = 74$

$$\sigma_{cr} = 16 \text{ KSI}$$

HORIZONTAL ELEMENTS.

$$P_{cr} = (20\ ksi)(0.0733)$$

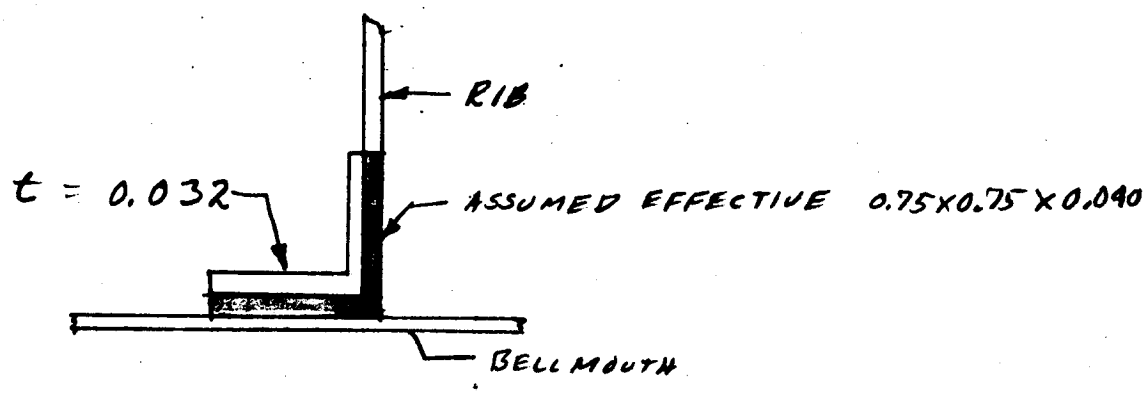
$$\boxed{P_{cr} = 1466\ lbs.}$$ ← HOR. A.F. MEMBERS ON RIBS

VERTICAL ELEMENTS.

$$P_{cr} = (16\ ksi)(0.0733)$$

$$\boxed{P_{cr} = 1172\ lbs.}$$ ← VERT. A.F. MEMBERS ON RIBS. EXCEPT ENGINE MOUNTS

VERTICAL MEMBERS ON INBOARD EDGE AT ENGINE MOUNT POINTS.



LOCAL BUCKLING. PROJECTING ELEMENT.

NO CHANGE DUE TO CUTBACK AT ENDS OF 0.032 ANGLE. (SEE DWG. 7161-421003)

COLUMN BUCKLING: BSM FIG. 80.04.2-5

$$\frac{b}{t} = \frac{0.75}{0.072} = 10.4.$$

$$\bar{\sigma}_f = 35\ ksi$$

$$\frac{L}{\rho} = \frac{10.5}{0.141} = 74.4$$

$$\sigma_{cr} = 16\ ksi \quad (BSM\ FIG\ 90.02.2-2)$$

$$AREA = (0.072)(4.5 - 0.072) + \frac{1}{2}(0.75)(0.040)$$

$$A = 0.118$$

$$P_{cr} = (0.118)(16\ ksi)$$

$$\boxed{P_{cr} = 1890\ lbs.}$$ ← INBOARD VERTICAL AXIAL FORCE MEMBERS AT ENGINE MOUNTS

4.9.7. PART 7161-421003-33 & 35 - MIDDLE OUTBOARD AND INBOARD STRINGERS. (REGION OF SUPPORT FIXTURES.)

MAT'L. 2024-0 - ASSUME 2024-T4

ANGLE 1X1X0.063

AREA = (0.063)(2-0.063) = 0.122

LOCAL BUCKLING.

$$\frac{b}{t} = \frac{1}{0.063} = 15.9$$

BSM FIG. 80.04.2-5

$$\sigma_{cr} = 16 \text{ ksi}$$

COLUMN BUCKLING.

$$\sigma_f = 24 \text{ ksi}$$

BSM FIG 90.02.2-2.

$\frac{L}{\rho}$ FOR LOCAL BUCKLING = COLUMN BUCKLING.

$$\frac{L}{\rho} = 76$$

$L = (0.196)(76) = 15.1 \text{ in}$ OK LOCAL BUCKLING CONTROLS.

$$P_{cr} = (16 \text{ ksi})(0.122 \text{ in}^2) = 1952 \text{ lbs.}$$

$\boxed{P_{cr} = 1952 \text{ lbs.}}$ ← M. IN.BD & OUTBD STRINGERS. 33, 35.

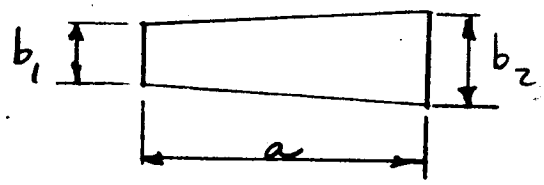
4.9.8 PARTS 7161-421003-7, 17 - OUTBOARD SKIN

MATL. 2024-T3

SHEAR PANEL $t = 0.040$

USE BSM FIG 110.02.2-2 FOR SHEAR BUCKLING.

THIS IS FOR RECTANGULAR PANELS — USE AVERAGE WIDTH OF TRAPEZOIDAL PANELS.



$$b = \frac{b_1 + b_2}{2} \qquad a = 10.8$$

GEOMETRY	b_1	b_2	b	b/a	b/t	τ_{cr}	CELLS
1	5.4	5.8	5.6	0.519	140	3.2	6 — 11
2	3.8	4.1	4.0	0.371	100	5.8	3,4, 13, 14, 28, 29
3	5.1	5.5	5.3	0.49	132	3.5	19 - 26
4	1.2	1.2	1.2	0.111	30	24.0	5, 12, 27
5	3.7	4.0	3.8	0.48*	95	6.8	1, 2, 15-18, 30, 31 UPPER
6	2.6	2.6	2.6	0.723•	65	16.0	1, 2, 15-18, 30, 31 LOWER

LOCATION OF CELLS IS DESIGNATED IN FIG. 6.

* $\frac{b}{a} = \frac{3.8}{7.9}$

• $\frac{b}{a} = \frac{2.6}{3.6}$

4.9.9. PART 7161-421003-15 - WEB

MAT'L 2024-T3

SHEAR PANELS USE BSM 110.02.2-2

$t = 0.040$; $a = 6.2$

GEOMETRY	b_1	b_2	b	b/a	b/t	τ_{cr}	CELLS
1	2.6	3.8	3.2	0.516	80	10	1-4, 13-18, 28-31
2	3.9	5.4	4.7	0.760	118	5.3	6-11
3	3.7	5.1	4.4	0.710	110	5.8	19-26
4	1.2	1.2	1.2	0.194	30	$24\tau_y$	5, 12, 27

4.9.10. PART 7161-421003-41→45 RIBS

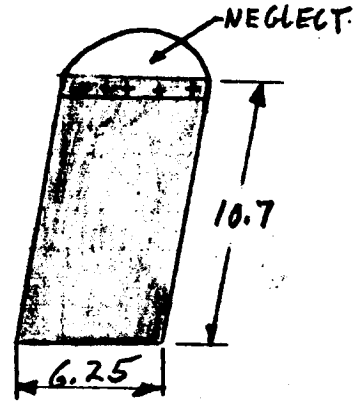
MAT'L 2024-0 ASSUME T4

$a = 10.7$, $b = 6.25$, $t = 0.040$

$\frac{b}{a} = 0.584$, $\frac{b}{t} = 156$

BSM 110.02.2-3

$\boxed{\tau_{cr} = 2.6 \text{ ksi}}$



4.9.11. PART 7161-421003-3 - BELLMOUTH.

MAT'L 6061-0 - USE 6061-T6 (F_{tu} = 42 ksi)

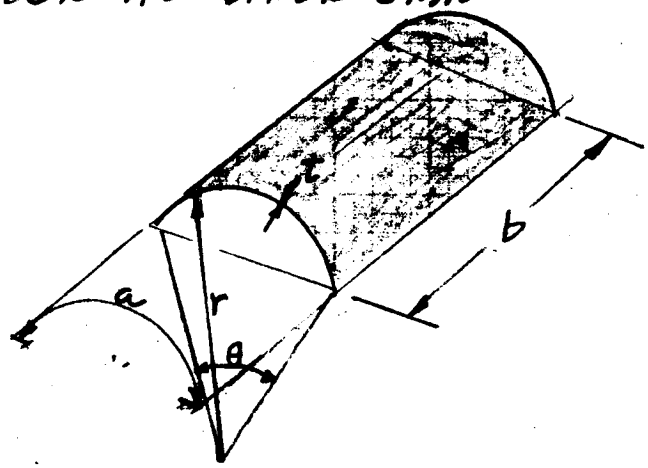
$t = 0.040$.

A CHECK AS INSIDE SKIN.

BSM 110.02.2-4

GEOMETRY	b	a	b/a	b/t	τ_{cr}	CELLS
1	2.9	10.5	0.28	73	9.9	3, 4, 13, 14, 28, 29
2	4.1	10.5	0.39	102	5.5	6-11
3	3.8	10.5	0.36	95	6.1	19-26
4	1.2	10.5	0.11	30	21.0	5, 12, 27
5	2.5	7.5	0.33	63	14.0	1, 2, 15-18, 30, 31 UPPER
6	2.4	2.5	0.96	60	18.0	1, 2, 15-18, 30, 31 LOWER

B CHECK AS UPPER SKIN.



$a = \frac{2\pi r}{360}\theta = 7.18$

$b = 5.8,\ 4.0$

$r = 3.81$

$t = 0.040$

$\theta = 108°$

B.1 $b = 5.8$

BSM FIG. 130.03.2-1

$Z = \frac{b^2}{rt}\sqrt{1-\mu^2} = 210$ $(\mu = 0.3)$

$\frac{a}{b} = 1.24$

$\Rightarrow K_s = 40$

$\frac{b}{t}\frac{1}{\sqrt{K_s}} = 22.9$

$\boxed{\tau_{cr} = 16.2 \text{ ksi}}$

B.2 $b = 4.0$

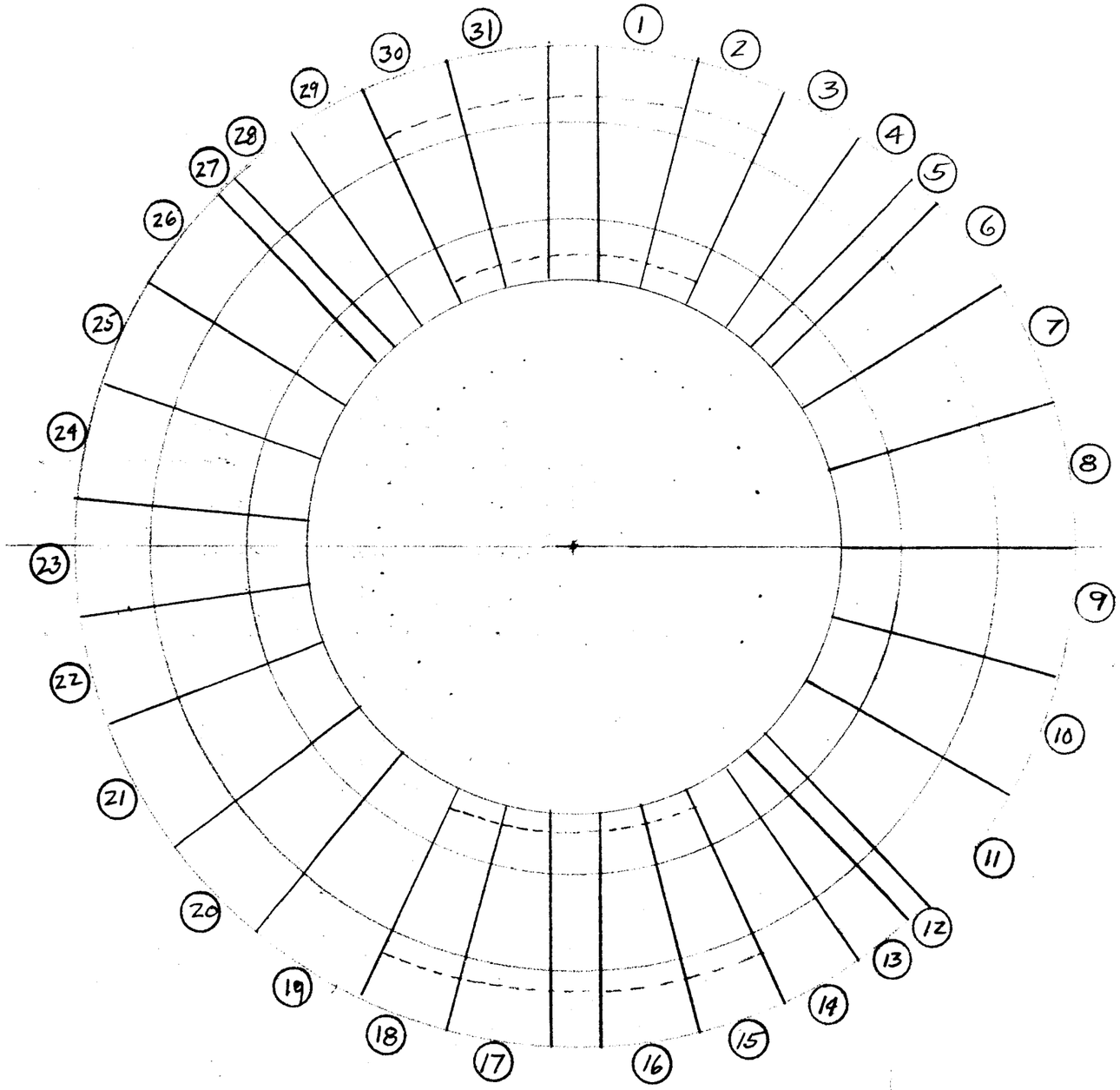
$Z = 100$

$\frac{a}{b} = 1.8$

$\Rightarrow K_s = 30$

$\frac{b}{t}\frac{1}{\sqrt{K_s}} = 18.2$

$\boxed{\tau_{cr} = 19.6 \text{ ksi}}$



A GIVEN CELL NUMBER REFERS TO ALL SHEAR PANELS WITHIN THAT CELL

Figure 4.6. Arrangement of Ribs in Ring

4.10. SUMMARY OF ELEMENT LOADS.

TABLE 4.3 SUMMARIZES MAXIMUM ELEMENT LOADS AND CRITICAL ELEMENT LOADS ALONG WITH THE LOCATION OF THE ELEMENT IN THE RING AND THE LOAD COMBINATION PRODUCING THE MAXIMUM VALUE.

UNDER AXIAL FORCE MEMBERS, ONLY THOSE MEMBERS CONSIDERED IN THE ANALYSIS ARE INCLUDED. TENSILE LOADS AS WELL AS COMPRESSIVE LOADS ARE PRESENTED. ALL CRITICAL LOADS ARE COMPRESSIVE.

UNDER SHEAR PANELS, THE PANELS IN THE FINAL DESIGN ARE TABULATED BY CELL NUMBER ALONG WITH THE CORRESPONDING (AS NEAR AS POSSIBLE) PANEL IN THE IDEALIZED STRUCTURE.

FICTITIOUS ELEMENTS USED TO SIMULATE SUPPORT FIXTURES ARE NOT INCLUDED.

LOAD COMBINATION NUMBERS ARE THOSE LISTED IN TABLE 4.2

THE FOLLOWING ABREVIATIONS ARE USED IN TABLE 4.3.

U.O.S.	UPPER	OUTBOARD	STRINGER
U.I.S	"	INBOARD	"
L.O.S	LOWER	OUTBOARD	"
L.I.S	"	INBOARD	"
M.I.S	MIDDLE	"	"
M.O.S	"	OUTBOARD	"
R	RIBS		
L.C.	LOAD COMBINATION (TABLE 2)		

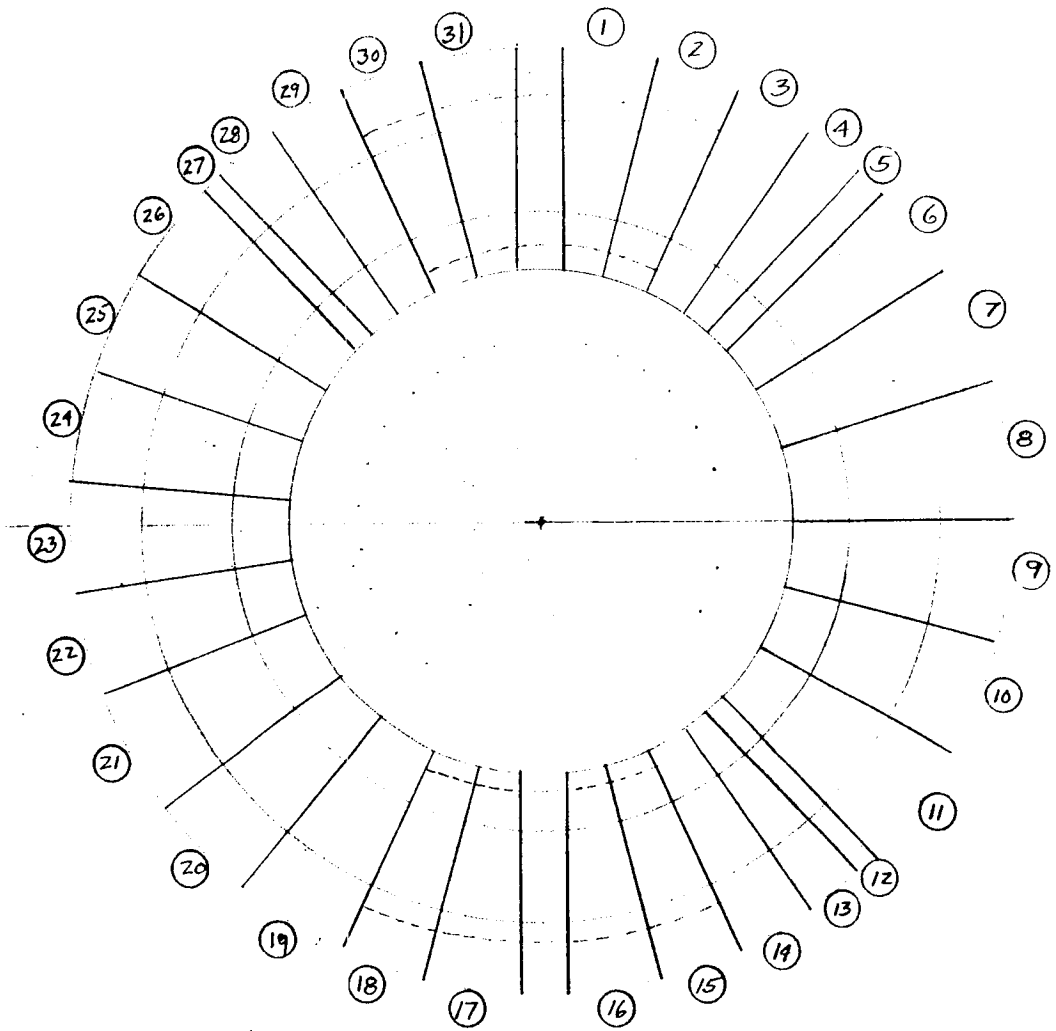
TABLE 4.3

MAXIMUM ELEMENT LOADS

ELEMENT NUMBER	POINTS		LOCATION	P_{cr}	MAXIMUM COMPRESSION	L.C.	MAXIMUM TENSION	L.C.	NOTES
1	1	2	RU	637	2251	91	2632	46	1-SEE Pg. 51
2	2	103	F	1172	61	58	102	46	
3	103	3	F	1172	59	72	97	48	
4	3	4	L	1466	240	34	202	60	
5	4	104	R	1172	475	48	304	89	
6	104	1	R	1172	305	48	213	89	
7	5	6	U	637	150	58	224	46	
8	6	112	F	1172	48	58	79	46	
9	112	7	F	1172	63	60	67	34	
10	7	8	L	1466	477	46	362	71	
11	8	111	R	1172	369	91	397	46	
12	111	5	R	1172	273	25	197	53	
13	9	10	U	637	95	70	118	47	
14	10	11	F	1172	71	91	77	46	
15	11	12	L	1466	503	46	376	60	
16	12	9	R	1172	34	48	29	89	
17	13	14	U	637	71	72	120	48	
18	14	15	F	1172	22	91	32	46	
19	15	16	L	1466	391	46	262	58	
20	16	13	R	1172	41	8	22	58	
21	17	18	U	637	80	91	129	46	
22	18	19	F	1172	15	91	23	46	
23	19	20	L	1466	257	46	161	58	
24	20	17	R	1172	38	48	19	72	
25	21	22	U	637	96	91	124	46	
26	22	23	F	1172	8	91	12	46	
27	23	24	L	1466	260	47	145	70	
28	24	21	R	1172	31	6	40	50	
29	25	26	U	637	92	20	90	74	
30	26	27	F	1172	6	47	4	90	
31	27	28	L	1466	289	47	184	90	
32	28	25	R	1172	24	47	17	90	
33	29	30	U	637	121	47	83	90	
34	30	31	F	1172	16	48	8	72	
35	31	32	L	1466	260	47	194	90	
36	32	29	R	1172	16	91	18	46	
37	33	34	U	637	114	47	71	70	
38	34	35	F	1172	21	48	10	72	
39	35	36	L	1466	155	47	139	90	
40	36	33	R	1172	17	91	25	46	
41	37	38	U	637	99	47	52	90	
42	38	39	F	1890	1228	47	847	90	
43	39	40	L	1466	878	90	1224	47	
44	40	37	R	1172	208	47	167	90	
45	132	133	U	637	210	46	111	91	
46	133	134	F	1890	830	13	604	65	
47	134	135	L	1466	698	65	1093	46	
48	135	132	R	1172	212	46	135	65	
49	41	42	U	637	375	46	207	58	
50	42	43	RF	1172	21	73	31	48	

TABLE 4.3. (CONT)

ELEMENT	POINTS		LOC.	P_{CR}	MAX COMP.	L.C.	MAX TEN.	L.C.	NOTES.
51	43	44	RL	1466	84	37	125	45	
52	44	41	R	1172	24	70	29	47	
53	45	46	U	637	349	46	207	58	
54	46	124	F	1172	19	91	28	46	
55	124	47	F	1172	68	72	110	48	
56	47	48	L	1466	66	70	120	47	
57	48	123	R	1172	32	46	22	58	
58	123	45	R	1172	71	48	34	72	
59	49	50	U	637	607	58	798	34	1
60	50	122	F	1172	59	72	105	48	
61	122	51	F	1172	59	72	105	48	
62	51	52	L	1466	33	46	30	65	
63	52	121	R	1172	369	48	233	72	
64	121	49	R	1172	152	46	103	58	
65	115	116	U	637	665	72	842	21	1
66	116	117	F	1172	65	58	107	46	
67	117	118	F	1172	65	58	106	46	
68	118	119	L	1466	98	46	69	91	
69	119	120	R	1172	320	46	218	58	
70	120	115	R	1172	160	48	98	72	
71	53	54	U	637	77	70	105	47	
72	54	126	F	1172	52	58	81	46	
73	126	55	F	1172	18	20	16	74	
74	55	56	L	1466	173	46	112	60	
75	56	125	R	1172	73	46	43	58	
76	125	53	R	1172	39	46	22	91	
77	57	58	U	637	105	70	129	20	
78	58	59	F	1172	19	91	24	46	
79	59	60	L	1466	249	46	178	60	
80	60	57	R	1172	18	46	11	91	
81	61	62	U	637	113	70	134	20	
82	62	63	F	1172	6	72	11	48	
83	63	64	L	1466	244	46	169	60	
84	64	61	R	1172	37	46	21	58	
85	65	66	U	637	107	72	139	21	
86	66	67	F	1172	124	60	178	46	
87	67	68	L	1466	190	46	128	58	
88	68	65	R	1172	108	60	168	46	
89	69	70	U	637	60	72	68	21	
90	70	157	F	1172	87	48	50	72	
91	157	71	F	1172	61	47	50	74	
92	71	72	L	1466	21	47	14	70	
93	72	156	R	1172	64	58	112	46	
94	156	69	R	1172	30	70	54	47	
95	148	149	U	637	33	33	29	57	
96	149	150	F	1172	285	46	154	58	
97	150	151	F	1172	277	46	147	58	
98	151	152	L	1466	25	70	32	47	
99	152	153	R	1172	200	34	191	60	
100	153	148	RR	1172	211	34	196	60	



A GIVEN CELL NUMBER REFERS TO ALL SHEAR PANELS WITHIN THAT CELL

Figure 4.6. Arrangement of Ribs in Ring

TABLE 4.3. (CONT)

ELEMENT	POINTS		LOC.	P_{CR}	MAX. COMP.	L.C.	MAX TEN.	L.C.	NOTES
101	73	74	RU	637	30	33	25	57	
102	74	75	F	1172	8	34	7	60	
103	75	76	L	1466	62	47	40	90	
104	76	73	R	1172	8	47	5	70	
105	142	143	U	637	32	33	24	57	
106	143	144	F	1172	783	46	577	60	
107	144	145	F	1172	783	46	575	60	
108	145	146	L	1466	67	60	71	34	
109	146	147	R	1172	268	48	136	72	
110	147	142	R	1172	268	48	138	72	
111	77	78	U	637	58	47	39	70	
112	78	155	F	1172	282	46	201	60	
113	155	79	F	1172	71	74	73	20	
114	79	80	L	1466	201	60	227	34	
115	80	154	R	1172	167	60	216	34	
116	154	77	R	1172	81	60	85	34	
117	81	82	U	637	209	20	196	74	
118	82	83	F	1172	131	58	199	46	
119	83	84	L	1466	307	60	314	34	
120	84	81	R	1172	150	60	234	46	
121	85	86	U	637	173	20	157	74	
122	86	87	F	1890	1372	46	982	91	
123	87	88	L	1466	828	91	1228	46	
124	88	85	R	1172	194	20	148	74	
125	137	138	U	637	185	47	148	70	
126	138	139	F	1890	698	33	564	57	
127	139	140	L	1466	566	92	984	45	
128	140	137	R	1172	269	20	199	74	
129	89	90	U	637	289	48	163	89	
130	90	91	F	1172	32	60	38	34	
131	91	92	L	1466	240	74	289	20	
132	92	89	R	1172	29	90	38	47	
133	93	94	U	637	351	46	246	60	
134	94	114	F	1172	34	74	41	20	
135	114	95	F	1172	40	50	69	47	
136	95	96	L	1466	234	74	267	20	
137	96	113	R	1172	67	45	55	92	
138	113	93	R	1172	61	46	31	91	
139	97	98	U	637	1321	89	1643	48	1
140	98	102	F	1172	71	57	103	45	
141	102	99	F	1172	71	57	103	45	
142	99	100	L	1466	174	34	170	60	
143	100	101	R	1172	576	46	399	91	
144	101	97	R	1172	298	45	221	92	
145	104	103							FICTITIOUS
146	111	112							
147	123	124							
148	121	122							
149	120	117							
150	125	126	R						

TABLE 4.3. (CONT)

ELEMENT	POINTS		LOC	P_{CR}	MAX. COMP.	L.C.	MAX TEN.	L.C.	NOTES.
151	156	157	R						FICTITIOUS
152	153	150							
153	147	144							
154	154	155							
155	113	114							
156	101	102	R						
157	1	5	U.O.S	4740	2821	91	2884	46	
158	5	9			1412	91	1498	46	
159	9	13			1757	91	2051	46	
160	13	17			1365	91	1800	46	
161	17	21			1039	58	1570	46	
162	21	25			833	58	1357	46	
163	25	29			662	59	1203	48	
164	29	33			707	72	1375	48	
165	33	37			807	72	1493	48	
166	37	132			794	72	1428	48	
167	132	41			611	72	1231	48	
168	41	45			278	59	556	48	
169	45	49			473	60	666	34	
170	49	115			221	73	264	21	
171	115	53			456	73	1006	21	
172	53	57			292	89	756	21	
173	57	61			365	91	520	46	
174	61	65			464	91	703	46	
175	65	69			670	60	1051	46	
176	69	148			1386	58	2188	46	
177	148	73			1568	58	2496	46	
178	73	142			1583	58	2567	46	
179	142	77			1379	58	2295	46	
180	77	81			580	58	1086	46	
181	81	85			782	70	1096	47	
182	85	137			818	70	1111	47	
183	137	89			678	72	1036	48	
184	89	93			560	89	761	48	
185	93	97			1506	89	1697	48	
186	97	1	U.O.S	4740	1860	60	1929	34	
187	2	6	U.I.S	3160	2734	46	1829	91	
188	6	10			602	46	349	58	
189	10	14			527	48	271	89	
190	14	18			618	91	703	46	
191	18	22			1097	91	1504	46	
192	22	26			1379	91	2075	46	
193	26	30			1445	91	2381	46	
194	30	34			1340	58	2389	46	
195	34	38			1126	58	2088	46	
196	38	133			904	59	1893	48	
197	133	42			741	89	1578	48	
198	42	46			215	90	360	47	
199	46	50			1156	46	775	91	
200	50	116	U.I.S	3160	2063	46	1162	91	

TABLE 4.3. (CONT)

ELEMENT	POINTS		LOC.	P_{CR} (lbs)	MAX. (lbs) COMP.	L.C.	MAX (lbs) TEN.	L.C.	NOTES
201	116	54	UIS	3160	1956	46	1079	91	
202	54	58			744	46	440	91	
203	58	62			884	34	808	58	
204	62	66			373	74	403	20	
205	66	70			510	91	923	46	
206	70	149			1409	91	2401	46	
207	149	74			1760	91	2940	46	
208	74	143			2085	91	3420	46	
209	143	78			2749	91	3653	46	
210	78	82			1447	60	2296	46	
211	82	86			2136	60	3158	46	
212	86	138			2061	60	2896	46	
213	138	90			1594	60	2235	46	
214	90	94			297	60	378	34	
215	94	98			1023	46	598	91	
216	98	2	UIS	3160	2516	46	1611	91	
217	4	8	LOS	3440	386	59	745	48	
218	8	12			233	89	385	48	
219	12	16			260	89	326	48	
220	16	20			651	46	471	91	
221	20	24			1126	46	713	91	
222	24	28			1424	46	813	91	
223	28	32			1521	46	834	58	
224	32	36			1500	48	754	59	
225	36	40			1686	48	872	72	
226	40	135			1441	48	815	72	
227	135	44			1294	48	794	72	
228	44	48			286	47	231	70	
229	48	52			399	91	604	46	
230	52	119			537	91	969	46	
231	119	56			487	91	873	46	
232	56	60			207	91	370	46	
233	60	64			159	91	279	46	
234	64	68			278	46	179	91	
235	68	72			150	46	87	91	
236	72	152			107	46	67	91	
237	146	80			308	46	227	60	
238	80	84			785	34	543	91	
239	84	88			2588	46	2041	60	
240	88	140			2475	34	1982	60	
241	140	92			1576	34	1183	58	
242	92	96			234	26	206	59	
243	96	100			328	91	717	46	
244	100	4	LOS	3440	434	91	843	46	
245	3	7	LIS	3440	1304	74	1646	47	
246	7	11			854	74	947	47	
247	11	15			1770	34	1642	60	
248	15	19			1608	46	1245	91	
249	19	23			1431	46	956	58	
250	23	27	LIS	3440	1254	46	742	58	

TABLE 4.3. (CONT)

ELEMENT	POINTS		LOC.	P_{CR}	MAX. COMP.	L.C.	MAX TEN	L.C.	NOTES.
251	27	31	LIS	3440	1786	47	999	70	
252	31	35			2280	47	1357	70	
253	35	39			2516	47	1540	70	
254	39	134			1577	48	1061	72	
255	134	43			1963	48	1280	72	
256	43	47			668	48	445	72	
257	47	51			242	61	293	33	
258	51	118			369	57	535	45	
259	118	55			360	50	543	47	
260	55	59			211	90	350	47	
261	59	63			627	74	628	20	
262	63	67			988	34	852	60	
263	67	71			191	74	195	20	
264	71	151			128	34	106	60	
265	145	79			173	46	106	58	
266	79	83			270	47	159	70	
267	83	87			1200	45	645	63	
268	87	139			1527	47	1134	70	
269	139	91			1404	47	824	90	
270	91	95			393	48	242	89	
271	95	99			751	74	889	20	
272	99	3	LIS	3440	1199	74	1483	20	
273	104	111	MOS	1952	644	89	791	48	
274	123	121			350	20	336	74	
275	121	120			207	91	268	46	
276	120	125			213	91	352	46	
277	156	153			2470	46	1592	60	2. CUTOUT — FICTITIOUS
278	153	76			3147	46	2028	60	
279	76	147			3484	46	2242	60	
280	147	154			3163	46	2048	60	
281	113	101			807	47	786	90	
282	101	104	MOS		285	91	338	46	
283	103	112	MIS		1302	34	1279	60	
284	124	122			371	46	242	91	
285	122	117			202	90	216	47	
286	117	126			230	46	224	91	
287	157	150			2363	46	1679	58	2. CUTOUT — FICTITIOUS
288	150	75			2245	34	1497	58	
289	75	144			2856	46	1969	58	
290	144	155			2585	46	1758	58	
291	114	102			493	26	470	52	
292	102	103	MIS.	1952	961	74	999	20	

TABLE 4.3. (CONT)

RIBS

ELEMENT	POINTS				$(\tau t)_{CR}$ lbs/in	$(\tau t)_{MAX}$	L.C.	NOTES.
330	1	2	103	104	104	106	46	3
331	104	103	3	4		82	47	
332	5	6	112	111		52	45	
333	111	112	7	8		52	47	
334	9	10	11	12		25	20	
335	13	14	15	16		46	46	
336	17	18	19	20		58	46	
337	21	22	23	24		63	46	
338	25	26	27	28		63	46	
339	29	30	31	32		63	48	
340	33	34	35	36		55	48	
341	37	38	39	40		60	47	
342	132	133	134	135		60	48	
343	41	42	43	44		12	47	
344	45	46	124	123		51	46	
345	123	124	47	48		55	48	
346	49	50	122	121		56	46	
347	121	122	51	52		75	48	
348	115	116	117	120		67	46	
349	120	117	118	119		54	46	
350	53	54	126	125		34	46	
351	125	126	55	56		28	34	
352	57	58	59	60		8	47	
353	61	62	63	64		12	46	
354	65	66	67	68		28	46	
355	69	70	157	156		95	46	
356	156	157	71	72		38	47	
357	148	149	150	153		74	46	
358	153	150	151	152		46	47	
359	73	74	75	76		77	46	
360	142	143	144	147		104	46	
361	147	144	145	146		69	34	
362	77	78	155	154		155	46	4.
363	154	155	79	80		80	34	
364	81	82	83	84		49	46	
365	85	86	87	88		47	46	
366	137	138	139	140		40	47	
367	89	90	91	92		8	34	
368	93	94	114	113		68	47	
369	113	114	95	96		65	45	
370	97	98	102	101		71	46	
371	101	102	99	100	104	92	45	

TABLE 4.3. (CONT)

UPPER HORIZONTAL SURFACE (BELLMOUTH)

CELL	ELEMENT	POINTS				$(\tau t)_{CR}$	$(\tau t)_{MAX}$	L.C.	NOTES.
1	372	1	2	6	5	784	490	46	
2	373	5	6	10	9		376	46	
3	373	5	6	10	9		376	46	
4	374	9	10	14	13		314	46	
5	374	9	10	14	13	784	314	46	
6	375	13	14	18	17	648	248	46	
7	376	17	18	22	21		171	46	
8	377	21	22	26	25		85	46	
9	378	25	26	30	29		37	47	
10	379	29	30	34	33		96	46	
11	380	33	34	38	37	648	175	46	
12	381	37	38	133	132	784	219	46	
13	382	132	133	42	41		233	46	
14	382	132	133	42	41		233	46	
15	383	41	42	46	45		281	46	
16	384	45	46	50	49		321	46	
17	386	115	116	54	53		149	48	
18	387	53	54	58	57	784	142	48	
19	388	57	58	62	61	648	155	46	
20	389	61	62	66	65		153	46	
21	390	65	66	70	69		129	46	
22	391	69	70	149	148		91	46	
23	392, 393	148 73	149 74	74 143	73 142		74, 52	48, 47	
24	394	142	143	78	77		25	47	
25	395	77	78	82	81		40	13	
26	396	81	82	86	85	648	120	46	
27	397	85	86	138	137	784	158	46	
28	398	137	138	90	89		221	46	
29	398	137	138	90	89		221	46	
30	399	89	90	94	93		277	46	
31	400	93	94	98	97	784	302	48	
	385	49	50	116	115		131	21	FOR
	401	97	98	2	1		313	45	REFERENCE

TABLE 4.3. (CONT)

LOWER HORIZONTAL SURFACE (WEB)									
CELL	ELEMENT	POINTS				$(\tau t)_{CR}$ lb/in	$(\tau t)_{MAX}$	L.C.	NOTES
1	402	4	3	7	8	400	184	46	
2	403	8	7	11	12		203	46	
3	403	8	7	11	12		203	46	
4	404	12	11	15	16	400	144	48	
5	404	12	11	15	16	960	144	48	
6	405	16	15	19	20	212	159	47	
7	406	20	19	23	24		148	47	
8	407	24	23	27	28		113	47	
9	408	28	27	31	32		55	74	
10	409	32	31	35	36		99	46	
11	410	36	35	39	40	212	136	46	
12	411	40	39	134	135	960	124	46	
13	412	135	134	43	44	400	122	48	
14	412	135	134	43	44		122	48	
15	413	44	43	47	48		188	48	
16	414	48	47	51	52		146	48	
17	416	119	118	55	56		69	46	
18	417	56	55	59	60	400	123	46	
19	418	60	59	63	64	232	114	46	
20	419	64	63	67	68		86	46	
21	420	68	67	71	72		88	47	
22	421	72	71	151	152		46	47	
23	435, 436	153 76	152 75	75 74	76 147		140, 150	20,20	
24	422	146	145	79	80		70	34	
25	423	80	79	83	84		183	34	
26	424	84	83	87	88	232	266	34	5
27	425	88	87	139	140	960	97	47	
28	426	140	139	91	92	400	295	20	
29	426	140	139	91	92		295	20	
30	427	92	91	95	96		290	20	
31	428	96	95	99	100	400	223	47	
	415						39	48	FOR REF-
	429						171	46	ERENCE

TABLE 4.3. (CONT)

OUTBOARD SKIN									
CELL	ELEMENT	POINTS				$(\tau t)_{cr}$	$(\tau t)_{max}$	L.C.	NOTES
1U	440	1	104	111	5	272	200	48	UPPER
1L	441	104	4	8	111	640	269	48	LOWER
2U						272	200	48	
2L	△					640	269	48	
3	442	9	12	16	13	232	187	46	
4	442	9	12	16	13	232	187	46	
5	443	13	16	20	17	960	163	48	
6	443	13	16	20	17	128	163	48	5
7	444	17	20	24	21		144	48	5
8	445	21	24	28	25		116	47	
9	446	25	28	32	29		79	47	
10	447	29	32	36	33		102	46	
11	448	33	36	40	37	128	142	46	5
12	449	37	40	135	132	960	143	46	
13	450	132	135	44	41	232	246	46	5
14	450	132	135	44	41	232	246	46	5
15U	△					272			
15L						640			
16U	451	45	123	121	49	272	246	48	
16L	452	123	48	52	121	640	228	48	
17U	455	115	120	125	53	272	134	46	
17L	456	120	119	56	125	640	123	46	
18U	△					272			
18L						640			
19	457	57	60	64	61	140	156	46	5
20	458	61	64	68	65		144	46	5
21	458	61	64	68	65		144	46	5
22	459,460	69/156	156/72	153/152	148/153		229, 69	46,46	6
23	461,462	148/73	153/76	76/147	73/142		130, 114	47,47	CUTOUT
24	463,464	142/147	147/146	154/80	77/154		187, 152	46,46	6
25	△								
26	465	81	84	88	85	140	109	46	
27	466	85	88	140	137	960	163	46	
28	467	137	140	92	89	232	206	45	
29	467	137	140	92	89	232	206	45	
30U	△					272			
30L						640			
31U	468	93	113	101	97	272	262	45	
31L	469	113	96	100	101	640	184	47	
	453						51	26	REFERENCE
	454						90	26	"

TABLE 4.3. (CONT)

SHEAR PANELS.

INBOARD SKIN (BELL MOUTH)									
CELL	ELEMENT	POINTS				$(\tau t)_{CR}$	$(\tau t)_{MAX}$	L.C.	NOTES
1U	472	2	103	112	6	560	192	46	
1L	473	103	3	7	112	720	168	34	
2U						560			
2L	Δ					720			
3	474	10	11	15	14	396	202	46	
4	474	10	11	15	14	396	202	46	
5	475	14	15	19	18	840	156	46	
6	475	14	15	19	18	220	156	46	
7	476	18	19	23	22		98	46	
8	477	22	23	27	26		34	46	
9	478	26	27	31	30		56	48	
10	479	30	31	35	34		119	48	
11	480	34	35	39	38	220	175	48	
12	481	38	39	134	133	840	158	46	
13	482	133	134	43	42	396	69	34	
14	482	133	134	43	42	396	69	39	
15U						560			
15L	Δ					720			
16U	483	46	124	122	50	560	40	34	
16L	484	124	47	51	122	720	19	33	
17U	487	116	117	126	54	560	43	48	
17L	488	117	118	55	126	720	19	48	
18U						560			
18L	Δ					720			
19	489	58	59	63	62	244	64	48	
20	490	62	63	67	66		58	48	
21	490	62	63	67	66		58	48	
22	491, 492	139, 149	157, 71	158, 81	149, 150		155, 104	34, 46	
23	493, 494	165, 149	74, 150	75, 144	74, 143		136, 207	34, 34	
24	495, 496	143, 144	144, 145	155, 79	78, 155		60, 230	47, 46	
25	Δ								
26	497	82	83	87	86	244	212	46	
27	498	86	87	139	138	840	78	47	
28	499	138	139	91	90	396	98	34	
29	499	138	139	91	90	396	98	34	
30U						560			
30L	Δ					720			
31U	500	94	114	102	98	560	69	34	
31L	501	114	95	99	102	720	142	34	
	485						20	21	DOOR PANEL
	486						6	73	"
	502						120	34	"
	503						125	34	"

TABLE 4.3 – NOTES.

(1.) THESE LOADS ARE ACTUALLY CARRIED BY THE SUPPORT FIXTURE.

(2.) ELEMENTS 277-280, 287-290 WERE PART OF THE CUTOUT. THE CUTOUT DOES NOT EXIST IN THE FINAL DESIGN.

(3.) PART OF THE SUPPORT FIXTURE

(4.) ADJACENT TO CUTOUT. ELEMENT 339 IS DIAMETRICALLY APPOSED. $(\tau t)_{max} = 63 \frac{lb}{in}$. WITHOUT THE CUTOUT, THE SHEAR FLOW IN ELEMENT 362 SHOULD BE REDUCED CONSIDERABLY. – OK

(5.) TAKING INTO CONSIDERATION THE RESERVE OF POST-BUCKLING STRENGTH OF SHEAR PANELS, LET SOME OF THE PANELS BUCKLE AT LOADS GREATER THAN LIMIT BUT LESS THAN ULTIMATE

(6.) DELETION OF THE CUTOUT WILL REDUCE THESE VALUES OF SHEAR FLOW.

4.11. CONNECTIONS:

4.11.1. RIVETS

(1) MS 20470 AD4

MMS TABLE. 8.1.1.1.1(c)

P_{su} = 388 lb. SINGLE SHEAR.

P_{su} = 776 lb DOUBLE SHEAR

SINGLE SHEAR REDUCTIONS FOR D/t

t = THINNEST SHEET IN SINGLE SHEAR.

t = MIDDLE SHEET IN DOUBLE SHEAR.

SINGLE SHEAR	t	DOUBLE SHEAR
0.964	0.032	0.688
0.966	0.040	0.792
1.0	0.050	0.870
1.0	0.063	0.935
1.0	0.071	0.974

SHEET BEARING STRENGTHS:

CHECK $\frac{e}{D}$ RATIO.

1 inch ANGLE $\frac{e}{D} = \frac{0.464}{0.125} = 3.7 > 2.0$ OK

0.75 ANGLE $\frac{e}{D} = \frac{0.355}{0.125} = 2.84 > 2.0$ OK

MH5 TABLE 8.1.1.1.1(f)

2024-T3 $K = 1.24$

2024-T4 $K = 1.18$

TABLE 8.1.1.1(e)

2024-T3

t	P_u	$K P_u$
0.040	514	636
0.050	643	796
0.063	810	1005
0.071	912	1130

2024-T4

t	P_u	$K P_u$
0.040	514	606
0.050	643	758
0.063	810	955
0.071	912	1078

THINEST SHEET IN ALL CASES IS 0.040

MINIMUM P_u IS FOR SINGLE SHEAR, $t = 0.040$

THEN:

$$P_u = (0.966)(388)$$

$$P_u = 374 \text{ lbs per rivet.}$$

MAXIMUM RIVET SPG. = 1 in

TRY ALL AT 1 INCH.

$$\text{SHEAR FLOW} = \frac{374 \text{ lbs.}}{1 \text{ inch}}$$

ALLOWABLE SHEAR STRESS FOR MS 20470-AD4 RIVETS.

$$\tau_{max} = \frac{374}{0.040} = 9350 \text{ psi.}$$

THIS CONTROLS OUTBOARD SKIN & WEB.

ELEMENTS. 402-429 WEB. OK

440-471 SKIN. OK

(2.) MS 20426 AD4 RIVETS.

MHS TABLE 3.2.6.0 (b.)

6061-T6.

$F_{Bu} = 88$ ksi

$F_{By} = 58$ ksi

USE $\frac{1}{2}$ COUNTERSUNK SHEET FOR THICKNESS IN BEARING.

$$t = \frac{0.040}{2} = 0.020$$

BRG. AREA = $(0.020)(0.1285) = 0.0025 \text{ in}^2$

$\frac{2}{3}(88 \text{ ksi}) = 58.6 \text{ ksi} > 58 \text{ ksi}$ (Yield below limit load)

FOR YIELDING AT LIMIT LOAD

$$F_{BU} = 1.5 F_{BY} = 1.5(58) = 87 \text{ ksi}$$

THEN FOR BEARING FAILURE, (YIELD AT LIMIT LOAD)

$$P_u = (87{,}000 \text{ psi})(0.0025 \text{ in}^2)$$

$$P_u = 217.5$$

SHEAR FLOW $= \frac{217.5 \text{ lbs}}{1 \text{ in}}$

$$\tau = \frac{217.5}{0.040} = 5438 \text{ psi}$$

CHECK:

INBOARD SURFACE BELLMOUTH – OK

RIBS OK

UPPER HORIZONTAL PANELS NG. $\tau_{max} = 13{,}251$ psi

TRY: MS 20470 AD4 ON UPPER OUTSIDE EDGE OF BELLMOUTH.

MIL5 TABLE 8.1.1.1.1.(f).

FOR 6061-T6. $k = 0.88$.

$$P_{Bu} = (514)(0.88) = 452 \text{ lbs} > P_{su}$$

AT PITCH OF 0.75 IN.

$$\text{SHEAR FLOW} = \frac{374}{0.75} = 498 \frac{\text{lb}}{\text{in}}$$

$$\tau = \frac{498}{0.040} = 12450 \text{ psi} > 12{,}251 \ \underline{\underline{\text{OK}}}$$

USE MS 20470 AD4 at 0.75" max pitch.

CHECK CONNECTIONS FROM RING TO SUPPORT FIXTURE

(1.) ANGLE FROM OUTBOARD SKIN TO SUPPORT FIXTURE

ALLOWABLE LOAD PER RIVET

$$P_u = 374 \text{ lbs}$$

THIS ANGLE MUST TRANSFER ALL SHEAR FROM THE OUTBOARD SKIN INTO THE SUPPORT FIXTURE. THE SKIN HAS ALREADY BEEN CHECKED AND FOUND SATISFACTORY IF RIVETS ARE SPACED AT 1 INCH PITCH. THESE ARE AT 0.75 in. PITCH. ∴ OK

(2.) RIVETS FROM FIXTURE TO RIBS

THESE CONNECTIONS TRANSMIT THE TORQUE FROM THE RING TO THE FIXTURE. THEREFORE, FIND THE MAXIMUM SHEAR FLOW IN BOXES ADJACENT TO SUPPORT AND APPLY AS TORQUE TO THE RIVET PATTERN.

THE MAXIMUM ALLOWABLE TORQUE IS:

$$T_{ALL} = \Sigma P_u a$$

WHERE P_u = ALLOWABLE LOAD PER RIVET

a = MOMENT ARM W.R.T. CENTROID OF RIVET GROUP.

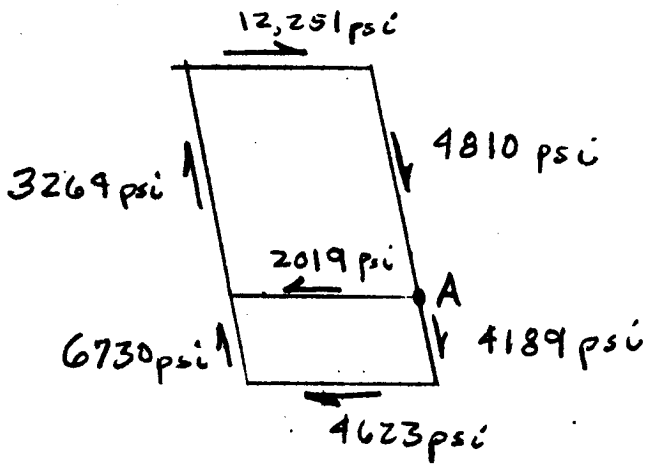
SINCE P_u IS CONSTANT

$$T_{ALL} = P_u \Sigma a$$

$$= 374 (105.2)$$

$$T_{ALL} = 39,400 \text{ in-lbs.}$$

THE MAXIMUM SHEAR FLOW OCCURS IN THE BOX TO THE RIGHT OF THE FWD SUPPORT DURING LOAD COMBINATION 46.



THE NET RESULT OF TORQUE DUE TO BENDING SHEAR FLOW MUST BE ZERO.

TAKE MOMENTS ABOUT (A).

$$T_{max} = 36,856 \text{ in-lbs.} < 39,400 \text{ in lbs.} \quad \underline{\underline{OK}}$$

CHECK BOLTS FROM SUPPORT FIXTURE TO RING.

LARGEST TRANSFER OF LOAD OCCURS WHEN AXIAL FORCE MEMBERS ON EITHER SIDE HAVE THE GREATEST ALGEBRAIC DIFFERENCE.

4.11.2. BOLTS:

AN 175-5

RATED STRENGTH - lbs

$P_{ut} = 6500$

$P_{yt} = 4980$

$P_{us} = 5750$

AN 174-5

RATED STRENGTH - lbs

$P_{ut} = 4080$

$P_{yt} = 3130$

$P_{us} = 3680$

6Z1-428-10

$P_{ut} = 8090$ lbs.

USE SAME STRENGTH AS 174-5 FOR CHECK.

ALLOWABLE BEARING VALUES.

MH5 TABLE 8.1.1.1.1(f)

2024-T4 $t = 0.063$ $K = 1.18$ ← CONTROLS.

2014-T6 $K = 1.29$

MH5 TABLE 8.1.1.1.1 (g)

$\frac{5}{16}$ BOLT, 0.063 PL $P = 1969$ $KP = 2320$

$\frac{1}{4}$ BOLT, 0.063 PL $P = 1575$ $KP = 1860$

$\frac{1}{4}$ BOLT, 0.071 PL. $P = 1775$ $KP = 2095$

ALLOWABLE LOADS ON BOLTS

UPPER OUTBOARD	6960 lbs.
UPPER INBOARD	6285 lbs.
MIDDLE OUTBOARD	6960 lbs
MIDDLE INBOARD	5580 lbs.

ALLOWABLE STRESS TRANSFER. (BASED ON AREAS USED FOR ANALYSIS.)

$$\sigma = \frac{P}{A}$$

U. OTBD. $\sigma = \frac{6960}{0.322} = 21{,}800$ psi

U. INBD $\sigma = \frac{6285}{0.174} = 36{,}100$ psi

M. OTBD. $\sigma = \frac{6960}{0.1957} = 39{,}200$ psi

M INBD $\sigma = \frac{5580}{0.1957} = 28{,}300$ psi

FROM THE TABLE OF MAXIMUM STRESSES TAKE THE SUM OF THE LARGEST ABSOLUTE VALUES. THESE VALUES ARE FICTITIOUS BECAUSE THEY COME FROM DIFFERENT LOADING CONDITIONS. HOWEVER, THEY ARE EQUAL TO OR GREATER THAN THE MAXIMUM LOAD TRANSFER.

ELEMENTS	LOC.	MAX. DIFF. (psi)
187, 215	UI	19,153
157, 185	UO	14,035
273, 281	MO	8,138
283, 291	MI	9058
169, 171	U.O.	4597
199, 201	U.I.	15,701
274, 276	MO	2792
284, 286	MI	3047

BOLTS. OK

4.11.3. SPLICES:

PART 21., ELEMENT 193

$P_{max} = 13,685 \text{ psi} (0.174) = 2380 \text{ lb.}$

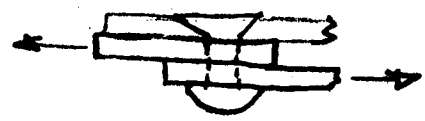
2 MS 20470 AD5 $\quad t = 0.071$

$P_{us} = 596 \text{ lbs.}$

2 MS 20426 AD5

USE $P_{us} = 596$

THE COUNTERSINK IS IN THE BELLMOUTH. THE ACTUAL LOAD TRANSFER IS DOWN ON THE FULL SHANK.



$P_{ALL} = 4(596) = 2384 \text{ lbs.}$ OK

PART 23 ELEMENT 163

$P_{max} = (3738 \text{ psi})(0.322) = 1200 \text{ lb.}$

THIS IS FOR PARTS 23 & 25. ASSUME 23 CARRIES $\frac{1}{2}$.

$P_{max} = 600 \text{ lb.}$

MS20426AD4 $P_{su} = 388 \text{ lb.}$

$3(388) = 1164 \text{ lb.} > 600 \text{ lb.}$ OK

SECTION 5

LEG

The vehicle has four legs to attach the four landing shock struts to the center body. Each leg is a triangular truss with three main chord members. The lower portion of the leg and each chord member (including the gussets) are heat treated and aged each as a sub-assembly and then the leg is made a complete assembly by welding the diagonals to the gussets. Only these welds are left in the as welded condition. Specifically these are the welds attaching each diagonal except the 5 end of 5-9 and 5-12. Also the 8 and 11 ends of the lower longerons are as welded. The remainder of the leg material is 6061-T6.

5.1 ANALYSIS OF LEGS.

The leg analysis was performed on an IBM 7090 digital computer using the Bell Aerosystems general purpose structural analysis program. The mechanics of this program are described in the discussion of the engine mount analysis.

5.2 LEG GEOMETRY.

The geometry of the leg is shown in Figures 5.1, 5.2 and 5.3. Points at which loads are introduced are (1) and (18). Support points are (7), (10) and (13), at which points the leg was assumed to be pinned to the center body structure. The leg consists of 31 members, 9 of which are assumed to be axial force members. The remaining 22 members were treated as flexural members in the analysis. Coordinates of the leg node points are given in Table 5.1.

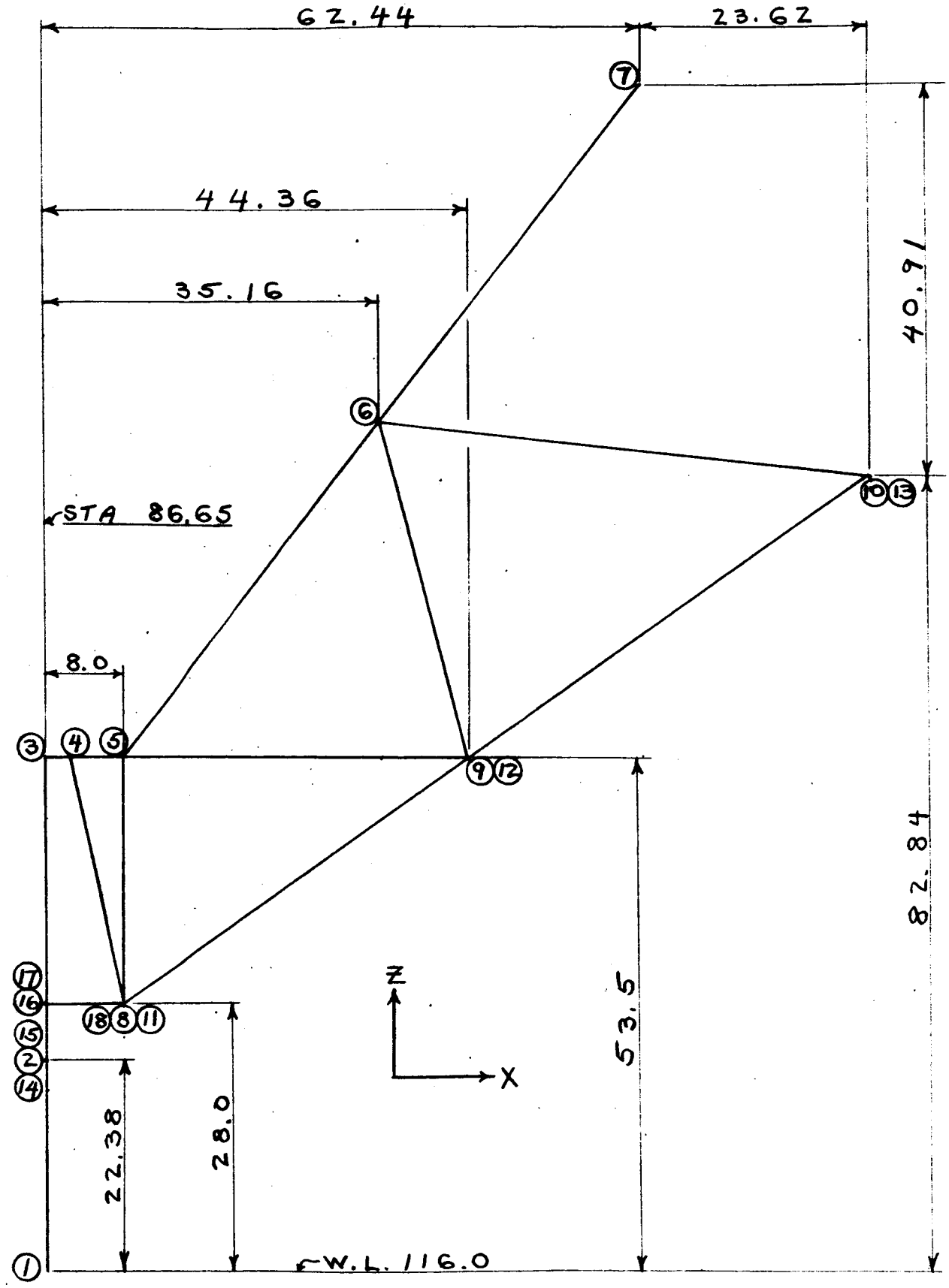


Figure 5.1. Leg - Side View

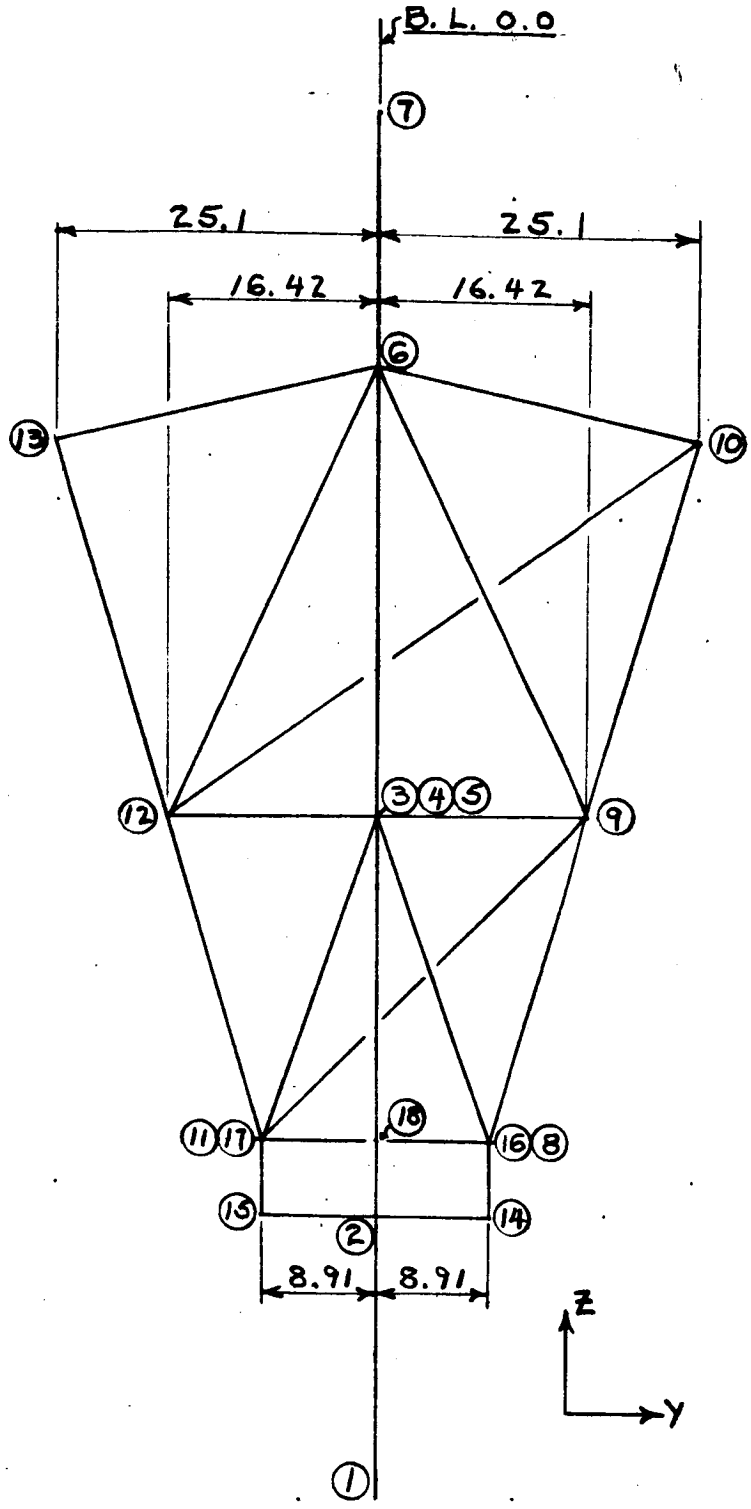


Figure 5.2. Leg - Front Elevation

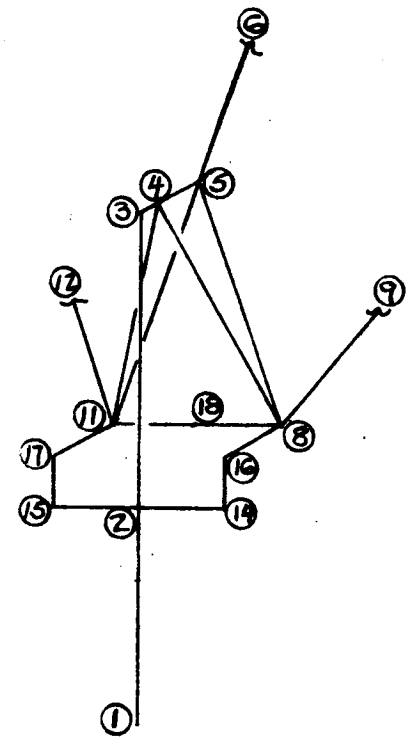


Figure 5.3. Lower Leg Schematic

TABLE 5.1

LEG NODE POINT COORDINATES

NODE POINT	X	Y	Z
1	86.65	0	116.00
2	86.65	0	138.38
3	86.65	0	169.50
4	89.15	0	169.50
5	94.65	0	169.50
6	121.81	0	204.63
7	149.09	0	239.75
8	94.65	8.91	144.00
9	131.01	16.42	169.50
10	172.71	25.10	198.84
11	94.65	- 8.91	144.00
12	131.01	-16.42	169.50
13	172.71	-25.10	198.84
14	86.65	8.91	138.38
15	86.65	- 8.91	138.38
16	86.65	8.91	144.00
17	86.65	- 8.91	144.00
18	94.65	0	144.00

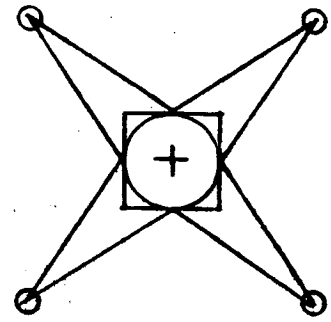
5.3. LOAD CONDITIONS (ULTIMATE)

THE LEG WAS ANALYZED FOR 6 CONDITIONS OF LOAD. FOUR OF THESE LOADS WERE ASSOCIATED WITH LANDING CONDITIONS. THE OTHER TWO LOADS WERE ASSOCIATED WITH GROUND CONDITIONS.

5.3.1. LANDING LOAD CONDITIONS

(1.) ALL FOUR LEGS STRIKE GROUND SIMULTANEOUSLY, OR TWO DIAGONAL LEGS STRIKE GROUND SIMULTANEOUSLY (P. 1.10)

P_z PER LEG = 3400#

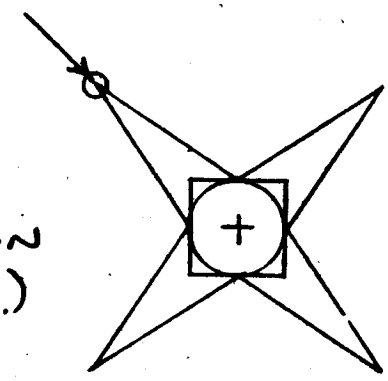


(2.) IMPACT ON ONE LEG ONLY. (P. 1.11)

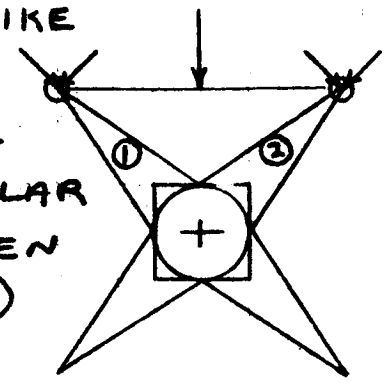
P_z = 1890 #

P_x = 2550 #

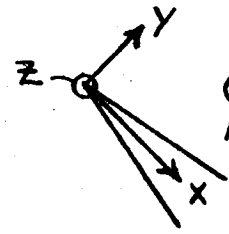
(P_x FORCE ACTS INWARD ON VEHICLE ALONG LEG ℄.)



(3.) TWO ADJACENT LEGS STRIKE GROUND SIMULTANEOUSLY. REACTION @ EACH LEG EQUAL AND DIRECTED PERPENDICULAR TO A LINE DRAWN BETWEEN CONTACT POINTS. (FIG. 1.1.)



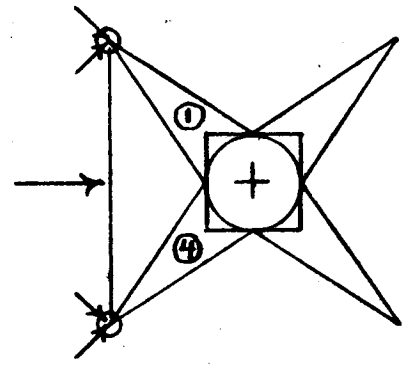
$P_{z_1} = 1890\#$
$P_{x_1} = 1275\#$
$P_{y_1} = -1275\#$
} PER LEG



(+) AXES FOR LEG 1

(4.) SAME AS 3) ABOVE, EXCEPT LEGS 1 & 4 STRIKE GROUND SIMULTANEOUSLY.

$P_{z_1} = 1890\#$
$P_{x_1} = 1275\#$
$P_{y_1} = 1275\#$
} PER LEG



5.3.2. GROUND LOAD CONDITIONS

(5.) JACKING ASSUMED ON ALL 4 LEGS. FORCE APPLIED @ NODE POINT 18. SEE FIG. 5.3.

$n_z = 1.5$ LIMIT (TABLE 1.3)

$$P = \frac{3400 \times 1.5 \times 1.5}{4} = 1910\#$$

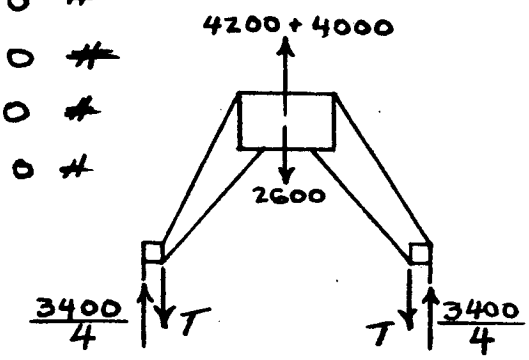
(6.) TIE DOWN CONDITION WITH FORCE APPLIED ON ALL 4 LEGS @ NODE POINT 18. TIE DOWN FORCE DOES NOT RELIEVE LOAD IN SHOCK STRUTS.

ENG. THRUST = 4200 #

ROCKET THRUST = 4000 #

SHOCK STRUT LOADS = 3400 #

VEH. WT. (MIN.) = 2600 #



$$T = \frac{4200 + 4000 + 3400 - 2600}{4}$$

$$T = \frac{9000}{4} = 2250\# \text{ (LIMIT)}$$

$$T = 1.5 \times 2250 = 3375\# \text{ (ULT)}$$

$$\text{SHOCK STRUT LOAD} = \frac{1.5 \times 3400}{4} = 1275\# \text{ (ULT)}$$

TABLE 5.2

SUMMARY OF LOADS

	LANDING CONDITIONS				GROUND CONDITIONS	
LOAD PT.	1	2	3	4	5	6
1x		2550	1275	1275		
1y			-1275	1275		
1z	3400	1890	1890	1890		1275
18z					1910	3375

TABLE 5.3

AXIAL FORCE MEMBERS

MEMBER	SIZE	LENGTH (IN.)	CRITICAL LOAD COND	MAX. LOAD	ALLOW. LOAD
6-7	2¼ x .049	44.3	1	6700	7100
9-10	2¼ x .049	51.7	3	3470	6600
12-13	2¼ x .049	51.7	4	4810	6600
9-12	1 x .035	32.8	4	1090	1140
12-10	1¾ x .035	65.7	3	1520	1640
6-9	1½ x .035	39.8	3	1240	2600
6-12	1½ x .035	39.8	4	1240	2600
6-10	1½ x .035	57.1	4	415	1310
6-13	1½ x .035	57.1	3	415	1310

5.4. FLEXURAL MEMBERS

FLEXURAL MEMBERS 1-2 AND 2-3 MAKE UP THE SHOCK STRUT FOR THE LEG. THIS PORTION OF THE STRUCTURE WAS DESIGNED AND FABRICATED BY THE BENDIX CORP., SOUTH BEND, IND. MEMBERS 3-4 AND 4-5 ARE COMPOSED OF PLATE ELEMENTS. MEMBERS 2-14 AND 2-15 MAKE UP A BRACKET ASSEMBLY MOUNTED ON THE SHOCK STRUT AND ARE FORMED FROM A SOLID PIECE OF 7075-T6 ALUMINUM STOCK. MEMBERS 14-16 AND 15-17 ARE RUBBER SHEAR PADS IN THE ACTUAL STRUCTURE AND WERE SIMULATED IN THE ANALYTICAL MODEL BY EXTREMELY FLEXIBLE MEMBERS. THE REMAINING FLEXURAL MEMBERS IN THE LEG ARE FORMED FROM 6061-T6 ALUMINUM TUBING.

TABLE 5.4

FLEXURAL MEMBERS

MEMB	SIZE	LENGTH (IN.)	CRIT. LOAD COND.	AXIAL LOAD (#)	BEND. MOMENT (IN.#)	MARGIN OF SAFETY
16-8	2¼x.120	8.0	3	-1200	9565	1.24
17-11	2¼x.120	8.0	4	-1200	9582	1.24
8-18	2½x.083	8.91	6	-1460	13710	0.27
11-18	2½x.083	8.91	6	-1460	13710	0.27
8-4	2¼x.049	27.55	2	+1569	758	HIGH
11-4	2¼x.049	27.55	2	+1428	685	HIGH
8-5	1x.049	22.0	1	-2413	945	0.07
11-5	1x.049	22.0	1	-2430	863	0.07
5-6	2¼x.049	44.3	1	-5202	2201	0.48
8-9	2¼x.049	45.11	2	-2785	4012	0.50
11-12	2¼x.049	45.11	4	-4926	2515	0.26
11-9	2x.049	51.1	3	-3053	1155	0.75
5-9	2x.035	39.82	4	-813	1901	1.15
5-12	2x.035	39.82	3	-769	1732	1.15

SECTION 6
CENTER BODY

The center body consists of a lower structural ring, four upper chord members of equal length arranged in a square, and eight diagonals from the four corners of the upper square to four hard points equally spaced about the lower ring. The upper corners and the lower hard points are the connections for the legs. The upper longeron of each leg is attached to an upper corner, and the two lower longerons of each leg are attached to adjacent hard points on the lower ring. The cockpit is mounted on the two forward upper corners and two intermediate points on the lower ring. The equipment section is mounted in a similar fashion on the aft side. Diagonal wires between opposite upper corners are required to stabilize the upper square but may be detached temporarily during engine removal.

6.1 ANALYSIS OF CENTER BODY STRUCTURE

The center body analysis was performed on an IBM 7090 digital computer using the Bell Aerosystems general purpose structural analysis program. The mechanics of this program are described in the discussion of the engine mount analysis.

6.2 CENTER BODY GEOMETRY

The center body structure consists of the members in the xy planes at elevations z = 200.0 and z = 239.75, the connecting members between these planes, and the structural ring. There are 39 members in this portion of the structure. The structural ring consists of 24 flexural members. 15 axial force members make up the remainder of the structure. The geometry of the structure is shown in Figure 6.1. Support points are 49, 50, 51, and 52. Specifically, the structure is restrained at 49 in the z direction, at 50 in the y and z directions, at 51 in the x and z directions, and at 52 in the y direction. Points at which loads are introduced are 1, 5, 7, 9, 13, 17, 19, 21, and at 49, 50, 51, 52 in those directions which do not have any restraint. Coordinates of the center cage node points are given in Table 6.1.

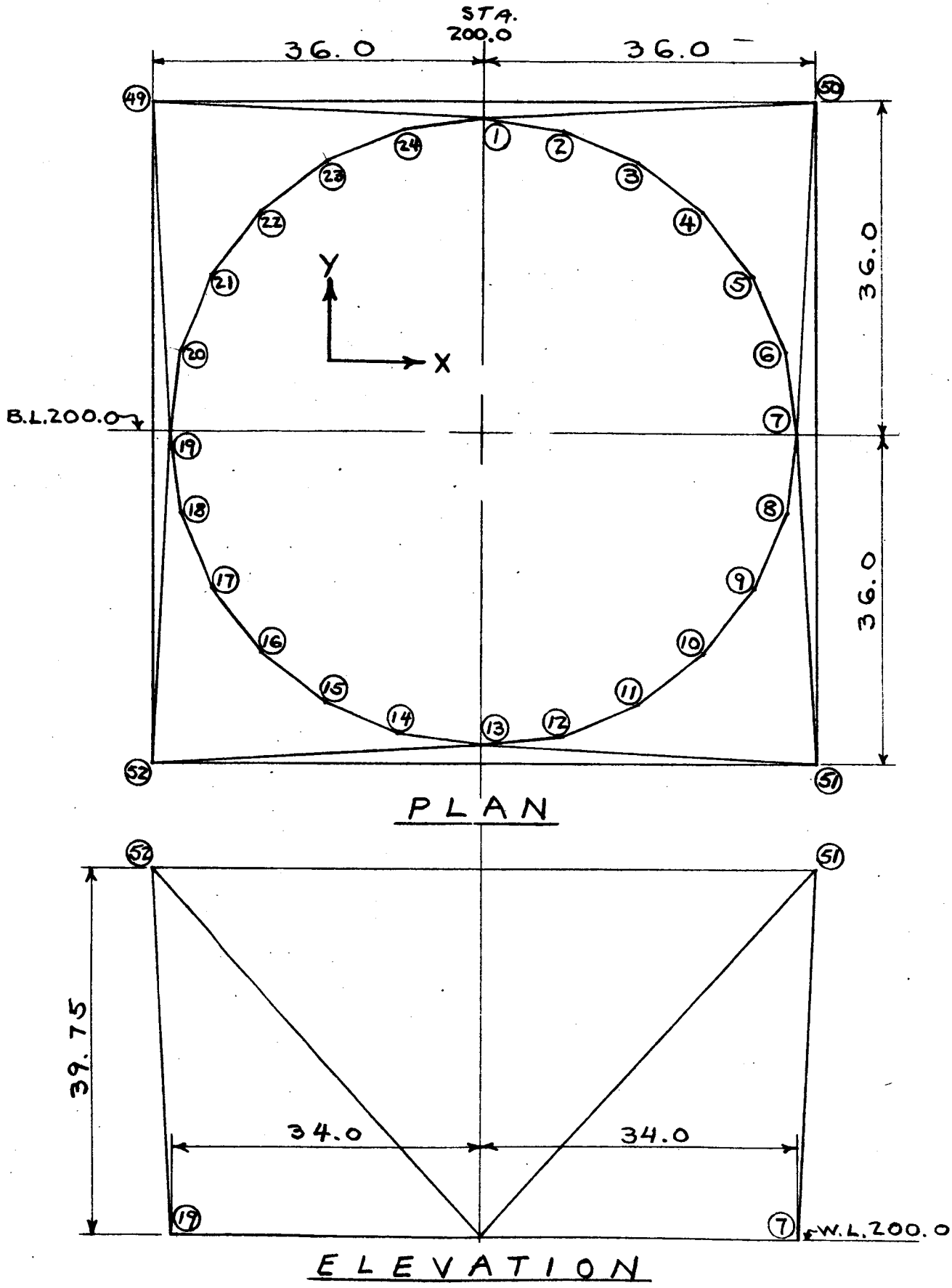


Figure 6.1. Center Body Structure Geometry

TABLE 6.1

CENTER CAGE COORDINATES

NODE PT.	X	Y	Z
1	200.00	234.00	200.00
2	208.81	232.84	
3	217.00	229.44	
4	224.04	224.04	
5	229.44	217.00	
6	232.84	208.81	
7	234.00	200.00	
8	232.84	191.19	
9	229.44	183.00	
10	224.04	175.96	
11	217.00	170.56	
12	208.81	167.16	
13	200.00	166.00	
14	191.19	167.16	
15	183.00	170.56	
16	175.96	175.96	
17	170.56	183.00	
18	167.16	191.19	
19	166.00	200.00	
20	167.16	208.81	
21	170.56	217.00	
22	175.96	224.04	
23	183.00	229.44	
24	191.19	232.84	200.00
49	164.00	236.00	239.75
50	236.00	236.00	
51	236.00	164.00	
52	164.00	164.00	239.75

6.3. LOAD CONDITIONS

THE CENTER BODY STRUCTURE WAS ANALYZED FOR 7 LOAD CONDITIONS, ALL OF WHICH ARE LANDING CONDITIONS. THESE CONDITIONS DEVELOP FROM VARIOUS COMBINATIONS OF THE LEG LOADS DESCRIBED IN THE LEG ANALYSIS SECTION. AS INDICATED IN THE LEG ANALYSIS SECTION, THE LEGS WERE ASSUMED PINNED TO THE CENTER BODY STRUCTURE AT THREE POINTS, WHICH THREE POINTS BECAME REACTIONS FOR THE LOADS INTRODUCED AT THE BASE OF THE LEGS. THESE LEG REACTIONS ARE NOW INTRODUCED AS LOAD INPUTS FOR THE CENTER BODY STRUCTURE. THE POINTS AT WHICH THESE LOADS ARE INTRODUCED ARE 1, 7, 13, & 19 ON THE STRUCTURAL RING, AND 49, 50, 51, & 52.

IN ADDITION TO THE LEG REACTIONS ON THE CENTER BODY STRUCTURE, THE VARIOUS COMBINATIONS OF LEG LOADS BRING ABOUT LOAD INPUTS TO THE CENTER BODY FROM BOTH THE COCKPIT SECTION AND THE EQUIPMENT SECTION. LOADS FROM THE COCKPIT SECTION ARE INTRODUCED TO THE CENTER BODY STRUCTURE AT NODE POINTS 17 & 21 ON THE STRUCTURAL RING, AND AT 49 & 52. LOADS FROM THE EQUIPMENT SECTION ENTER THE CENTER BODY STRUCTURE AT NODE POINTS 5 & 9 ON THE STRUCTURAL RING, AND AT 50 & 51.

ENGINE INERTIA REACTIONS FROM THE VARIOUS LEG LOAD COMBINATIONS WERE INTRODUCED AT NODE POINTS 1 & 13 ON THE STRUCTURAL RING AND AT 49, 50, 51 & 52.

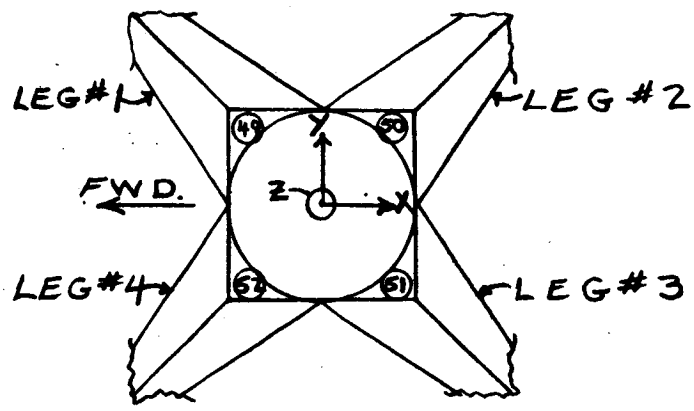
FINALLY, A STATICAL BALANCE ABOUT THE VEHICLE C.G. WAS ACHIEVED BY INTRODUCING AT NODE PT. 52, ONE-FOURTH OF THE VERTICAL INERTIA FORCE REQUIRED TO BALANCE FORCES IN THE VERTICAL DIRECTION. THIS REQUIRED EQUAL INERTIA REACTIONS AT NODE POINTS 49, 50, & 51 TO MAINTAIN $\Sigma M_{C.G.} = 0$. SINCE 49, 50, & 51 ARE VERTICAL REACTION POINTS IN THE PROGRAM ANALYSIS, THIS PROVIDED A CHECK

LOAD CONDITIONS (CONT.)

ON THE CORRECTNESS OF THE PROGRAM SOLUTIONS.

THE SEVEN LEG LOAD COMBINATIONS, ALL LOADS ULTIMATE, USED IN THE ANALYSIS OF THE CENTER BODY ARE (SEE SKETCH AT END OF LOAD LIST)*:

1. ALL FOUR LEGS STRIKE GROUND SIMULTANEOUSLY. 3400 # VERTICAL LOAD APPLIED AT BASE OF EACH LEG.
2. TWO DIAGONALLY OPPOSITE LEGS (#1 & #3) STRIKE GROUND SIMULTANEOUSLY. 3400 # VERTICAL LOAD APPLIED AT BASE OF EACH LEG.
3. SAME AS 2. BUT INVOLVING LEGS #2 & #4.
4. LEG #1 STRIKES GROUND. LOADS APPLIED AT LEG BASE ARE: 1890 # VERTICALLY (Z), 1800 # LATERALLY (Y) & LONGITUDINALLY (X).
5. SAME AS 4. BUT INVOLVING LEG #2.
6. LEGS #1 & #2 STRIKE GROUND SIMULTANEOUSLY. LOADS APPLIED AT EACH LEG BASE ARE: 1890 # VERTICALLY (Z), 1800 # LATERALLY (Y).
7. SAME AS 6. BUT INVOLVING LEGS #2 & #3. (1800 # IS LONGITUDINAL (X))



*SEE STRUCT. CRITERIA - AIRFRAME DESIGN LOAD CONDITIONS

6.4. MEMBER SIZES

THE 15 AXIAL FORCE MEMBERS REFERRED TO IN THE GEOMETRY SECTION ABOVE, CONSIST OF: 4 MEMBERS IN THE XY PLANE AT W.L. 239.75, 8 DIAGONAL MEMBERS BETWEEN THE NODE POINTS AT W.L. 239.75 AND THE STRUCTURAL RING WHICH LIES IN THE XY PLANE AT W.L. 200.0, 2 TIE RODS RUNNING DIAGONALLY BETWEEN THE NODE POINTS AT W.L. 239.75, AND A TIE BETWEEN NODE POINTS 1 & 13 ON THE STRUCTURAL RING. THIS LATTER MEMBER IS A FICTITIOUS MEMBER, INSTALLED TO PROVIDE THE SAME DEGREE OF STIFFNESS BETWEEN NODE POINTS 1 & 13 AS WILL BE PROVIDED BY THE GIMBAL RING WHICH IS MOUNTED ON THE STRUCTURAL RING AT THESE NODE POINTS.

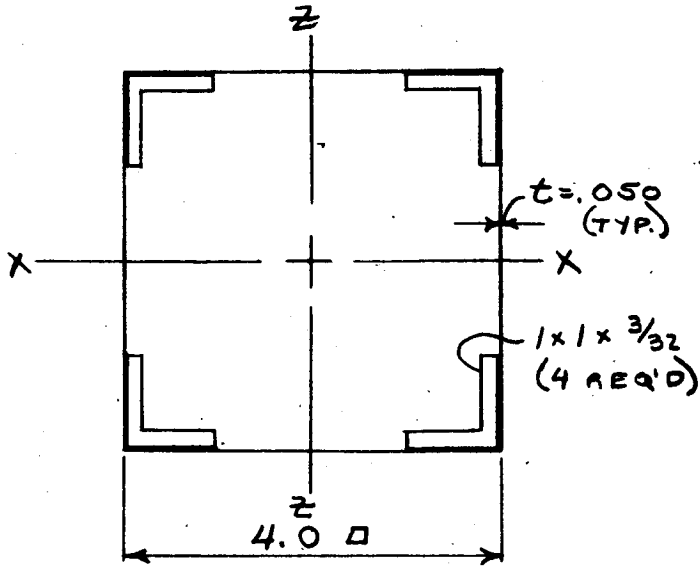
THE TWO DIAGONAL TIE RODS ARE EXTRA FLEXIBLE GALVANIZED STEEL CABLE, 7/32" DIAMETER. ALL REMAINING AXIAL FORCE MEMBERS ARE 6061-T6 ALUMINUM ALLOY.

THE STRUCTURAL RING WAS DIVIDED INTO 24 ELEMENTS FOR THE PURPOSE OF ANALYSIS, ALL ELEMENTS BEING IDENTICALLY SIMILAR. PROGRAM RESULTS FOR ALL 7 LOAD CONDITIONS WERE CHECKED TO DETERMINE THE MAXIMUM LOAD CONDITION EXISTING IN A SINGLE ELEMENT. THIS MAXIMUM LOAD DETERMINED THE STRUCTURAL RING DESIGN. THE STRUCTURAL RING MATERIAL IS 2024-T4 ALUMINUM ALLOY.

TABLE 6.2

AXIAL FORCE MEMBER SIZES

MEMB	SIZE	LENGTH (IN.)	CRIT. LOAD COND.	MAX. LOAD	ALLOW. LOAD
49-50	2½ x .049	72.0	1	2270 C	5400
50-51	2½ x .049	72.0	1	5000 C	5400
51-52	2½ x .049	72.0	1	2270 C	5400
52-49	2½ x .049	72.0	1	4440 C	5400
49-51	7/32" d	101.82	3	4400 T	5600
50-52	7/32" d	101.82	2	5500 T	5600
49-1	2 x .049	53.67	7	3500 C	4880
1-50	2 x .049	53.67	4	2220 C	4880
50-7	2 x .049	53.67	2	1090 C	4880
7-51	2 x .049	53.67	6	2885 C	4880
51-13	2 x .049	53.67	7	2260 C	4880
13-52	2 x .049	53.67	7	2550 C	4880
52-19	2 x .049	53.67	6	2155 C	4880
19-49	2 x .049	53.67	6	1780 C	4880



$I_{x-x} = 2.86 \text{ IN}^4$

(I DOES NOT INCLUDE SKIN MATERIAL BETWEEN ANGLES)

$A = 1.52 \text{ IN}^2$

$L = 8.89 \text{ IN.}$

CRITICAL LOAD CONDITION IS LOAD 2.

$P = 3137\#, \; M_{x-x} = 30500 \text{ IN.}\#$

$$f_c = P/A = \frac{3137}{1.52} = 2060 \text{ PSI}$$

$$f_b = \frac{Mc}{I} = \frac{30500\,(2.0)}{2.86} = 21350 \text{ PSI.}$$

SINCE COLUMN ALLOWABLE FOR THIS GEOMETRY WOULD BE VERY HIGH, CHECK MAX. COMPRESSION DEVELOPED IN ANGLE FLANGE.

$$f_{c_{max}} = 2060 + 21350 = 23400 \text{ PSI.}$$

$$b/t = \frac{1.0}{.0938} = 10.67$$

$f_{c_\omega} = 32500$ PSI. (B.S.M., FIG. 80.04.2-5)

$$M.S. = \frac{32500}{23400} - 1.0 = 0.39$$

Figure 6.2. Flexural Member Sizes

SECTION 7

H_2O_2 TANK TRUSS

Each tank is mounted at the vertical and longitudinal center of gravity of the vehicle, one on each side of the center body. Each tank is supported by a pair of identical (mirror image) three member trusses. Two lower members attach to the center body lower ring, and the third member is attached to an upper corner. All of the longitudinal inertia is carried by one truss of each pair and this is the one analyzed in this report.

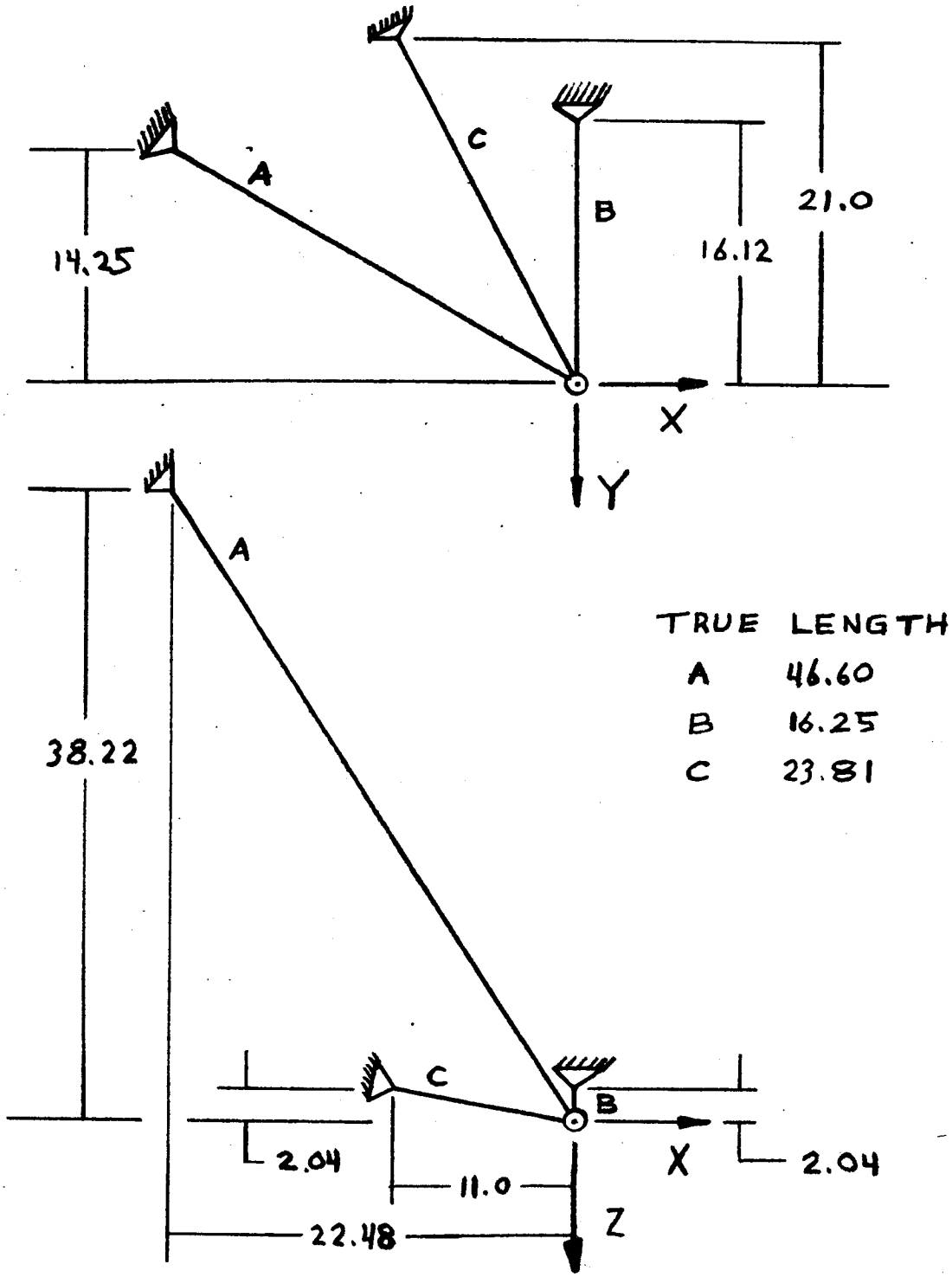


Figure 7.1. H_2O_2 Tank Truss Geometry

TABLE 7.1

H_2O_2 TANK TRUSS ULTIMATE LOADS

COND	n_z	n_x	n_y	A	B	C
T_1	8.5			3560	2200	-3720
T_2	1.64	.92		728	-736	577
T_3	1.64	-.92		644	1586	-2013
T_4	1.64		.92	735	707	-769
T_5	1.64		-.92	637	143	-667
T_6	2.78	1.04		1211	-610	267
T_7	2.78	-1.04		1115	2050	-2697
T_8	2.78		1.04	1813	1039	-1273
T_9	2.78		-1.04	613	401	-1157
T_{10}	2.49	.80	1.04	1627	-48	-20
T_{11}	2.49	.80	-1.04	547	-686	96
T_{12}	2.49	-.80	-1.04	455	1338	-2160
T_{13}	2.49	-.80	1.04	1555	1976	-2276

TENSION IS + LOAD

DESIGN WEIGHT SUPPORTED BY ONE PAIR OF TRUSSES (ONE TANK) = 450 POUNDS

ONE TRUSS SUPPORTS 1/2 OF TANK IN Z and Y DIRECTION AND ALL OF TANK IN X DIRECTION

SECTION 8
GIMBAL RING

The gimbal ring is positioned in a horizontal plane at the vehicle center of gravity. The function of the ring is to permit the engine to be mounted in a vertical attitude and allow the vehicle to be tilted 40° relative to the engine in the pitch and/or roll direction. To accomplish this motion, the ring contains two sets of bearings mounted on horizontal axes spaced at 90° to each other. The ring pitches on trunnions mounted on two opposite hard points on the center body lower ring on the vehicle y axis, thus pitching the vehicle relative to the engine. The engine and engine mount roll on the bearings in the ring on the vehicle x axis. The pitch actuator is anchored on the center body lower ring and operates on a crank arm at the starboard bearing of the gimbal ring. The roll actuator is anchored to the gimbal ring and operates on a crank arm at the forward side of the engine mount on the same fitting that picks up the forward bearing of the gimbal ring.

The ring is a square tube 3 inches on a side with a 0.156 inch wall thickness. Diameter of the ring is 29.5 inches at the centerline of the tube. Fittings for the bearings are inserted at four places and a fitting to anchor the roll actuator is attached at an intermediate position. The pitch crank arm is machined integral with one of the bearing fittings.

The roll bearings are offset 0.375 inches down from the horizontal plane of the pitch bearings. This is the amount of vertical deflection of the gimbal ring when subject to a 1700 pound up load. The basis for this load is engine thrust (2500) minus engine weight (800) at approximately midway during flight in the lunar mode (vehicle weight is 3000 pounds).

8.1. ANALYSIS OF GIMBAL RING

The gimbal ring analysis was performed on an IBM 7090 digital computer using the Bell Aerosystems general purpose structural analysis program. The mechanics of this program are described in the discussion of the engine mount analysis.

8.2. GIMBAL RING GEOMETRY

The gimbal ring, when in the neutral position, lies in the xy plane at W.L. 199.812. The engine mount is attached to the gimbal ring along the roll axis. The gimbal ring is attached to the structural ring along the pitch axis.

For purposes of analysis, the gimbal ring was divided into 24 identically similar elements, numbered as shown in Figure 8.1. The engine mount attachments are at node points (1) and (13). The gimbal ring to structural ring attachments occur at node points (7) and (19). A roll actuator is connected between the engine mount and node point (3) on the gimbal ring. A pitch actuator is connected between the structural ring and a crank arm at the starboard mount between the gimbal and structural rings.

Node points (7) and (19) are support points in the analysis. The gimbal ring is supported in the x, y, and z directions at these points and is fixed against rotation about the pitch axis at node point (7).

Points at which loads enter the gimbal ring are node points (1), (3), and (13). Inertia forces introduce themselves at points (1) and (13) while roll actuator forces enter the structure at point (3).

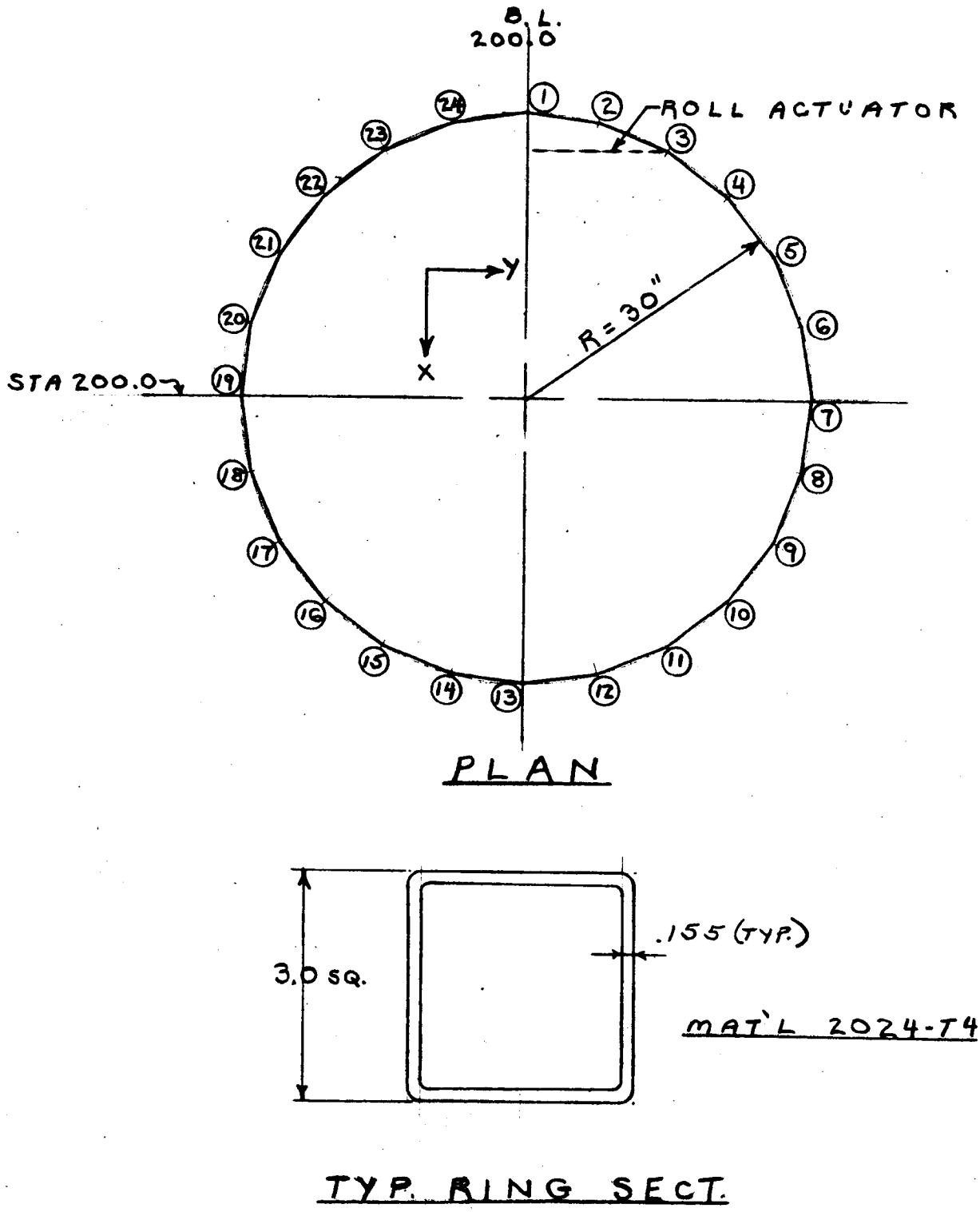


Figure 8.1. Gimball Ring Elements

TABLE 8.1

NODE POINT COORDINATES

NODE PT.	X	Y	Z *
1	170.00	200.00	199.812
2	171.10	207.76	↑
3	174.02	215.00	
4	178.79	221.21	
5	185.00	225.98	
6	193.24	228.90	
7	200.00	230.00	
8	207.76	228.90	
9	215.00	225.98	
10	221.21	221.21	
11	225.98	215.00	
12	228.90	207.76	
13	230.00	200.00	
14	228.90	193.24	
15	225.98	185.00	
16	221.21	178.79	
17	215.00	174.02	
18	207.76	171.10	
19	200.00	170.00	
20	193.24	171.10	
21	185.00	174.02	
22	178.79	178.79	
23	174.02	185.00	↓
24	171.10	193.24	199.812

* WITH RING IN NEUTRAL POSITION

8.3. LOAD CONDITIONS

GENERAL LOADING INFORMATION CONCERNING ITEM WEIGHTS, ENGINE AND ROCKET THRUSTS, AND ANGLES OF ROLL AND PITCH ARE AS LISTED IN THE ENGINE MOUNT SECTION, SECTION 4. THE GIMBAL RING WAS ANALYZED FOR 24 IN FLIGHT LOAD CONDITIONS, AND VARIOUS COMBINATIONS THEREOF, AND 2 GROUND CONDITIONS.

8.3.1. IN FLIGHT LOAD CONDITIONS

(1.) MAX ROLL ANGLE = +40°. ENG. THRUST MAX.

(2.) MAX. ROLL ANGLE = +40°. ENG. THRUST MAX. NEG. ROLLING MOMENT ASSOCIATED WITH RESTORATION FROM FULL POSITIVE ROLL. (REFERRED TO IN FOLLOWING AS: ROLL ACTUATOR MAX (-)

(3.) MAX ROLL ANGLE = +40°. ENG. THRUST ZERO. ROLL ACTUATOR MAX (-)

(4.) MAX ROLL ANGLE = -40°. ENG. THRUST MAX.

(5.) MAX ROLL ANGLE = -40°. ENG. THRUST MAX ROLL ACTUATOR MAX (+)

(6.) MAX. ROLL ANGLE = -40°. ENG. THRUST ZERO. ROLL ACTUATOR MAX (+)

(7.) ROLL POSITION NEUTRAL. ENG. THRUST MAX. ROLL ACTUATOR MAX (+)

(8.) ROLL POSITION NEUTRAL. ENG. THRUST MAX. ROLL ACTUATOR MAX (-)

(9.) ROLL POSITION NEUTRAL. ENG. THRUST ZERO. ROLL ACTUATOR MAX (+)

(10.) ROLL POSITION NEUTRAL. ENG. THRUST ZERO. ROLL ACTUATOR MAX (-)

(11.) MAX. PITCH ANGLE = +54°. ENG. THRUST MAX.

(12.) MAX. PITCH ANGLE = +54°. ENG. THRUST MAX. PITCH ACTUATOR MAX (-)

(13.) MAX. PITCH ANGLE = +54°. ENG. THRUST ZERO. PITCH ACTUATOR. MAX (-)

IN FLIGHT LOAD CONDITIONS (CONT.)

(14.) MAX. PITCH ANGLE = -54°. ENG. THRUST MAX.
(15.) MAX. PITCH ANGLE = -54°. ENG. THRUST MAX. PITCH ACTUATOR MAX (+)
(16.) MAX. PITCH ANGLE = -54°. ENG. THRUST ZERO. PITCH ACTUATOR MAX (+)
(17.) PITCH POSITION NEUTRAL. ENG. THRUST MAX. PITCH ACTUATOR MAX (+)
(18.) PITCH POSITION NEUTRAL. ENG. THRUST MAX. PITCH ACTUATOR MAX. (-)
(19.) PITCH POSITION NEUTRAL. ENG. THRUST ZERO. PITCH ACTUATOR MAX (+)
(20.) PITCH POSITION NEUTRAL. ENG. THRUST ZERO. PITCH ACTUATOR MAX (-)
(21.) MAX. ROLL ANGLE = +40°. ENG. THRUST ZERO. ROCKET THRUST MAX.
(22.) MAX. ROLL ANGLE = -40°. ENG. THRUST ZERO. ROCKET THRUST MAX.
(23.) MAX. PITCH ANGLE = +54°. ENG. THRUST ZERO. ROCKET THRUST MAX.
(24.) MAX. PITCH ANGLE = -54°. ENG. THRUST ZERO. ROCKET THRUST MAX.

8.3.2. GROUND LOAD CONDITIONS

(1.) VEHICLE TIED DOWN. ENG. THRUST MAX.
(2.) MIN. WT. LANDING CONDITION. ROCKET THRUST MAX. VERTICAL.

TABLE 8.2

COMBINATIONS OF IN-FLIGHT CONDITIONS

	IN FLIGHT LOAD CONDITIONS																							
LOAD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	•																							
2	•											•												
3	•														•									
4	•																•							
5	•																	•						
6		•																						
7		•										•												
8		•													•									
9		•															•							
10		•																•						
11			•																					
12			•										•											
13			•													•								
14			•																•					
15			•																	•				
16				•																				
17				•								•												
18				•											•									
19				•													•							
20				•														•						
21					•																			
22					•							•												
23					•										•									
24					•												•							
25					•													•						
26						•																		
27						•							•											
28						•										•								
29						•													•					
30						•														•				

TABLE 8.2. (CONT)

	IN FLIGHT LOAD CONDITIONS																							
LOAD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
31							•																	
32							•					•												
33							•								•									
34							•										•							
35							•											•						
36								•																
37								•				•												
38								•							•									
39								•									•							
40								•										•						
41									•															
42									•				•											
43									•							•								
44									•										•					
45									•											•				
46										•														
47										•			•											
48										•						•								
49										•									•					
50										•										•				
51											•													
52												•												
53													•											
54															•									
55																•								
56																	•							
57																		•						
58																			•					
59																				•				
60	•																				•			

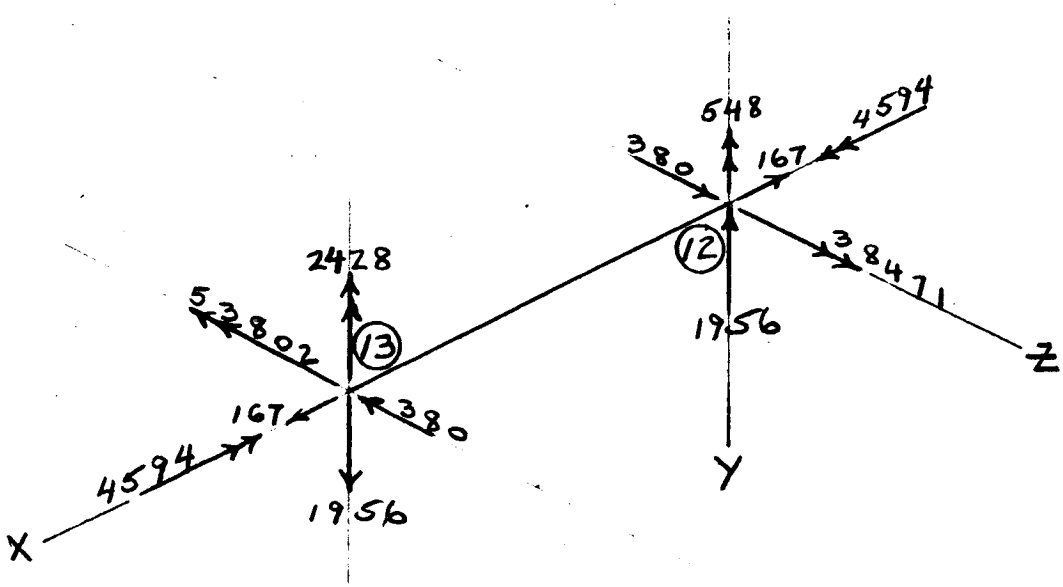
TABLE 8.2. (CONT)

	IN FLIGHT LOAD CONDITIONS																							
LOAD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
61	•											•									•			
62	•														•						•			
63	•																•				•			
64	•																	•			•			
65		•																			•			
66		•										•									•			
67		•													•						•			
68		•															•				•			
69		•																•			•			
70			•																			•		
71			•									•										•		
72			•												•							•		
73			•														•					•		
74			•															•				•		
75				•																		•		
76				•								•										•		
77				•											•							•		
78				•													•					•		
79				•														•				•		
80							•					•											•	
81								•				•											•	
82												•											•	
83							•								•									•
84								•							•									•
85															•									•

8.4. RING SECTION

THE GIMBAL RING WAS ANALYZED FOR THE 85 IN FLIGHT LOAD CONDITIONS TABULATED ON THE PRECEEDING PAGES, AS WELL AS THE TWO GROUND CONDITIONS SPECIFIED (PARAGRAPH 8.3.2.) THE RESULTS OF THIS ANALYSIS WERE EXAMINED TO DETERMINE THE MAXIMUM LOAD CONDITION ON ANY OF THE 24 FLEXURAL ELEMENTS WHICH CONSTITUTE THE GIMBAL RING. THIS CONDITION DESIGNED THE RING.

THE CRITICAL CONDITION WAS DETERMINED TO BE IN FLIGHT LOAD CONDITION 37 WHICH COMBINES LOADS 8 & 12. THE CRITICAL ELEMENT WAS THAT ELEMENT BETWEEN NODE POINTS (12) & (13). THE LOADS ON THIS ELEMENT FOR THIS LOAD CONDITION ARE AS SHOWN BELOW.



RING SECTION (CONT)

@ NODE PT. 13

$M_{z-z} = 53802$ IN.# , $I_{Y-Y} = I_{Z-Z} = 2.4$ IN^4

$M_{Y-Y} = 2428$ IN.# , $A = 1.76$ IN^2

$T = 4594$ IN.# , (SEE TYP. RING SECT, FIG. 8.1)

$V_Y = 1956$ #

$$f_b = \frac{M_{z-z}\, c}{I_{z-z}} + \frac{M_{Y-Y}\, c}{I_{Y-Y}}$$

$$= \frac{53802\,(1.5)}{2.4} + \frac{2428\,(1.5)}{2.4}$$

$f_b = 35200$ PSI.

$$q_T = T/2A = \frac{4594}{3.52} = 1304 \text{ \#/IN.}$$

$$q_V = \frac{V_Y}{2d_Y} = \frac{1956}{2(3)} = 326 \text{ \#/IN.}$$

$q_{TOT} = 1630$ #/IN.

$$f_s = \frac{q}{t} = \frac{1630}{.155} = 10500 \text{ PSI.}$$

$$f_{n\,max} = \frac{f_x + f_y}{2} \pm \sqrt{\left(\frac{f_x - f_y}{2}\right)^2 + (f_s)^2}$$

$$= \frac{35200}{2} \pm \sqrt{(17600)^2 + (10500)^2}$$

$$= 17600 \pm 20500$$

$f_{n\,max} = 38100$ PSI. (PRINCIPAL STRESS)

$f_{cy} = 40000$ PSI.

$$M.S. = \frac{40000}{38100} - 1 = .05$$

RING SECTION (CONC.)

CHECK BUCKLING STRESS COND. UNDER COMBINED LOADS.

$$f_b = \frac{53802\,(1.5)}{2.4} = 33600 \text{ PSI.}$$

$$q_T = \frac{4594}{3.52} = 1304 \text{ \#/IN.}$$

$$q_V = \frac{380}{2(3)} = 63 \text{ \#/IN.}$$

$$q_{TOT.} = 1367 \text{ \#/IN.}$$

$$f_s = \frac{q}{t} = \frac{1367}{.155} = 8820 \text{ PSI.}$$

(REF. B.S.M., SECT. 140.02)

$f_{s_{cr}} = 23500$ PSI. (FIG. 110.02.2-3, BSM)

$$b/t = \frac{2.845}{.155} = 18.35$$

$f_{bcr} = f_{cy} = 40000$ PSI. (FIG. 80.04.2-5, BSM)

$$R_s = \frac{f_s}{f_{s_{cr}}} = \frac{8820}{23500} = 0.375$$

$$R_c = \frac{f_b}{f_{bcr}} = \frac{33600}{40000} = 0.840$$

$R_{c_a} = 0.95$ (FIG. 140.02.1-1, BSM)

$$M.S. = \frac{R_{c_a}}{R_c} - 1 = \frac{0.95}{0.84} - 1$$

$$M.S. = 0.13$$