COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME VIII

UNCLASSIFIED APPENDICES

FINAL REPORT

SEPTEMBER 15 1969

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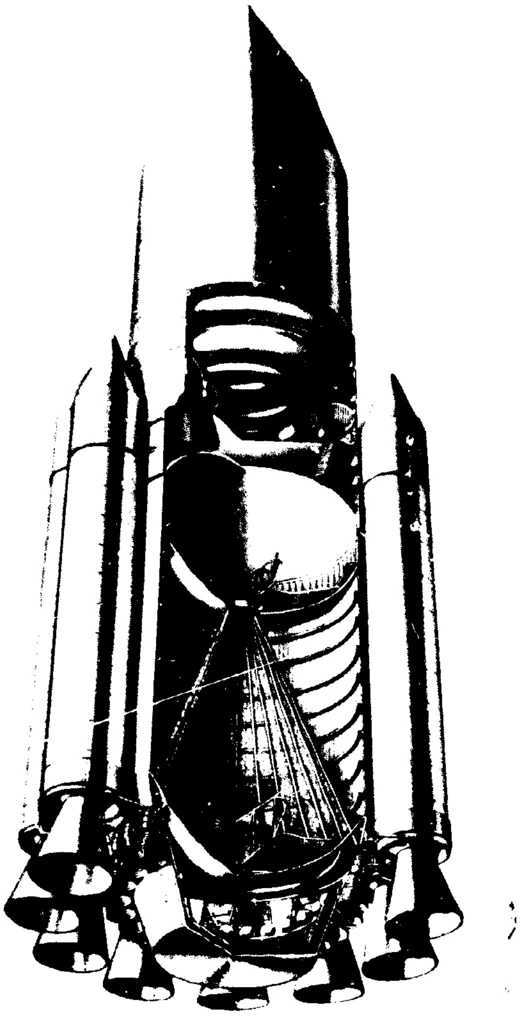

PREPARED UNDER CONTRACT
NAS 2-5056

BY THE BOEING COMPANY
AEROSPACE GROUP
SOUTHEAST DIVISION

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D5-13463-8

FINAL REPORT
FOR
COST STUDIES OF MULTIPURPOSE LARGE LAUNCH VEHICLES

VOLUME VIII
FLIGHT CONTROL AND SEPARATION AND STRESS ANALYSIS

(UNCLASSIFIED APPENDICES)

PREPARED UNDER CONTRACT NAS2-5056
FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF ADVANCE RESEARCH AND TECHNOLOGY
MISSION ANALYSIS DIVISION
SEPTEMBER 15, 1969

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ABSTRACT

Nine volumes including this volume present the final report documentation outlining the accomplishments for the "Cost Studies of the Multipurpose Large Launch Vehicles" (MLLLV). NASA/OART Contract NAS2-5056. This volume presents those unclassified appendices including flight control and separation analysis and stress analysis.

The MLLV family will consist of a single-stage-to-orbit configuration plus other configurations consisting of a main stage (as used for the single-stage-to-orbit configuration) with various quantities of 260 inch diameter solid rocket motor (SRM) strap-on stages and/or injection stage modules. The main stage will employ LOX/LH_2 propellant with either a multichamber/plug or toroidal/aerospike engine system. The single-stage-to-orbit configuration will have a payload capability of approximately 500,000 pounds to a 100 nautical mile earth orbit. With the addition of the strap-on SRM stages and/or LOX/LH_2 injection stage modules, this payload capability can be increased incrementally to as much as 1,850,000 pounds.

The contract consisted of four study phases. The Phase I activity was a detailed cost analysis of an Advanced Multipurpose Large Launch Vehicle (AMLLV) family as previously defined in NASA/OART Contract NAS2-4079. Costs for vehicle design, test, transportation, manufacture and launch were defined. Resource implications for the AMLLV configurations were determined to support the cost analysis.

The Phase II study activity consisted of the conceptual design and resource analysis of a smaller or half size Multipurpose Large Launch Vehicle (MLLV) family.

The Phase III activity consisted of a detailed cost analysis of the smaller Multipurpose Large Launch Vehicle configurations as defined in Phase II. Costs for vehicle design, test, transportation, manufacture and launch were determined.

The Phase IV activity assessed the results of the study including the implications on performance, resources and cost of vehicle size, program options, and vehicle configuration options. The study results provided data in sufficient depth to permit analysis of the cost/performance potential of the various options and/or advanced technologies.

ABSTRACT (Continued)

KEY WORDS

Advanced Multipurpose Large Launch Vehicles (AMLLV)
Half Size Multipurpose Large Launch Vehicles (MLLV)
Single-Stage-to-Orbit
Multichamber/Plug Engine System
Toroidal/Aerospike Engine System
260-Inch Solid Propellant Rocket Motor (SRM)
Orbital Injection Stage
Contract NAS2-4079
Contract NAS2-5056
Payload to 100 NM Orbit
Cost
Resources
Zero Stage Vehicles
Parallel Stage Vehicles
Main Stage Throttling

CONTENTS

CONTENTS (Continued)

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FOREWORD

This unclassified appendix volume; Flight Control and Separation Analysis, and Stress Analysis; is one of nine volumes documenting the results of a twelve month study program "Cost Studies of Multipurpose Large Launch Vehicles", NASA/OART Contract NAS2-5056. The objective of this study was to define cost, cost sensitivities, and cost/size sensitivities of launch vehicles so that current and future technology programs may be planned to meet the technology requirements for follow-on space vehicles. The baseline vehicles utilized to make this assessment were:

a. The Advanced Multipurpose Large Launch Vehicles (AMLLV) as defined under NASA/OART Contract NAS2-4079.

b. The Multipurpose Large Launch Vehicles (MLLV) as defined under this contract and described in Volume II, "Half Size Vehicle (MLLV) Conceptual Design".

The program documentation includes a Summary Volume, a Design Volume, a Resources Volume, Cost Volumes, Cost Implications Volume, and Appendices Volumes. Individual designations for these volumes are as follows:

Volume I	Summary
Volume II	Half Size Vehicle (MLLV) Conceptual Design
Volume III	Resource Implications
Volume IV	Baseline AMLLV Costs
Volume V	Baseline MLLV Costs
Volume VI	Cost Implications of Vehicle Size, Technology Configurations, and Program Options
Volume VII	Advanced Technology Implications
Volume VIII	Flight Control and Separation, and Stress Analysis (Unclassified Appendices)
Volume IX	Propulsion Data and Trajectories (Classified Appendices)

FOREWORD (Continued)

Data on the 260-inch diameter solid propellant rocket motor were obtained from the Aerojet General Corporation. Data on the multichamber/plug propulsion system were obtained from the Pratt and Whitney Division of the United Aircraft Corporation and the Rocketdyne Division of the North American Rockwell Corporation. Data on the toroidal/aerospike propulsion system were obtained from the Rocketdyne Division of the North American Rockwell Corporation.

These propulsion data were obtained from the propulsion contractors at no cost to the contract. The material received encompassed not only the technical data, but resources, schedules and advanced technology information. This support materially aided The Boeing Company in the preparation of a complete and meaningful study and is gratefully acknowledged.

This study was administered under the direction of NASA/OART Mission Analysis Division, Ames Research Center, Moffett Field, California, under the direction of the technical monitor, Mr. Edward W. Gomersall.

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APPENDIX A

FLIGHT CONTROL AND SEPARATION ANALYSIS

(REFERENCE SECTION 4.2.5, VOLUME II

HALF-SIZE VEHICLE (MLLV) CONCEPTUAL DESIGN)

FLIGHT CONTROL AND SEPARATION ANALYSIS

The thrust deflection requirements for the single stage to orbit vehicle and for the maximum payload vehicle (main stage plus eight strap-on solid motors stages plus a three module injection stage) shown in Sections 4.2.5 were calculated using a digital computer program. The program is described in the Boeing Document BHA-0034, Title, "Two Degree Rigid Body Control Program" dated February 5, 1968. The objective of this two degree rigid body control program, with off nominal conditions, is to perform vehicle wind response studies including the effective variations in vehicle data. The program provides a preliminary rapid point time analysis of vehicles with or without perturbations (scatter effects) included. This program was developed to compute a time history of vehicle control responses for a specific flight time. These computations are: instantaneous wind velocity, the angle of attack, the nozzle gimbal command angle, altitude acceleration, attitude rate, attitude error, lateral acceleration, displacements, and the normal accelerations at specific time intervals during the flight history, and the root sum squared (RSS) values applied to determine a worse case with all scatter terms in the worst direction.

All analyses are conducted in yaw plane since the most adverse wind effects occur in this plane. The yaw attitude is commanded to be zero degrees. All locations are considered relative to the gimbal.

The vehicle is a mathematical model of a rigid airplane and all sensors are assumed to be located at the vehicles center of gravity. The thrust vector control response is rapid enough to be approximated by an ideal servo-mechanism.

Applying the above program to the control requirements, it was ascertained that the maximum effective gimbal angle at approximately 3.9 degrees would be required for the single stage to orbit vehicle. With the addition of four fins, each of 100 square feet, the thrust deflection requirements would be reduced from 3.9 degrees to approximately 3 degrees.

A similar analysis of the solid motor thrust deflection envelope using the reference computer program, indicated that the thrust deflection requirements of the solid motor would have to be approximately 3.9 degrees also. For the applications involving solid motor strap-on stages, this capability must be built into each of the strap-on solid motor stages. At the solid motor tail-off, there exists a requirement for thrust deflection capability. This capability is partically provided by the main stage thrust deflection system. This system is activated as the solid motor enters the tail-off portion of its operations.

A.1 Flight Control Requirements During Strap-off Stage Tailoff

An analysis was undertaken to determine if the MLLV configurations with strap-on stages were controllable during SRM stage tailoff and main-stage ignition. Information received from the SRM contractor indicated that the three sigma variation in the burn time of the 260" SRM is 2.3 percent, or three seconds variation for the MLLV 260" SRM stages. For the maximum vehicle configuration, there are eight strap-on SRM stages, so that the burn time variation, per engine of the eight stages, using a root mean square (RSS) value is:

$$\Delta t = 1/8 \sqrt{8 t^2} = 1/8 \sqrt{8 \times 9} = \frac{\sqrt{72}}{8} = 1.06 \text{ Seconds}$$

The core will be operating at approximately ten percent of its thrust during the time the SRM is tailing off. The core thrust at this time will be 1,035,000 pounds-force. The control moment arm extends from the center of gravity to the gimbal plane (92.9 feet). The core control moment is:

$$1{,}035{,}000 \times 92.9 \times \sin 5^{\circ} = 8{,}390{,}000 \text{ foot lbs.}$$

The core control moment, coupled with the control moment available from the SRM, provide the controlling torque just prior to tailoff. The SRM control moment is the product of thrust of the SRM during tailoff times the number of strap-on stages (8), times the moment arm, times the SRM nozzle cant angle which is equal to:

$$2.1 \times 8 \times 9.29 \times 10^{7} \times \sin 5^{\circ} = 1.36 \times 10^{8} \text{ foot lbs.}$$

The SRM stage unstabilizing moment is the product of its moment arm (85.3') and its thrust imbalance, $4.2 \times 2.12 \times 10^5 = 8.9 \times 10^5$ lbs.

The unstabilizing moment is therefore, $85.3 \times 8.9 \times 10^5 = 7.6 \times 10^7$ foot lbs.

Total controlling torque just prior to full-core thrust = ΣMc

$\Sigma Mc = (1.36 \times 10^8 + .084 \times 10^8) = 1.444 \times 10^8$ foot lbs.

unstabilizing moment = $\Sigma Mc = 7.6 \times 10^7$ foot lbs.

$\Sigma Mc > \Sigma Mn$.: Control is maintained during SRM tailoff.

A.2 Strap-on Stage Separation Impulse Requirements

Paragraph 4.2.6.4 of Volume 2, Half-Size Vehicle (MLLV) Conceptual Design, defined the impulse requirements for the strap-on stages. The back-up calculations are presented below. The SRM stage length used was 157.67 feet. The plume angle from the main stage used was 30°. For the SRM stage to have sufficient clearance from the vehicle after separation so as not to impact the main stage structure, the translational requirement is 157.67 tan 30° = 91 feet.

If the relative axial, translational acceleration is 38.505 ft/sec^2, then

$$t^2 = \frac{2s}{a} = \frac{2(157.67)}{38.505} = 8.19 \qquad t = 2.86 \text{ seconds}$$

$$\bar{a} = \frac{2s}{t^2} = \frac{2(91)}{8.19} = 22.57 \text{ ft/sec}^2 \text{ (lateral translational acceleration)}$$

Mass of SRM = 10,000 slugs at burnout, therefore

F = Ma

= 10,000 x 22.57 lbs.

= 225,700 lbs   Impulse = Thrust x time = 225,700 x 2.86

= 645,000 lb. sec

From $S = 1/2\ at^2$, the lateral and axial displacement versus time can be determined as shown below.

$$S = 1/2\ at^2$$

t(sec)	t^2 (sec^2)	Lateral (feet)	Axial (feet)
0	0	0	0
.4	.16	1.8	3.08
.8	.64	7.21	12.30
1.2	1.44	16.2	27.75
1.6	2.56	28.8	49.30
2.0	4.00	45.02	77.00
2.4	5.76	64.95	111.00
2.8	7.82	88.05	150.5
2.86	8.19	92.10	157.67

The displacement for the SRM was also determined for the condition where the separation impulse is stopped after 2.0 and 2.4 seconds, respectively. This is shown below:

t (sec)	t^2 (sec^2)	$S_{Lateral}$ Engine off -2 sec.	$S_{Lateral}$ Engine off-2.4 sec.
0	0	0	0
.4	.16	1.8	1.8
.8	.64	7.21	7.21
1.2	1.44	16.2	16.2
1.6	2.56	28.8	28.8
2.0	4.00	45.02	49.36
2.4	5.76	63.02	65.00
2.8	7.82	81.02	86.75
2.86	8.19	83.82	90.00

The velocity at the time of engine off for each of the two above conditions is:

At 2 sec engine off	At 2.4 sec engine off
$V = \sqrt{2\ as}$	$V = \sqrt{2\ as}$
$V = \sqrt{2(22.57)\ (45)}$	$V = \sqrt{2(22.57)(65)}$
$V = 45.1$ ft/sec	$V = 54.3$ ft/sec
$\therefore S = 45.1\ t$	$\therefore S = 54.3t$

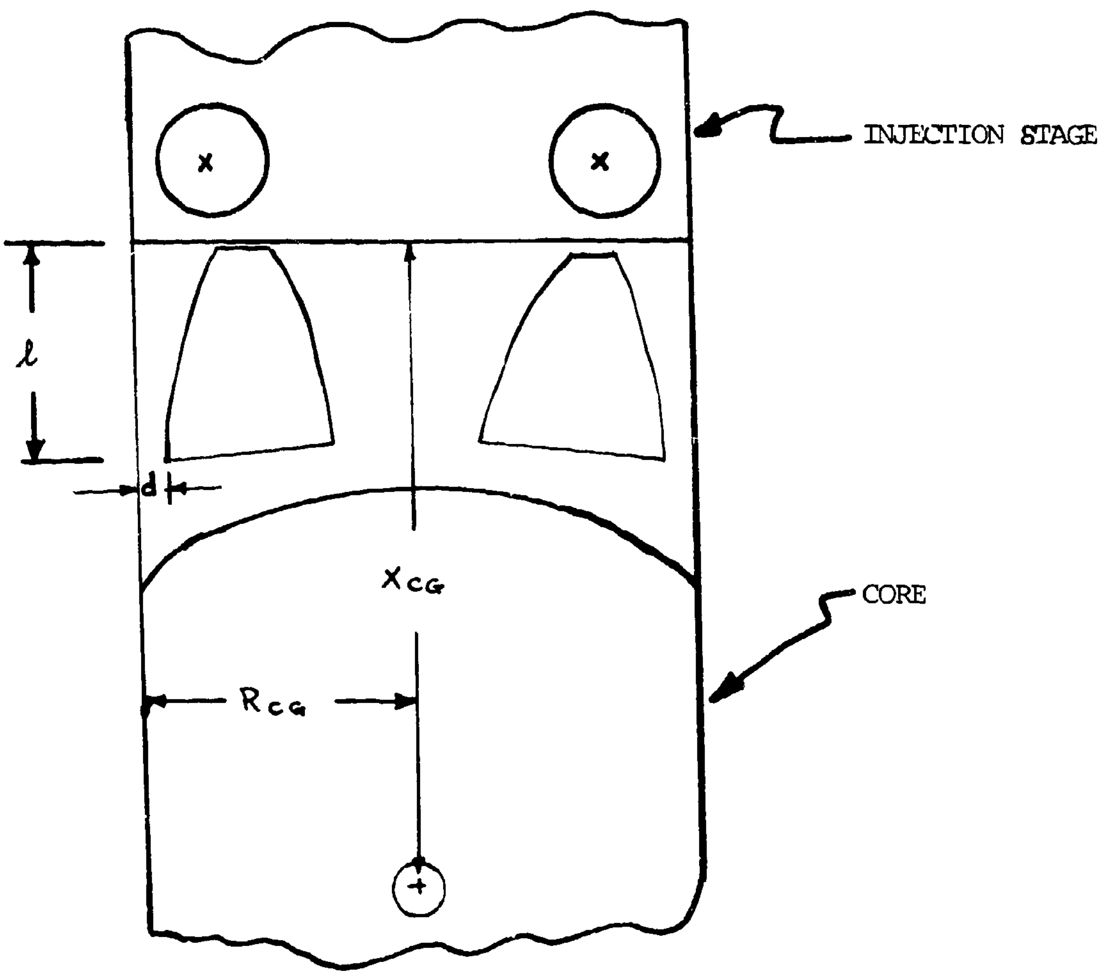
Employing higher thrust values for shorter time spans shows the following lateral displacement for twice the separation thrust level and for four times the thrust level.

Time		Twice Thrust		Four Times Thrust	
t (sec)	t^2 (sec^2)	Lateral (feet)	Velocity (feet/sec)	Lateral feet	Velocity (feet/sec)
0	0	0	0	0	0
.4	.16	3.6	18	7.2	36
.8	.64	14.3	35.9	28.8	71.8
1.2	1.44	32.4	54	65.0	108
1.6	2.56	57.2	72	115	144

A.3 Main Stage/Injection Stage Separation

Paragraph 4.2.6.1 of Volume 2, Half-Size Vehicle (MLLV) Conceptual Design presented the separation requirements for the main stage/injection stage. The back-up calculations are presented below:

Main Stage	Mass = 15,310 slugs; Weight = 493,500 lbs.
Main Stage	$Ip = 28.578 \times 10^6$ slug - ft^2
Main Stage	X_{cg} = 70.3 feet from separation plane
	d = 0.833 feet - lateral clearance
	1 = 3.81 feet - Longitudinal displacement required for clearance
	R_{cg} = 28.8 feet - retro moment arm



The equation used to determine the longitudinal clearance was:

t = Clearance time in sec.

A = Acceleration in fps

g = Acceleration level

F - Thrust force in lbs.

g_o = Reference acceleration level (gravity)

$$g = \frac{A}{go}$$

$$A = F/M$$

$$t = \sqrt{\frac{21}{A}}$$

For the rotational clearance the equasion used was:

θ_o = Allowable rotation in deg.

θ_a = Rotation in deg. resulting from retros

Fi = Inoperative percent retro force, inoperative in lbs.

Rcg - Retro Force moment arm in feet

$\ddot{\theta}$ = Angular Acceleration in RAD/sec^2

$$\theta_a = 1/2\ \ddot{\theta} t^2$$

$$\ddot{\theta} = \frac{Fi\ Rcg}{Ip}$$

$$\theta_o = \frac{d}{Xcg} \quad ; \text{ for small angle}$$

Assuming an acceleration of one g and a thrust of 493,500 pounds for separation rocket

$$t = \sqrt{\frac{21}{A}} = \frac{7.61}{28.98} \ ; \quad t^2 = \frac{21}{A} = \frac{2 \times 3.81}{32.2} = .236$$

t = .557 seconds

If the acceleration is reduced 10 percent:

$$t^2 = \frac{21}{A} = \frac{7.61}{28.98}\ ;\ t = .69 \text{ seconds}$$

For θ $\quad \ddot{\theta} = \frac{(4.9350)\ (38.8)}{28.578 \times 10^6} (10^5) = .0499 \text{ Rad/sec}^2 = 2.86\ ^\circ/\text{sec}^2$

$$\theta = 1/2\ \ddot{\theta}t^2 = (1.43)\ (.236) = .338^\circ$$

$$\dot{\theta} = \ddot{\theta}t = (286)\ (.357) = 1.59^\circ/\text{sec}$$

$$\Delta t = .135,\ \Delta\theta = \dot{\theta}\Delta t = (1.59)\ (.135) = .214$$

$$\bar{\theta} = .338 + .214 = .552$$

If the acceleration is reduced 20 percent:

$$t^2 = \frac{761}{25.76} = .296 \qquad t = .876 \text{ sec.}$$

$$\ddot{\theta} = \frac{(98,700)\ (38.8)}{28.578 \times 10^6} = .0998 \text{ Rad/sec}^2 = 5.72\ ^\circ/\text{sec}^2$$

$$\theta = 1/2\ \ddot{\theta}t^2 = (2.86)\ (236) = .676^\circ$$

$$\dot{\theta} = \ddot{\theta}t = (5.72)\ (.557) = 3.18^\circ/\text{sec}$$

$$\Delta t = .319$$

$$\Delta\theta = \dot{\theta}\ \Delta t = (3.18\ (.319) = 7.055^\circ$$

$$\bar{\theta} = \theta + \Delta\theta = 1.015 + .676 = 1.691$$

A.4 Payload/Injection Stage Retro Impulse

Paragraph 4.2.6.3 of Volume 2, Half-Size Vehicle (MLLV) Conceptual Design outlines the separation system requirements for the payload/injection stage. The three different retro impulses investigated were 18,500, 37,000, and 74,000 foot pounds. The mass to be separated was 119,100 pounds (3700 slugs). The thrust, burn time and acceleration for separation velocity of 20, 10, and 5 feet per second were computed.

Retro Impulse 74,000 #/sec - Separation velocity 20ft/sec

Burn Time (sec)	Thrust (lbs)	Acceleration (ft/sec)	g's
30	2,467	.666	0.0207
20	3,700	1.0	0.0311
10	7,400	2.0	0.0622
5	14,800	4.0	0.1241
3	24,667	6.67	0.207

Retro Impulse 37,000 #/sec - Separation velocity -10 ft/sec

Burn Time (sec)	Thrust (lbs)	Acceleration (ft/sec)	g's
30	1,234	.332	0.0130
20	1,850	.666	0.0207
10	3,700	1	0.0311
5	7,400	2	0.0622
3	1,480	4	0.1241

Retro Impulse 18,500 #/sec - Separation velocity -5 ft/sec

Burn Time (sec)	Thrust (lbs)	Acceleration (ft/sec)	g's
30	617	0.167	0.00517
20	925	0.25	0.00776
10	1,850	0.5	0.0155
5	3,700	1.0	0.0311
3	6,167	1.67	0.0517
2	9,250	2.5	0.0776
1	18,500	5.0	0.155
0.8	23,150	6.25	0.194

From the above data, figure 4.2.6.3-1 of paragraph 4.2.6.3 of volume II was prepared. For any separation velocity, the "g" level, impulse and burn time can be determined

APPENDIX B
STRESS ANALYSES
(Reference 4.3.3.1, Volume II
Half Size Vehicle (MLLV) Conceptual Design)

B-I SUMMARY

Primary structure requirements for the MLLV main stage were determined based upon the design load envelope from engine ignition to cut-off for two modes of operation. The operational modes are:

a. Single-Stage to Orbit

b. Core plus injection stage with zero staging of 8-260 inch diameter solid motor strap-ons

The propellant tanks were sized for the highest loads and internal pressures associated with the above operational modes. The forward and aft skirts were, however, designed to meet specific mission requirements. This approach results in one set of tank configurations capable of all modes of operation and two sets of skirts. The aft skirt designs were further identified to meet the requirements of the following different engine configurations: One aft skirt design is for the multi-chamber engine and the other aft skirt design is for the segmented toroidal engine. Both aft skirts will be adequate for the above listed two operational modes with the provision of heavier aft thrust ring section to support the solids strap-on attachment loads.

The design of the MLLV is similar to the Saturn V/S-IC in that the tankage is a welded integrally stiffened structure and the skirts are mechanically fastened hat-stiffened structures. The MLLV propellants are LOX-LH_2 requiring the tankage material to perform satisfactorily at cryogenic temperature. The requirement of cryogenic properties of material compatibility with LOX and liquid hydrogen and other considerations have narrowed the selection of baseline material to aluminum alloy.

2219-T87 aluminum alloy was chosen for the tankage construction for its excellent fusion weldability and other good qualities particularly in the fracture toughness area.

Aluminum alloy 7075-T6 was chosen over 7178-T6 for the skirts primarily because of corrosion resistance even though the 7078 has a slightly higher strength-to-weight ratio. The 7075-T6 alloy is also supported by previous successful applications on the S-IC and numerous aircraft structures. Table B-I lists the MLLV structural materials and method of construction.

STRUCTURAL COMPONENT	STAGE LOCATION		STRUCTURAL MATERIALS	CONSTRUCTION
	FROM STA.	TO STA.		
FORWARD SKIRT	1450	1690	7075-T6 ALUMINUM	SKIN, STRINGER, FRAME
FORWARD LOX TANK BULKHEAD	1450	1690	2219-T87 ALUMINUM	MONOCOQUE
LOX TANK WALL	1396	1450	2219-T87 ALUMINUM	MONOCOQUE (SHORT CYLINDER BETWEEN Y-RINGS)
COMMON BULKHEAD	1203	1396	2219-T87 ALUMINIM FACINGS, 5052 ALUMINUM CORE	HONEYCOMB SANDWICH
LH_2 TANK WALL	493	1396	2219-T87 ALUMINUM	SKIN, STRINGER, FRAME
AFT BULKHEAD	300	493	2219-T87 ALUMINUM	MONOCOQUE
THRUST STRUCTURE	355	493	7075-T6 ALUMINUM	SKIN, STRINGER, FRAME

TABLE B-I MLLV BASELINE STRUCTURAL DESIGN

Since the magnitudes of applied loading were essentially the same for the multichamber engine and the toroidal engine baseline core concepts, these two vehicles are identical in all areas except the thrust skirts. The difference arises from the assumptions that the toroidal engine thrust is a uniformly distributed force at the engine skirt interface, and the multichamber engine thrust consists of concentrated forces applied at 24 equally spaced points around the thrust structure periphery. The aft skirt structural sizes are shown in Table B-II.

Preliminary design sizing of the multichamber thrust skirt structural elements required the evaluation of shear lag effect, reference 9, caused by the concentrated thrust loads. This approach was used to size the thrust posts and stiffened shell to obtain a uniform axial load distribution at the juncture of the LH_2 tank and the thrust structure. General and local instability failure modes of the stiffened shell were evaluated in the upper region of the thrust structure where the axial compressive load distribution was assumed to be uniform. General instability as applied to axially compressed cylinders in this report is defined as the failure mode in which the intermediate rings and the stringer-shell elements buckle together. Local instability considers the buckling of individual panels between stiffeners, the skin-stiffener panel buckling between two rings, the crippling of stiffener elements, and local yielding of individual element at end attachments where secondary stresses may represent a sizable portion of the total stress (Reference 2). The approximate optimum design approach for achieving the simultaneous failure modes of both general and local instability as advanced in Reference 3 was used as a guide to size the intermediate rings. Timoshenko's criterion of sizing rings and Shanley's criterion for ring stiffness (Reference 7) were also evaluated for comparison. The lower thrust ring was sized for strength requirements dictated by the calculated internal load distribution (Reference 3) induced in the ring by the radial thrust load component at the engine-skirt interface. The upper thrust ring was combined with the LH_2 tank Y-ring. Thus, the Y-ring was sized for the distributed radial load at the forward end of the thrust skirt and for the discontinuity forces induced by the maximum internal tank pressure in the vicinity of the LH_2 cylinder-bulkhead juncture. The Y-ring also serves as a stabilizing ring for the LH_2 tank and thrust structure.

The toroidal engine thrust structure was analyzed as a stiffened cylinder subjected to a uniformly distributed loading at the engine-skirt interface. The method of stability analysis (Reference 2) was the same as that used for the multichamber thrust structure. The interface between the engine and thrust structure was assumed to be a pinned connection with the result that no bending moment was applied to the skirt at the engine attachment.

PROPULSION SYSTEM	LOCATION (STATION)	RING AREA (IN^2)	THRUST POST AREA (IN^2)	SKIN - STRINGER (IN.)				
				a	t_1	t_2	t_3	t_4
MULTI-CHAMBER ENGINE	355	50.5*	[illegible]	3.0	.125	[illegible]	[illegible]	[illegible]
	355	18.9	STRAIGHT ↕ TAPER	↕	↕	STRAIGHT ↕ TAPER	STRAIGHT ↕ TAPER	STRAIGHT ↕ TAPER
	401	8.0						
	447	8.0						
	493	9.4	3.5	3.0	0.125	0.08	0.08	0.125
TOROIDAL ENGINE	355	50.5*	NO THRUST POSTS	3.0	0.125	0.08	0.08	0.125
	355	18.9		↕	↕	↕	↕	↕
	401	10.0						
	447	10.0						
	493	9.4		3.0	0.125	0.08	0.08	0.125

*THE LARGER AREA IS USED ON THE SOLID ROCKET MOTOR STRAP-ON VEHICLE

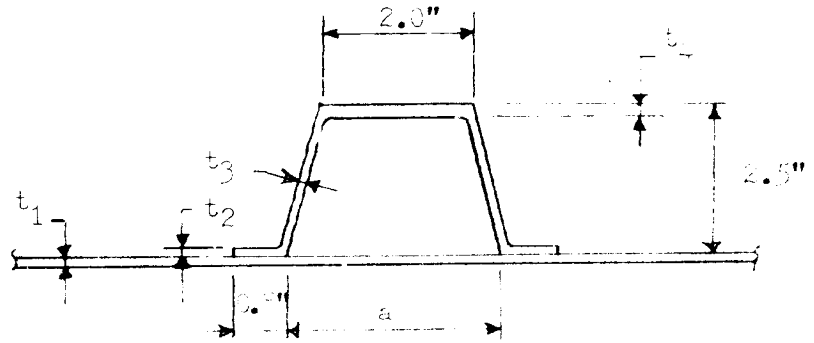


TABLE B-II [illegible] AFT SKIRT STRUCTURAL SIZES

The forward skirt, which is subjected to concentrated axial and radial loads as well as uniformly distributed loading, was sized by using the same approach as for the multichamber engine thrust structure. A combination of concentrated load and uniformly distributed loading occurs during holddown, single stage rebound, and solid motor strap-on firing. The shear lag analysis was used to size the posts and adjacent skin for concentrated axial loads on the posts in order to assure a uniform axial load distribution at the LOX tank upper Y-ring. Shell stability requirements were satisfied by sizing the longitudinal skin stiffeners and intermediate rings for uniform axial compressive loading. Strength requirements dictated the size of the thrust ring located to react radial concentrated loading. Table B-III lists the forward skirt structural sizes.

The sidewall configuration of the propellant tanks was sized for the maximum loading conditions for all modes of operation. The tank skin thickness was determined by the circumferential membrane stresses induced by internal pressure. The pressures in the LOX tank were high enough to require a tank wall skin thickness capable of carrying the design axial compressive loading in that region. An elastic stability analysis was performed to size integral tee stiffeners for compressive loading in the LH_2 tank. The design analysis evaluated general and local instability modes in accordance with Reference 2. The longitudinal stiffeners were sized and spaced so that the entire skin was effective in carrying the axial compressive load. Stiffener spacing was determined by the Von Karman effective width formula.

The tank bulkheads are all 0.707 semi-ellipsoidal shell configuration except as noted in the difference at the Y-ring connections for the LH_2 aft bulkhead and the LOX aft bulkhead. The forward LOX and aft LH_2 bulkheads are monocoque shells which were designed for the nonuniform internal pressure applied to the bulkheads for the strap-on configuration. The analysis considered the meridional membrane stresses for determining required skin thickness at various points on the shell. The common bulkhead is a sandwich construction sized for nonuniform internal pressure for the strap-on vehicle configuration, and for a uniform external pressure applied near LOX depletion for the core vehicle. The internal pressures designed the face sheet thickness required for bulkhead strength, and the external pressure loading due to differences in ullage pressures in the two tanks dictated honeycomb core requirements for bulkhead stability. Figure B-1 defines the propellant tank structural sizes.

The LOX ducts inside the LH_2 tank were sized for possible negative pressure requirement only. The lateral support system for LOX ducts was not considered for this preliminary stage of design.

VEHICLE OPERATIONAL MODE	LOCATION (STATION)	RING AREA (IN^2)	THRUST POST (IN^2)	SKIN - STRINGER (IN) t_1	t_2	t_3	t_4	a	b
SINGLE STAGE (CORE + ONE INJECTION STAGE)	1460	——	10	0.11	0.072	0.072	0.10	3.20	2.50
	1515	6	1						
	1572	6							
	1630	66.75	50						
	1690	12.0	5	0.11	0.072	0.072	0.10	3.20	2.50
CORE + 8-SRMS + 3 INJECTION STAGES	1460	——	12	0.125	0.075	0.075	0.10	3.40	2.75
	1515	8	1	1		1	1		1
	1572	8							
	1630	87.7	98	0.135		0.10	0.135		3.50
	1690	8	24						
INJECTION STAGES ANALYSIS	1740	*24.10	3.2						
	1775	*20.75	5.4						
	1874	11.0	——						
	1978	11.0	——						
	2078	12.0	——	0.135	0.075	0.10	0.135	3.40	3.50

1 STRAIGHT TAPER BETWEEN ENDS AND MAXIMUM SECTION

* INJECTION STAGE THRUST RINGS

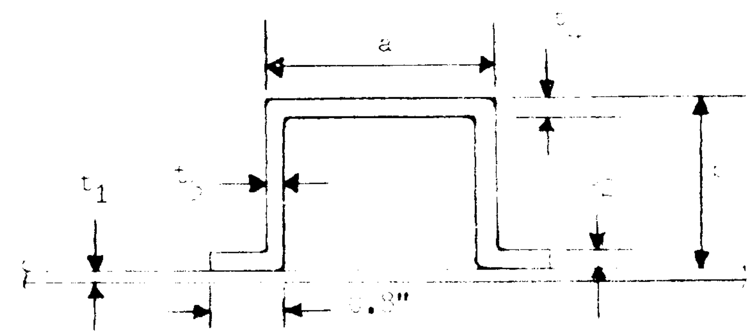
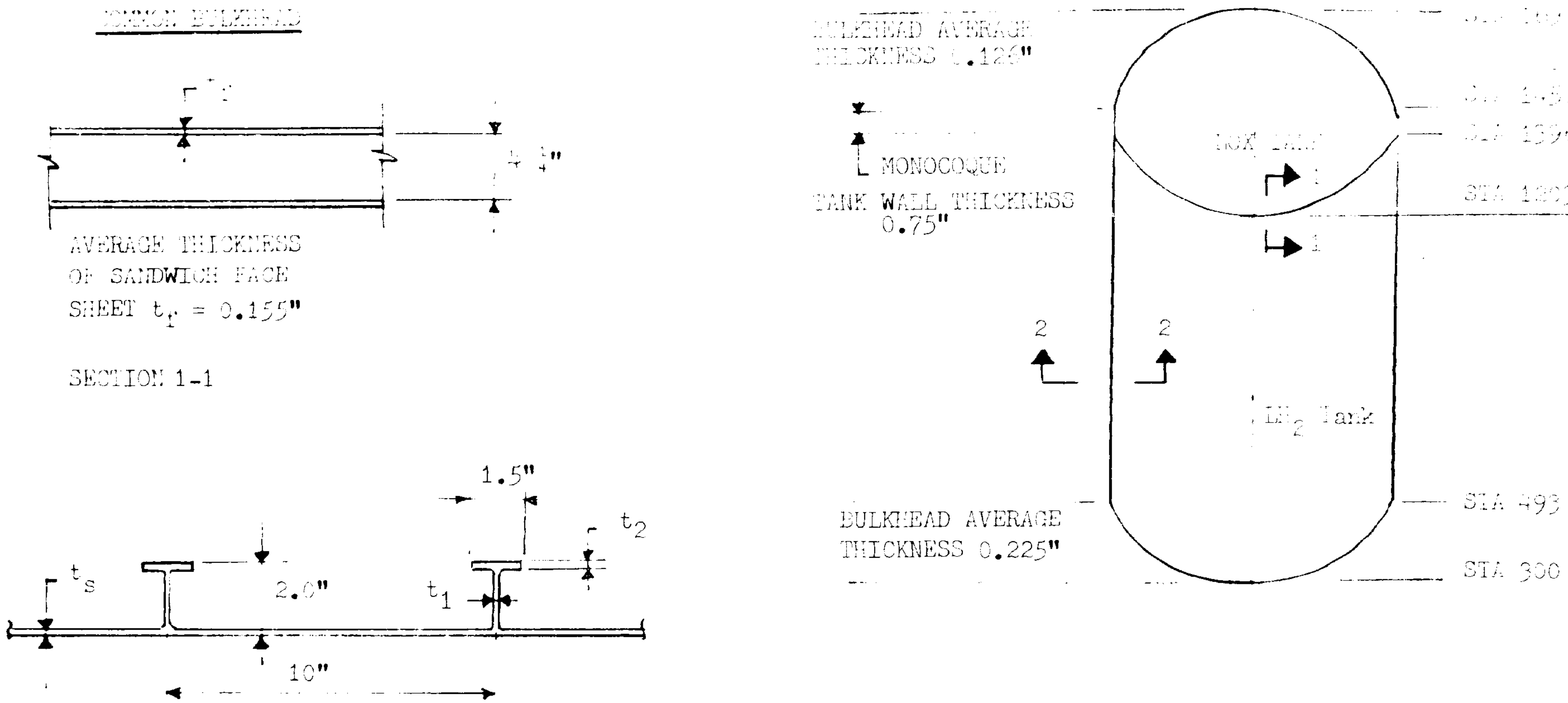


TABLE B-III MLLV FORWARD SKIRT AND 3 INJECTION STAGE STRUCTURAL SIZES



LOCATION	t_s (IN)	t_1 (IN)	t_2 (IN)	LH_2 TANK INTERM. RINGS
STA 505	0.26	0.10	0.15	AREA 2.5 IN^2/RING
STA 1381	0.22	0.10	0.20	SPACING 62.5"

FIGURE B-1

The injection stage design loads results from operation of the main stage plus a three module injection stage and 8-260 inch diameter zero stage solid motor strap-ons vehicle as shown in Figure B-2.

The monocoque Torus shaped propellant tanks were sized for a combined maximum internal pressure and bending load. Honeycomb sandwich web panels were provided inside the tanks at 45° apart for Torsional rigidity. The skirt enclosing the three module injection stage propellant tanks was sized for the stability critical N_c load induced at max q α for the MLLV Core plus 8-SRM plus 3 module injection stage. The thrust structure for the injection stage consists of two thrust rings, and six diagonal thrust posts. Each diagonal thrust post will transmit the vertical thrust component to the reinforced skirt. The skirt reinforcing serves as a tapered vertical thrust post to shear the engine thrust load into the skirt skin during injection stage engine firing. The two thrust rings will react the coupling load which results from engine mounting plus engine gimbaling. The diagonal thrust post was assemed to be pin connect at the ends.

The LOX tank was assumed to be hung from the LH_2 tank through a cylindrical skirt which is welded to the LH_2 tank wall. The LH_2 tank was assumed to be supported by the injection stage skirt. The design of the feed line system was not covered at the present conceptual phase of study. 2219-T87 alluminum alloy was chosen for the Toroidal propellant tanks construction for its excellent fusion weldability and other good qualities particularly in the fracture toughness area.

Aluminum alloy 7075-T6 was chosen for the injection stages skirt and thrust structure because of its good strength to weight ratio and corrosion resistance. In addition, it is supported by prior successful applications on the Saturn V and numerous aircraft.

A stress analysis of the main stage structural impact for a change in payload density from 5 Lbs/Ft^3 to 2 Lbs/Ft^3 was undertaken to determine the payload sensitivity. From review of the loads which result from the change in payload density it was apparent that the aft thrust skirt, LH_2 tank wall, and the forward skirts all required reevaluation for higher compressive N_c loads. The change in payload density thus resulted a small increase in Aft thrust skirt section and significant increases in LH_2 wall and forward skirt sizes as depicted in the stress analyses. The payload sensitivity is discussed in Paragraph 4.3.7 of Volume 2, Half Size Vehicle (MLLV) Conceptual Design.

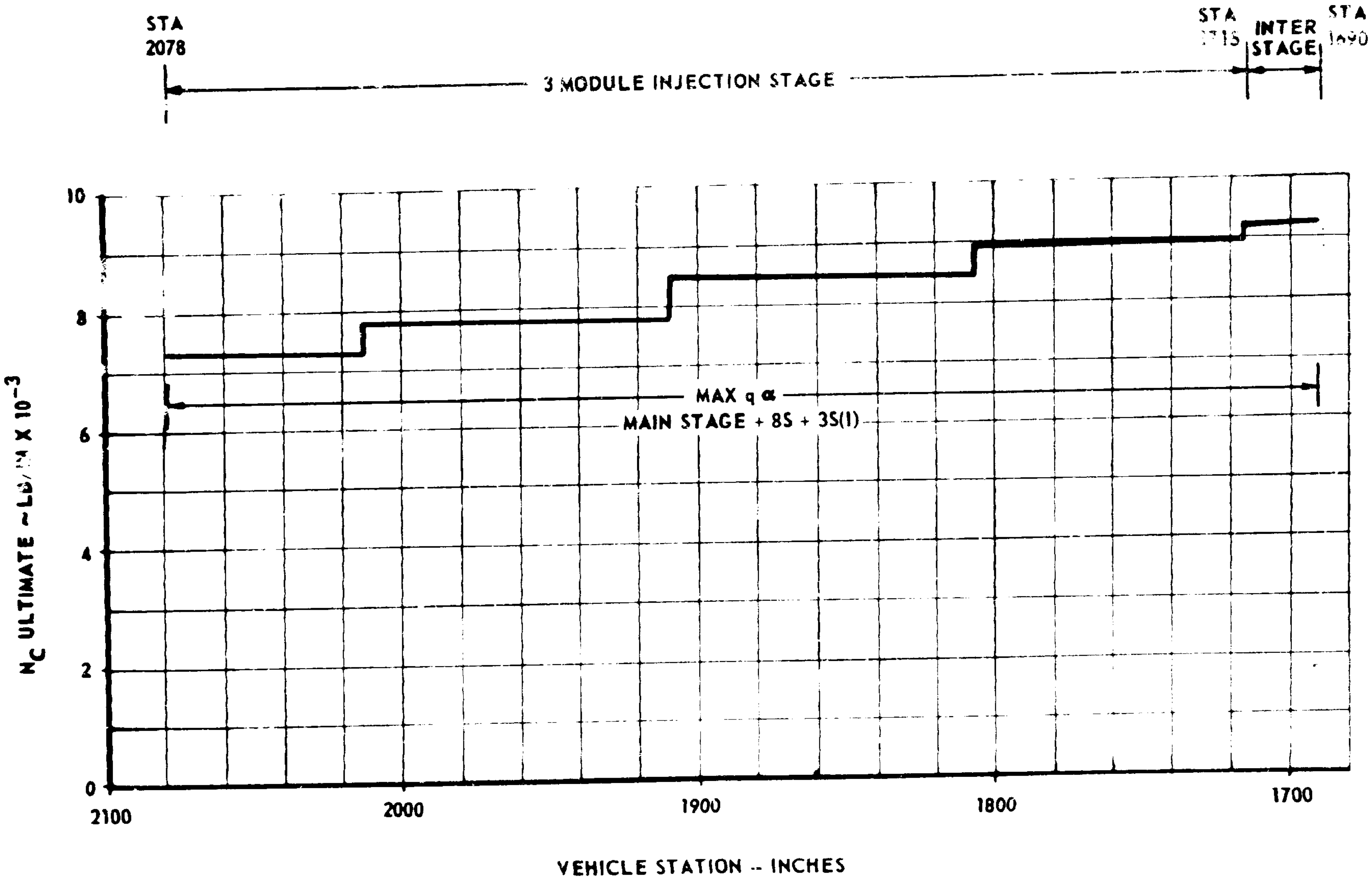


FIGURE B-2 ULTIMATE COMBINED COMPRESSIVE LOAD ENVELOPE FOR THREE MODULE INJECTION STAGE

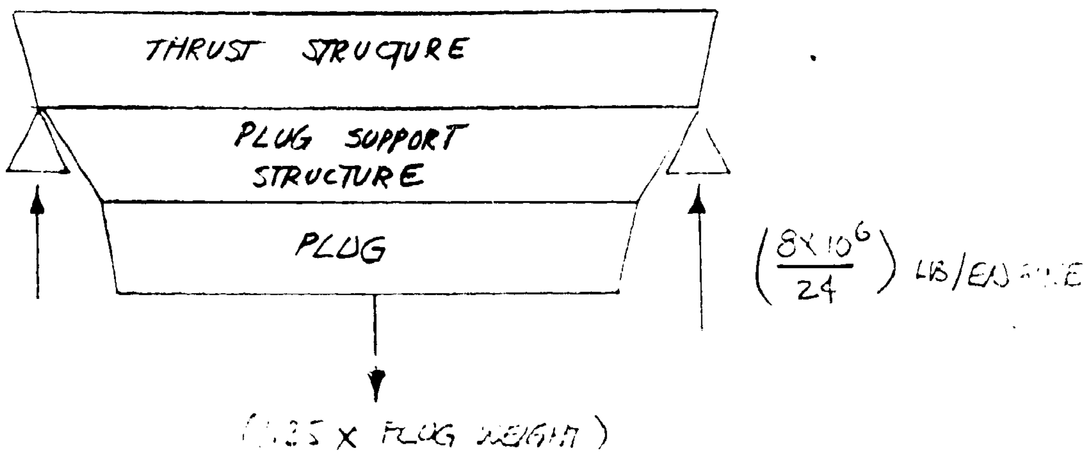
B-2
MLLV SINGLE STAGE
TO ORBIT VEHICLE

B-2.1

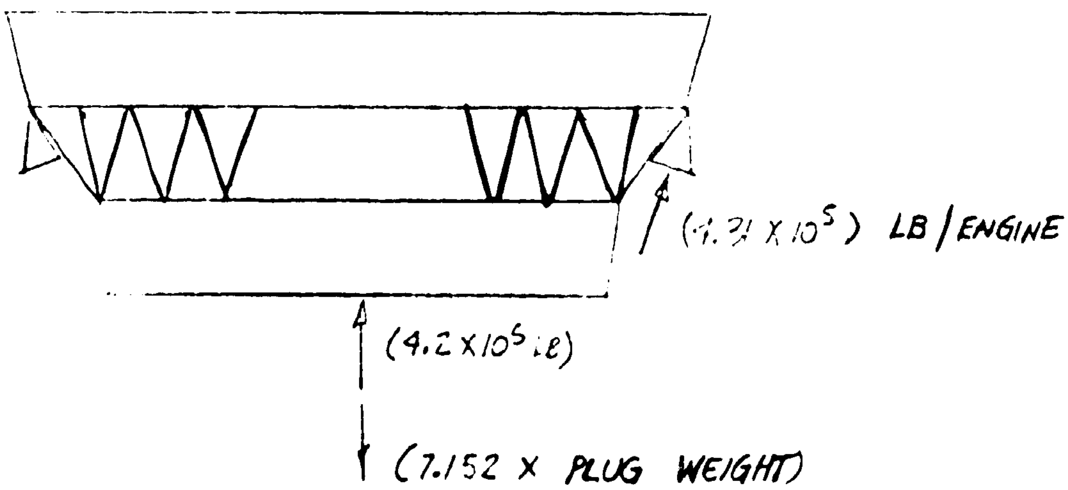
MLLV SINGLE STAGE
PLUG NOZZLE SUPPORTING
STRUCTURE ANALYSIS

LIMIT LOADING CONDITIONS FOR MLLV MULTICHAMBER THRUST STRUCTURE

I) SINGLE STAGE AT LIFT-OFF



II) SINGLE STAGE AT ENGINE THROTTLING



PLUG WEIGHT = 10,500#

PLUG NOZZLE SUPPORT ASSEMBLY

APPROXIMATE INVESTIGATION

GIVEN PLUG WT = 10,500 LB

FOR THE CASE AT ENGINE THROTTLING

NET UPWARD PLUG NOZZLE LOAD

$$P = (4.2\times10^5 - 7.152\times10{,}500)\times1.4 = 483000\text{ LB}$$

THIS LOAD WILL BE ADDED TO THE THRUST LOAD FROM ROCKET ENGINE

$$p_u = \frac{483000}{2\pi\times314.4} = 244\text{ LB}/''$$

CORRECTED TO 10° 30' GIMBAL ANGLE

$$P_u = \frac{244}{\cos 10°30'} = \frac{244}{0.98325} = 247\ \#/''$$

COMBINED ENGINE THRUST PLUS PLUG NOZZLE LOAD GIVES

$$N_c = 7000 + 247 = 7{,}247\text{ LB}/''$$

$$\text{Av. } f_c = \frac{7{,}697}{t_a} = \frac{7697}{0.227} = 31{,}900\text{ PSI}$$

FOR STABILITY OF INTERFRAME BUCKLING BETWEEN RING FRAMES

$$M.S = \frac{8570}{7230} - 1 = +0.19$$

CORRECTED N_c AT UPPER END OF THRUST STRUCTURE

FOR GENERAL INSTABILITY STRESS

$$N_{CR} = 7410 \text{ LB/IN}$$

$$MS = \frac{7410}{7247} - 1 = \underline{+0.025} \longrightarrow$$

HENCE THE THRUST STRUCTURE IS OK FOR THIS COMBINED THRUST PLUS PLUG NOZZLE LOAD

NO REVISION OF THRUST SKIRT IS NEEDED.

INVESTIGATION OF LOAD PATH DUE TO PLUG NOZZLE SUPPORT

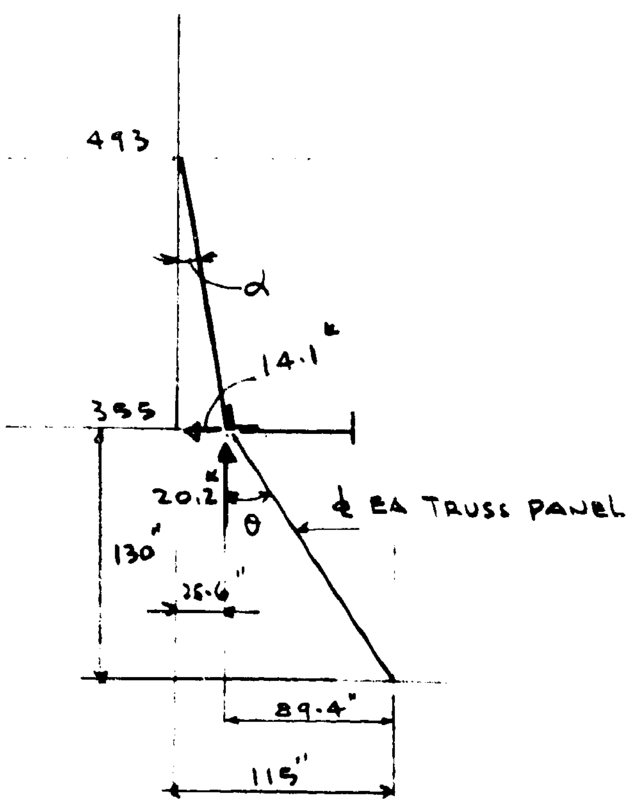
ASSUME LOAD FROM PLUG NOZZLE TO BE SUPPORTED BY 24 TRUSS PANEL PTS @ LOWER THRUST RING & THRUST SKIRT.

TOTAL REACTION FROM PLUG NOZZLE LOAD

= 483 000 LBS

EACH PANEL PT REACTION (VERT.)

$$V_p = \frac{483}{24} = 20.2^k$$



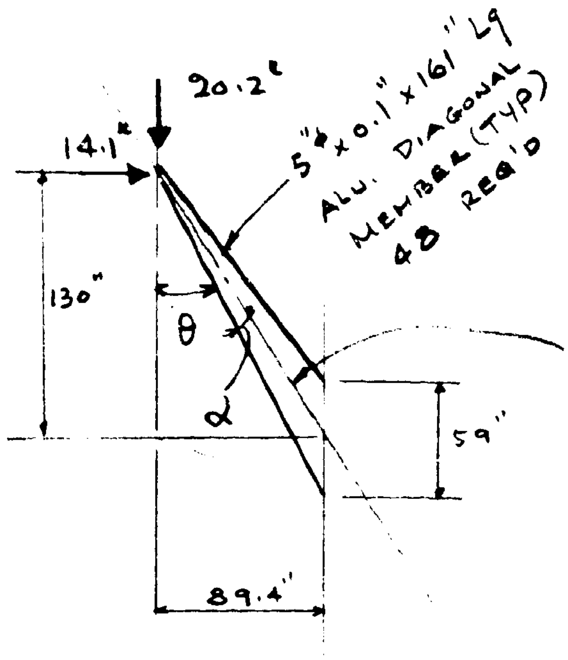
$$\tan\theta = \frac{89.4}{130} = 0.693$$

$$V_H = 20.2 \times 0.693 = 14.1^k$$

THIS FORCE WILL BE ADDED TO AFT THRUST RING DESIGN

PLUG NOZZLE SUPPORT ASSEMBLY

APPROXIMATE DESIGN OF TRUSS MEMBERS



$C = 2\pi R = 6.28 \times 225 = 1412"$

EACH TRUSS PANEL WILL HAVE

$$b = \frac{C}{24} = \frac{1412}{24} = 59"$$

℄ LENGTH $= \sqrt{89.4^2 + 130^2}$

$= \sqrt{8100 + 16900}$

$= \sqrt{25000} = 158"$

LENGTH OF TRUSS DIAGONAL

$$l_D = \sqrt{158^2 + 29.5^2} = 161"$$

$$\cos\theta = \frac{130}{161} = 0.808$$

$$\therefore \theta = 36°10'$$

$$\Sigma F_z = 0 \quad 2 S_D \cos\theta - 20.2 = 0$$

$$S_D = \frac{20.2}{2 \times 0.808} = 12.5^k$$

THE FORCE IN TRUSS DIAGONAL IS 12.5^k

DESIGN OF DIAGONAL MEMBERS

GIVEN LOAD 13^{K}

ASSUME $5''\phi$ TUBE $t = 0.1''$

$$\rho = 0.707 \times 2.5 = 1.77$$

$$L/\rho = \frac{161}{1.77} = 91'' \qquad L = 161''$$

$$I = \pi R^3 t = \pi \times 15.6 \times 0.1 = 4.9 \text{ IN}^4$$

$$P_{CR} = \frac{\pi^2 E I}{L^2} = \frac{9.85 \times 10.4 \times 10^6 \times 4.9}{26000} = 0.0193 \times 10^6$$

$$= 19300$$

$$M.S = \frac{19300}{13000} - 1 = \underline{+0.485}$$

TOTAL 48 DIAGONALS ARE REQUIRED

$5''\phi \times 0.1'' \times 161''$ LG ALUM. 7075-T6

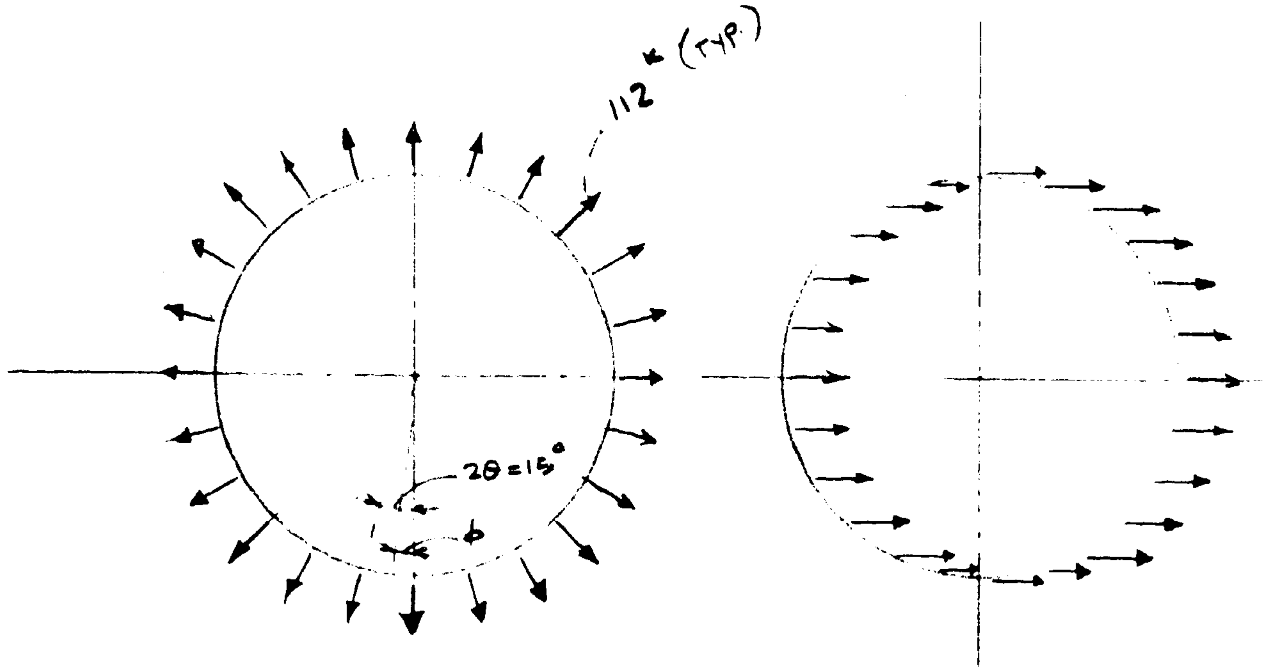
DESIGN IS ON CONSERVATIVE SIDE TO TAKE CARE OF VIBRATION ENVIRONMENT.

B-2.2

MLLV SINGLE STAGE
CORE VEHICLE AFT SKIRT
LOWER THRUST RING ANALYSIS

MATERIAL-ALUMINUM 7075-T6

ANALYSIS OF AFT SKIRT THRUST RING SECTION
(SINGLE STAGE)



LOADING CASE 1 LOADING CASE 2

LOADING CASE 1

GIVEN EACH ENGINE THRUST LOAD

$$T = \frac{10.35 \times 10^6 \times 1.4}{24} = \frac{14.5 \times 10^6}{24} = 0.604 \times 10^6 \text{ LB/ENGINE}$$

$$\sin 10°30' = 0.1822$$

THE RADIAL THRUST AT EACH THRUST POST

$$P_r = \frac{0.604 \times 10^6}{0.9833} \sin 10°30' = 0.112 \times 10^6$$

$$= 112\,000 \text{ LB/EA. ENGINE}$$

ANALYSIS OF LOADING CASE 1

REF. ▷ ROARK FORMULAS FOR STRESS & STRAIN
P. 158. CASE 9.

GIVEN $R = 300$ ±

$2\theta = 15^\circ$

$\theta = 7.5^\circ = \pi/24$

AT $\phi = 2\theta = 15^\circ$

$$+M = \tfrac{1}{2} PR \left(\frac{1}{s} - \frac{1}{\theta} \right)$$

$$= \tfrac{1}{2}\, 112 \times 300 \left(\frac{1}{\sin 7.5^\circ} - \frac{1}{\pi/24} \right)$$

$$= 56 \times 300 \left(\overset{7.66283}{\frac{1}{0.1305}} - \overset{7.63941}{\frac{24}{\pi}} \right)$$

$$= 16800 \times 0.02342 = 394 \text{ in-kip}$$

AT $\phi = 0^\circ$

$$-M = -\tfrac{1}{2} PR \left(\frac{24}{\pi} - \cot \overset{\theta}{7.5^\circ} \right)$$

$$= -\tfrac{1}{2}\, 112 \times 300 \left(\overset{0.0436}{7.63941 - 7.5958} \right) = -732 \text{ in-k}$$

AXIAL TENSION AT LOAD PT

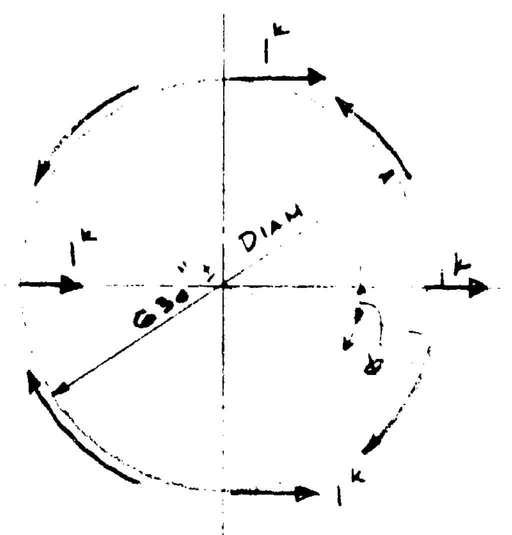
$$N = \tfrac{1}{2} P \times \cot\theta = \tfrac{1}{2} P \times \cot 7.5^\circ$$

$$= \tfrac{1}{2}\, 112 \times 7.5958 = 425 \text{ kips}$$

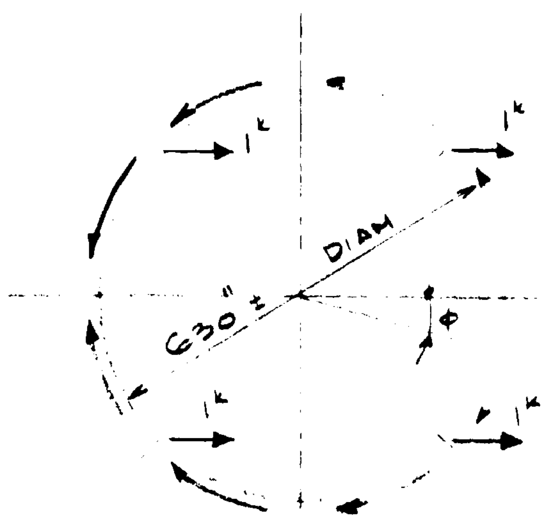
ANALYSIS OF AFT SKIRT THRUST RING FOR HORIZONTAL ONE WAY SIDE LOAD   LOADING CASE II

FOR SIMPLE ANALYSIS ON CONSERVATIVE SIDE, THE ONE WAY SIDE LOADS AT EACH ENGINE LOCATION ARE REGROUPED TO BE APPLIED AT 90° & 45° @ EACH QUARTER OF RING

FOR 1K LOAD



CASE 10 RING-IN-PLANE LOADING
NASA-STRUCTURES MANUAL



CASE 11 RING IN-PLANE LOADING
NASA-STRUCTURES MANUAL

ASSUME UNIT LOAD APPLICATION FOR MOMENT INFLUENCE

CASE 10 BENDING MOMENT

$\phi = 0°$ $M = -0.14\,P\,R = -0.14 \times 1 \times 315 = -44.1''\text{-K}$

$\phi = 45°$ $M = +0.05\,P\,R = +0.05 \times 1 \times 315 = +15.8''\text{-K}$

$\phi = 90°$ $M = 0$

$\phi = 135°$ $M = -0.05\,P\,R = -0.05 \times 1 \times 315 = -15.8''\text{-K}$

$\phi = 180°$ $M = +0.14\,P\,R = +44.1''\text{-K}$

CASE 10 CONTINUED

AXIAL FORCE EVALUATION

$\phi = 0°$ $N = +0.65\,P = 0.65$

$\phi = 45°$ $N = +0.45\,P = 0.45$

$\phi = 90°$ $N = -0.50\,P = -0.50$

$\phi = 180°$ $N = -0.65\,P = -0.65$

CASE 11 BENDING MOMENT

$\phi = 0°$ $M = +0.071\,PR = +22.4$ "-k

$\phi = 45°$ $M = -0.097\,PR = -30.6$ "-k

$\phi = 90°$ $M = 0$

$\phi = 135°$ $M = +0.097\,PR = +30.6$ "-k

$\phi = 180°$ $M = -0.071\,PR = -22.4$ "-k

CASE 11 AXIAL FORCE

$\phi = 0°$ $N = 0.64\,P = +0.64$

$\phi = 45°$ $N = 0.81\,P = +0.81$

$\phi = 90°$ $N = 0 = 0$

$\phi = 135°$ $N = -0.81\,P = -0.81$

$\phi = 180°$ $N = -0.64\,P = -0.64$

SUMMATION OF MOMENTS FROM CASE 10 & CASE 11
AT VARIOUS ANGULAR LOCATIONS FOR 1^k LOAD

$\phi = 0°$ $\quad M = -44.1 + 22.4 = -21.7$ ''-k

$\phi = 45°$ $\quad M = +15.8 - 30.6 = -14.8$ ''-k

$\phi = 90°$ $\quad M = 0 + 0 = 0$

$\phi = 135°$ $\quad M = +30.6 - 15.8 = +14.8$ ''-k

$\phi = 180°$ $\quad M = -22.4 + 44.1 = +21.7$ ''-k

SUMMATION OF AXIAL FORCES FROM CASE 10 & CASE 11
AT VARIOUS ANGULAR LOCATIONS FOR 1^k LOAD

$\phi = 0°$ $\quad N = 0.65 + 0.64 = +1.29^k$

$\phi = 45°$ $\quad N = +0.45 + 0.81 = +1.26^k$

$\phi = 90°$ $\quad N = -0.50 + 0 = -0.50^k$

$\phi = 180°$ $\quad N = -0.65 - 0.64 = -1.29^k$

AFT THRUST RING DESIGN FOR LOADING

CASE II (ACTUAL LOADING)

BASED UPON LOAD DATA (GIMBAL LOAD)

EACH ENGINE SHALL HAVE A SIDE LOAD

$P_H = 23.26 \times 1.4 = 32.8^k$

ASSUME 3 LOADS CONCENTRATION AT 45° & 90° ANGULAR PT

THEN

$\Sigma P_H = 3 \times 32.8 = 98.5^k$

FROM 1^k LOAD

AT $\phi = 0°$ $M = -98.5 \times 21.7 = -2140$ ''-k MAX

FROM 1^k LOAD

AT $\phi = 0°$ $N = 1.29 \times 98.5 = 127$ ''-k

AFT THRUST RING DESIGN FOR LOADING CASE III

PLUG NOZZLE SUPPORTING LOAD

$P_H = 14.1^k$ ULT AT EACH ENGINE PT

USE MOMENT COEFF. FROM LOADING CASE 1

$$-M = -\tfrac{1}{2}\, 14.1 \times 300 \times \overset{M_{coeff}}{0.0436}$$

$$= -7.05 \times 300 \times 0.0436 = 92.2^{''-k}$$

$$N = \frac{1}{2} P \times \cot\theta = \frac{1}{2}\, 14.1 \times 7.5958 = 53.5^k$$

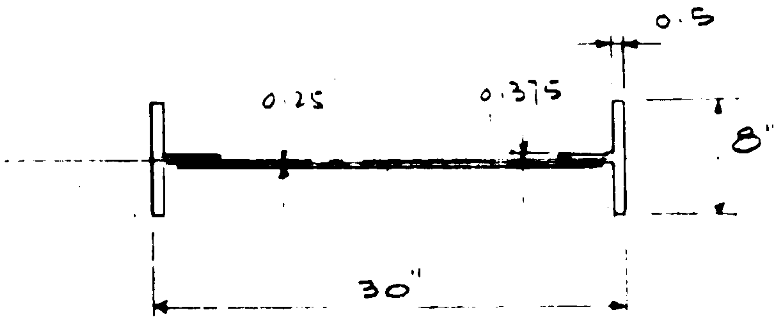
SUMMATION OF THE MAXIMUM MOMENT VALUE @ $\phi = 0°$ FOR ALL THREE LOADING CASES (I, II & III)

$$M_1 = -732$$
$$M_2 = -2140$$
$$M_3 = -92$$

$$\Sigma M = -732 - 2140 - 92 = -2{,}964 \text{ "-K}$$

$$\Sigma N = 425 + 127 + 54 = 606^{K}$$

SIZING OF AFT THRUST RING



$$A_1 = 8 \times 0.5 \times 2 = 8.0$$
$$A_2 = 2 \times 4.5 \times 0.375 = 3.37$$
$$A_3 = 26 \times 0.25 = 6.50$$
$$A_R = 18.87 \text{ } \square''$$

$$I_1 = 8 \times 15^2 = 1800$$
$$I_2 = 3.37 \times 12.25^2 = 505$$
$$I_3 = \tfrac{1}{12}\, 0.25 \times 30^3 = 560$$
$$2{,}865$$

$$S = \frac{2865}{15} = 191 \text{ IN}^3$$

BENDING STRESS IN THE RING

a. $\sigma_b = \dfrac{2865}{191} = 15.10 \; ^{K}/_{\square''}$

AXIAL STRESS

b $\sigma_a = \dfrac{606}{18.87} = 32.10$

$\overline{47.20} \; ^{K}/_{\square''}$

$M.S = \dfrac{69}{47.2} - 1 = \underline{+0.46}$ ⟶

CONSERVATIVE DESIGN ON THIS RING APPEARS IN ORDER FOR PROVISION OF VIBRATION ENVIRONMENT

B.2-3

SINGLE STAGE
MULTI-CHAMBER ENGINE CONCEPT
AFT SKIRT THRUST STRUCTURE ANALYSIS

1. Shear Lag Analysis

2. Skirt and Thrust Post Sizing

N_c = 7,000 Lb/In. (Ult.)
(At Upper End of Skirt)

MAX THRUST PER THRUST POST AT LOWER END

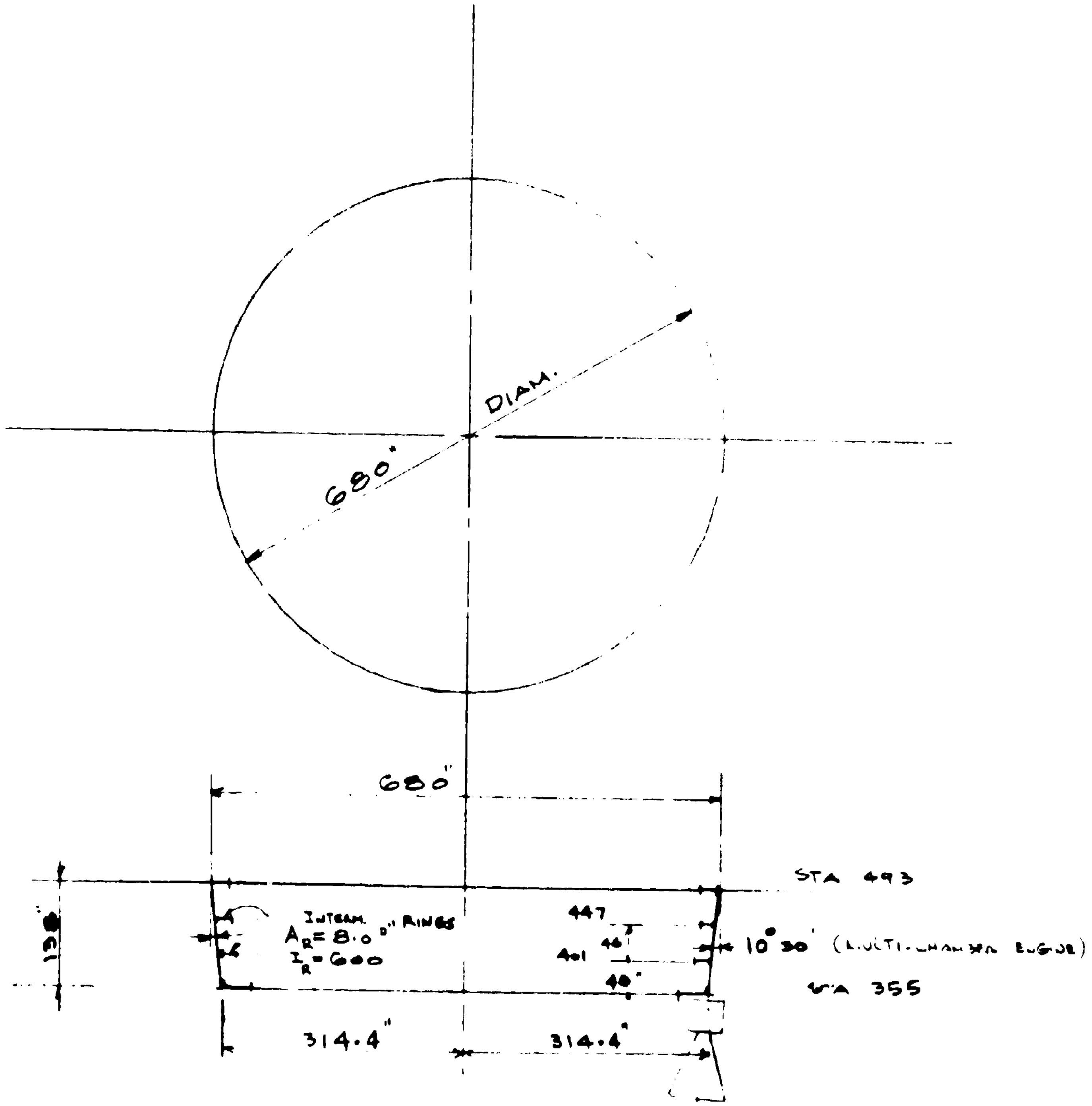
T = 615,000 Lb/In (Ult)
(In Meridianal Direction)

Total T = 14.5 X 10^6 Lbs. (Vertical)
From 24 Engines

SINGLE STAGE ORBIT MLLV STAGE

THRUST STRUCTURE CONFIGURATION ANALYSIS

MULTI-CHAMBER ENGINE CONCEPT



FOR TOROIDAL ENGINE

$$\tan 5^\circ = \frac{a}{138}$$

$$a = 138 \tan 5^\circ = 138 \times 0.08749 = 12.06$$

FOR MULTI-CHAMBER ENGINE

$$\tan 10^\circ 30' = \frac{a}{138}\;; \qquad a = 138 \times \tan 10^\circ 30' = 138 \times 0.18534 = 25.6'$$

THRUST STRUCTURE   I   MULTI-CHAMBER ENGINE CONFIGURATION

SINGLE STAGE TO ORBIT

GIVEN THRUST AT CUT-OFF $= 10.35 \times 10^6 \times 1.4 = 14.5 \times 10^6$

SPACING OF THRUST POSTS

$$S = \frac{2\pi R}{24} = \frac{2\pi \times 314.4}{24} = 82.5''$$

ENGINE THRUST AT EACH THRUST POST

$$T = \frac{14.5 \times 10^6}{24} = 0.604 \times 10^6 \text{ LB}$$

THE UNIT THRUST LOAD PER INCH OF SKIRT

$$N_c = \frac{14.5 \times 10^6}{2\pi \times 314.4} = \frac{14.5 \times 10^6}{1975} = 0.00733 \times 10^6$$

$$= 7330 \text{ LB/''} \quad \text{IN VERTICAL DIRECTION}$$

THRUST IN THE DIRECTION OF SKIRT

$$N_c' = \frac{N_c}{\cos 10^\circ 30'} = \frac{7330}{0.98325} = 7{,}450 \text{ LB/''}$$

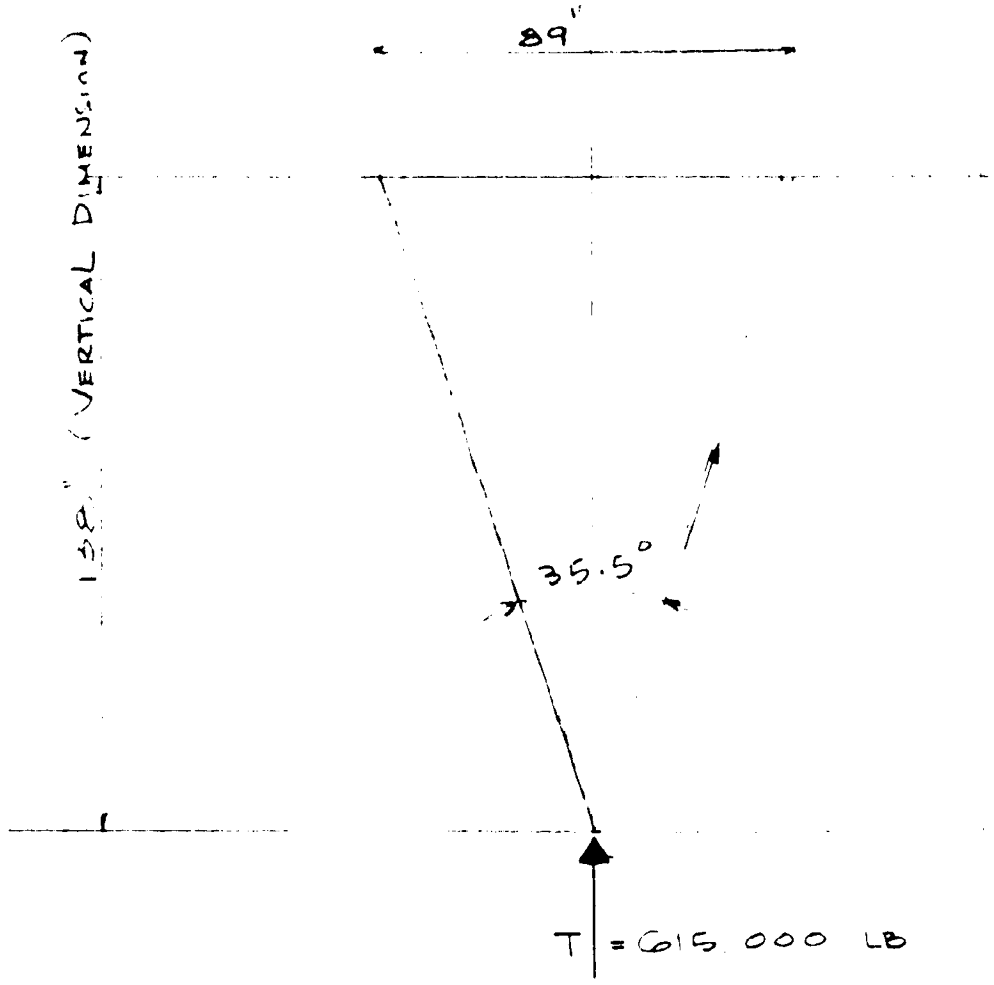
TOTAL THRUST LOAD AT EACH THRUST POST

$$N_{c_p} = 7450 \times 82.5 = 615{,}000 \text{ LB}$$

THRUST DISTRIBUTION AT UPPER END OF THRUST STRUCTURE

$$N_c = \frac{14.5 \times 10^6}{2\pi \times 340 \times 0.983} = \underline{6930} \text{ \#/''}$$

SHEAR LAG PATH



SLANTED LENGTH OF THRUST SKIRT

$$L_s = \frac{L}{\cos 10^\circ 30'} = \frac{138}{0.9833} = 140.5''$$

ASSUME 7075-T6 DIE FORGED MATERIAL TO BE USED AS THRUST POST

$$F_{cy} = 57000 \text{ PSI}$$

THE MAXIMUM POST AREA AT LOAD END

$$A_p = \frac{613{,}000}{57{,}000} = 10.8 \ \square''$$

ASSUME THE POST AREA AS 12 □" AT B[illegible]

& 3 □" AT TOP

INVESTIGATION OF LOCAL BULKLING STRESS OF STRUCTURAL ELEMENTS

a) PANEL BULKLING OF SKIRT ELEMENT

$$\tau_c = \frac{4 \times \pi^2 E}{12(1-\nu^2)} \left(\frac{t_s}{b}\right)^2$$

$$= \frac{4 \times 9.85 \times 10 \times 10^6}{10.92} \left(\frac{0.125}{3.8}\right)^2$$

$$= \frac{4 \times 9.85 \times 10^7 \times 1.08 \times 10^{-3}}{10.70} = 39800 \text{ PSI}$$

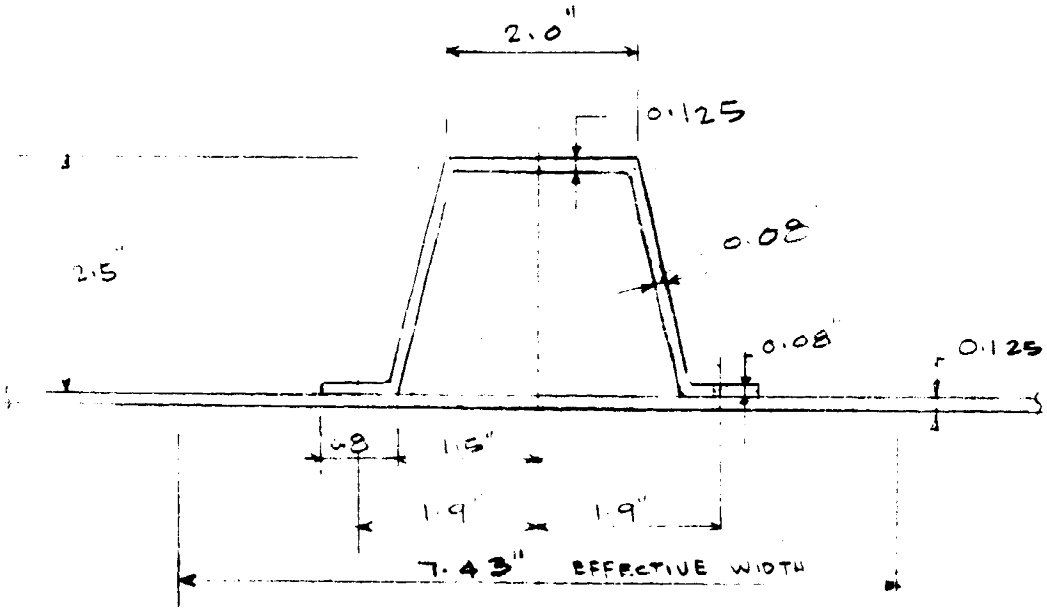
b) SLANTED WEB

1.038×10^{-3}

$$\tau_c = \frac{4 \times \pi^2 E}{12(1-\nu^2)} \left(\frac{t_s}{b}\right)^2 = \frac{4 \times 9.85 \times 10^7}{10.70} \left(\frac{0.08}{2.48}\right)^2$$

$$= 38200 \text{ PSI}$$

STIFFENER CONFIGURATION AT UPPER END OF THRUST SKIRT



SLANTED LENGTH $L_s = \sqrt{0.6^2 + 2.4^2} = \sqrt{0.36 + 5.76} = 2.49$

	A	Y	AY	AY²	I₀
$A_1 = 2.0 \times 0.125$	0.250	2.500	0.625	1.560	0.000326
$A_2 = 2 \times$ [illegible] $\times 0.08$	0.397	1.313	0.523	0.686	0.178500
$A_3 = 1.4 \times 0.08$	0.112	0.165	0.019	[illegible]	[illegible]
$A_4 = \cancel{7.6}\ 7.43 \times 0.125$	0.929	0.0625	0.059	0	0.00124
	1.688		1.226	2.253	0.178950

$$\bar{Y} = \frac{1.226}{1.688} = 0.7280$$

$$I_c = 2.253 + 0.179 - 1.688 \times \underbrace{0.728^2}_{0.894} = 1.538 \ \text{in}^4$$

$$\rho = \sqrt{\frac{I_c}{A}} = \sqrt{\frac{1.538}{1.688}} = 0.955$$

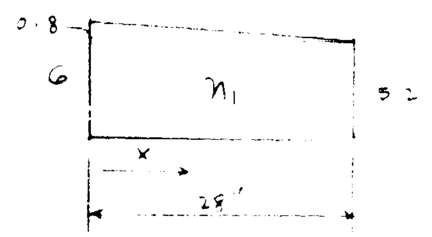
ASSUME RING IS PLACED @ 69" o/c

$$L/\rho = \frac{69}{0.955} = 75.3$$ FALL IN LONG EULER COLUMN CATEGORY

$$t_a = \frac{1.688}{7.43} = 0.227"$$

AT ELEMENT $n = 1$ SHEAR STRAIN

AF

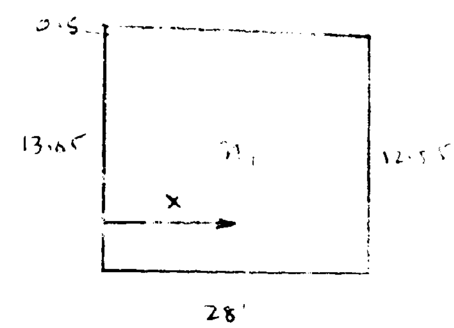


$$\bar{\gamma}_1 = -\frac{P}{G t_n} \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$= -\frac{0.302 \times 10^6}{3.9 \times 10^6 \times 0.1125} \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$A_F = 6.0 - 0.0286\,x$$

$$A_T = 13.05 - 0.0179\,x \approx 13.05$$



AT

$$\bar{\gamma}_1 = \frac{-0.69}{13.05} \frac{d}{dx}(6.0 - 0.0286\,x)$$

$$= \frac{+0.69 \times 0.0286}{13.05} = 0.00151$$

IF $A_T \neq 13.05$

$$\bar{\gamma}_1 = -0.69 \frac{(13.05 - 0.0179x)(-0.0286) - (6.0 - 0.0286x)(-0.0179)}{(13.05 - 0.0179x)^2}$$

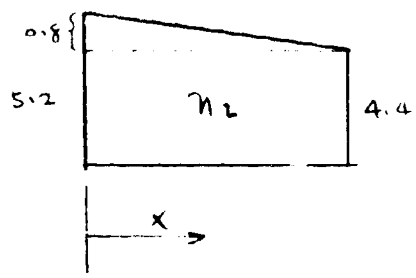
$$= -0.69 \frac{(-0.373 + 0.000512x) - [-0.1072 + 0.000512x]}{(13.05 - 0.0179x)^2}$$

$$\bar{\gamma}_{1\,x=14} = \frac{+0.69 \times 0.2655}{(13.05 - 0.25)^2} = \underline{0.00112}$$

SHEAR STRAIN IS MORE ACCURATE

AT ELEMENT $n = 2$ SHEAR STRAIN

$$\bar{\gamma}_2 = -0.69 \frac{d}{dX}\left(\frac{A_F}{A_T}\right)$$



$$A_F = 5.2 - 0.0286\,X$$

$$A_T = 12.546 - 0.0180\,X$$

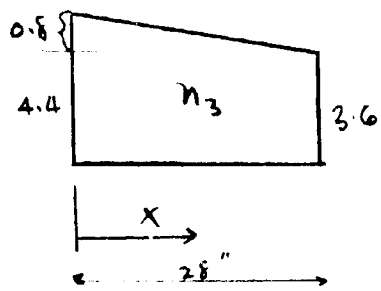
$$\bar{\gamma}_{2\,(X=14)} = -0.69 \frac{[12.546-0.0180X][-0.0286] - [5.2-0.0286X][-0.0180]}{[12.546-0.0180X]^2}$$

$$= -0.69 \frac{[-0.359 + \cancel{0.000514X} + 0.0936 - \cancel{0.000514X}]}{[150]} \qquad X = 14$$

$$= 0.00122$$

AT ELEMENT $n = 3$ SHEAR STRAIN

$$\bar{\gamma}_3 = -0.69 \frac{d}{dX}\left(\frac{A_F}{A_T}\right)$$



$$A_F = 4.4 - 0.0286\,X$$

$$A_T = 12.038 - 0.018\,X$$

$$\bar{\gamma}_{3\,(X=14)} = -0.69 \frac{[12.04-0.0180X](-0.0286) - [4.4-0.0286X](-0.0180)}{[12.04-0.0180X]^2}$$

$$= -0.69 \frac{(-0.345 + 0.0792)}{138} = 0.00128$$

INVESTIGATION OF INTERFRAME BUCKLING STRESSES

a) APPLY CONSERVATIVE EULER COLUMN FORMULA

FOR $L = 69''$

$$P_{CR} = \frac{\pi^2 E I}{L^2}$$

$$= \frac{9.85 \times 10^7 \times 1.538}{4750} = 0.0320 \times 10^6$$

$$= 32030 \text{ LB}$$ SHY

b) USING MODIFIED N_c FORMULA FROM D5-13272

$$N_{CR} = \frac{K_c \pi^2 E t_1^{*3}}{12(1-\nu^2) L_R^2}$$

$I_s = \frac{1.538}{7.43} = 0.207$ $''^4/''$

$$t_1^* = \sqrt[4]{12 I_s t_s}$$

$t_1^{*3} = 0.411$

$$= \sqrt[4]{12 \times 0.207 \times 0.125} = 0.745$$

$$Z_L = \frac{L_R^2}{R t_1^*} (1-\nu^2)^{1/2} = \frac{4750}{340 \times 0.745} \times 0.945 = 17.7$$

FROM TN3783 $K_c \approx 6$

$$N_{CR} = \frac{6 \times 9.85 \times 10^7 \times 0.411}{10.7 \times 4750} = 0.0056 \times 10^6$$

$$= 4{,}775 \text{ LB}/''$$ SHY

NEED RING @ 47'' ±

$$N_{CR} = \frac{5 \times 9.85 \times 10^7 \times 0.411}{10.7 \times 2210} = 8570 \text{ LB}/''$$

$$M.S = \frac{8570}{6930} - 1 = +\underline{0.23}$$ →

(C) INVESTIGATION OF GENERAL INSTABILITY OF THRUST SKIRT SECTION ▷ D5-13272

$$t^* = \sqrt[4]{12\, I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

ASSUME $A_R = 5.0$ □"

$A_R/L_R = \frac{5.0}{47} = 0.1063$

$I_s = 0.207$

$t_s = 0.125$

$$t^* = \sqrt[4]{12 \times 0.207\,(0.1063 + 0.125)} = \sqrt[4]{0.703} = 0.870$$

$$R/t^* = 340/0.870 = 392$$

$C^* = 1.15$ APPROXIMATION FROM D5-13272

$$\sigma_{CR} = C^* E \frac{t^*}{R}$$

$$= \frac{1.15 \times 10.4 \times 10^6}{392} = 30{,}600 \text{ PSI}$$ SH

INCREASE RING SIZE TO 8 □"

$A_R/L_R = \frac{8.0}{47} = 0.1700$

$t_s = 0.1250$

0.2950

$$t^* = \sqrt[4]{12 \times 0.207 \times 0.2950} = 0.924$$

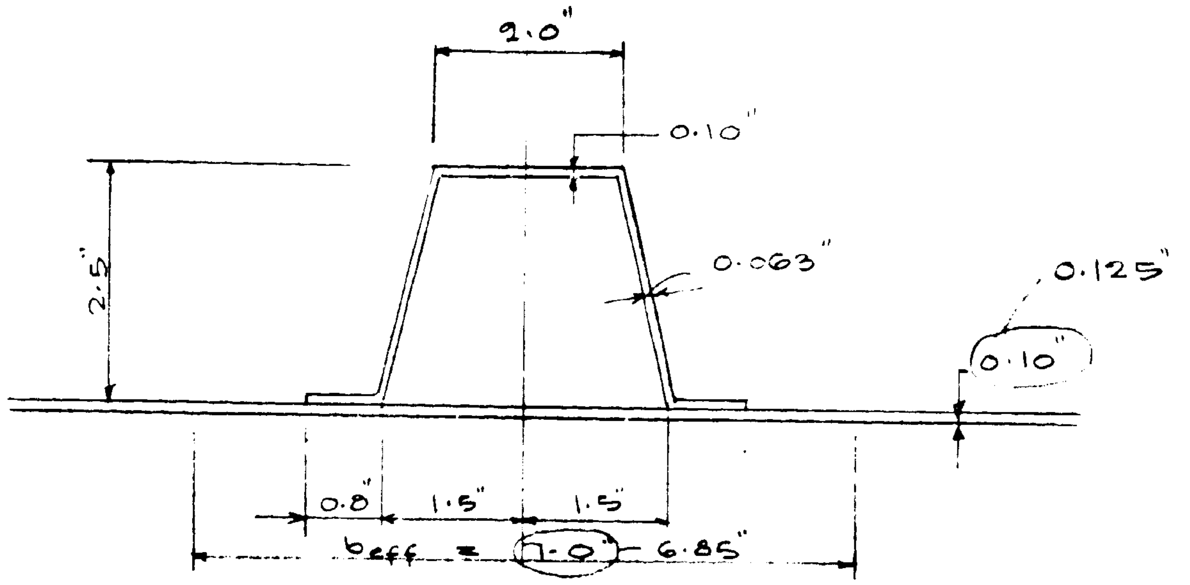
$$R/t^* = 340/0.924 = 368$$

$$\sigma_{CR} = \frac{1.15 \times 10.4 \times 10^6}{368} = 32{,}500 \text{ PSI}$$

ACTUAL $\sigma_c = 7000/0.227 = 30{,}700$ PSI

$$M.S. = \frac{32{,}500}{30{,}700} - 1 = \underline{+0.06}$$

STIFFENER CONFIGURATION (AT LOWER END OF THRUST SKIRT)



$\pi D = 3.14 \times 628.8 = 1970$ IN

$\pi D = 3.14 \times 680.0 = 2140$

SPACING OF STIFFENERS = 7.0"

A

$A_1 = 2.0 \times 0.10 = 0.200$

$A_2 = 6.85 \times \overset{0.125}{0.10} = 0.685$ — 0.855

$A_3 = 2 \times 2.45 \times 0.063 = 0.309$

$A_4 = 1.4 \times 0.063 = 0.088$

1.282 in^2 — 1.452 BY INCREASING SKIN to 0.125" AT BOTT

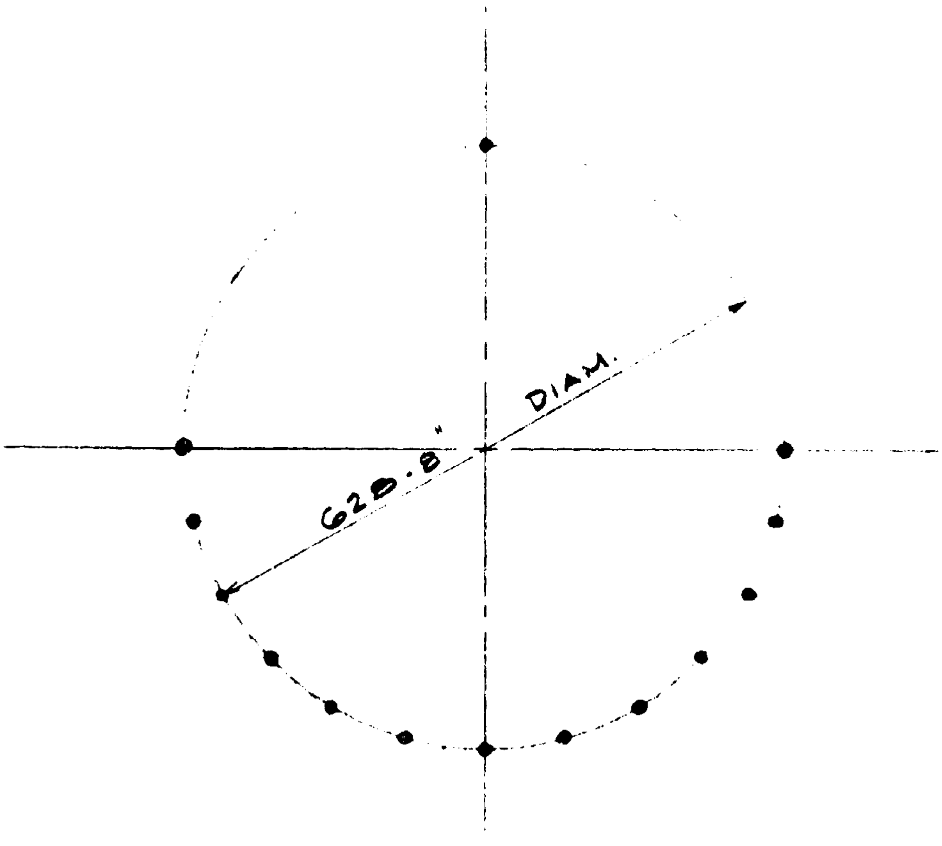
CHECK EFFECTIVE PANEL WIDTH

FOR HAT STIFFENER $\dfrac{b_{eff}}{2} = 1.7 \times t_s \sqrt{\dfrac{E}{f_c}}$

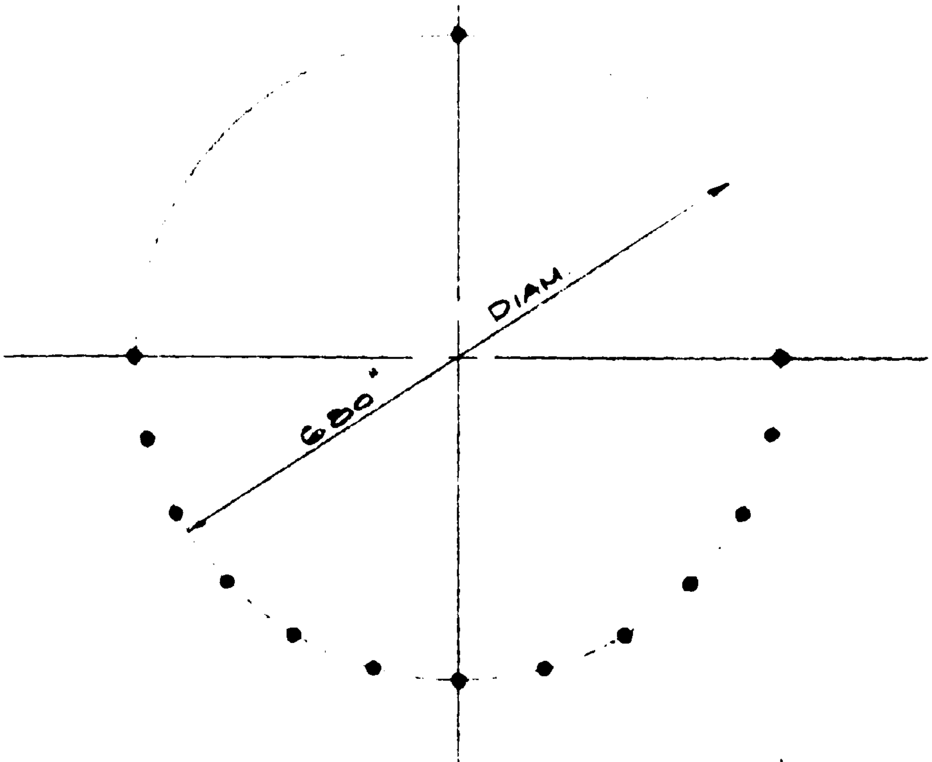
$= 1.7 \times 0.125 \sqrt{\dfrac{10.4 \times 10^6}{33 \times 10^3}} = 1.7 \times 0.125 \times 17.6 = 3.8"$

$b_{eff} = 2 \times 3.8 = 7.6"$

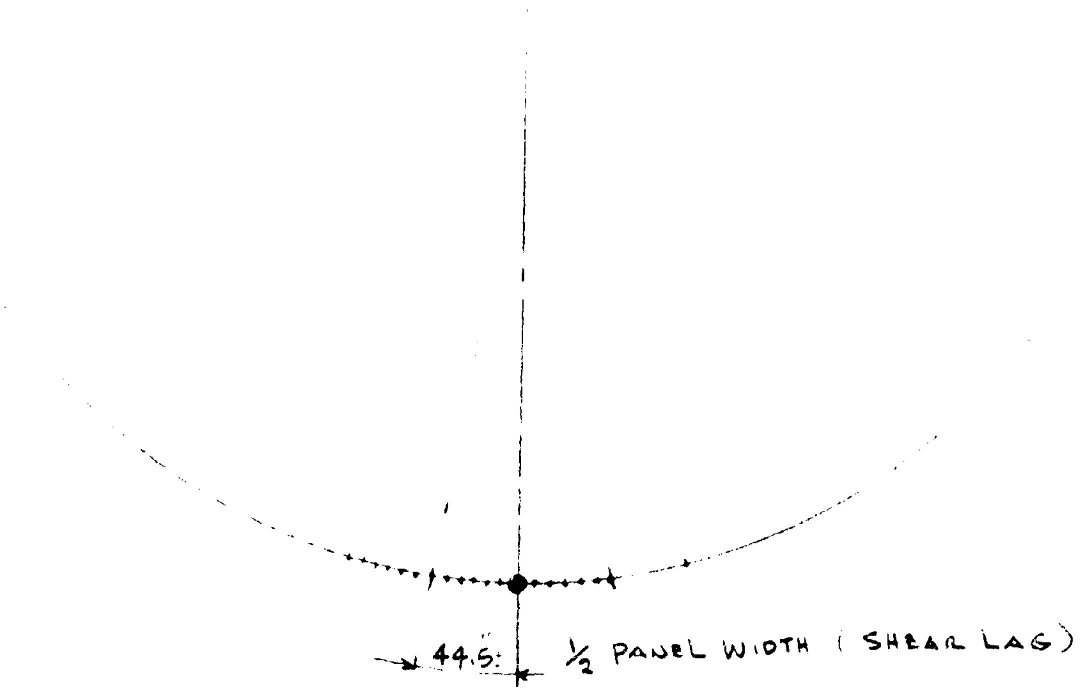
$b_{eff} = 7.43$ ok



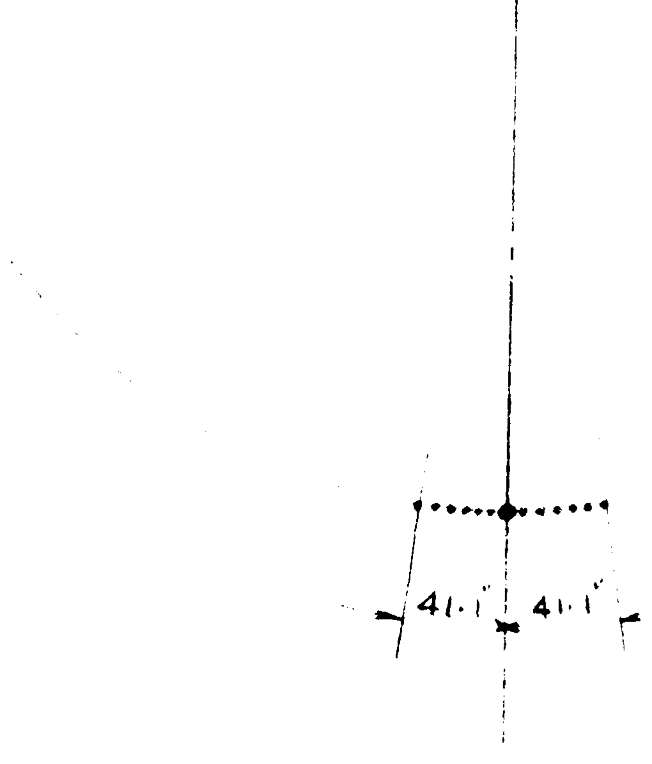
LOWER SKIRT THRUST POST LOCATION
@ 82.25" ℄



UPPER SKIRT THRUST POST LOCATION @ 89" o/c



UPPER END OF THRUST SKIRT STIFFENER LAYOUT



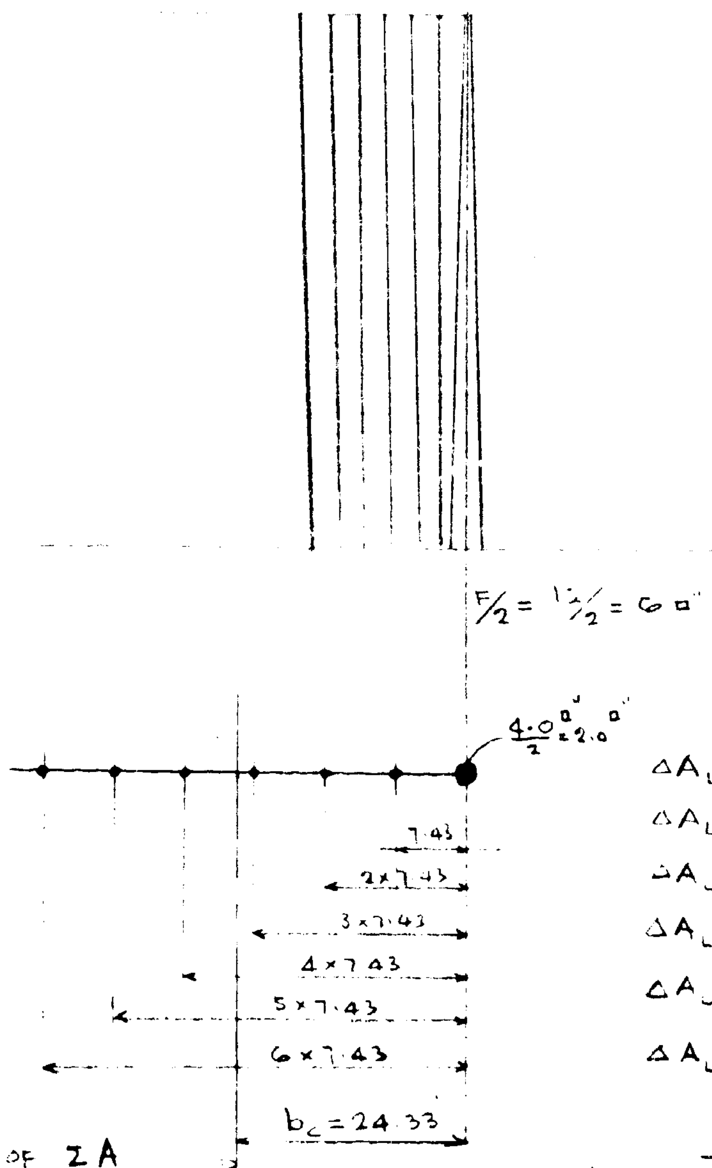
LOWER END OF THRUST SKIRT STIFFENERS LAYOUT

SHEAR LAG ANALYSIS

CENTROID CALCULATION OF STIFFENER GROUP (STRINGER

SINCE THE THRUST POST IS SYMMETICALLY LOCATED

TREAT HAFT PANEL WOULD BE ADEQUATE.



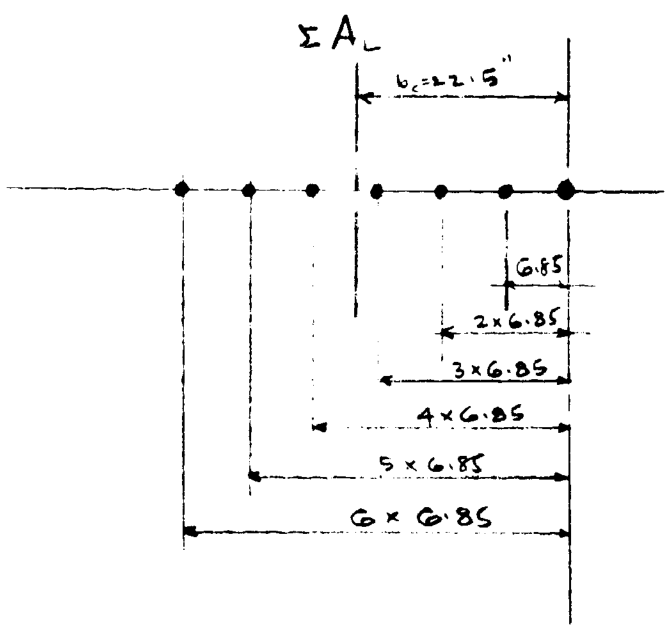
C.g OF ΣA_L

	A_L	$A_L \times X$
ΔA_{L_1} =	1.689 × 7.43 ×	= [illegible]
ΔA_{L_2} =	1.688 × 7.43 × 2	= [illegible]
ΔA_{L_3} =	1.688 × 7.43 × 3	= [illegible]
ΔA_{L_4} =	1.688 × 7.43 × 4	= [illegible]
ΔA_{L_5} =	1.688 × 7.43 × 5	= [illegible]
ΔA_{L_6} =	0.844 × 7.43 × 6	= [illegible]
	8.514	[illegible]

$$b_c = \bar{X}_u = \frac{225.59}{9.2740} = 24.33$$

C.G OF UPPER SKIRT STRINGER SECTION

C. G. OF LOWER SKIRT STRINGER SECTION



	A_L		$A_L \times x$
ΔA_{L_1}	$= 1.282 \times 6.85 \times 1$	=	8.78
ΔA_{L_2}	$= 1.282 \times 6.85 \times 2$	=	17.60
ΔA_{L_3}	$= 1.282 \times 6.85 \times 3$	=	26.35
ΔA_{L_4}	$= 1.282 \times 6.85 \times 4$	=	35.10
ΔA_{L_5}	$= 1.282 \times 6.85 \times 5$	=	43.90
ΔA_{L_6}	$= 0.641 \times 6.85 \times 6$	=	26.35
	7.051		158.08

$$b_c' = \bar{x}_L = \frac{158.08}{7.051} = 22.5''$$

AVERAGE $$\bar{b}_c = \frac{b_c + b_c'}{2} = \frac{24.33 + 22.5}{2} = 23.42$$

APPLICATION OF THE EQUATION OF SUBSTITED PANEL WIDTH BY ▷ P. KUHN (STRESSES IN AIRCRAFT STRUCTURES)

▷
$$b_s = \left(0.65 + \frac{0.35}{n^2}\right)\bar{b}_c$$

$$= \left(0.65 + \frac{0.35}{5.5^2}\right) \times 23.42$$

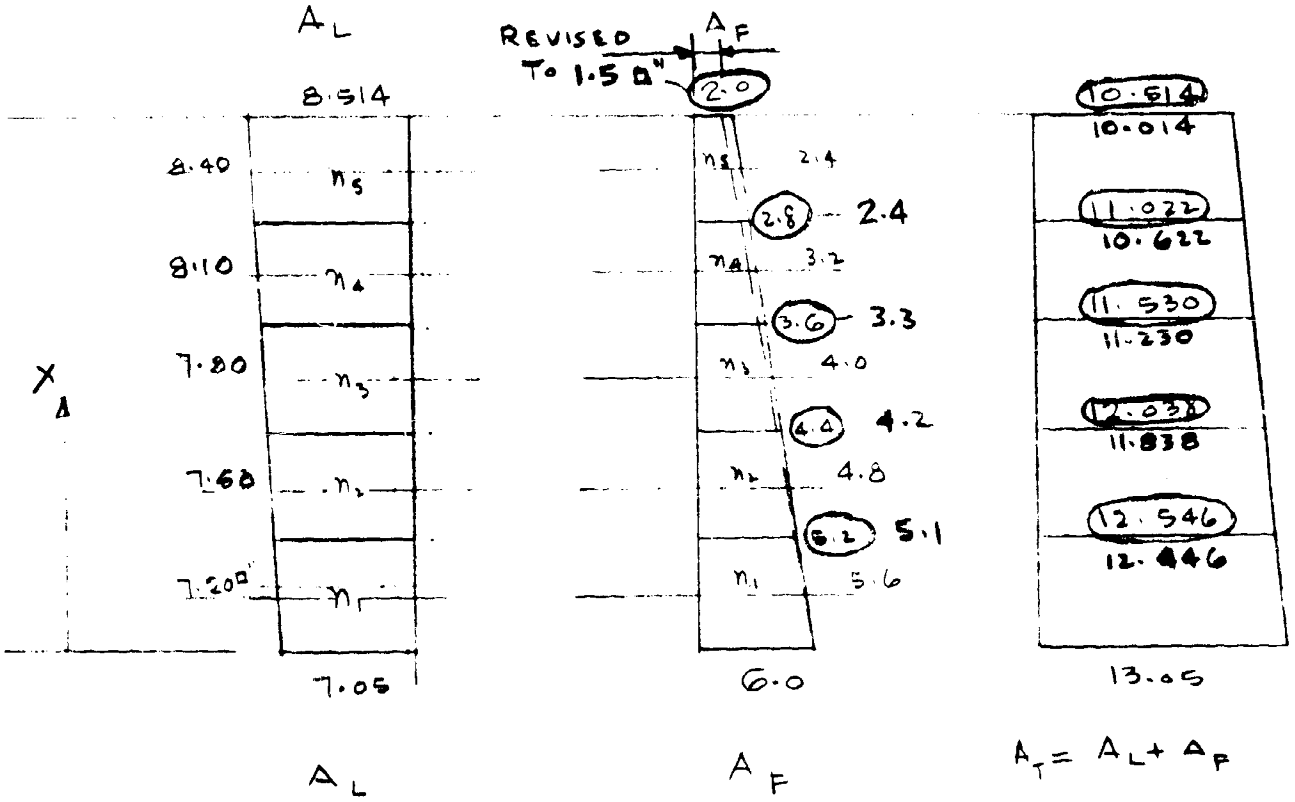
$$= 0.667 \times 23.42 = 15.65''$$

COMPUTATION OF SHEAR LAG PARAMETER

$$K = \sqrt{\frac{Gt}{Eb_s}\left(\frac{1}{A_F} + \frac{1}{A_L}\right)}$$

$b_s = 15.65$

Assum $t_{AV} = 0.1125$



$$K_1 = \sqrt{\frac{3.9\times10^6 \times 0.1125}{10.4\times10^6\times15.65}\left(\frac{1}{5.6} + \frac{1}{7.20}\right)} = 2.925\times10^{-2}$$

0.00269

$$K_2 = \sqrt{0.269\times10^{-2}\left(\frac{1}{4.8} + \frac{1}{7.50}\right)} = 3.03\times10^{-2}$$

$$K_3 = \sqrt{0.269\times10^{-2}\left(\frac{1}{4.0} + \frac{1}{7.80}\right)} = 3.23\times10^{-2}$$

$$K_4 = \sqrt{0.269\times10^{-2}\left(\frac{1}{3.2} + \frac{1}{8.10}\right)} = 3.43\times10^{-2}$$

$$K_5 = \sqrt{0.269\times10^{-2}\left(\frac{1}{2.4} + \frac{1}{8.4}\right)} = 3.80\times10^{-2}$$

COMPUTATION OF UNIT SHEAR DEFORMATIONS
ϕ & γ FOR UNIT FORCE

$$\phi_n = \frac{k_n}{G t_n \tanh k_n a_n}$$

HERE $a_n = 28''$ BAY LENGTH

$$\gamma_n = \frac{k_n}{G t_n \sinh k_n a_n}$$

$\bar{t}_n = 0.1125$

$$\phi_1 = \frac{2.925 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \tanh \underset{0.675}{0.8185}} = 9.88 \times 10^{-8}$$

$$\gamma_1 = \frac{2.925 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \sinh \underset{0.915}{0.8185}} = 7.28 \times 10^{-8}$$

$$\phi_2 = \frac{3.03 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \tanh \underset{0.690}{0.8480}} = 10.03 \times 10^{-8}$$

$$\gamma_2 = \frac{3.03 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \sinh \underset{0.956}{0.848}} = 7.22 \times 10^{-8}$$

$$\phi_3 = \frac{3.23 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \tanh \underset{0.721}{0.905}} = 10.21 \times 10^{-8}$$

$$\gamma_3 = \frac{3.23 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \sinh \underset{1.040}{0.905}} = 7.075 \times 10^{-8}$$

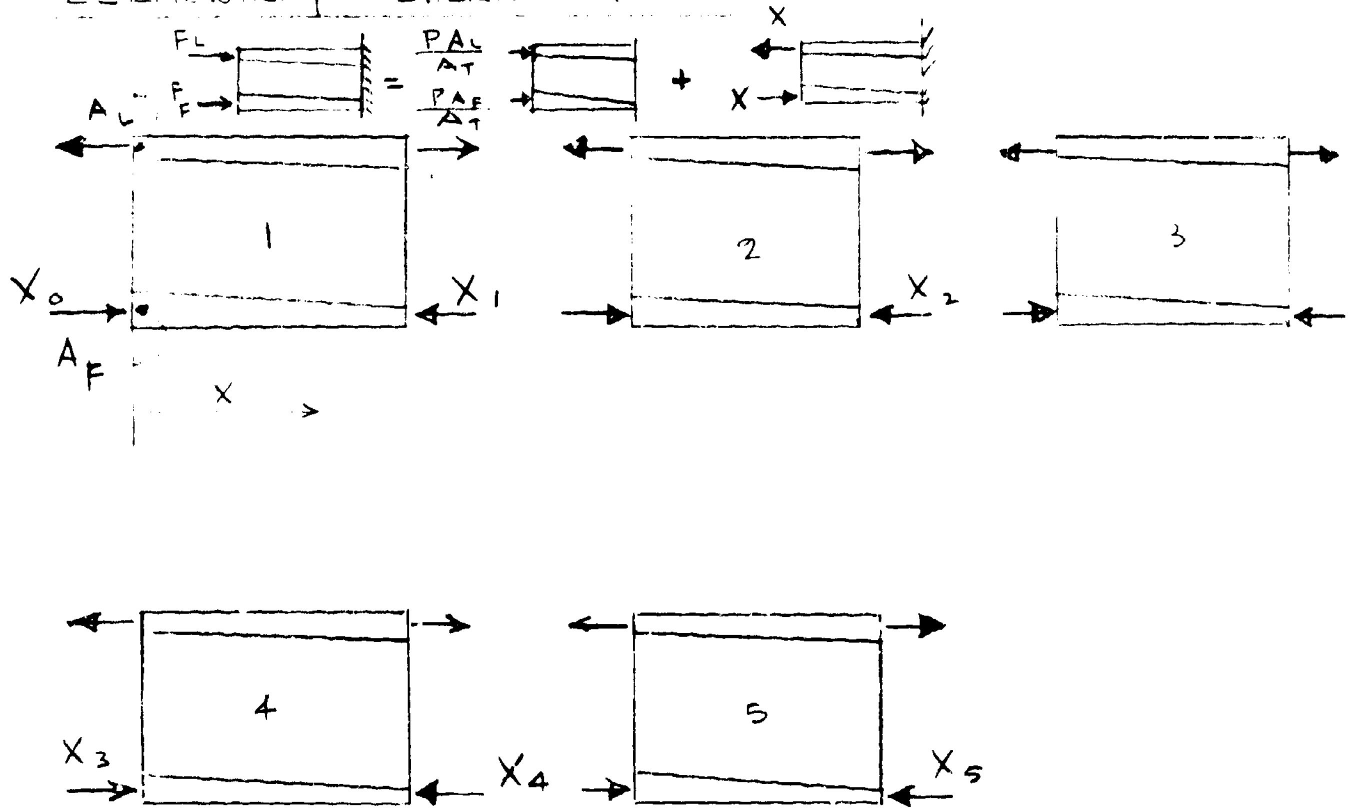
$$\phi_4 = \frac{3.43 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \tanh \underset{0.744}{0.96}} = 10.52 \times 10^{-8}$$

$$\gamma_4 = \frac{3.43 \times 10^{-2}}{3.9 \times 10^{6} \times 0.1125 \times \sinh \underset{1.1144}{0.96}} = 6.85 \times 10^{-8}$$

$$\phi_5 = \frac{3.80}{3.9 \times 10^{6} \times 0.1125 \times \tanh \underset{0.788}{1.065}} = 11.0 \times 10^{-8}$$

$$\gamma_5 = \frac{3.8}{3.9 \times 10^{6} \times 0.1125 \times \sinh \underset{1.286}{1.065}} = 6.74 \times 10^{-8}$$

ELEMENTARY SHEAR STRAIN



SINCE SHEAR FLOW

$$\bar{q} = \frac{dF_L}{dx} = P\frac{d}{dx}\left(\frac{A_L}{A_T}\right) = -P\frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

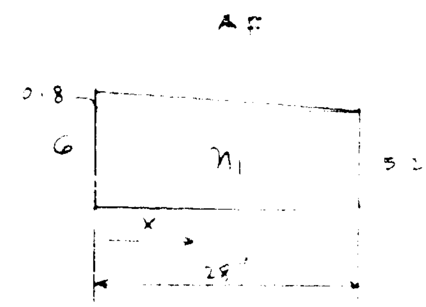
& SHEAR STRAIN

$$\bar{\gamma}_n = \frac{\bar{q}}{G t_n} = \frac{P}{G t_n}\frac{d}{dx}\left(\frac{A_L}{A_T}\right)$$

$$= -\frac{P}{G t_n}\frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$P = \frac{0.604\times10^6}{2} = 0.302\times10^6$$ LBS. HALF FLANGE POST

AT ELEMENT $n = 1$ SHEAR STRAIN

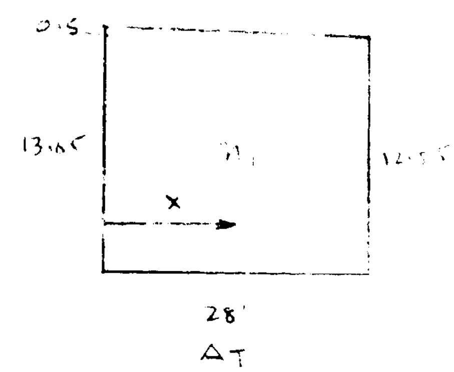


$$\bar{\gamma}_1 = -\frac{P}{G t_n} \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$= -\frac{0.302 \times 10^6}{3.9 \times 10^6 \times 0.1125} \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$A_F = 6.0 - 0.0286\,x$$

$$A_T = 13.05 - 0.0179\,x \approx 13.05$$



$$\bar{\gamma}_1 = \frac{-0.69}{13.05} \frac{d}{dx}(6.0 - 0.0286\,x)$$

$$= \frac{+0.69 \times 0.0286}{13.05} = 0.00151$$

IF $A_T \neq 13.05$

$$\bar{\gamma}_1 = -0.69 \; \frac{(13.05 - 0.0179x)(-0.0286) - (6.0 - 0.0286x)(-0.0179)}{(13.05 - 0.0179x)^2}$$

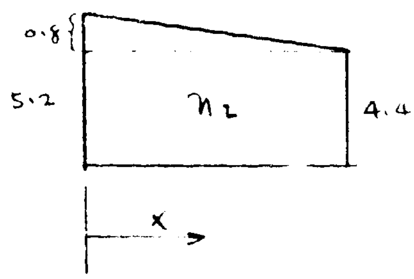
$$= -0.69 \; \frac{(-0.373 + 0.000512x) - [-0.1072 + 0.000512x]}{(13.05 - 0.0179x)^2}$$

$$\bar{\gamma}_{1\,x=14} = \frac{+0.69 \times 0.2655}{(13.05 - 0.25)^2} = \underline{0.00112}$$

SHEAR STRAIN IS MORE ACCURA[TE]

AT ELEMENT $n=2$ SHEAR STRAIN

$$\bar{\gamma}_2 = -0.69 \frac{d}{dX}\left(\frac{A_F}{A_T}\right)$$



$A_F = 5.2 - 0.0286\,X$

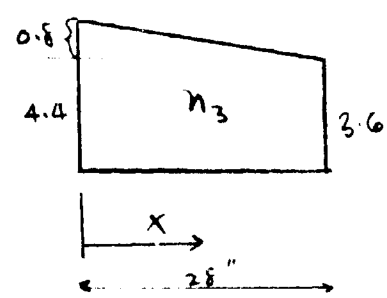
$A_T = 12.546 - 0.0180\,X$

$$\bar{\gamma}_{2\,(X=14)} = -0.69 \frac{[12.546-0.0180X][-0.0286] - [5.2-0.0286X][-0.0180]}{[12.546-0.0180X]^2}$$

$$= -0.69 \frac{[-0.359 + \cancel{0.000514X} + 0.0936 - \cancel{0.000514X}]}{[150]} \qquad X=14$$

$$= 0.00122$$

AT ELEMENT $n=3$ SHEAR STRAIN



$$\bar{\gamma}_3 = -0.69 \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$A_F = 4.4 - 0.0286\,X$

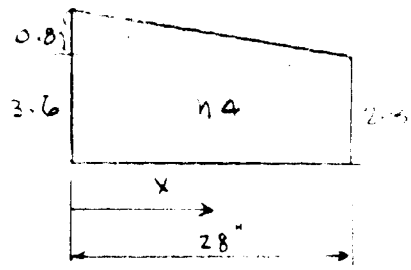
$A_T = 12.038 - 0.018\,X$

$$\bar{\gamma}_{3\,(X=14)} = -0.69 \frac{[12.04-0.0180X](-0.0286) - [4.4-0.0286X](-0.0180)}{[12.04-0.0180X]^2}$$

$$= -0.69 \frac{(-0.345 + 0.0792)}{138} = 0.00128$$

AT ELEMENT $n = 4$ SHEAR STRAIN

$$\bar{\Gamma}_4 = -0.69 \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$



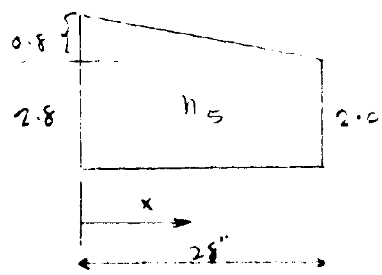
$A_F = 3.6 - 0.0286x$

$A_T = 11.530 - 0.018x$

$$\bar{\Gamma}_4 = -0.69 \frac{[11.53 - 0.018x](-0.0286) - [3.6 - 0.0286x](-0.018)}{[11.530 - 0.018x]^2}$$

$$= -0.69 \frac{(-0.330 + 0.065)}{127} = 0.00144$$

AT ELEMENT $n = 5$ SHEAR STRAIN



$$\bar{\Gamma}_5 = -0.69 \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$A_F = 2.8 - 0.0286x$

$A_T = 11.022 - 0.018x$

$$\bar{\Gamma}_5 = -0.69 \frac{[11.022 - 0.018x](-0.0286) - [2.8 - 0.0286x](-0.018)}{[11.022 - 0.018x]^2}$$

$$= -0.69 \frac{(-0.315 + 0.0504)}{116} = 0.001575$$

APPLICATION OF THE RECURRENCE EQUATION FOR THE RELATIONS OF THE FLANGE FORCE WITH RESPECT TO SHEAR FLOWS & SHEAR STRAINS

$$q_n X_{n-1} - (p_n + p_{n+1}) X_n + q_{n+1} X_{n+1} = -\bar{r}_n + \bar{r}_{n+1}$$

FOR $n=1$

$$q_1 X_0 - (p_1 + p_2) X_1 + q_2 X_2 = -\bar{r}_1 + \bar{r}_2$$

$$X_0 = P \frac{A_L}{A_T} = 0.302 \times 10^6 \times \frac{7.05}{13.05} = 0.163 \times 10^6$$

$$7.28 \times 10^{-8} \times 0.163 \times 10^6 - (9.88 + 10.03) \times 10^{-8} X_1 + 7.22 \times 10^{-8} X_2 = -0.00112 + 0.00122$$

$$1.188 \times 10^{-2} - 19.91 \times 10^{-8} X_1 + 7.22 \times 10^{-8} X_2 = 0.0001$$

$$-19.91 \times 10^{-8} X_1 + 7.22 \times 10^{-8} X_2 = -0.01178$$

$$-19.91 X_1 + 7.22 X_2 = -0.01178 \times 10^8 = -1.178 \times 10^6$$

ie $$-19.91 X_1 + 7.22 X_2 = -1178 \times 10^3 \qquad (1)$$

FOR $n=2$

$$q_2 X_1 - (p_2 + p_3) X_2 + q_3 X_3 = -\bar{r}_2 + \bar{r}_3$$

$$7.22 \times 10^{-8} X_1 - 20.24 \times 10^{-8} X_2 + 7.075 \times 10^{-8} X_3 = +6.0 \times 10^{-5}$$

$$7.22 X_1 - 20.24 X_2 + 7.075 X_3 = +6.0 \times 10^3 \qquad (2)$$

FOR $n=3$

$$q_3 X_2 - (p_3 + p_4) X_3 + q_4 X_4 = -\bar{r}_3 + \bar{r}_4$$

$$7.075 \times 10^{-8} X_2 - 20.73 \times 10^{-8} X_3 + 6.85 \times 10^{-8} X_4 = 1.6 \times 10^{-4}$$

$$7.075 X_2 - 20.73 X_3 + 6.85 X_4 = 16 \times 10^3 \qquad (3)$$

FOR $n = 4$

$$q_4 X_3 - (p_4 + p_5) X_4 + q_5 X_5 = -\bar{r}_4 + \bar{r}_5$$

$$6.85 \times 10^{-8} X_3 - 21.52 \times 10^{-8} X_4 + 6.74 \times 10^{-8} X_5 = 1.35 \times 10^{-4}$$

$$6.85 X_3 - 21.52 X_4 + \cancel{6.74 X_5}^{\,0} = 13.5 \times 10^3$$

$$6.85 X_3 - 21.52 X_4 = 13.5 \times 10^3 \qquad (4)$$

SOLVE THE FOLLOWING 4 SIMULTANEOUS EQUATIONS

$$-19.91 X_1 + 7.22 X_2 + 0 + 0 = -1178 \times 10^3 \qquad (1)$$

$$7.220 X_1 - 20.24 X_2 + 7.075 X_3 + 0 = 6.0 \times 10^3 \qquad (2)$$

$$7.075 X_2 - 20.73 X_3 + 6.85 X_4 = 16 \times 10^3 \qquad (3)$$

$$6.86 X_3 - 21.52 X_4 = 13.5 \times 10^3 \qquad (4)$$

SOLVE (4) FOR X_4

$$X_4 = \frac{6.85 X_3 - 13.5 \times 10^3}{21.52} \qquad (5)$$

SUBSTITUTE (5) INTO (3)

$$7.075 X_2 - 20.73 X_3 + \frac{6.85 X_3 - 13.5 \times 10^3}{3.14} = 16 \times 10^3$$

$$7.075 X_2 - 20.73 X_3 + 2.18 X_3 - 4.31 \times 10^3 = 16 \times 10^3$$

$$7.075 X_2 - 18.55 X_3 = 20.31 \times 10^3 \qquad (6)$$

SOLVE (1) FOR X_1

$$X_1 = \frac{7.22 X_2 + 1178 \times 10^3}{19.91} \qquad (7)$$

SUBSTITUTE (7) INTO (2)

$$7.22\left[\frac{7.22X_2 + 1178\times10^3}{19.91}\right] - 20.24\,X_2 + 7.075X_3 = 6.0\times10^3$$

$$(2.62X_2 + 427\times10^3) - 20.24\,X_2 + 7.075\,X_3 = 6.0\times10^3$$

$$2.62X_2 + 427\times10^3 - 20.24X_2 + 7.075\,X_3 = 6.0\times10^3$$

$$-17.62\,X_2 + 7.075\,X_3 = -421\times10^3 \quad\text{—— (8)}$$

$$7.075\,X_2 - 18.55\,X_3 = 20.31\times10^3 \quad\text{—— (6)}$$

$2.49\times(6)$

$$17.62\,X_2 - 46.10\,X_3 = 50.50\times10^3 \quad\text{—— (9)}$$

(8) + (9)

$$-39.025\,X_3 = -370.5\times10^3$$

$$X_3 = \frac{370.5}{39.025}\times10^3$$

$$= 9.49\times10^3 = \underline{9490}^{\#} \quad (10)$$

SUBST. (10) INTO (8)

$$-17.62\,X_2 + 7.075\times9490 = -421\times10^3$$

$$X_2 = \frac{488,100}{17.62} = \underline{27,700}\ \text{LB} \quad (11)$$

SUBSTITUTE (11) INTO (7)

$$X_1 = \frac{7.22\times27,700 + 1178000}{19.91} = \frac{1,378,000}{19.91}$$

$$= 69,250\ \text{LB}$$

SUBSTITUTE X_3 INTO (5)

$$X_4 = \frac{6.83\times9490 - 13500}{21.52} = \frac{64900 - 13500}{21.52} = \underline{\underline{2390}}^{\#}$$

THE COMPLETE SOLUTIONS FOR FLANGE FORCES ARE

$$X_0 = 0.163 \times 10^6 \text{ LB}$$

$$X_1 = 69,250 \text{ LB}$$

$$X_2 = 27,700 \text{ LB}$$

$$X_3 = 9,490 \text{ LB}$$

$$X_4 = 2,390 \text{ LB}$$

$$X_5 = 0$$

CHECK SOLUTIONS IN EQUATION (2)

$$7.22 \times 69,250 - 20.24 \times 27,700 + 7.075 \times 9490 = 6000$$

$$500000 - 561000 + 67000 - 6000 \approx 0 \quad \text{OK}$$

CHECK (3)

$$7.075 \times 27,700 - 20.73 \times 9490 + 6.85 \times 2,390 = 16 \times 10^3$$

$$196,000 - 197000 + 16350 - 16000$$

$$212400 - 21300 \approx 0 \qquad \text{OK}$$

COMPUTATION OF COMPRESSIVE STRESSES IN FLANGE :

$$\sigma_{F_n} = \frac{P}{A_{T_n}} + \frac{X_n}{A_{F_n}}$$

$x = 0$ $\quad \sigma_{F_0} = \frac{302,000}{13.05} + \frac{163000}{6.0} = 23100 + 27200$

$= 50300$ PSI

$x = 28''$ $\quad \sigma_{F_{28}} = \frac{\overset{24050}{302,000}}{12.546} + \frac{\overset{13350}{69,250}}{5.2} = 37,400$ PSI

$x = 56''$ $\quad \sigma_{F_{56}} = \frac{\overset{25100}{302,000}}{12.038} + \frac{\overset{6300}{27,700}}{4.4} = 31,400$ PSI

$x = 84$ $\quad \sigma_{F_{84}} = \frac{\overset{26200}{302,000}}{11.530} + \frac{\overset{2640}{9490}}{3.6} = 28,840$ PSI

$x = 112$ $\quad \sigma_{F_{112}} = \frac{\overset{27400}{302,000}}{11.022} + \frac{\overset{855}{2390}}{2.8} = 28,255$ PSI

$x = 140$ $\quad \sigma_{F_{140}} = \frac{302,000}{10.514} + 0 = 28,700$ PSI

FROM STRESS LEVEL IN THE FLANGE AS CALCULATED ABOVE, IT IS OBVIOUS THAT THE FLANGE AREA AT TOP OF POST MAY BE REDUCED TO 3 □" INSTEAD OF 4 □" AS ORIGINALLY ASSUMED.

THIS WILL MAKE NEARLY UNIFORM STRESS DISTR. AT FLANGE AND STRINGERS

REVISED COMPUTATION OF COMPRESSIVE STRESSES IN FLANGE (AFTER REDUCING TOP FLANGE AREA TO 3 □" INSTEAD OF 4 □")

ASSUME FLANGE FORCE WILL NOT CHANGE SIGNIFICANTLY

$$\sigma_{F_n} = \frac{P}{A_{T_n}} + \frac{X_n}{A_{F_n}}$$

$X_0 = 0$ $\quad \sigma_{F_0} = \dfrac{302{,}000}{13.05} + \dfrac{163000}{6.0} = 50{,}300$ PSI

$X = 28''$ $\quad \sigma_{F_{28}} = \dfrac{\overset{24.300}{302{,}000}}{12.446} + \dfrac{\overset{13.600}{69{,}250}}{5.1} = 37{,}900$ PSI

$X = 56''$ $\quad \sigma_{F_{56}} = \dfrac{\overset{25{,}500}{302{,}000}}{11.838} + \dfrac{\overset{6600}{27{,}700}}{4.2} = 32{,}100$ PSI

$X = 84''$ $\quad \sigma_{F_{84}} = \dfrac{\overset{26.900}{302{,}000}}{11.230} + \dfrac{\overset{2880}{9490}}{3.3} = 29{,}780$ PSI

$X = 112$ $\quad \sigma_{F_{112}} = \dfrac{\overset{28400}{302{,}000}}{10.622} + \dfrac{\overset{9960}{2{,}390}}{2.4} = 29{,}360$ PSI

$X = 140$ $\quad \sigma_{F_{140}} = \dfrac{302{,}000}{10.014} + 0 = 30{,}200$ PSI

COMPUTATION OF CHORDWISE DISTRIBUTION OF COMPRESSIVE STRESSES

ASSUME THE DISTRIBUTION TO FOLLOW A CUBIC CURVE THE SHEAR LAG CORRECTION TO THE FLANGE STRESS AT A GIVEN STATION IS

$$\Delta \sigma_F = \frac{X}{A_F}$$

THE ORDINATE OF THE CURVE AT A GIVEN DISTANCE y FROM THE CENTER LINE IS

$$\Delta \sigma = \Delta \sigma_F - D\left[1 - \left(\frac{2y}{b}\right)^3\right]$$

WHERE $D = \frac{4}{3} X \left(\frac{1}{A_F} + \frac{1}{A_L}\right)$

$$\sigma = \frac{P}{A_T} + \Delta \sigma$$

STA.	X	A_F	A_L	$\frac{1}{A_F} + \frac{1}{A_L}$	D	$\Delta \sigma_F$	$\frac{P}{A_T}$
0	163,000	6.0	7.050	0.3081	67000	27200	23,100
28	69,250	5.1	7.343	0.3320	30600	13,350	24,300
56	27,700	4.2	7.636	0.3690	13600	6,300	25,500
84	9,490	3.3	7.929	0.4290	5400	2,640	26,900
112	2,390	2.4	8.222	0.5385	1710	855	28,400
140	0	1.5	8.514	0.7835	0	0	30,200

COMPUTATION OF PARAMETERS FOR CHORDWISE DISTRIBUTION OF FLANGE STRESSES

AT $X = 28''$ AV. $b = 85.5$ $b/2 = 42.7$

y	$2y/b$	$(2y/b)^3$	$1-(2y/b)^3$	$D\left[1-\left(\frac{2y}{b}\right)^3\right]$	$\Delta\sigma$	σ
0	0	0	1	30,600	-17,250	7,050
10	0.234	0.0128	0.9872	30,200	-16,850	7,450
20	0.469	0.1027	0.8973	27,300	-13,950	10,350
30	0.702	0.344	0.6560	20,070	-6,720	1[illegible],580
42.75	1.0	1	0	0	+13,350	3[illegible],650

AT $X = 56''$

0		13,600	-7,250	18,250
10		13,420	-7,120	18,380
20		12,200	-5,900	19,600
30		8,910	-2,610	22,890
42.75		0	6,300	31,800

X = 84"

y		$1-(2y/b)^3$	$D[1-(2y/b)^3]$	ΔT	T
0			5400	-2,760	24,140
10			5330	-2,670	24,230
20			4840	-2,200	24,700
30			3540	-900	26,000
42.75			0	2,640	29,540

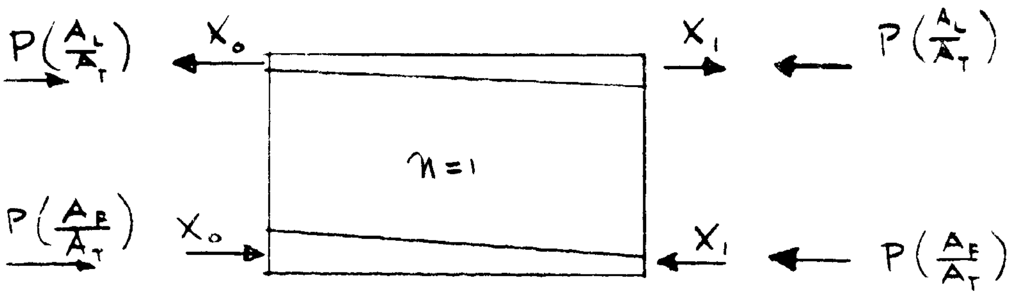
X = 112

0			1710	-855	27,545
10			1690	-835	27,565
20			1535	-680	27,720
30			1122	-267	28,133
42.75			0	855	29,255

x = 140

			0	0	30,200
			0	0	30,200
			0	0	30,200
			0	0	30,200
			0	0	30,200

COMPUTATIONS OF SHEAR STRAINS & SHEAR FLOW



FOR X=0 SHEAR STRAIN

$$\gamma_0 = p_1 X_0 - q_1 X_1 + \bar{\gamma}_1$$

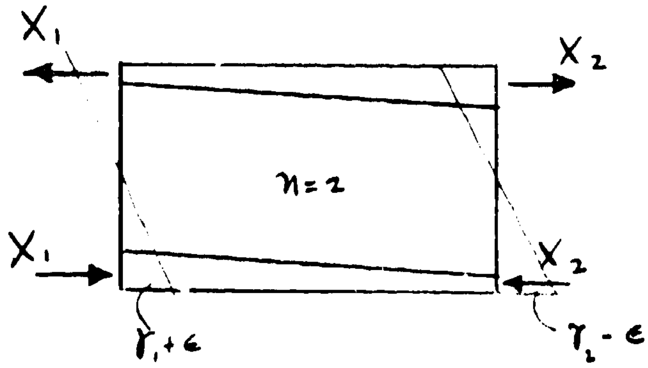
$$= 9.88\times10^{-8} \times 0.163\times10^{6} - 7.28\times10^{-8} \times 0.0693\times10^{6} + 0.0012$$

$$= 1.61\times10^{-2} - 0.505\times10^{-2} + 0.0012 = 0.01225$$

SHEAR FLOW

$$q_0 = G t_0 \gamma_0 = 3.9\times10^{6} \times 0.1125 \times 0.01225 = 5360\ \#/'' \ \text{ULT}$$

FOR X=28



$$\gamma_{1+\epsilon} = p_2(X_1) - q_2 X_2 + \bar{\gamma}_{2\ AVG}$$

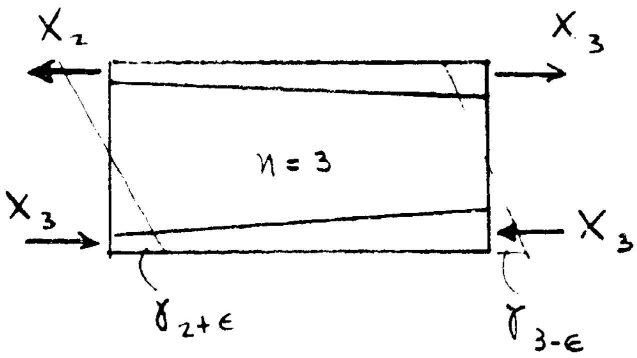
$$= 10.03\times10^{-8} \times 0.06925\times10^{6} - 7.22\times10^{-8} \times 0.0277\times10^{6} + 0.00122$$

$$= 0.00612$$

SHEAR FLOW

$$q_{1+\epsilon} = G t_1 \gamma_{1+\epsilon} = 3.9\times10^{6} \times 0.105 \times 0.00612 = 2510\ \#/''$$

FOR $X = 56$



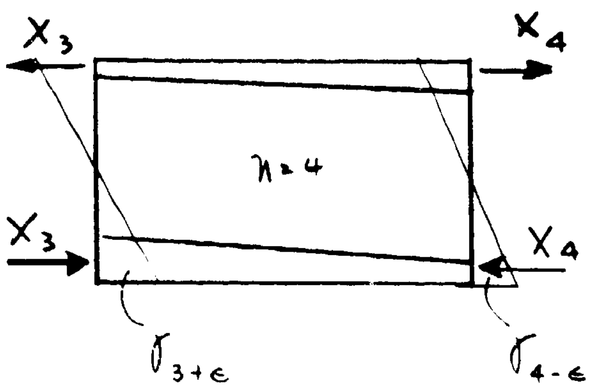
$$\gamma_{2+\epsilon} = p_3 X_2 - \xi_3 X_3 + \bar{\gamma}_{3_{AVG}}$$

$$= 10.21\times10^{-8}\times0.0277\times10^{6} - 7.075\times10^{-8}\times0.00949\times10^{6} + 0.00128$$

$$= 0.283\times10^{-2} - 0.067\times10^{-2} + 0.00128 = 0.00344$$

$$q_{2+\epsilon} = 3.9\times10^{6}\times0.110\times0.00344 = 1480 \ \text{\#/"}$$

FOR $X = 84$



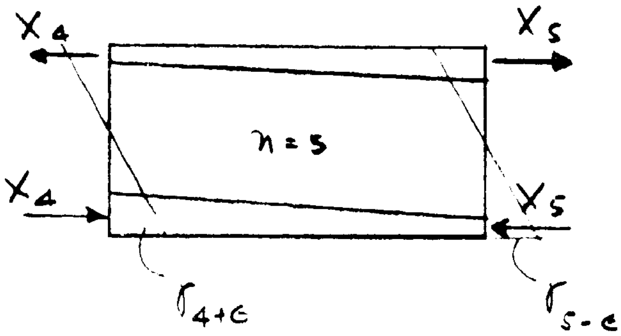
$$\gamma_{3+\epsilon} = p_4 X_3 - \xi_4 X_4 + \bar{\bar{\gamma}}_{4_{AVG}}$$

$$= 10.52\times0.00949\times10^{-2} - 6.85\times10^{-8}\times0.00239\times10^{6} + 0.00144$$

$$= 0.0999\times10^{-2} - 0.01635\times10^{-2} + 0.00144 = 0.002275$$

$$q_{3+\epsilon} = 3.9\times10^{6}\times\overset{t}{0.115}\times0.002275 = 1025 \ \text{\#/"}$$

FOR X = 112



$$\gamma_{4+6} = p_5 X_4 - q_5 X_5 + \bar{\gamma}_{5\ AVG}$$

$$\gamma_{5-6} = \overset{0}{\cancel{q_5 X_5}} - \overset{0}{\cancel{p_5 X_5}} + \bar{\gamma}_{5\ AVG}$$

$(X_5 = 0)$

$$\gamma_{4+6} = 11.0 \times 10^{-8} \times 0.00239 \times 10^{6} - 6.74 \times 10^{-8} \times 0 + 0.001575$$

$$= 0.0263 \times 10^{-2} + 0.001575 = 0.001838$$

$$q_{4+6} = 3.9 \times 10^{6} \times 0.120 \times 0.00184 = 860\ \#/''$$

$$\gamma_{5-6} = 0.001575$$

$$q_{5-6} = 3.9 \times 10^{6} \times 0.125 \times 0.001575 = 767\ \#/''$$

▷ P. KUHN STRESS IN AIRCRAFT STRUCTURE FIG 4.18 P.131

CHORD WISE DISTRIBUTION OF SHEAR FLOW ▷

$$K_0 = K_1 = 0.0293$$

$$X' = 0.5 / K_0 = \frac{0.5}{0.0293} = 17.05 \quad \text{SAY } 17''$$

$$K' = K @ X'$$

$$K' = 10^{-1} \sqrt{0.269 \left(\frac{1}{5.4} + \frac{1}{7.25} \right)} = 2.95 \times 10^{-2} = \underline{0.0295}$$

X	0 + ε	28	56	84	112	140
$K'x$	0	0.825	1.65	2.48	3.31	4.14
f @ 0.25	0.065	0.360	0.44	0.44	0.44	0.44
f @ 0.50	0.250	0.655	0.75	0.75	0.75	0.75
f @ 0.75	0.565	0.880	0.94	0.94	0.94	0.94

MULTIPLY THE CHORDWISE SHEAR FLOW DISTRIBUTION COEFFICIENT OBTAINED ABOVE FROM REF. "P. KUHN" BY SHEAR VALUE ALONG ℄ THRUST POST
THEN THE SHEAR DISTRIBUTION AT 25 %, 50 % 75 % & 100 % CAN BE PLOTTED IN FIG. 3

COMPUTATION OF CHORDWISE SHEAR FLOW CHART (FIG. 3)

AT X = 0 100 % OF CHORD LENGTH

100 % OF CHORD LG	$q = 5.36 \times 1.0$	=	5.36
75 %	$q = 5.36 \times 0.565$	=	3.03
50 %	$q = 5.36 \times 0.250$	=	1.34
25 %	$q = 5.36 \times 0.065$	=	0.35

AT X = 28" $q = 2.50$

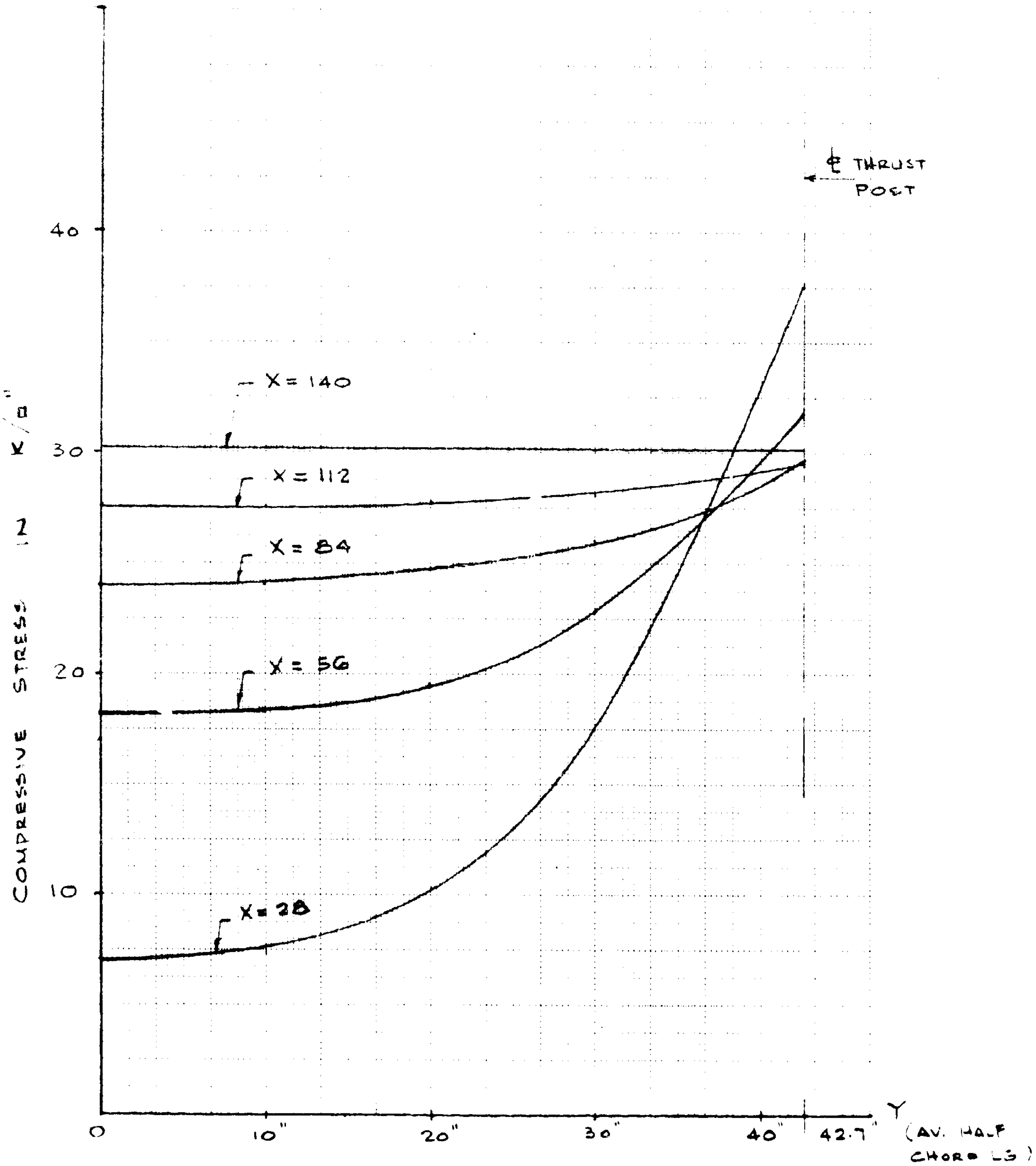
100 %	$q = 2.50 \times 1.0$	=	2.50
75 %	$q = 2.50 \times 0.88$	=	2.20
50 %	$q = 2.50 \times 0.655$	=	1.64
25 %	$q = 2.50 \times 0.36$	=	0.90

AT X = 56 $q = 1.50$ k/"

100 %	$q = 1.50 \times 1.0$	=	1.50
75 %	$q = 1.50 \times 0.94$	=	1.41
50 %	$q = 1.50 \times 0.75$	=	1.125
25 %	$q = 1.50 \times 0.44$	=	0.66
0 %	$q = 0$		

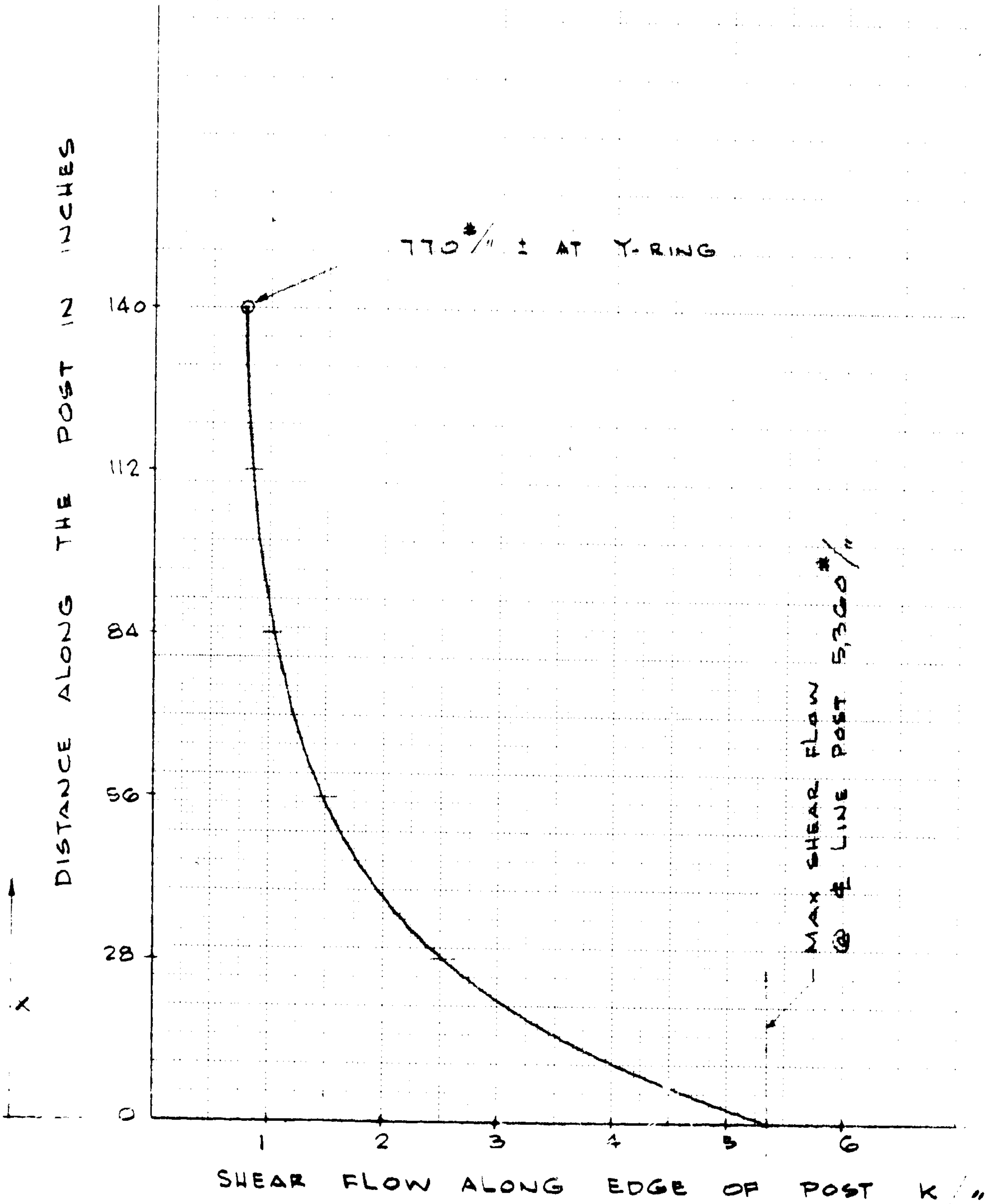
AT X = 84 $q = 1.03$ k/"

100 %	$q = 1.03 \times 1.0$	=	1.03 k/"
75 %	$q = 1.03 \times 0.94$	=	0.97
50 %	$q = 1.03 \times 0.75$	=	0.775
25 %	$q = 1.03 \times 0.44$	=	0.452

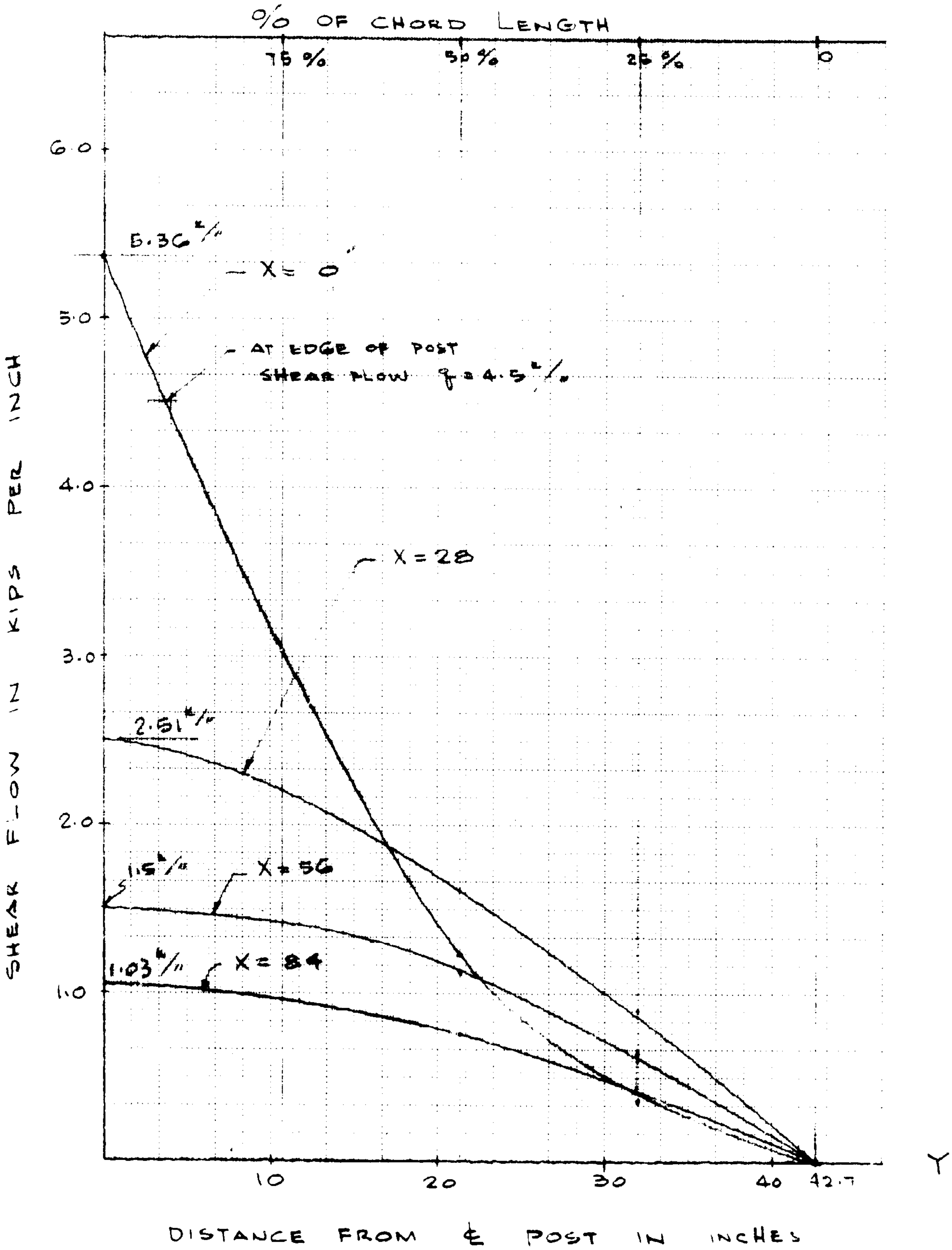


CHORD WISE DISTRIBUTION

FIG. 1


770#/" ± AT Y-RING
DISTANCE ALONG THE POST IN INCHES
x
140
112
84
56
28
0
1
2
3
4
5
6
MAX SHEAR FLOW
@ ℄ LINE POST 5,360#/"
SHEAR FLOW ALONG EDGE OF POST K/"

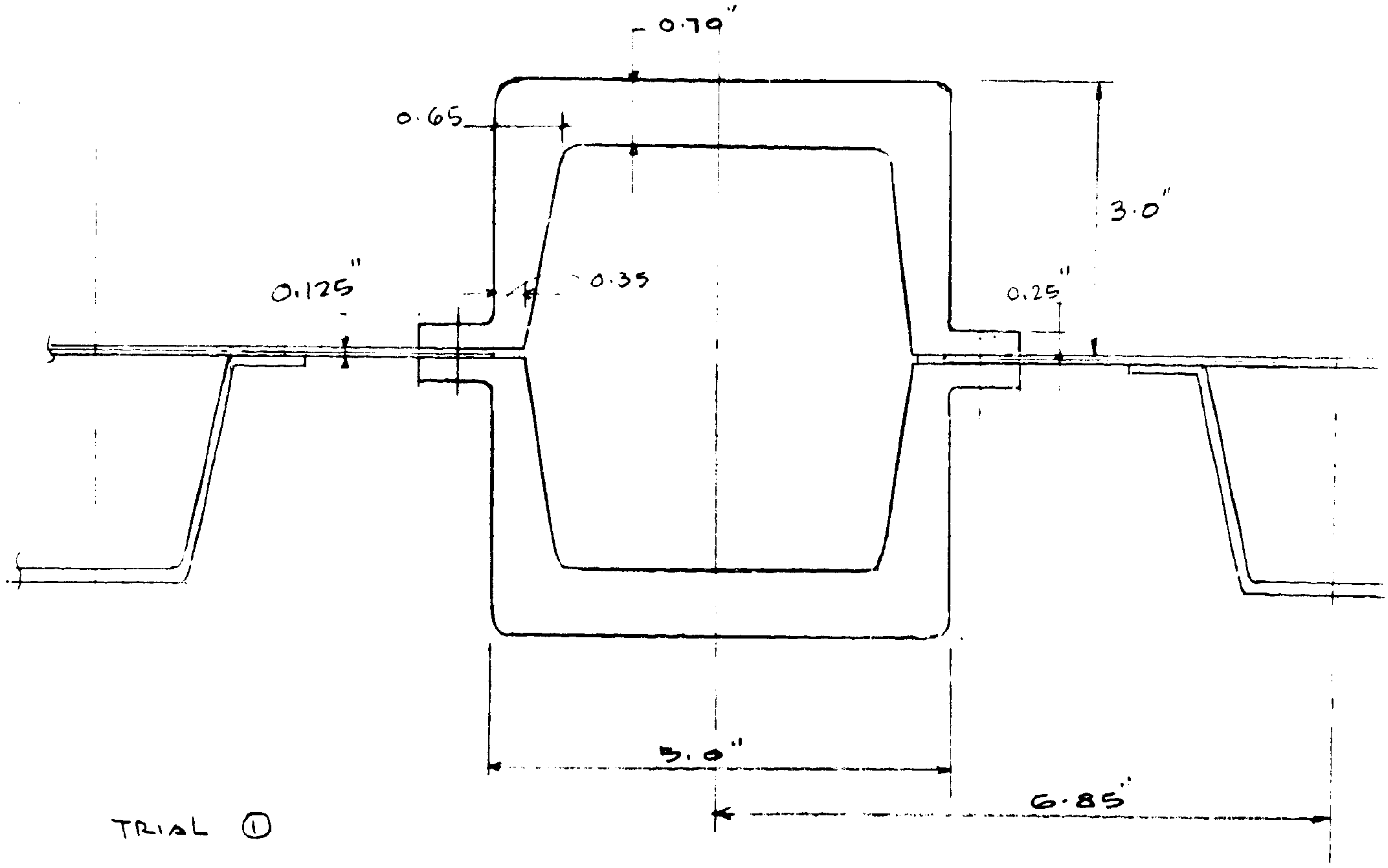
F.G. 2



% OF CHORD LENGTH
75 %
50 %
25 %
0
6.0
5.0
4.0
3.0
2.0
1.0
5.36 k/in
X = 0"
AT EDGE OF POST
SHEAR FLOW q = 4.5 k/in
X = 28
2.51 k/in
1.5 k/in
X = 56
1.03 k/in
X = 84
SHEAR FLOW IN KIPS PER INCH
10
20
30
40
42.7
Y
DISTANCE FROM ℄ POST IN INCHES

FIG. 3

SIZING OF THRUST POST AREA (LOWER END)



TRIAL ①

AREA OF THRUST POST

$2 \times 5 \times 0.70 = 7.0$

$4 \times \frac{1}{2}(0.35 + 0.65) \times 2.25 = 4.6$

$4 \times 0.8 \times 0.25 = 0.8$

$12.40 \ \square''$

MAX. COMPRESSIVE STRESS AT POST

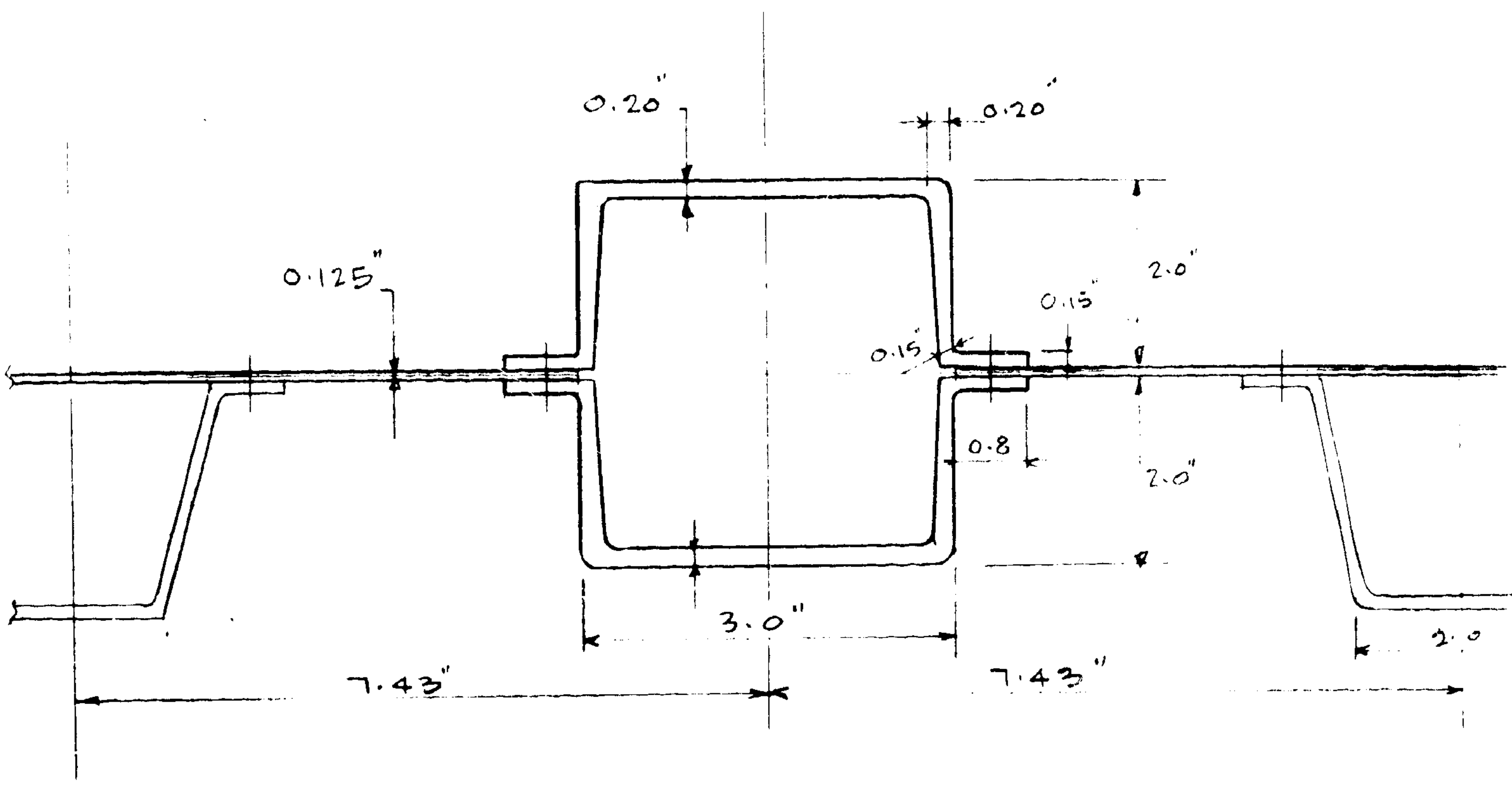
$$f_{c_p} = \frac{615000}{12.4} = 49{,}750 \text{ PSI}$$

ALLOWABLE f_{cy} FOR DIE-FORGED 7075-T6

$$f_{cy} = 57000 \text{ PSI}$$

$$M.S = \frac{57000}{49750} - 1 = \underline{+0.145} \longrightarrow$$

SIZING OF UPPER POST AREA



AREA OF THRUST POST (UPPER SECTION)

$2 \times 3 \times 0.2 = 1.2$ □"
$4 \times 1.8 \times 0.175 = 1.26$
$4 \times 0.8 \times 0.15 = 0.48$
$4.4 \times 0.125 = 0.51$

3.45 □"

INVESTIGATION OF PEAK LOAD N_c AT Y-RING BASED UPON CHORD WISE DISTRIBUTION OF THE COMPRESSIVE STRESS FROM SHEAR LAG ANALYSIS

GIVEN $A_p = 3.45 \square''$

ASSUME EFFECTIVE WIDTH OF POST TO COVER 8.0''

$$\sigma = 30200 \times \frac{1}{\cos 10^\circ 30'} \leftarrow \text{CONE ANGLE}$$

$$= \frac{30200}{0.98325} = 30700 \ \#/\square''$$

THEN THE PEAK DISTRIBUTION OF N_c LOAD OVER THRUST POST AREA IS

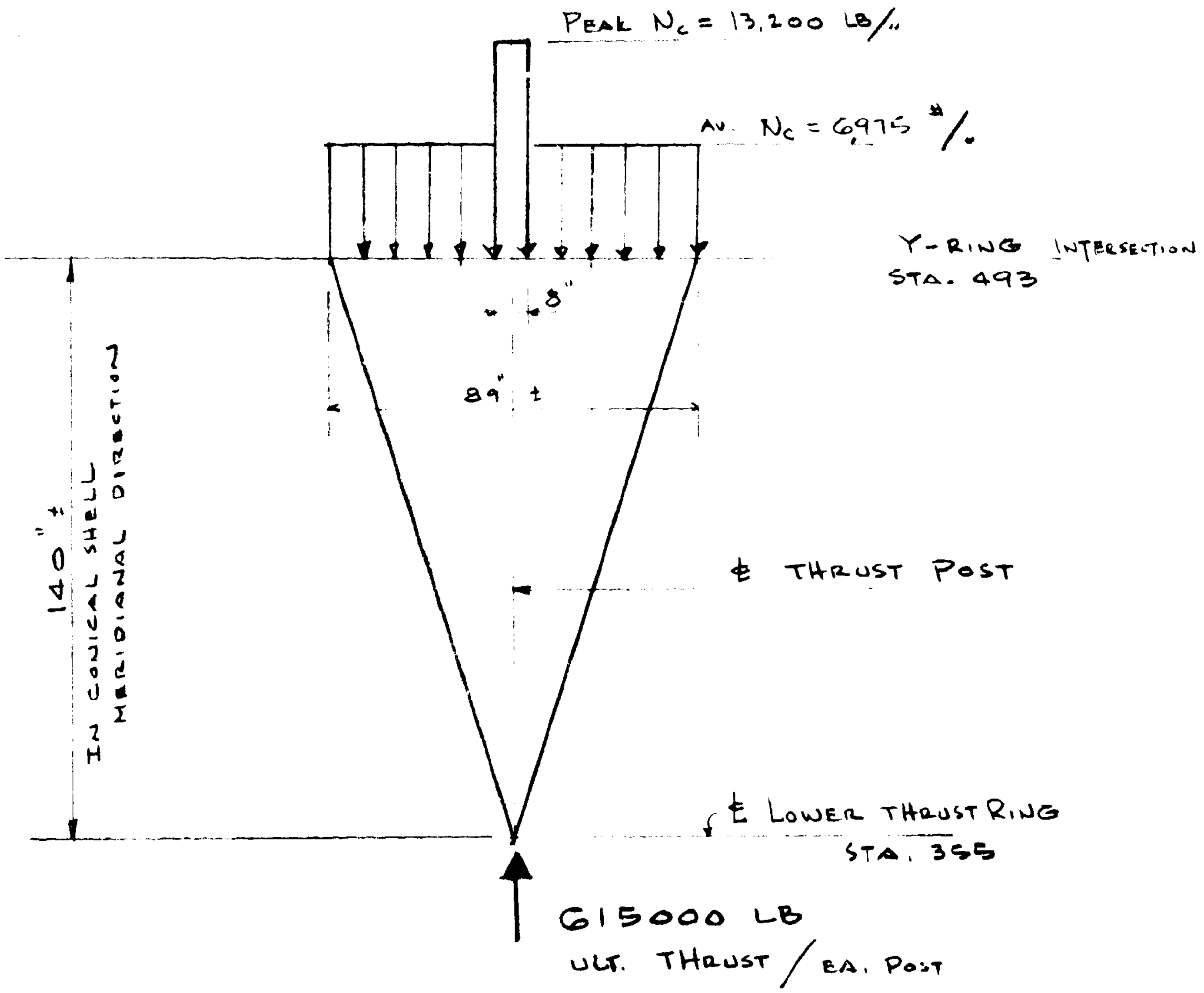
$$N_{c_{max}} = \frac{3.45 \times 30700}{8} = \underline{13,200} \ \#/''$$

THE AVERAGE N_c DISTRIBUTION BEYOND THE POST AREA IS

$$N_c = \frac{1.688 \times 30700}{7.43} = \underline{6,975} \ \#/''$$

N_c LOAD DISTRIBUTION DIAGRAM

(ALONG CONICAL SHELL MERIDIANAL DIRECTION)



INVESTIGATION OF SHEAR BUCKLING STRESS BASED UPON LOAD DISTRIBUTION FROM SHEAR LAG ANALYSIS

GIVEN $b = 3.43$
$t = 0.1$

APPLY SHEAR BUCKLING STRESS EQUATION FROM TN-3783 (NASA TECH NOTES)

$$F_{s_{cr}} = \frac{K_s \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$$Z_b = \frac{b^2}{rt}\left(1-\nu_e^2\right)^{1/2} = \frac{3.43^2}{314 \times 0.1}(0.945)$$

$$= 0.433$$

$K_s = 5.5$ FROM FIG 49 TN-3783

$$F_{s_{cr}} = \frac{5.5 \times 9.85 \times 10.4 \times 10^6}{12(1-\nu^2)}\left(\frac{0.1}{3.43}\right)^2$$

$$= \frac{5.5 \times 9.85 \times 10.4 \times 10^6 \times 8.5 \times 10^{-4}}{10.7}$$

$$= 44600 \text{ PSI}$$

FROM FIG. 3. MAX SHEAR FLOW @ 3" FROM ℄ POST IS 4.6 k/"

ACTUAL SHEAR STRESS

$$f_s = q/t = 46000 \text{ PSI}$$

THIS RESULT

$$M.S = \frac{44600}{46000} - 1 = \underline{-0.03} \longrightarrow$$

SINCE A NEGATIVE M.S IS PRESENT DUE TO THINNING THICKNESS TO 0.10 AT BOTTOM.

FOR CONSERVATIVE APPROACH, IT IS ADVISABLE TO USE CONSTANT THICKNESS 0.125 AT BOTTOM SKIRT ALSO. THEN FOR $t = 0.125$ & $b = 3.8_{MAX}$

$$F_{S_{CR}} = \frac{5.5 \times 9.85 \times 10.4 \times 10^{6}}{10.7} \times 1.08 \times 10^{-3}$$

$$= 57000 \text{ PSI}$$

$$f_s = 4700 \times 1/t = \frac{4700}{0.125} = 37600 \text{ PSI}$$

$$M.S = \frac{57000}{37600} - 1 = \underline{\underline{+0.515}} \longrightarrow$$

IF $t = 0.11$ IS SELECTED

$$F_{S_{CR}} = \frac{5.5 \times 9.85 \times 10.4 \times 10^{6}}{10.7} \times 8.4 \times 10^{-4}$$

$$= 44000 \text{ PSI}$$

$$f_s = \frac{4700}{0.11} = 42700 \text{ PSI}$$

$$M.S = \frac{44000}{42700} - 1 = \underline{\underline{+0.03}} \longrightarrow$$

FOR WT SAKE USE 0.11" SKIN THICKNESS AT BOTT.

* BUT FABRICATING COST MAY PREFER A CONSTANT THICKNESS FOR SKIN AT THE EXPENSE OF INSIGNIFICANT WT. PENALTY.

B-2.4

SEGMENTAL
TOROIDAL ENGINE AFT THRUST
STRUCTURE ANALYSIS

N_c = 7,100 Lb/In (Ult.) At Lower End

N_c = 6,950 Lb/In (Ult.) At Upper End

Total Thrust T = 14.5×10^6 Lb/In (Ult.)

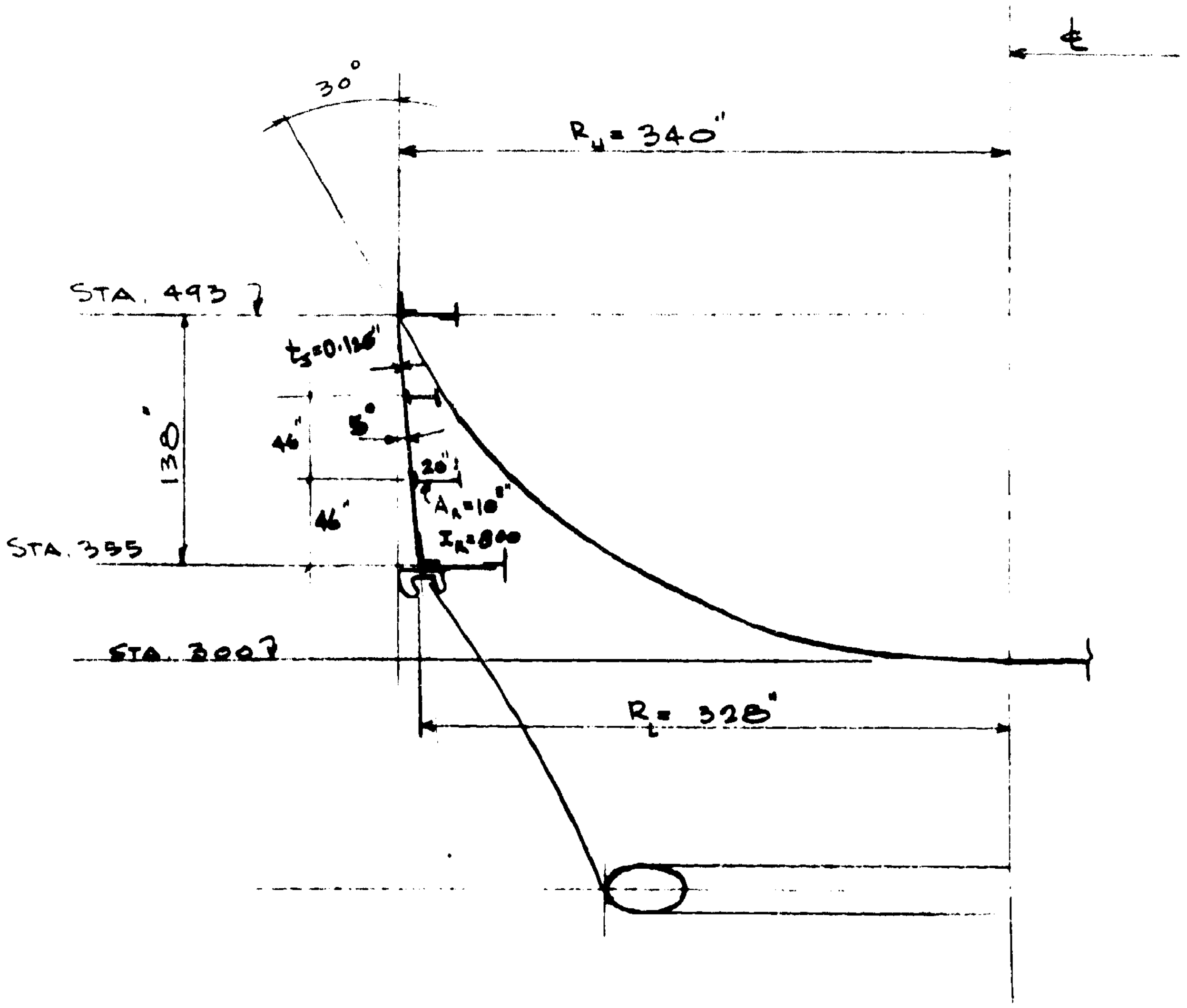
TOROIDAL ENGINE CONCEPT

THRUST STRUCTURE ANALYSIS

ASSUMPTIONS :

a) ENGINE THRUST MAGNITUDE FOR BOTH MULTI-CHAMBER ENGINE AND TOROIDAL ENGINE ARE IDENTICAL

b) THRUST AT THRUST STRUCTURE IS ASSUMED TO BE UNIFORMLY DISTRIBUTED. SHEAR LAG ANALYSIS IS NOT REQUIRED.



AT LOWER END $N_c = 7100$ #/" (IN MERIDIANAL DIRECTION OF CONICAL THRUST STRUCTURE)

TOROIDAL ENGINE THRUST STRUCTURE ANALYSIS

SINGLE STAGE TO ORBIT

GIVEN THRUST AT CUT OFF

$$T = 10.35 \times 10^6 \times 1.4 = 14.5 \times 10^6$$

THE CIRCUMF. LENGTH AT LOWER END OF SKIRT

$$L_c = 2\pi \times 328 = 2060 \text{ IN}$$

UNIT THRUST PER INCH

$$N_c = \frac{14.5 \times 10^6}{2060} = 7050 \text{ LB}/''$$

CORRECTED TO THRUST IN MERIDIANAL DIRECTION

$$N_c = \frac{7050}{\cos 5^\circ} = \frac{7050}{0.9962} = 7100 \text{ LB}/''$$

USING SKIN STRINGER SECTION

IF HAT STIFFENER SECTION IS USED. &

ASSUME STRESS LEVEL IS @ 35000 PSI

$$b_{EFF.} = 1.7\,t\sqrt{\frac{10.4 \times 10^6}{3.5 \times 10^4}}$$

$$= 1.7\,t \times 17.3 = 1.7 \times 0.125 \times 17.3$$

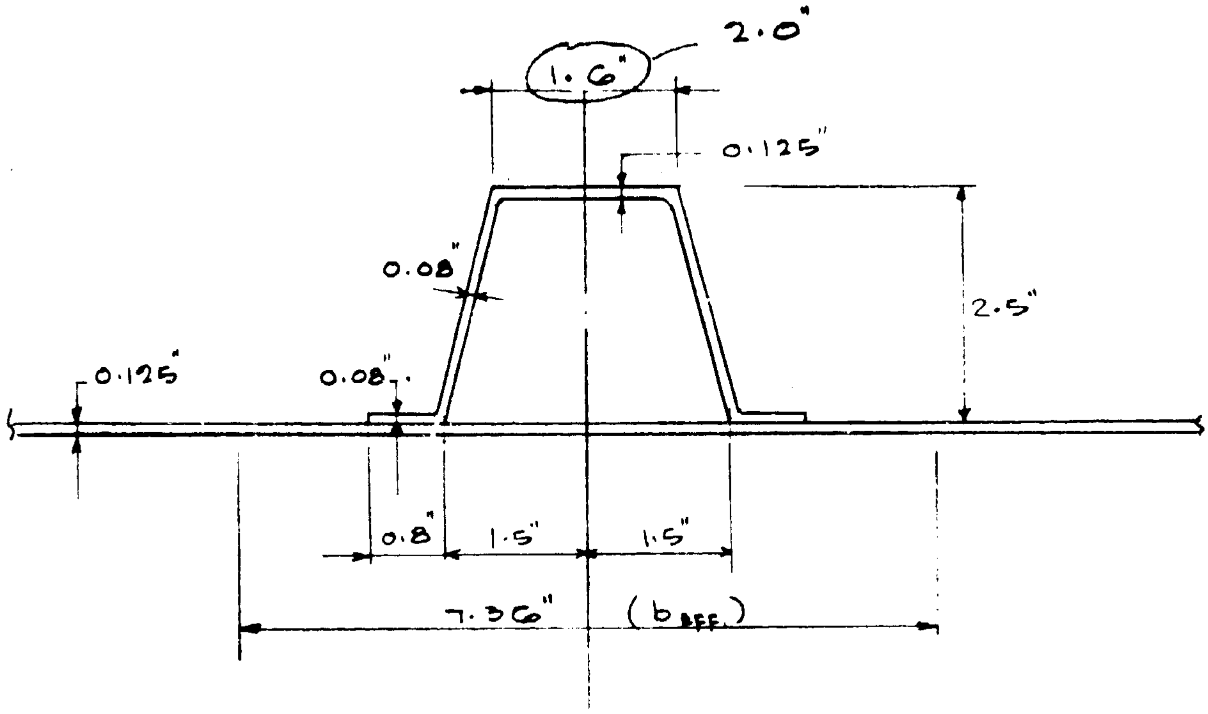
$$= 3.68$$

STIFFENER SECTION IS

$$S = 2 \times 3.68 = 7.36''$$

NEED 280 HAT STIFFENERS @ 7.36" o/c

3 SIZING OF SKIN-STRINGER SECTION



	A 0.25	Y	AY	AY^2	I_o
$A_1 = 1.6 \times 0.125 =$	0.200	2.500	0.500	1.2500	$\frac{1}{12} 1.6 \times 0.125^3 = 0.00026$
$A_2 = 2 \times 2.45 \times 0.08 =$	0.392	1.313	0.515	0.6760	$\frac{1}{12} 0.08 \times 2.38^3 = 0.0895$
$A_3 = 2 \times 0.7 \times 0.08 =$	0.112	0.165	0.019	0.0031	0
$A_4 = 7.36 \times 0.125 =$	0.920	0.063	0.058	0.0037	0.0012
	1.624 (1.674 0")		1.092	1.9328	0.0910

$$\bar{Y} = \frac{1.092}{1.624} = \cancel{0.673}\ 0.726$$ SEE NEXT SH

$$I_c = AY^2 + I_o - A\bar{Y}^2$$

1.450

$$= 1.933 + 0.0910 - 1.624 \times 0.673^2 = 1.289 \text{ IN}^4$$ (SEE NEXT SH)

$$I_s = 1.289/7.36 = \cancel{0.175}\ 0.197 \text{ IN}^4/''$$ (SEE NEXT SH)

$$\bar{t} = \frac{1.624}{7.36} = 0.2205$$

$$\rho = \sqrt{\frac{1.289}{1.624}} = 0.892$$

$$L'/\rho = 47/0.892 = 52.75$$ (ASSUME 2 INTERMEDIATE RINGS)

FINAL TRIAL SECTION FOR GENERAL INSTABILITY

IF HAT STIFFENER FLANGE IS MADE 2" WIDE

	A	Y	AY	AY^2	I_o
$A_1 = 2.0 \times 0.125 =$	0.250	2.50	0.625	1.5600	0.000325
$A_2 = 2 \times 2.45 \times 0.08 =$	0.392	1.313	0.515	0.6760	0.089500
$A_3 = 2 \times 0.7 \times 0.08 =$	0.112	0.165	0.019	0.0031	
$A_4 = 7.36 \times 0.125 =$	0.920	0.063	0.058	0.0037	0.001200
$\Sigma A =$	1.674 □"		1.217	2.2428	0.091025

$$\bar{Y} = \frac{1.217}{1.674} = 0.726$$

$$I_c = 2.2428 + 0.091025 - 1.674 \times 0.726^2 = 1.450 \text{ IN}^4$$

$$I_s = \frac{1.45}{7.36} = 0.197 \text{ IN}^4/''$$

$$\bar{t} = \frac{1.674}{7.36} = .227$$

$$t^* = \sqrt[4]{12\, I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$= \sqrt[4]{12 \times 0.197\,(0.217 + 0.125)} = 0.947$$

$$R/t^* = 340/0.947 = 359$$

INVESTIGATION OF LOCAL BUCKLING STRESSES

a. PANEL BUCKLING STRESS BETWEEN STIFFENERS

$$b = 3.8''$$

$$t_s = 0.125''$$

$$\sigma_{CR} = \frac{K_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t_s}{b}\right)^2$$

$$= \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.125}{3.8}\right)^2$$

$$= 41300 \ \#/\square''$$

ACTUAL COMPRESSIVE STRESS FROM LOAD

$$\sigma_C = \frac{7100 \times 7.36}{1.624} = 32{,}200 \text{ PSI}$$

$$M.S = \frac{41300}{32{,}200} - 1 = \underline{+0.28}$$

b WEB PANEL BUCKLING STRESS (STIFFENER WEB)

$$\sigma_{CR} = \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.08}{2.45}\right)^2 = 40{,}600 \ \#/\square''$$

c. HOR LEG CONNECTION

$$\sigma_{CR} = \frac{0.5 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.08}{0.8}\right)^2 = 48{,}000 \text{ PSI}$$

d. OUTSIDE FLANGE

$$\sigma_{CR} = \frac{4.0 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.125}{1.6}\right)^2 = 234{,}000 \text{ PSI}$$

1. STIFFENER CRIPPLING STRESS IS

$$\sigma_{cc} = \frac{0.2 \times 234000 + 0.392 \times 40600 + 0.112 \times 48000}{0.704}$$

$$= 96700 \text{ PSI} \quad \text{WHICH IS} > 65000 \text{ PSI } (F_{cy})$$

USE $F_{cy} = 65,000$ PSI AS THE MAX σ_{cc} VALUE

2. CHECK INTERFRAME BUCKLING STRESS BY USING JOHNSON-EULER FORMULA (CONSERVATIVE DESIGN)

$$\sigma_{CR} = F_{cc} - \frac{F_{cc}^2 \left(\frac{L'}{\rho}\right)^2}{4\pi^2 E}$$

$$= 65000 - \frac{(65000)^2 \times 2770}{4 \times 9.85 \times 10.4 \times 10^6}$$

$$= 65000 - \frac{4.22 \times 10^9 \times 2.77 \times 10^3}{39.4 \times 10.4 \times 10^6} = 36,500 \text{ PSI}$$

$$M.S = \frac{36,500}{32,200} - 1 = +\underline{0.135} \longrightarrow$$

3. APPLICATION OF INTERFRAME BUCKLING STRESS EQUATION

$$t_1^* = \sqrt[4]{12 I_s t_s}$$

$$= \sqrt[4]{12 \times 0.175 \times 0.125} = \sqrt[4]{0.262} = 0.715$$

$$t_1^{*2} = 0.51$$

$$t_1^{*3} = 0.365$$

$$Z_L = \frac{2220}{328 \times 0.715} \times 0.945 = 8.95$$

$$L_R = 47''$$

FROM FIG. 6 TN 3783

FOR $Z_L = 9$ & $R/t^* \approx 500$ $K_c = 5.5 \pm$

$$N_{CR} = \frac{K_c \pi^2 E t_1^{*3}}{12(1-\nu^2) L_R^2} = \frac{5.5 \times 9.85 \times 10.4 \times 10^6}{10.7 \times 2220} \times 0.365$$

$$= 8700 \text{ LB}/''$$

$$N_c = 7100 \text{ LB}/''$$

$$M.S = \frac{8700}{7100} - 1 = \underline{\underline{+0.225}} \longrightarrow$$

FROM 1, 2, & 3 ITEM INVESTIGATION, IT IS CONCLUDED THAT LOCAL BUCKLING IS NOT A PROBLEM

SIZING OF INTERMEDIATE RING FRAME

1) TIMOSHENKO'S CRITERION

GIVEN $a_x = 332''$

$I_s = 0.197 \text{ IN}^4/''$

$a_R = 322$

$L_R = 47$

$$A_R = \frac{4\pi^2 I_s a_x a_R}{L_R^3}$$

$$= \frac{4 \times 9.85 \times 0.197 \times 322 \times 332}{47^3}$$

$$= 8.5 \ \square''$$

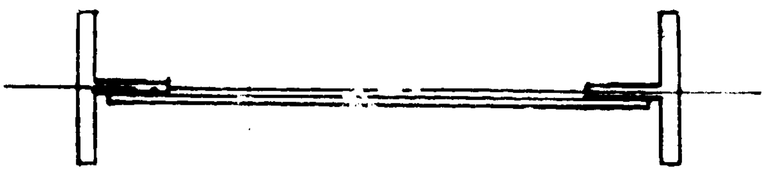
2) SHANLEY'S CRITERION

$$I_R = \frac{0.785 R_{cyl}^4 \times N_c}{1000 \times E \times L_R}$$

$$= \frac{0.785 \times 1.21 \times 10^{10} \times 7100}{\cancel{10^3} \times 10.4 \times \cancel{10^6} \times 47}$$

$$= \frac{0.785 \times 1.21 \times 71000}{10.4 \times 47} = 139 \text{ IN}^4$$

ASSUME RING SIZE $A_R = 6.0 \ \square''$



$A_1 = 4 \times 0.40 = 1.6$

$A_2 = 4 \times 0.40 = 1.6$

$A_3 = 4 \times 0.25 = 1.0$

$A_4 = 14 \times 0.125 = 1.75$

$5.95 \approx 6 \square$

$I_1 = 3.2 \times 64 = 204$

$I_2 = 1.6 \times 6.55^2 = 68$

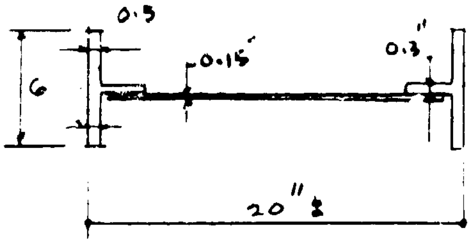
$I_3 = \frac{1}{12} 0.125 \times 14^3 = 29$

301

3) FROM SUBSEQUENT INVESTIGATION IT IS FOUND THAT TIMOSHENKO'S A_R AND SHANLEY'S I_R ARE BOTH INADEQUATE FOR THE DESIGNED CONFIGURATION BY USING GENERAL INSTABILITY ANALYSIS PER REF D5-13272. INCREASING A_R TO 10 □" AND USING $I_R = 800$ IN^4, THE ALLOWABLE CRITICAL BUCKLING STRESS IS FOUND OK. FROM THEORITICAL APPLICATION OF STRESS EQUATION FROM D5-13272.

THE VALIDITY OF METHOD DEVELOPED IN D5-13272 HAS HAD GOOD CORRELATIONS WITH SOME TEST DATA SURVEYED THUS FAR FOR CYLINDERS WITH DIAMETERS RANGING FROM 50 TO 400 INCHES. IT SHOULD ALSO BE APPLICABLE TO LARGER DIAMETER AS WELL. IT IS NOTED ALSO THAT THE FINAL SELECTION OF AREA A_R IS MORE OR LESS BASED ON TIMOSHENKO'S RING AREA CRITERION IN THIS PARTICULAR CONFIGURATION.

ASSUMED INTERM. RING SECTION :



$A_1 = 2 \times 6 \times 0.5 = 6.0$

$A_2 = 5 \times 0.30 = 1.50$

$A_3 = 17 \times 0.15 = 2.55$

$\quad\quad 10.05$ □"

$I_1 = 6 \times 9.75^2 = 585$

$I_2 = 1.5 \times 8.25^2 = 102$

$I_3 = \frac{1}{12} 0.15 \times 17^3 = 62$

$\quad\quad 759$

$I_R \approx 760$

GENERAL INSTABILITY INVESTIGATION

REFERENCE D5-13272, GENERAL INSTABILITY STRESS EQUATION

GIVEN DATA

$A_R = 6.0$

$L_R = 47.0$

$R = 340$ (ASSUME MAX CYLINDER RADIUS)

$t_s = 0.125$

$I_s = 0.175 \text{ IN}^4/$

$t_a = \dfrac{1.624}{7.36} = 0.2205$

$I_R \approx 280 \text{ IN}^4$

$L = 140''$

$$t^* = \sqrt[4]{12\, I_s\left(\frac{A_R}{L_R} + t_s\right)} = \sqrt[4]{12 \times 0.175\left(\frac{6.0}{47.0} + 0.125\right)} = 0.85$$

0.255

$$R/t^* = 340/0.85 = 400$$

$$m \approx 0.87\sqrt{400} \approx 20 \times 0.87 \approx 17.4$$

(DONNELL'S EQUATION FOR MONOCOQUE CYL.)

USE TEST DATA AS A GUIDE ASSUME

$m \approx 8$

$n = 3$

$$\gamma = \frac{t^* R^2}{I_s} = \frac{0.85 \times 115500}{0.175} = 5.6 \times 10^5$$

$$\psi = \frac{2\pi n R}{L} = \frac{2\pi \times 3 \times 340}{140} = 45.8$$

$$\psi^2 \gamma = 2100 \times 5.6 \times 10^5 = 11.8 \times 10^8$$

$U = 0.00025$

$$\rho = 0.00025 \times 1.6 \times 10^5 = 2.5 \times 10^{-4} \times 1.6 \times 10^5 = 40$$

$$K = 1 + \frac{2\rho}{m^{1.5} n^{0.5} D} = 1 + \frac{80}{8^{1.5} 3^{0.5} D} = 1 + \frac{2.046}{D} = 1 + \frac{B_1}{D}$$

22.6   1.732

$$B_1 = 2.046$$

$$\phi = \frac{4R^4}{I_s t^*} = \frac{4 \times 1.335 \times 10^{10}}{0.175 \times 0.85} = 35.95 \times 10^{10} = 3.595 \times 10^{11}$$

$$\phi - 8\Gamma \left(\frac{R}{t^*}\right)^2 = -3.595 \times 10^{11}$$

$$H_x = \frac{E t_a}{1-\nu^2} = \frac{E \times 0.2205}{0.891} = 0.2475\ E$$

$$H_\theta = E \frac{A_R}{L_R} + E t_s = E \times \frac{6.0}{47} + E \times 0.125 = 0.252\ E$$

$$\frac{H_x}{H_\theta} = 0.9830$$

$$D_x = E I_s = E \times 0.175 = 0.175\ E$$

$$D_\theta = \frac{E \times 0.125^3}{12(1-\nu^2)} + E\frac{I_R}{L_R} = 0.000163E + 5.95E = 5.9502E$$

$$D_t \approx 0$$

$$\xi = \frac{m^4}{\psi^2} + \frac{H_x}{H_\theta}\psi^2 + 2(1+\nu)m^2 = \frac{4086}{2100} + 0.983 \times 2100 + 2.66 \times 64 = 2237$$

2   2065   170

$$b = \psi^4 + \frac{m^2}{D_x}\left(3 D_\theta m^2 + 0\right) + \frac{R^2 t^* E}{\xi^2 D_x}\left\{m^4 + 2(1+\nu)m^2\psi^2 + \psi^4 \frac{H_x}{H_\theta}\right\}$$

0.4175×10^6 0.326×10^6 0.3575×10^6

$$= 4.41 \times 10^6 + \frac{4086 \times 3 \times 5.95\,\cancel{E}}{0.176\,\cancel{E}} + \frac{1.155 \times 10^5 \times 0.85\,\cancel{E}}{5.0 \times 10^6 \times 0.175\,\cancel{E}}\left\{4086 + 2.66 \times 64 \times 2100 + 0.983 \times 4.41 \times 10^6\right\}$$

0.1124 4.33×10^6

$$= 5.354 \times 10^6$$

$$A_1 = \frac{\psi^2 \gamma}{\left[\phi - 8\gamma\left(\frac{R}{t^*}\right)^2\right]} = \frac{-11.8 \times 10^{8}}{3.595 \times 10^{11}} = -3.28 \times 10^{-3}$$

$$C_1 = \frac{b}{\left[\phi - 8\gamma\left(\frac{R}{t^*}\right)^2\right]} = \frac{-5.354 \times 10^{6}}{3.595 \times 10^{11}} = -14.9 \times 10^{-6}$$

1.355

$$D = \frac{B_1}{2} - \frac{2C_1}{A_1^2 B_1} = \frac{2.046}{2} + \frac{2 \times 14.9 \times 10^{-6}}{10.75 \times 10^{-6} \times 2.046}$$

$$D = 2.378$$

$$D^2 = 5.65488$$

$$B_1 D = 4.86539$$

$$B_1 D + D^2 = 10.52027$$

$$A_1(B_1 D + D^2) = -34.50649 \times 10^{-3}$$

$$A_1^2 (B_1 D + D^2)^2 = 1190.69785 \times 10^{-6}$$

$$-4C_1 D^2 =$$

$$+59.6\, D^2 \times 10^{-6} = 337.03085 \times 10^{-6}$$

$$1527.72870 \times 10^{-6}$$

$$\sqrt{A_1^2 (B_1 D + D^2)^2 - 4C_1 D^2} = 39.08617$$

$$34.50649$$

$$4.57968 \times 10^{-3}$$

$$S = \frac{4.57968 \times 10^{-3}}{2} = 2.28984 \times 10^{-3}$$

$$= 0.229 \times 10^{-2}$$

$$\sigma_{CR} = 10.4 \times 0.229 \times 10^{4} = 23{,}800 \text{ PSI}$$

GENERAL INSTABILITY IS SHY

GENERAL INSTABILITY ANALYSIS

INCREASE RING SIZE TO 10.0"

$$t^* = \sqrt[4]{12 \times 0.175 \times \left(\frac{10}{46} + 0.125\right)} = 0.921$$

$$R/t^* = 340/0.921 = 369$$

$$\left(R/t^*\right)^2 = 1.36 \times 10^5$$

$$m = 8$$

$$n = 3$$

$$\gamma = \frac{t^* \times R^2}{I_s} = \frac{0.921 \times 1.155 \times 10^5}{0.175} = 6.085 \times 10^5$$

$$\psi = 45.8$$

$$\psi^2 \gamma = 2100 \times 6.085 \times 10^5 = 12.8 \times 10^8$$

$$U = 0.0002$$

$$\rho = 0.0002 \times \left(\frac{R}{t^*}\right)^2 = 0.0002 \times 1.36 \times 10^5 = 27.2$$

$$K = 1 + \frac{2\rho}{m^{1.5} n^{0.5} D} = 1 + \frac{54.4}{22.6 \times 1.732\, D} = 1 + \frac{1.39}{D} = 1 + \frac{B_1}{D}$$

$$B_1 = 1.39$$

$$\phi = \frac{4 \times R^4}{I_s t^*} = \frac{4 \times 1.335 \times 10^{10}}{0.175 \times 0.921} = 3.32 \times 10^{11}$$

$$\phi - 8\gamma \left(\frac{R}{t^*}\right)^2 = -3.32 \times 10^{11}$$

$$H_x = \frac{E t_a}{1 - \nu^2} = 0.2475$$

$$H_\theta = E \times \frac{10.0}{46} + E \times 0.125 = 0.342\,E$$

$$\frac{H_x}{H_\theta} = 0.725$$

$$D_x = E I_s = 0.175\,E$$

$$D_\theta = 0.000163E + \frac{E \times 700}{47} \approx 14.9\,E$$

(14.9)

$D_t \approx 0$

$$\xi = 2 + 0.725 \times 2100 + 2.66 \times 64 = 1692$$

(1520, 170)

$$\xi^2 = 2.86 \times 10^6$$

$$b = 4.41 \times 10^6 + \frac{4086 \times 3 \times 14.9}{0.175} + \frac{1.155 \times 10^5 \times 0.921}{2.86 \times 10^6 \times 0.175} \left\{ 4086 + 0.358 \times 10^6 + 3.19 \times 10^6 \right.$$

(1.045×10^6, 0.2125, 0.756×10^6)

$$= 6.211 \times 10^6$$

$$A_1 = \frac{-12.8 \times 10^8}{3.32 \times 10^{11}} = -3.85 \times 10^{-3}$$

$$C_1 = \frac{b}{\left\{ \phi - 8\gamma \left(\frac{R}{t^*}\right)^2 \right\}} = \frac{-6.211 \times 10^6}{3.32 \times 10^{11}} = -18.72 \times 10^{-6}$$

$$D = \frac{1.39}{2} + \frac{2 \times 18.72}{14.8 \times 1.39} = 2.520$$

(0.695, 1.825)

$$D^2 = 6.3504$$

$$B_1 D = 3.5028$$

$$D^2 + B_1 D = 9.8532$$

$$A_1 (D^2 + B_1 D) = -37.93482 \times 10^{-3}$$

$$A_1^2 (D^2 + B_1 D)^2 = 1439.05057 \times 10^{-6}$$

$$4C_1 D^2 = 475.51795 \times 10^{-6}$$

$$1914.56852 \times 10^{-6}$$

$$\sqrt{1914.56852 \times 10^{-6}} = 43.75578 \times 10^{-3}$$

$$- 37.93482 \times 10^{-3}$$

$$5.82096$$

$$S = 0.291048 \times 10^{-2}$$

$$\tau_{CR} = E \times S = 30{,}269 \text{ PSI} \quad \text{STILL SHY}$$

CHANGING RING MOMENT OF INERTIA

$I_R = 900 \qquad A_R = 10 \square''$

$D_\theta \approx E\, I_R / L_R = \dfrac{900\,E}{46} = 19.6$

$b = 4.41 \times 10^6 + \dfrac{4086 \times 3 \times 19.6}{0.175} + 0.756 \times 10^6 = 6.55 \times 10^6$

1.38

$A_1 = -3.85 \times 10^{-3}$

$C_1 = -\dfrac{6.55 \times 10^6}{3.32 \times 10^{11}} = -19.75 \times 10^{-6}$

1.92

$D = 0.695 + \dfrac{2 \times 19.75}{14.8 \times 1.39} = 2.615$

$D^2 = 6.83823$

$B_1 D = 3.63485$

$D^2 + B_1 D = 10.47308$

$A_1 (D^2 + B_1 D) = 40.32136 \times 10^{-3}$

$A_1^2 (D^2 + B_1 D)^2 = 1625.81207 \times 10^{-6}$

$-4 C_1 D^2 = 540.20200 \times 10^{-6}$

$2166.01407 \times 10^{-6}$

$\sqrt{2166.01407 \times 10^{-6}} = 46.5405$

-40.3214

6.2191×10^{-3}

$S = 0.31096 \times 10^{-2}$

$\sigma_{CR} = 32{,}339$ PSI

$M.S = \dfrac{32{,}339}{32{,}300} - 1 \approx 0$ OK

GENERAL INSTABILITY ANALYSIS (FINAL RESULT)

GIVEN DATA

$t_s = 0.125$

$\bar{t}_a = 0.227$

$I_s = 0.197 \text{ IN}^4/''$

$A_R = 10.0$; $I_R \approx 800$

$L_R = 46.0$

$t^* = 0.947$

$R = 340$

$R/t^* = 359$; $(R/t^*)^2 = 129{,}000$

$m \approx 8$ (ASSUMED)

$n \approx 3$ (ASSUMED)

$$\gamma = \frac{t^* R^2}{I_s} = \frac{0.947 \times 115500}{0.197} = 5.56 \times 10^5$$

$$\psi = \frac{2\pi \times 3 \times 340}{140} = 45.8$$

$\psi^2 = 2100$

$\psi^4 = 4.41 \times 10^6$

$\psi^2 \gamma = 2100 \times 5.56 \times 10^5 = 11.7 \times 10^8$

$\omega = 0.00020$

$\rho = 0.00020 \times 1.29 \times 10^5 = 25.8$

$$K = 1 + \frac{2\rho}{m^{1.5} n^{0.5} D} = 1 + \frac{51.6}{22.6 \times 1.732\, D} = 1 + \frac{1.316}{D} = 1 + \frac{B_1}{D}$$

$B_1 = 1.316$

$$\phi = \frac{4R^4}{I_s t^*} = \frac{4 \times 1.335 \times 10^{10}}{0.197 \times 0.947} = 28.65 \times 10^{10} = 2.865 \times 10^{11}$$

$$\phi - 8\gamma (R/t^*)^2 = -2.87 \times 10^{11}$$

$$H_x = \frac{E t_a}{1-\nu^2} = \frac{0.227\,E}{0.891} = 0.255\,E$$

$$H_\theta = E\,\frac{A_R}{L_R} + E t_s = E \times \frac{10}{46} + E \times 0.125 = 0.3425\,E$$

$$\frac{H_x}{H_\theta} = \frac{0.255}{0.3425} = 0.745$$

$$D_x = E I_s = 0.197\,E$$

$$D_\theta = E \times \frac{I_R}{L_R} = E \times \frac{800}{46} = 17.4\,E$$

$$D_t \approx 0$$

$$\xi = \frac{4086}{2100} + \overset{1565}{0.745 \times 2100} + \overset{170}{2.66 \times 64} = 1737$$

$$\xi^2 = 3.01 \cdot 10^6$$

$$b = 4.41 \times 10^6 + \frac{4086 \times 3 \times 17.4}{0.197} + \frac{\overset{0.185}{1.155 \times 10^5} \times 0.947}{3.01 \times 10^6 \times 0.197} \left\{ 0.00409 \times 10^6 + 0.358 \times 10^6 + 3.29 \times 10^6 \right\}$$

$$= 4.41 \times 10^6 + 1.085 \times 10^6 + 0.676 \times 10^6$$

$$= 6.171 \times 10^6$$

$$A_1 = \frac{\phi^2 r}{\left[\phi - 8r\left(\frac{R}{t^*}\right)^2\right]} = \frac{11.7 \times 10^8}{-2.87 \times 10^{11}} = -4.07 \times 10^{-3}$$

$$C_1 = \frac{b}{\left[\phi - 8r\left(\frac{R}{t^*}\right)^2\right]} = \frac{6.171 \times 10^6}{-2.87 \times 10^{11}} = -21.5 \times 10^{-6}$$

$$D = \frac{B_1}{2} - \frac{2C_1}{A_1^2 B_1} = \overset{0.658}{\frac{1.316}{2}} + \overset{1.975}{\frac{2 \times 21.5}{16.55 \times 1.316}} = 2.633$$

$$D^2 = 6.93269$$

$$B_1 D = 3.46503$$

$$D^2 + B_1 D = 10.39772$$

$$A_1 (D^2 + B_1 D) = -42.31872$$

$$A_1^2 (D^2 + B_1 D)^2 = +1790.87406$$

$$-4C_1 D^2 = 596.21134$$

$$2387.08540$$

$$\sqrt{A_1^2(D^2+B_1D)^2-4C_1D^2} = \sqrt{2387.0854 \times 10^{-6}} = 48.8578 \times 10^{-3}$$

$$-A_1(D^2+B_1D) \qquad = -42.3187 \times 10^{-3}$$

$$6.5391 \times 10^{-3}$$

CRITICAL STRAIN

$$S = \frac{6.5391}{2} \times 10^{-3} = 3.2696 \times 10^{-3}$$

$$\sigma_{CR} = E \times S = 10.4 \times 10^{6} \times 0.32696 \times 10^{-2}$$

$$= 34000 \text{ PSI}$$

$$\sigma_{CR} = C^* E \, t^*/R$$

$$C^* = \frac{34000 \times 359}{10.4 \times 10^6} = .174$$

ACTUAL COMPRESSIVE STRESS

$$\sigma_c = \frac{7100}{0.227} = 31,300 \text{ PSI}$$

$$M.S = \frac{34000}{31300} - 1 = \underline{\underline{+0.09}}$$

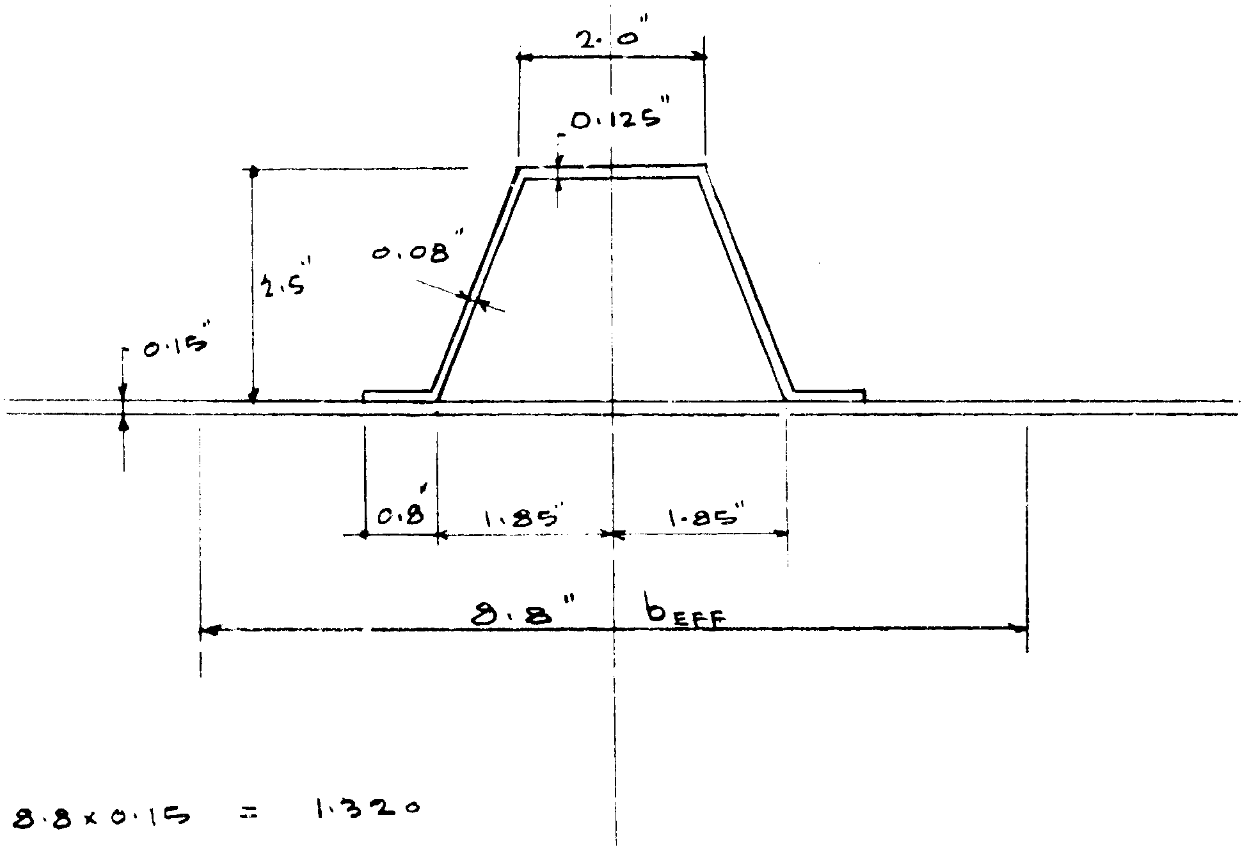
ALTERNATIVE STIFFENER PANEL SECTION STUDY

TRY INCREASE OF SKIN THICKNESS TO 0.14"

$$b_{eff/2} = 1.7 \times 0.14 \sqrt{\frac{10.4 \times 10^6}{35 \times 10^3}} = 1.7 \times 0.14 \times 17.25 = 4.1''$$

FOR $t = 0.15$

$$b_{eff/2} = 1.7 \times 0.15 \times 17.25 = 4.4''$$



$A_1 = 8.8 \times 0.15 = 1.320$

$A_2 = 1.4 \times 0.08 = 0.112$

$A_3 = 2 \times 2.52 \times 0.08 = 0.404$

$A_4 = 2 \times 0.125 = 0.250$

$\quad 2.086$

$t_a = 0.237 > 0.227$

NOT ECONOMICAL

THIS INVESTIGATION SUGGESTS THAT THE DESIGNED SECTION AS DONE BEFORE MAY BE CLOSE TO AN OPTIMUM SECTION

B-2.5

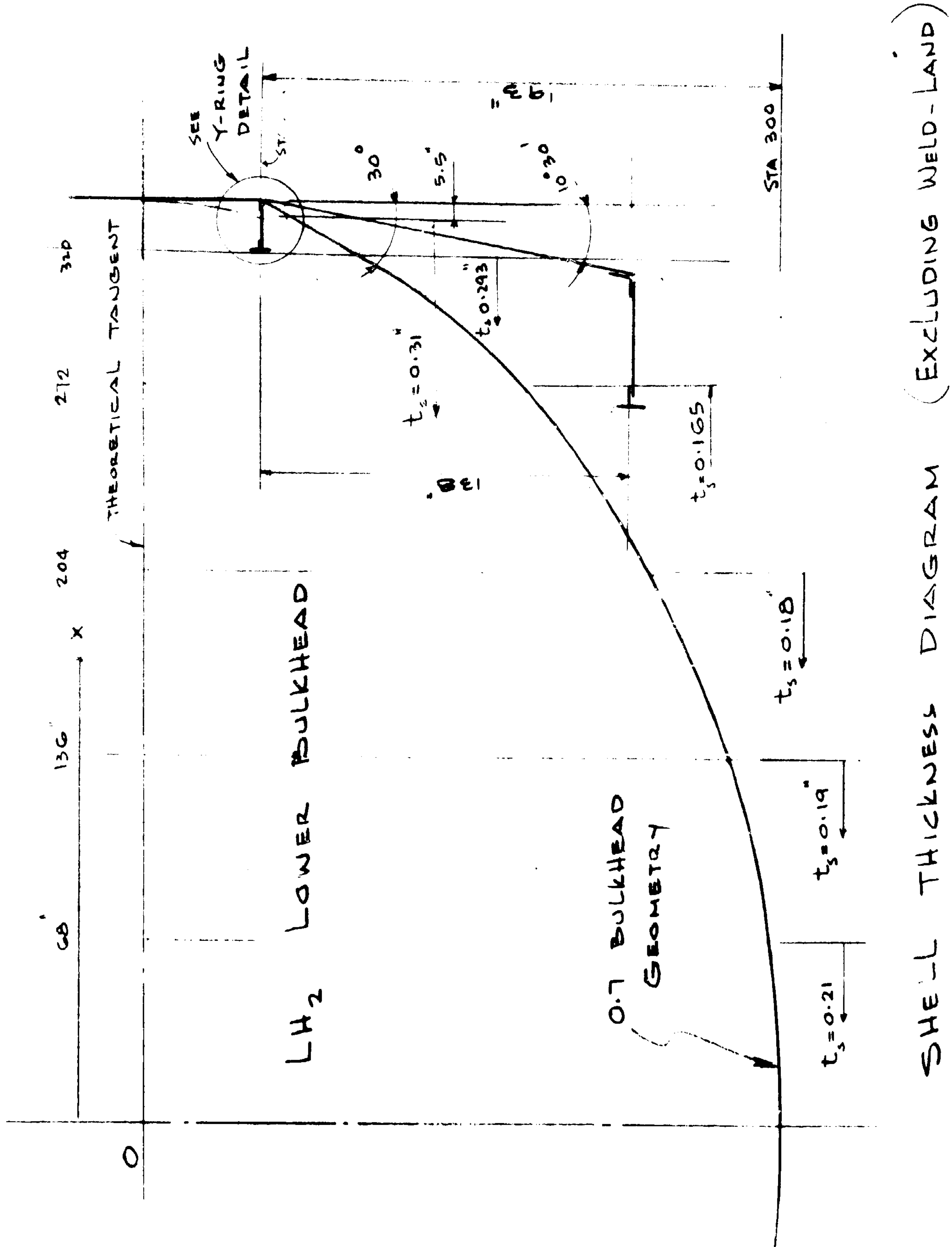
SINGLE STAGE MLLV
CORE VEHICLE

ANALYSIS OF LH_2
LOWER BULKHEAD SHELL
CONFIGURATION

Material 2219-T87 For Bulkhead Construction
Weld-Land Stress Properties
$f_{tu} = 16,000$ PSI

Non-Weld Area Stress Properties
$f_{tu} = 63,000$ PSI

SHELL THICKNESS PRESENTATION OF LH_2 - LOWER BULKHEAD CONSTRUCTION



SIZING OF LH_2 TANK LOWER BULKHEAD

ASSUME 0.707 BULKHEAD GEOMETRY

$a = 340$

$b = 236$

AT TOP OF SHELL $\quad r_1 = r_2 :: a^2/b = \frac{340^2}{236} = 490''$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

$$b^2x^2 + a^2y^2 = a^2b^2$$

$$b^2x^2 = a^2b^2 - a^2y^2 = a^2(b^2 - y^2)$$

$$x^2 = \frac{a^2}{b^2}(b^2 - y^2)$$

$$x = \frac{a}{b}\sqrt{b^2 - y^2}$$

$$y = \frac{b}{a}\sqrt{a^2 - x^2}$$

$x = 68''$ $\quad y = 0.695\sqrt{115600 - 4624} = 232''$

$x = 136$ $\quad y = 0.695\sqrt{115,600 - 18500} = 217''$

$x = 204$ $\quad y = 0.695\sqrt{115600 - 41600} = 189''$

$x = 272$ $\quad y = 0.695\sqrt{115,600 - 73800} = 142.2''$

$x = 340$ $\quad y = 0$

$$r_1 = r_2^3 \frac{b^2}{a^4}$$

$$r_2 = \frac{(a^4 y^2 + b^4 x^2)^{1/2}}{b^2}$$

① FOR $x = 68$, $a = 340$

$y = 232$, $b = 236$

$$r_2 = \frac{(a^4 y^2 + b^4 x^2)^{1/2}}{b^2} = \frac{(1.34 \times 10^{10} \times 53800 + 0.309 \times 10^{10} \times 4624)^{1/2}}{55600}$$

$$= 488$$

$$r_1 = r_2^3 \frac{b^2}{a^4} = 488^3 \times \frac{236^2}{1.34 \times 10^{10}} = \frac{646 \times 10^{10}}{1.34} = 482$$

② FOR $x = 136$

$y = 217$

$$r_2 = \frac{\overbrace{(1.34 \times 10^{10} \times 47000 + 0.309 \times 10^{10} \times 18450)^{1/2}}^{262}}{55600} = \frac{262 \times 10^5}{55600}$$

$$= 472$$

$$r_1 = 472^3 \times \frac{236^2}{1.34 \times 10^{10}} = 436''$$

③ FOR $x = 204$

$y = 189$

$$r_2 = \frac{(1.34 \times 10^{10} \times 35650 + 0.309 \times 10^{10} \times 41600)^{1/2}}{55600} = \frac{247 \times 10^5}{55600} = 447$$

$$r_1 = 447^3 \times \frac{236^2}{1.34 \times 10^{10}} = 371''$$

(4) FOR $X = 272$

$y \doteq 142.2$

$$r_2 = \frac{\left(1.34 \times 10^{10} \times 20200 + 0.309 \times 10^{10} \times 74000\right)^{1/2}}{55600} = \frac{224 \times 10^5}{55600} = 402.5$$

$$r_1 = 402.5^3 \times \frac{236^2}{1.34 \times 10^{10}} = 270$$

(5) FOR $X = 340$ $y = 0$

$$r_2 = \frac{b^2}{b^2} x = 340$$

$$r_1 = 340^3 \frac{236^2}{340^4} = 163.5$$

SIZING OF THICKNESS OF LH_2 LOWER BULKHEAD SHELL

BASED UPON VARIOUS COORDINATES LOCATION

a) $X = 0, \quad Y = 236$ $\qquad$ B.F. = 0.95

$$N_\phi = N_\theta = \frac{pa^2}{2b} \times \frac{1}{B.F}$$

$$= \frac{50 \times 340^2}{2 \times 236 \times 0.95} = 12900 \text{ LB/"}$$

$$t = \frac{12900}{63000} = 0.205" \quad \text{SAY } 0.21"$$

AT WELD LAND

$$N_\phi = N_\theta = \frac{D.F \times pa^2}{2b \times B.F} = 1.2 \times 12900 = 15500 \text{ LB/"}$$

$$t = \frac{15500}{16000} = 0.97"$$

b) $X = 68$

$Y = 232$

$$N_\phi = \frac{pr_2}{2 \times B.F} = \frac{50 \times 488}{2 \times 0.95} = 12850 \text{ LB/"}$$

$$t = \frac{12850}{63000} = 0.204"$$

$$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right) = 50\left(488 - \frac{488^2}{2 \times 432}\right) = 12550 \text{ LB/"}$$

MAX $t = 0.204"$ $\qquad$ N_ϕ GOVERNS DESIGN

c) $X = 136$

$Y = 217$

$$N_\phi = \frac{pr_2}{2} = \frac{50 \times 472}{2} = 11800 \text{ LB/"}$$

$$t = \frac{11800}{63000} = 0.188"$$

$$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right)$$

$$= 50\left(412 - \frac{412^2}{2\times436}\right) = 10850$$

N_ϕ STILL GOVERNS THE DESIGN

AT WELD LAND

$$N_\phi = 1.2 \times 11800 = 14140$$

$$t_w = \frac{14140}{16000} = 0.883''$$

d) $x = 204$

$y = 189$

$r_2 = 447$

$r_1 = 371$

$$N_\phi = \frac{p r_2}{2} = \frac{50\times447}{2} = 11200 \text{ LB}$$

$$t = \frac{11200}{63000} = 0.177''$$

$$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right) = 50\left(447 - \frac{447^2}{2\times371}\right) = 8,900 \text{ LB/''}$$

N_ϕ GOVERNS SHELL DESIGN

AT WELD LAND

$$N_\phi = 1.2 \times 11200 = 13450 \text{ LB/''}$$

$$t_w = \frac{13450}{16000} = 0.84''$$

e) $x = 272$ (CONNECTION TO CONICAL PORTION)

$y = 142$

$r_1 = 270$

$r_2 = 402.5$

$$N_\phi = \frac{p r_2}{2} = \frac{50 \times 402.5}{2} = 10500 \text{ LB/in}$$

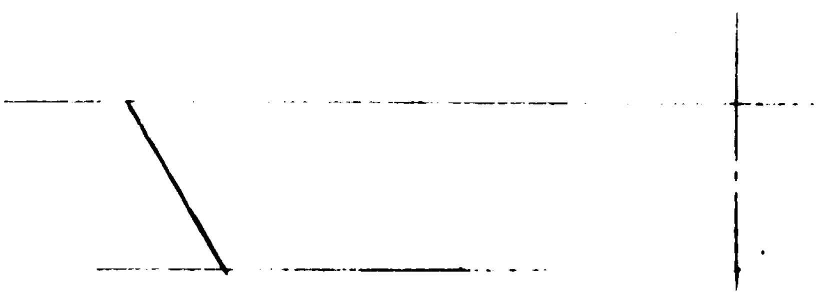
$$t = \frac{10500}{63000} = 0.16''$$

$$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right) = 50\left(402.5 - \frac{402.5^2}{540}\right) = 5130 \text{ LB/in}$$

N_ϕ GOVERNS DESIGN

DISCUSSION:

IT IS SOMEWHERE IN $X = 272 \pm$ THE BULKHEAD SHELL STARTS TO BECOME CONICAL SHAPE. THE HOOP STRESS WILL GOVERN THE THICKNESS DESIGN OF THE CONICAL PORTION



$$N_\phi = \frac{pR}{2\cos\alpha} = \frac{50 \times 272}{2\cos\alpha} = \frac{25 \times 272}{0.866} = 7850 \text{ LB/in}$$

$$N_\theta = 2 \times 7850 = 15700$$

$$t = \frac{15700}{63000} = 0.25''$$

AT WELD LAND

$$t = \frac{15700 \times 1.2}{16000} = 1.18''$$

THICKNESS REQUIREMENT AT THE REGION OF JUNCTION BETWEEN CONICAL SHELL & CONICAL ELEMENT OF THE Y-RING SECTION

$$11 \sin 30^\circ = 11 \times 0.5 = 5.5''$$

$$X = 340 - 5.5 = 334.5''$$

$$N_\theta = \frac{p \times 334.5}{\cos 30^\circ} = \frac{50 \times 334.5}{0.866} = 19350 \text{ LB}/''$$

$$t = \frac{19350}{63000} = 0.307'' \quad \text{SAY} \quad 0.31''$$

AT WELD LAND

$$t_w = \frac{1.2 \times 19350}{16000} = 1.45''$$

AT $X = 320''$

$$N_\theta = \frac{p \times 320}{\cos 30^\circ} = \frac{50 \times 320}{0.866} = 18500 \, \#/''$$

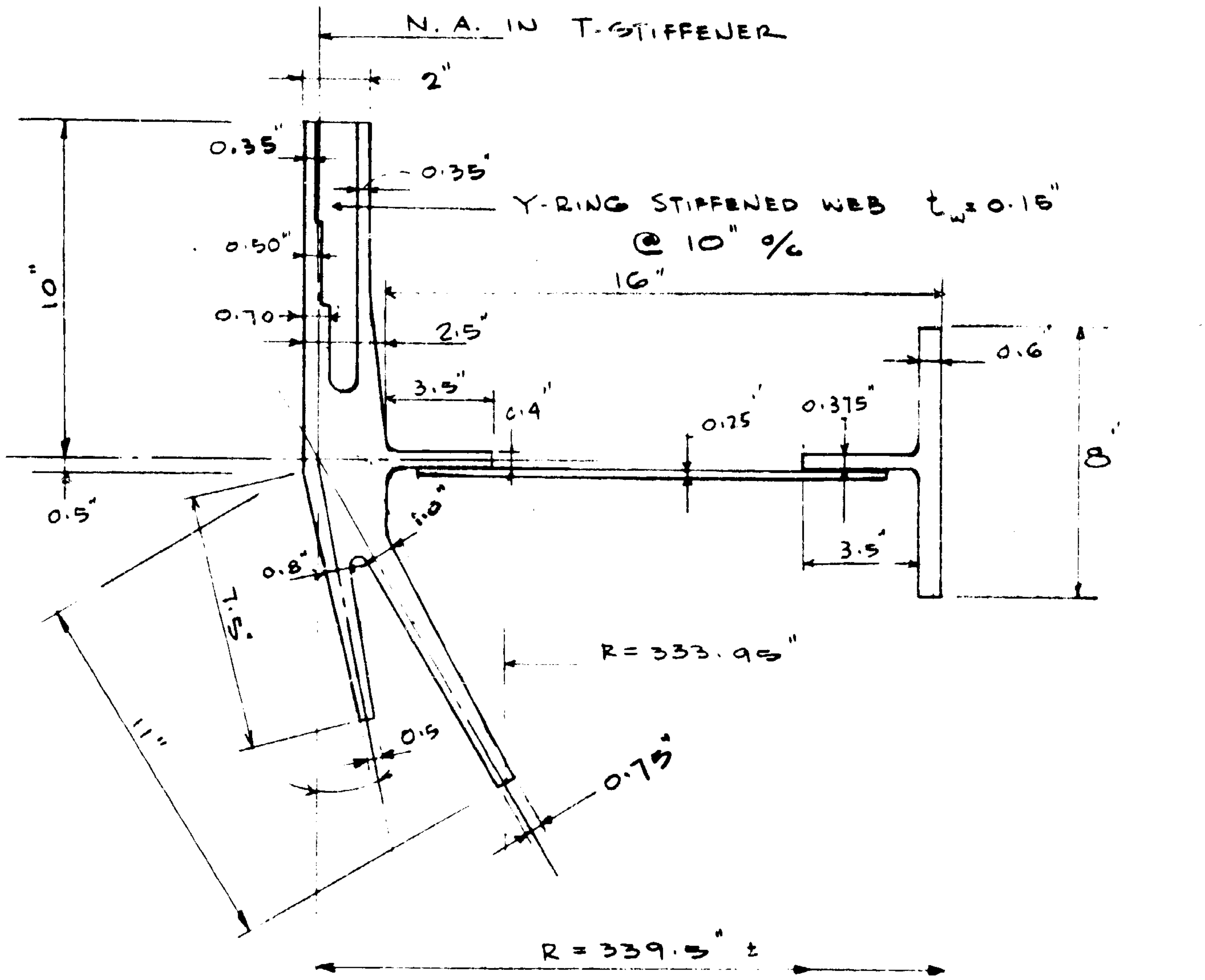
$$t = \frac{18500}{63000} = 0.293$$

B-2.6

ANALYSIS OF LH_2 LOWER
BULKHEAD Y-RING SECTION
SINGLE STAGE

SINGLE STAGE

MULTI-CHAMBER ENGINE Y-RING AT LOWER HEAD



ASSUMED DIE-FORGED 2219-T87 ALUMINUM

Y-RING SECTION

LH_2 AFT TANK HEAD Y-RING ANALYSIS

1.) APPROXIMATE SIZING OF TANK WALL THICKNESS BASED UPON PRESSURE ONLY

$$S_2 = \frac{pR \times D.F.}{t}$$

$p = 50$ PSI ULT

D.F. = 1.2

$$t = \frac{50 \times 340 \times 1.2}{34500}$$

$$= 0.582''$$

STIFFENED Y-RING PROVIDES TOTAL OF 0.70" SKIN

2) APPROXIMATE SIZING OF MEMBRANE LOAD THICKNESS REQUIREMENT AT WELDED JT.

$$S_2 = \frac{pR \times 1.2}{\cos\alpha \times t}$$

$$t_1 = \frac{pR \times 1.2}{S_2 \cos\alpha} = \frac{50 \times 334 \times 1.2}{16000 \times 0.866} = 1.45''$$

THIS IS THE WELDLAND THICKNESS REQUIREMENT

WELD STRENGTH $f_{tu} = 34500$ PSI

$$t_2 = \frac{pR \times 1.2}{S_2 \cos\alpha} = \frac{50 \times 334 \times 1.2}{34500 \times 0.866} = 0.67''$$

THIS IS THE MIN. THICKNESS REQUIREMENT BEYOND WELDLAND. HOWEVER THE BENDING STRESS DUE TO DISCONTINUITY WILL REQUIRE THICKER SKIN HENCE ASSUME MIN 0.60" FOR SKIN THICKNESS AT Y-RING CONICAL END

SIMULATED Y-RING ANALYSIS

EQUIVALENT CYLINDER END Y-RING SKIN THICKNESS. USE AV. SHEARED THICKNESS APPROACH

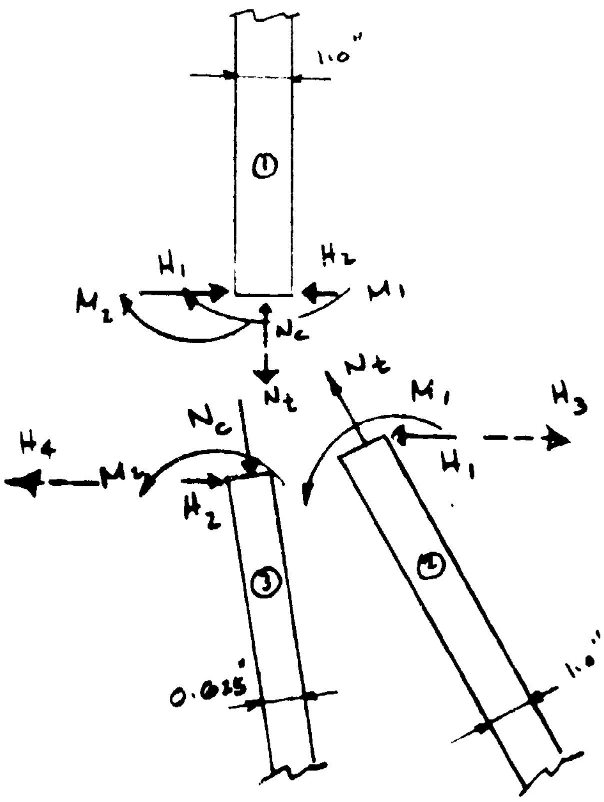
$$\text{CYLINDER } t_{AV} = \frac{2.75\times0.7 + 2.75\times0.50 + 2.75\times0.35 + 2.5\times0.7 + 2.5\times0.45 + 2\times2.5}{12}$$

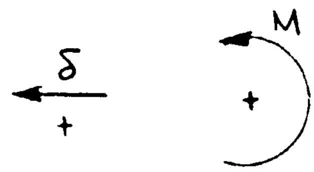
$$= \frac{1.92 + 1.375 + 0.96 + 1.75 + 1.12 + 5.0}{12} \approx 1.0''$$

CONE $t_{AV} \approx 1.0$

THRUST SKIRT $t_{AV} \approx 0.625$

ASSUME ELEMENT 1, 2 & 3 ARE ALL LONG CYLINDERS





SOLUTIONS ARE:

$M_1 = 4,650$ IN-LB

$M_2 = 2,910$ IN-LB

$H_1 = 5,590$ LB/IN

$H_2 = 1,820$ LB/IN

$H_3 = 9,830$ LB/IN

$H_4 = 2,400$ LB/IN

COMPUTATION OF GEOMETRIC PARAMETERS

SHELL ①

$$\lambda = \frac{1.279}{\sqrt{Rt}} = \frac{1.279}{\sqrt{340 \times 1.0}} = \frac{1.279}{18.5} = 0.0692$$

$$D = \frac{Et^3}{12(1-\nu^2)} = \frac{E}{10.7} = 0.0933\,E$$

SHELL ②

$$\beta = 1.279\sqrt{\frac{R_2}{t}} = 1.279 \times 19.8 = 25.30$$

$$R_2 = \frac{340}{\sin 60^\circ} = \frac{340}{0.866} = 392$$

$$K_1 = 1 - \frac{1-2\nu}{2\beta}\cot(\phi - \omega) = 1 - \frac{1-0.66}{50.6} \times 0.5774 \approx 1$$

$$K_2 \approx 1$$

SHELL ③
As a cylinder

$$\lambda = \frac{1.279}{\sqrt{Rt}} = \frac{1.279}{\sqrt{340 \times 0.625}} = \frac{1.279}{14.6} = 0.875$$

$$D = \frac{Et^3}{12(1-\nu^2)} = \frac{0.244\,E}{10.7} = 0.0228\,E$$

TENSILE FORCE DUE TO PRESSURIZATION IN CONICAL PORTION OF THE BULKHEAD IS

$$N_t = pR/\cos\alpha = 50 \times 340/0.866 = 19{,}650 \text{ LB}/''$$

$$H_3 = N_t \sin\alpha = 19{,}650 \times \sin 30^\circ = 9{,}830 \text{ LB}/''$$

$$H_4 = N_c \sin\theta = 13200 \sin 10^\circ 30' = 13200 \times 0.1822 = 2400\ ^{\#}/''$$

TREAT SHELL ③ AS A CONICAL SHELL

$$R_2 = \frac{340}{\sin 79^\circ 30'} = \frac{340}{0.9838} = 346''$$

$$\beta = 1.279\sqrt{\frac{R_2}{t_{AV}}} = 1.279\sqrt{\frac{346}{0.625}} = 29.8$$

$$K_1 \approx K_2 \approx 1$$

DEFLECTION OF SHELL 1

$$\delta_1^{H_1} = -\frac{H_1}{2D\lambda^3} = -\frac{H_1}{2\times 0.0933E\times 3.31\times 10^{-4}} = \frac{-H_1}{6.63\times 10^{-4}\times 9.33\times 10^{-2}E}$$

$$= -0.01615\times 10^{6}\,H_1/E = -\frac{16150\,H_1}{E}$$

$$\delta_1^{H_2} = \frac{H_2}{2D\lambda^3} = \frac{H_2}{2\times 0.0933E\times 3.31\times 10^{-4}} = \frac{16150\,H_2}{E}$$

$$\delta_1^{M_1} = \frac{+M_1}{2D\lambda^2} = +\frac{M_1}{2\times 0.0933E\times 4.79\times 10^{-3}} = +\frac{M_1}{9.58\times 9.33\times 10^{-5}}$$

$$= +0.0112\times 10^{5}\,M_1/E = +\frac{1120\,M_1}{E}$$

$$\delta_2^{M_2} = \frac{1120\,M_2}{E}$$

$$\delta_2^{p} = \frac{R}{E}(S_2-\nu S_1) = \frac{340}{E}(17000-0.33\times 8500) = \frac{4.83\times 10^{6}}{E}$$

ROTATION OF SHELL 1

$$\theta_1^{H_1} = +\frac{H_1}{2D\lambda^2} = \frac{1120\,H_1}{E}$$

$$\theta_1^{H_2} = -\frac{H_2}{2D\lambda^2} = -\frac{1120\,H_2}{E}$$

$$\theta_1^{M_1} = -\frac{M_1}{\lambda D} = -\frac{M_1}{0.0692\times 0.0933E} = -\frac{155\,M_1}{E}$$

$$\theta_2^{M_2} = -\frac{155\,M_2}{E}$$

$$\theta_1^{p} \simeq 0$$

DEFLECTION OF SHELL ②

▷ ROARK FORMULA FOR STRESS & STRAIN P. 272 CASE 14 & 15

$$\delta_2^{H_1} = \frac{H_1}{E \times t}\left(\beta R_2 \sin^2\phi\right)\left(k_2 + \frac{1}{k_1}\right)$$

$$= \frac{H_1}{E \times 1}\left(25.3 \times 392 \times 0.866^2\right)(1+1) = \frac{14830 H_1}{E}$$

0.748

$$\delta_2^{H_3} = \frac{-H_3}{E\,t}\left(\beta R_2 \sin^2\phi\right)\left(k_2 + \frac{1}{k_1}\right)$$

$$= -\frac{9,830}{E \times 1}\left(25.3 \times 392 \times 0.748\right) \times 2 = -\frac{14.58 \times 10^7}{E}$$

(THIS IS THE INWARD DEFLECTION CAUSED BY THE IMAGINARY FORCE, H_3, USED TO ELIMINATE THE HORIZONTAL COMPONENT DUE TO N_t AT SHELL ②)

$$\delta_2^{M_1} = +\frac{M_1}{E\,t}\left(\frac{2\beta^2 \sin\phi}{k_1}\right) = \frac{M_1}{E}\left(\frac{2 \times 25.3^2 \times 0.866}{1}\right) = \frac{1110 M_1}{E}$$

$$\delta_2^{p} = \frac{R}{E}\left(S_2 - \nu S_1\right) = \frac{340}{E}\left(19600 - 3240\right) = 5.55 \times 10^6/E$$

ROTATION OF SHELL ②

$$\theta_2^{H_1} = +\frac{H_1}{E\,t}\left(2\beta^2 \sin\phi\right)\left(\frac{1}{k_1}\right) = \frac{H_1}{E\,t}\left(2 \times 25.3^2 \times 0.866\right) \times \frac{1}{1}$$

$$= \frac{1110 H_1}{E}$$

$$\theta_2^{H_3} = -\frac{H_3}{E\,t}\left(2\beta^2 \sin\phi\right)\left(\frac{1}{k_1}\right) = -\frac{H_3}{E \times 1}\left(2 \times 25.3^2 \times 0.866\right) \times \frac{1}{1}$$

$$= -\frac{10.9 \times 10^6}{E}$$

$$\theta_2^{M_1} = +\frac{M_1}{E\,t}\left(\frac{4\beta^3}{R_2 k_1}\right) = \frac{M_1 \times 4 \times 640 \times 25.3}{392 \times 1\ E} = \frac{1650 M_1}{E}$$

$$\theta_2^{p} = \frac{2pR\sin\alpha\left(1 - \frac{1}{2}\nu\right)}{E\,t} = \frac{2 \times 340 \times 50 \times 0.5\,(0.835)}{E} = \frac{14200}{E}$$

DEFLECTION OF SHELL 3

$$\delta_3^{H_2} = -\frac{H_2}{E \times t}\left(\beta R_2 \sin^2\phi\right)\left(k_2 + \frac{1}{k_1}\right)$$

$$= -\frac{H_2}{E \times 0.625}\left(29.8 \times 346 \times 0.9838^2\right) \times 2 = \frac{-32000 H_2}{E}$$

$$\delta_3^{H_4} = \frac{H_4 \times 32000}{E} = \frac{2400 \times 32000}{E} = \frac{7.67 \times 10^6}{E}$$

$$\delta_3^{M_2} = \frac{M_2}{Et}\left(\frac{2\beta^2 \sin\phi}{k_1}\right) = \frac{M_2 \times 2 \times 890 \times 0.9838}{E} = \frac{1750\, M_2}{E}$$

$$\delta_3^{p} = 0$$

ROTATION OF SHELL 3

$$\theta_3^{H_2} = -\frac{H_2}{Et}\left(2\beta^2 \sin\phi\right)\left(\frac{1}{k_1}\right)$$

$$= -\frac{H_2}{E \times 0.625}\left(2 \times 29.8^2 \times 0.9838\right) \times \frac{1}{1} = \frac{-2795 H_2}{E}$$

$$\theta_3^{M_2} = +\frac{M_2}{E \times 0.625}\left(\frac{4\beta^3}{R_2 k_1}\right) = \frac{M_2 \times 4 \times 29.8^3}{E \times 0.625 \times 346 \times 1} = \frac{490\, M_2}{E}$$

$$\theta_3^{H_4} = +\frac{2795 \times H_4}{E} = \frac{2795 \times 2400}{E} = \frac{6.71 \times 10^6}{E}$$

$$\theta_3^{p} = 0$$

SET UP COMPATIBLE EQUATIONS

$$\delta_1 = \delta_2$$

$$-16150H_1 + 16150H_2 + 1120M_1 + 1120M_2 + 4.83\times10^6 = 14830H_1 - 14.58\times10^7 + 1110M_1 + 5.55\times10^6$$

$$-30980H_1 + 16150H_2 + 0 + 1120M_2 + 13.86\times10^7 = 0 \quad (1)$$

$$\theta_1 = \theta_2$$

$$1120H_1 - 1120H_2 - 155M_1 - 155M_2 = 1110H_1 - 10.9\times10^6 + 1650M_1 + 0.0142\times10^6$$

$$-1120H_2 - 1805M_1 - 155M_2 + 10.886\times10^6 = 0 \quad (2)$$

$$\delta_1 = \bar{\delta}_3$$

$$-16150H_1 + 16150H_2 + 1120M_1 + 1120M_2 + 4.83\times10^6 = -32000H_2 + 7.67\times10^6 + 1750M_2$$

$$-16150H_1 + 48150H_2 + 1120M_1 - 630M_2 - 2.84\times10^6 = 0 \quad (3)$$

$$\theta_1 = \theta_3$$

$$1120H_1 - 1120H_2 - 155M_1 - 155M_2 = -2795H_2 + 490M_2 + 6.71\times10^6$$

$$1120H_1 + 1675H_2 - 155M_1 - 645M_2 - 6.71\times10^6 = 0 \quad (4)$$

SOLVE THE FOLLOWING 4 SIMULTANEOUS EQUATIONS

$$-30980 H_1 + 16150 H_2 + 0 + 1120 M_2 + 138.6 \times 10^6 = 0 \quad (1)$$

$$-1120 H_2 - 1805 M_1 - 155 M_2 + 10.89 \times 10^6 = 0 \quad (2)$$

$$-16150 H_1 + 48150 H_2 + 1120 M_1 - 630 M_2 - 2.84 \times 10^6 = 0 \quad (3)$$

$$1120 H_1 + 1675 H_2 - 155 M_1 - 645 M_2 - 6.71 \times 10^6 = 0 \quad (4)$$

1.918 × (3)
$$-30980 H_1 + 92400 H_2 + 2146 M_1 - 1210 M_2 - 5.45 \times 10^6 = 0 \quad (5)$$

27.7 × (4)
$$+30980 H_1 + 46400 H_2 - 4290 M_1 - 17850 M_2 - 185.8 \times 10^6 = 0 \quad (6)$$

$$-30980 H_1 + 16150 H_2 + 0 + 1120 M_2 + 138.6 \times 10^6 = 0 \quad (7)$$

$$-1120 H_2 - 1805 M_1 - 155 M_2 + 10.89 \times 10^6 = 0 \quad (8)$$

(5) + (6)
$$138{,}800 H_2 - 2144 M_1 - 19060 M_2 - 191.25 \times 10^6 = 0 \quad (9)$$

(6) + (7)
$$62{,}550 H_2 - 4290 M_1 - 16730 M_2 - 47.20 \times 10^6 = 0 \quad (10)$$

123.8 × (8)
$$-138{,}800 H_2 - 223{,}500 M_1 - 19200 M_2 + 1350 \times 10^6 = 0 \quad (11)$$

$$+138{,}800 H_2 - 2144 M_1 - 19060 M_2 - 191.25 \times 10^6 = 0 \quad (12)$$

2.22 × (10)
$$138{,}800 H_2 - 9500 M_1 - 37200 M_2 - 104.7 \times 10^6 = 0 \quad (13)$$

(11) + (12)
$$-225{,}644 M_1 - 38{,}260 M_2 + 1158.75 \times 10^6 = 0 \quad (14)$$

(12) − (13)
$$7{,}356 M_1 + 18{,}140 M_2 - 86.55 \times 10^6 = 0 \quad (15)$$

30.7 × (15)
$$+225{,}644 M_1 + 556{,}000 M_2 - 2666 \times 10^6 = 0 \quad (16)$$

(14) + (16)
$$517{,}740 M_2 - 1507.25 \times 10^6 = 0$$

$$M_2 = \frac{1507.25 \times 10^6}{517{,}740} = \underline{\underline{2910}}\ ''\# \quad (17)$$

SUBSTITUTE (17) INTO (14)

$$-225{,}644 M_1 - 111.2 \times 10^6 + 115875 \times 10^6 = 0$$

$$M_1 = \frac{1047.55 \times 10^6}{225{,}644} = \underline{\underline{4650}}\ ''\# \quad (18)$$

SUBSTITUTE (17) & (18) INTO (8)

$$\overset{8.4\times10^6}{} \qquad \overset{-.45\times10^6}{}$$

$$-1120\,H_2 - 1805\times4650 - 155\times2910 + 10.89\times10^6 = 0$$

$$H_2 = \frac{2.039\times10^6}{1120} = \underline{\underline{1820}}\ \#/'' \qquad (19)$$

SUBSTITUTE (17), (18) & (19) INTO (4)

$$\overset{3.05\times10^6}{} \qquad \overset{0.721\times10^6}{} \qquad \overset{1.876\times10^6}{}$$

$$1120H_1 + 1675\times1820 - 155\times4650 - 645\times2910 - 6.71\times10^6 = 0$$

$$H_1 = \frac{6.261\times10^6}{1120} = \underline{\underline{5590}}\ \#/''$$

CHECK EQ (1)

$$\overset{-173.2\times10^6}{} \qquad \overset{29.4\times10^6}{} \qquad \overset{3.26\times10^6}{}$$

$$-30980\times5590 + 16150\times1820 + 1120\times2910 + 138.6\times10^6 = 0$$

$$-173.2\times10^6 + 171.3 \approx 0 \qquad \text{OK}$$

CHECK EQ. (2)

$$\overset{-2.04\times10^6}{} \qquad \overset{8.4\times10^6}{} \qquad \overset{0.451\times10^6}{}$$

$$-1120\times1820 - 1805\times4650 - 155\times2910 + 10.89\times10^6 = 0$$

$$-10.89\times10^6 + 10.89\times10^6 = 0 \ \checkmark \qquad \text{OK}$$

CHECK EQ. (3)

$$-16150\times5590 + 48150\times1820 + 1120\times4650 - 630\times2910 - 2.84\times10^6 = 0$$

$$-90.3\times10^6 + 87.6\times10^6 + 5.21\times10^6 - 1.83\times10^6 - 2.84\times10^6 = 0$$

$$-94.87\times10^6 + 92.81\times10^6 \approx 0 \qquad \checkmark$$

OK

SUPERSEDED

SET UP COMPATIBLE EQUATIONS

$$\delta_1 = \delta_2$$

$$-16150H_1 + 16150H_2 + \overset{0}{\cancel{1120}}M_1 + 1120M_2 = 14830H_1 - 14.58\times10^{7} + 1110M_1$$

$$-30980H_1 + 16150H_2 + 0 + 1120M_2 + 14.58\times10^{7} = 0 \qquad 1$$

$$\theta_1 = \theta_2$$

$$1120H_1 - 1120H_2 - 155M_1 - 155M_2 = 1110H_1 - 10.9\times10^{6} + 1650M_1$$

$$0 - 1120H_2 - 1805M_1 - 155M_2 + 10.9\times10^{6} = 0 \qquad 2$$

$$\delta_1 = \delta_3$$

$$-16150H_1 + 16150H_2 + 1120M_1 + 1120M_2 = -32000H_2 + 7.67\times10^{6} + 1750M_2$$

$$-16150H_1 + 48150H_2 + 1120M_1 - 630M_2 - 7.67\times10^{6} = 0 \qquad 3$$

$$\theta_1 = \theta_3$$

$$1120H_1 - 1120H_2 - 155M_1 - 155M_2 = -2795H_2 + 490M_2 + 6.71\times10^{6}$$

$$1120H_1 + 1675H_2 - 155M_1 - 645M_2 - 6.71\times10^{6} = 0 \qquad 4$$

THE SOLUTIONS OF 4 SIMULTANEOUS EQUATIONS ARE :

$$-30980 H_1 + 16150 H_2 + 0 + 1120 M_2 + 145.8 \times 10^6 = 0 \quad (1)$$

$$-1120 H_2 - 1805 M_1 - 155 M_2 + 10.9 \times 10^6 = 0 \quad (2)$$

$$-16150 H_1 + 48150 H_2 + 1120 M_1 - 630 M_2 - 7.67 \times 10^6 = 0 \quad (3)$$

$$1120 H_1 + 1675 H_2 - 155 M_1 - 645 M_2 - 6.71 \times 10^6 = 0 \quad (4)$$

1.918 × (3)

$$-30980 H_1 + 92400 H_2 + 2146 M_1 - 1210 M_2 - 14.73 \times 10^6 = 0 \quad (5)$$

27.7 × (4)

$$+30980 H_1 + 46400 H_2 - 4290 M_1 - 17860 M_2 - 185.8 \times 10^6 = 0 \quad (6)$$

$$-30980 H_1 + 16150 H_2 + 0 + 1120 M_2 + 145.8 \times 10^6 = 0 \quad (7)$$

$$-1120 H_2 - 1805 M_1 - 155 M_2 + 10.9 \times 10^6 = 0 \quad (8)$$

(5) + (6) $\quad 138,800 H_2 - 2144 M_1 - 19060 M_2 - 200.53 \times 10^6 = 0 \quad (9)$

(6) + (7) $\quad 62,550 H_2 - 4290 M_1 - 16730 M_2 - 40 \times 10^6 = 0 \quad (10)$

123.8 × (8) $\quad -138,800 H_2 - 223500 M_1 - 19200 M_2 + 1350 \times 10^6 = 0 \quad (11)$

$\quad 138,800 H_2 - 2144 M_1 - 19060 M_2 - 200.53 \times 10^6 = 0 \quad (12)$

2.22 × (10) $\quad 138,800 H_2 - 9500 M_1 - 37200 M_2 - 88.8 \times 10^6 = 0 \quad (13)$

(11) + (12) $\quad -225,644 M_1 - 38260 M_2 + 1149.5 \times 10^6 = 0 \quad (14)$

(12) − (13) $\quad 7,356 M_1 + 18140 M_2 - 111.73 \times 10^6 = 0 \quad (15)$

30.7 × (15) $\quad +225,644 M_1 + 556000 M_2 - 3426 \times 10^6 = 0 \quad (16)$

(14) + (16) $\quad 517,740 M_2 - 2275.5 \times 10^6 = 0$

$$M_2 = \frac{2275.5 \times \cancel{10^6}}{0.5177 \times \cancel{10^6}} = 4390 \text{ ''-\#} \quad (17)$$

SUBSTITUTE (17) INTO (15)

$$7356 M_1 + \overset{79.7 \times 10^6}{18140 \times 4390} - 111.73 \times 10^6 = 0$$

$$M_1 = \frac{32.03 \times 10^6}{7356} = 0.00435 \times 10^6 = 4350 \text{ ''-\#} \quad (18)$$

SUBSTITUTE (17) & (18) INTO (B)

$$\overset{7.85\times10^6}{} \quad \overset{0.68\times10^6}{}$$

$$-1120\,H_2 - 1805\times4350 - 155\times4390 + 10.9\times10^6 = 0$$

$$H_2 = \frac{2.37\times10^6}{1120} = 2{,}115 \text{ LB}/'' \quad (19)$$

SUBSTITUTE (17), (18) & (19) INTO (4)

$$\overset{3.54\times10^6}{} \quad \overset{-.673\times10^6}{} \quad \overset{-2.83\times10^6}{}$$

$$1120\,H_1 + 1675\times2115 - 155\times4350 - 645\times4390 - 6.71\times10^6 = 0$$

$$1120\,H_1 = 6.673\times10^6$$

$$H_1 = \frac{6.673\times10^6}{1120} = 5{,}960 \ \#/'' \quad (20)$$

CHECK EQ. (1)

$$-30980\times5{,}960 + 6150\times2{,}115 + 1120\times4390 + 145.8\times10^8 = 0$$

$$-184.6\times10^6 + 34.1\times10^6 + 4.91\times10^6 + 145.8\times10^6 = 0$$

$$-184.6\times10^6 + 184.7\times10^6 = 0 \qquad \text{OK}$$

CHECK EQ. (2)

$$\overset{-2.37\times10^6}{} \quad \overset{-7.85\times10^6}{} \quad \overset{-0.681\times10^6}{}$$

$$-1120\times2{,}115 - 1805\times4350 - 155\times4390 + 10.9\times10^6 = 0$$

$$-10.91\times10^6 + 10.90\times10^6 = 0 \qquad \text{OK}$$

CHECK EQ. (3)

$$-16150\times5{,}960 + 48150\times2115 + 1120\times4350 - 630\times4390 - 7.67\times10^6$$

$$-96.1\times10^6 + 101.8\times10^6 + 4.86\times10^6 - 2.77\times10^6 - 7.67\times10^6$$

$$106.66\times10^6 - 106.54\times10^6 \approx 0 \qquad \text{OK}$$

INVESTIGATION OF STRESSES IN SHELL ①

SINCE Y-RING IS A FORGED SECTION, ELEMENT SKIN IS THICK & STIFF.

λ VALUE IS INSIGNIFICANT AND THE DECAY COEFF. OF MOMENT FROM HETENYI IS NEGLIGIBLE.

IT IS ON THE CONSERVATIVE SIDE TO INVESTIGATE SECTION AT TOP OF Y-RING END BY USING 85% OF THE TOTAL DISCONTINUITY MOMENT

IS $0.85 \times (M_1 + M_2) = (4650 + 2910) \times 0.85 = 6{,}430^{\text{''-\#}}$

$$I_s = 0.35 \times 2 \times 0.825^2 = 0.70 \times 0.68 = 0.475 \text{ IN}^4/\text{''}$$

$$N_t = \frac{340 \times 50}{2} = 8500$$

$$N_c = 13200$$

NET $N_c = 13200 - 8500 = 4700$ LB/''

ASSUME MISMATCH BENDING MOMENT

$$M = 4700 \times \frac{\overset{0.044}{0.25 \times 0.35}}{2} = 207^{\text{''-\#}}$$

TOTAL $M = 6{,}430 + 207 = 6{,}637^{\text{''-\#}}$

a) BENDING STRESS AT THE WELD JT.

$$\sigma_b = \frac{6637}{0.475} \times 1 = 13{,}950 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_a = \frac{4700}{0.70} = 6{,}720 \text{ PSI}$$

COMBINED MERIDIANAL STRESS

$$\Sigma \sigma = 13{,}950 + 6720 = 20{,}670 \text{ PSI}$$

INVESTIGATION OF HOOP STRESS AT Y-RING JOINT

@ SHELL ①

$$\text{MAX } t = 2.5'' \qquad \lambda = \frac{1.279}{\sqrt{340 \times 2.5}} = 0.044$$

a) MEMBRANE STRESS DUE TO INTERNAL PRESSURE

$$\sigma_2 = \frac{pr}{t} = \frac{340 \times 50}{2.5} = 6800 \ \#/\square'' \quad \text{TENSION}$$

b) DIRECT HOOP STRESS DUE TO ΣH

$$\Sigma H = H_1 - H_2 = 5590 - 1820 = 3{,}770 \ \#/$$

$$\sigma_2' = -\frac{2H}{t} \lambda R = \frac{2 \times 3{,}770}{2.5} \times 0.044 \times 340$$

$$= -45{,}200 \text{ PSI} \quad \text{COMPRESSIVE STRESS}$$

c) DIRECT HOOP STRESS DUE TO M.

$$\sigma_2'' = \frac{2M}{t} \lambda^2 R = \frac{2 \times 7560}{2.5} \times 0.00194 \times 340 = 4{,}000 \text{ PSI}$$

TENSION

d) HOOP STRESS DUE TO POISSON BENDING

$$\sigma_2''' = 0.3 \times \frac{6 \times 8{,}740}{6.25} = \pm 2{,}520 \text{ PSI}$$

COMBINED STRESS

$$\Sigma \sigma_2 = 6800 - 45{,}200 + 4000 - 2520 = -36930 \text{ PSI} \quad \text{O.F}$$

$$\Sigma \sigma_2 = 6800 - 45{,}200 + 4000 + 2520 = -31{,}890 \text{ PSI} \quad \text{I.F}$$

COMPR STRESS OVER THE WHOLE SECTION

INVESTIGATION OF HOOP COMPR. STRESS CAPABILITY OF Y-RING INTERSECTION

ON CONSERVATIVE APPROACH, TREAT Y-RING INTERSECTION JT. AS A RING (IGNORE ADD'L WEB & CAP)

ASSUME $n = 3$

$$\gamma_{CR} = \frac{(n^2-1)EI}{(1-\nu^2)R^3}$$

$$I = \frac{1}{12}\, 1.0 \times 2.5^3 = 1.3$$

$$R = 339$$

$$R^3 = 38,900,000 = 38.9 \times 10^6$$

$$\gamma_{CR} = \frac{8 \times 10.4 \times \cancel{10^6} \times 1.3}{0.91 \times 38.9 \times \cancel{10^6}} = 3.06 \text{ PSI}$$

MAX HOOP COMPR. CAPABILITY

$$\sigma_{CR} = \frac{\gamma_{CR} \times R}{t} = \frac{3.06 \times 340}{2.5}$$

$$= 417 \text{ PSI}$$

FROM THE ABOVE INVESTIGATION, ADD'L WEB & CAP ARE NEEDED FOR LARGER STIFFNESS AT Y-RING INTERSECTION

INVESTIGATION OF STRESSES AT THE CONICAL BULKHEAD PORTION SHELL 2

ASSUME MIN $t = 1.0''$

GIVEN $M_1 = 4,650$ "-#

$H_1 = 5,590$ #/"

$H_3 = 9,830$ #/"

STRESSES IN MERIDIANAL DIRECTION

a) BENDING STRESS

$$\sigma_b = \frac{6 \times 4,650}{1} = 27900$$

b) AXIAL STRESS

$$\sigma_a = \frac{8500}{0.866} = \frac{9800}{37,700}$$

$$M.S = \frac{60,000}{37,700} - 1 = +0.59$$

STRESS IN HOOP DIRECTION ASSUME $t = 2.0''$

a) MEMBRANE HOOP STRESS

$$\sigma_2 = \frac{pR}{t \cos\alpha} = \frac{50 \times 346}{2 \times 0.866} = 9,800 \text{ PSI}$$

TENSILE

b) DIRECT HOOP STRESS DUE TO M

$$\sigma_2' = \frac{M_1}{t R_2}\left(\frac{2\beta^2}{K_1}\right) = \frac{4650}{2 \times 392} 2 \times 17.9^2 = 3,800 \text{ PSI}$$

TENSILE

c) DIRECT HOOP STRESS DUE TO ΣH

$$\Sigma H = -9830 + 5{,}590 = -4{,}240 \ \#/''$$

$$\sigma_2'' = \frac{\Sigma H}{t}\left(\frac{1}{K_1} + \frac{K_1+K_2}{2}\right)\beta \sin\phi$$

$t = 2.0$

$$= \frac{-4240}{2.0} \times 2 \times 17.9 \times 0.866 = -65{,}600 \text{ PSI}$$

COMPRESSIVE

FOR $t = 2.0''$ $\quad \beta = 1.279 \times \sqrt{\frac{R}{t}}$

$$= 1.279\sqrt{\frac{392}{2.0}} = 1.279 \times 14 = 17.9$$

d) POISSON BENDING STRESS

$$\sigma_b = \frac{0.33 \times 6 \times 4{,}650}{4} = 2300 \text{ PSI}$$

COMBINED HOOP STRESS

$$\Sigma \sigma_2 = 9800 + 3800 - 65{,}600 + 2300$$

$$= -49{,}700 \text{ Compr. I.F.}$$

$$\Sigma \sigma_2 = 9800 + 3800 - 65{,}600 - 2300$$

$$= -54{,}300 \text{ PSI} \quad \text{O.F}$$

Compr STRESS

TREAT THIS ELEMENT AS SHORT CYLINDER
THE ALLOWABLE Compr STRESS WILL BE OK

OR BY COUNTING THE ADD'L STIFFNESS FROM WEB & CAP. AND USING RING ANALOGY, THE ALLOWABLE HOOP COMPR. STRESS WOULD BE OK ALSO

INVESTIGATION OF STRESSES IN SHELL (3) AT Y-RING INTERSECTION

ASSUME $t \approx 0.8''$

$$R/t = 340/0.8 = 425$$

MAX. COMPRESSIVE STRESS CAPABILITY AS A MONOCOQUE LONG CYLINDER

$$\sigma_{CR} = CE\ t/R = \frac{0.3 \times 10.4 \times 10^6}{425} = 7350 \text{ PSI}$$

a) BENDING STRESS

$$\sigma_b = \frac{6 \times 2910}{0.64} = 27200 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_a = \frac{13200}{0.8} = 16,500 \text{ PSI}$$

FROM ABOVE EVALUATION, IT IS OBVIOUS THAT MONOCOQUE SKIN OF 0.8 MAY BE OK FOR A SHORT CYLINDER APPROACH, BUT IT WILL NOT WORK AS A LONG CYLINDER

USING SHORT CYLINDER CRITICAL STRESS FORMULA TN-3783 EQUATION 29 P. 25

$$\sigma_c = \frac{k_c \pi^2 E t^2}{12(1-\nu^2) L^2}$$

USING AV. $t = 0.625''$

$$Z_L = \frac{L^2}{Rt}(1-\nu^2)^{1/2} < 1$$

$$k_c = 4 \qquad L = 7.5$$

$$R/t = 340/0.625 = 545$$

$$\sigma_c = \frac{4 \times 9.85 \times 10.4 \times 10^6 \times 0.625^2}{10.7 \times 56.5}$$

$$= 0.265 \times 10^6 = 265\,000 \text{ PSI}$$

$f_{cy} \approx 50000$ psi IS THE ALLOWABLE UPPER LIMIT.

USING 0.625 AS THE AV. THICKNESS

$$\sigma_b = \frac{6 \times 2910}{0.39} = 44700 \text{ PSI}$$

$$R_b = \frac{44700}{1.4 \times 63000} = 0.507$$

$$\sigma_d = \frac{13200}{0.625} = 21100 \text{ PSI}$$

$$R_d = \frac{21100}{50000} = 0.422$$

$$M.S = \frac{1}{0.929} - 1 = \underline{+0.075} \longrightarrow$$

PRACTICALLY STIFFENERS ARE CONNECTED AT Y-RING LEG BY BOLTS. THE STIFFENESS WILL BE IMMENSELY INCREASED. HENCE THE SUGGESTED Y-RING SECTION MAY BE OK

ANALYSIS OF ADD'L RING SECTION AT THE Y-RING INTERSECTION

THE ADD'L RING SECTION IS DESIGNED PRIMARILY TO SUPPORT THE HORIZONTAL THRUST LOAD COMPONENT FROM THE THRUST SKIRT. IT ALSO SERVES THE PURPOSE TO STABILIZE THE Y-RING SECTION AGAINST THE HOOP COMPRESSIVE STRESSES INDUCED BY THE DISCONTINUITY FORCES IN CYLINDER AND CONICAL BULKHEAD SHELL

GIVEN SKEWED THRUST LOAD

$$N_c = 7000 \text{ LB}/''$$

$$\sin 10^\circ 30' = 0.1822$$

a) $$(N_c)_H = N_c \sin 10^\circ 30' = 7000 \times 0.1822$$

$$= 1{,}275 \text{ LB}/''$$

AT THRUST POST LOCATION ADD'L PEAK THRUST LOAD

b) $$\Delta N_c = (13200-7000) \times 6.85 = 41^k$$

$$(\Delta N_c)_H = 41 \times \sin 9^\circ 30' = 41 \times 0.1822 = 7.5^k/_{POST}$$

RING AREA REQ'D TO SUPPORT THE UNIFORM HOR. THRUST IS

a) $$A_R = \frac{1275 \times 340}{63000} = 6.9 \square''$$

b ASSUME THE REMAINDER OF PEAK LOAD AT THRUST POST ACTED LIKE CONCENTRATED LOAD OF 7.5^{k} @ EA. POST. OR 15° ($\pi/12$)

THE BENDING MOMENT DUE TO THIS CONC. LOAD IS

$$M = \tfrac{1}{2} PR \left(\frac{24}{\pi} - \cot 7.5°\right)$$

$$= \tfrac{1}{2}\, 7.5 \times 340 \left(\overset{0.0436}{7.64 - 7.596}\right) = 56 \text{ in-kip.}$$

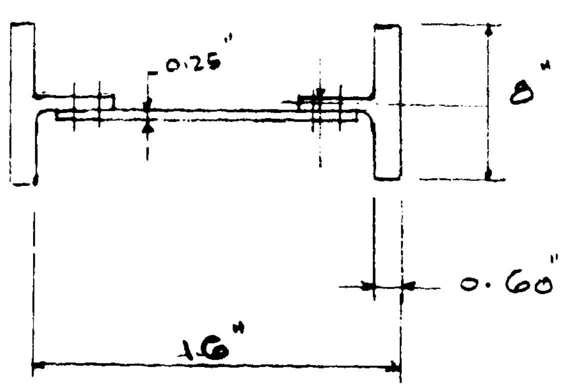
THE MAX. TENSION LOAD AT LOAD PT DUE TO RING ACTION

$$T = \tfrac{1}{2}\, 7.5 \cot 7.5°$$

$$= 3.75 \times 7.596 = 28.4 \text{ kips}$$

MAX. AXIAL LOAD IS THEN

$$\Sigma T = 28400 + \overset{435\,000}{1275 \times 340} = 463{,}400 \text{ LB.}$$



$A_1 = 8 \times 0.6 = 4.8$

$A_2 = 3.5 \times 0.375 = 1.33$

$A_3 = 14 \times 0.25 = 3.5$

$\quad 9.63 \square''$

ASSUME A SIMULATED RING SECTION. ONLY USE THE PART OF THE MOM. OF INERTIA VALUE

$$I_1 = 4.8 \times 7.7^2 = 283$$

$$I_2 = 1.33 \times 5.65^2 = 43$$

$$I_3 = \frac{1}{12} 0.25 \times 14^3 = \underline{57}$$

$$383 \text{ IN}^4$$

STRESSES IN RING SECTION

a) BENDING STRESS

GIVEN M = 56000 "·#

$$\sigma_b = \frac{56000 \times 10}{383} = 1465 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_a = \frac{463,400}{9.63} = 48,200 \text{ PSI}$$

$$M.S = \frac{63000}{49670} - 1 = \underline{+0.265}$$

B-2.7

SINGLE STAGE VEHICLE
ANALYSIS OF LH_2 TANK SIDE WALLS

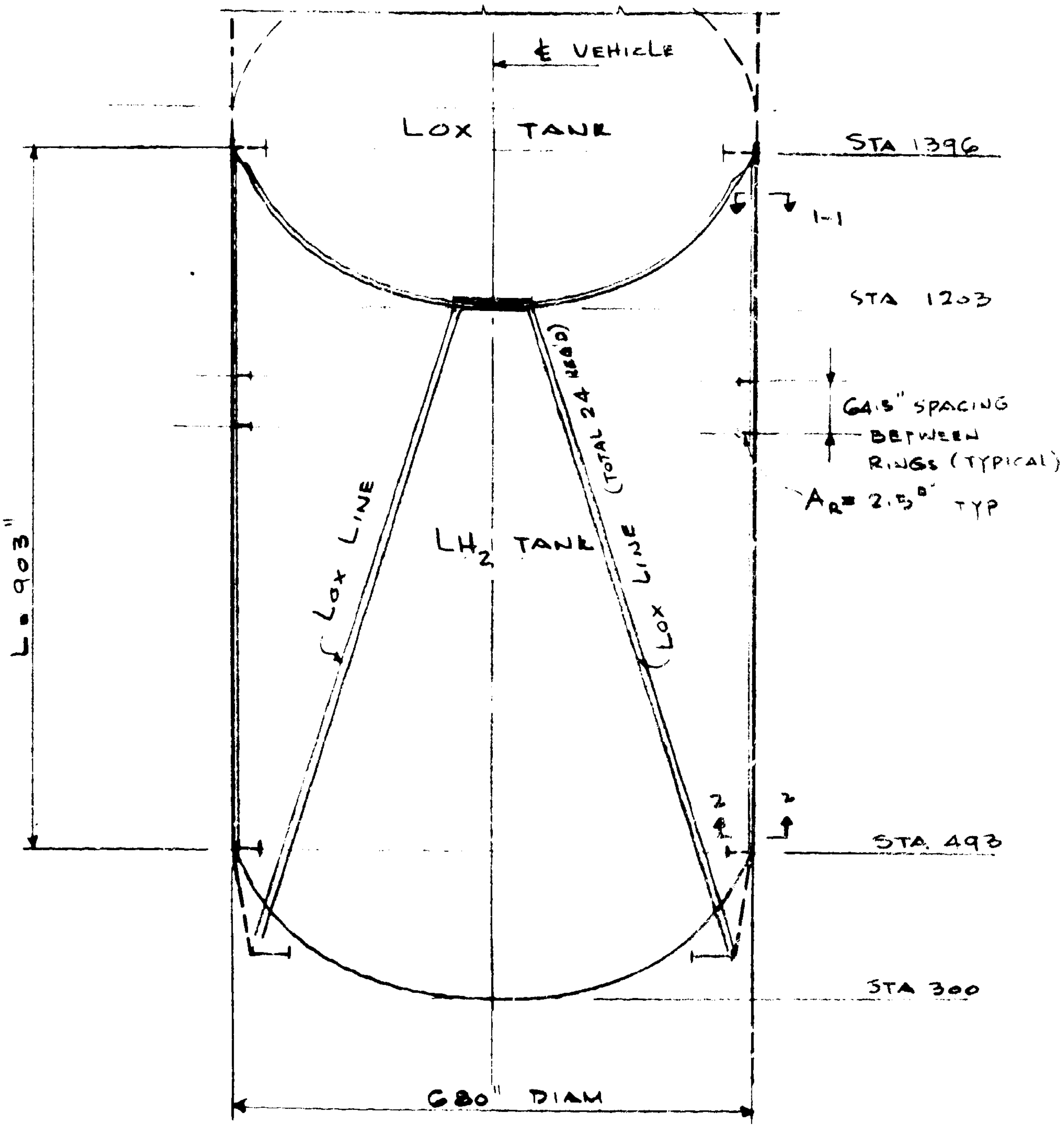
Design Ultimate Pressure at Sta 500 $p = 47.5$ PSI

Design Ultimate Pressure at Sta 1,395 $p = 40$ PSI

Given Max $N_c = 3{,}200$ Lb/In Sta 1,390

$N_c = 2{,}800$ Lb/In Sta 498

LIQUID HYDROGEN TANK CONFIGURATION

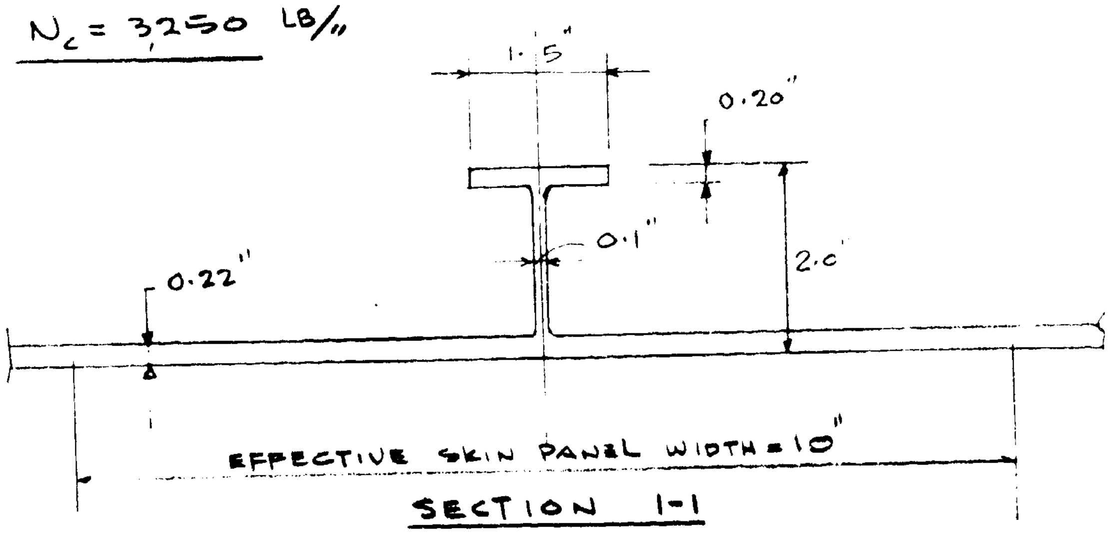


LH_2 TANK CONFIGURATION

SIZING OF FWD END SECTION OF LH_2 TANK

SKIN - STIFFENER SECTION @ STA 1390 ±

$N_c = 3,250$ LB/IN



SECTION 1-1

ASSUME STRESS LEVEL

$f_c = 15000$ PSI

$$b_{eff} = 1.7t\sqrt{\frac{E}{f_c}} = 1.7 \times 0.22\sqrt{\frac{10.4\times10^6}{1.5\times10^4}}$$

$$= 1.7 \times 0.22 \times 26.3 = 9.86'' \quad \text{SAY } 10''$$

	A	Y	AY	AY^2	I_o
$A_1 =$	$10 \times 0.22 = 2.200$	0.110	0.2420	0.0266	0.00886
$A_2 =$	$1.55 \times 0.10 = 0.158$	1.010	0.1595	0.1610	0.03290
$A_3 =$	$1.50 \times 0.20 = 0.300$	1.90	0.5900	1.1200	0.00099
	2.658		0.9915	1.3076	0.04275

$$\bar{Y} = \frac{0.9915}{2.658} = 0.374''$$

$$I_c = 1.3076 + 0.04275 - 2.658 \times 0.374^2$$

$$= 0.9162$$

$$I_s = 0.09762$$

$$t_a = 2.658/10 = 0.2658$$

SIZING OF INTERMEDIATE RING FRAMES

TIMOSHENKO'S CRITERION

GIVEN

$$a_x = 340 \text{ IN}$$
$$a_R = 330 \text{ IN}$$
$$I_s = 0.1535 \text{ IN}^4/$$
$$L_R = 64.5 \text{ IN}$$

$$A_R = \frac{4\pi^2 I_s \, a_x \, a_R}{L_R^3}$$

$$= \frac{4 \times 9.85 \times 0.09762 \times 343 \times 330}{267000} = 1.62 \ \square''$$

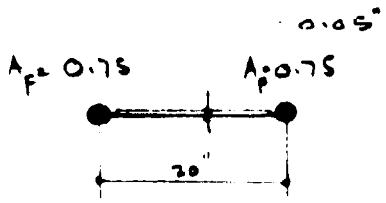
SHANLEY'S CRITERION (MODIFIED)

$$I_R = \frac{0.785 \, R_{cyl}^4 \times N_c}{1000 \, E_R \times L_R}$$

$$= \frac{0.785 \times 1.335 \times \cancel{10}^{4} \times 2.8 \times \cancel{10}^{3}}{\cancel{1000} \times 10.4 \times \cancel{10}^{6} \times 64.5}$$

$$= \frac{0.785 \times 1.335 \times 28000}{10.4 \times 64.5} = 44$$

ASSUME RING AREA $= 2.50 \ \square''$ FOR STABILITY PURPOSE AND MAINTAINING CIRCULARITY OF TANK SHAPE.



$$I = 1.5 \times 10^2 = 150 \text{ IN}^4 \text{ MIN}$$

LH_2 TANK SIDE WALL — SKIN THICKNESS REQUIREMENT

ASSUMPTION : SKIN DESIGNED FOR INTERNAL PRESSURE

AT BOTTOM END OF LH_2 TANK WALL   STA 498

$$p = 47.5 \text{ psi}$$

ASSUME 2219-T87 ALUMINUM ALLOY

$$f_{tu} = 62000 \text{ psi}$$

$$t = \frac{pr}{f_t} = \frac{47.5 \times 340}{62000} = 0.26''$$

AT TOP END OF LH_2 TANK WALL   STA 1390

$$p = 40 \text{ psi}$$

$$t = \frac{40 \times 340}{62000} = 0.22''$$

ASSUME 8 GIRTH WELDS (CIRCUMFERENTIAL WELDING JT)

USE PROOF TEST PRESSURE CRITERION $p_p = 1.1 \times p_{LIMIT}$

$$t = 1.2 \times \frac{39.0 \times 340}{2 \times 16000} = 0.50''$$

THICKNESS @ GIRTH WELD-LANDS

$$t = \frac{1.2 \times 39.0 \times 340}{16000} = 1.0''$$

THICKNESS @ LONGITUDINAL WELD LAND

8 LONGITUDINAL WELDS ARE SUGGESTED

A.) INVESTIGATION OF GENERAL INSTABILITY STRESS FOR LH_2 TANK WALL (LONG CYLINDER APPROACH)

USING APPROXIMATE STRESS EQUATION

$$\sigma_{CR} = C^* E \frac{t^*}{R}$$

$L/D = 903/680 = 1.33$

$A_R = 2.50$

$L_R = 64.5$

$I_s = 0.09762$

$t_s = 0.22$

$R = 340$

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$= \sqrt[4]{12 \times 0.09762 \left(\frac{2.5}{64.5} + 0.22\right)}$$

$$= \sqrt[4]{0.3025} = 0.741$$

$$R/t^* = \frac{340}{0.741} = 458$$

FOR APPROXIMATION APPLY BUCKLING COEFF. CHART

FOR $m = 8$

$n = 3$

$U = 0.00025$

EXTRAPOLATE FROM THE ATTACHED CHART (FIG. 13)

$$C^* \approx 0.65$$

$$\sigma_{CR} = \frac{0.65 \times 10.4 \times 10^6}{458} = 14,750 \text{ PSI}$$

$$t_a = 0.2658$$

$$N_{CR} = 14,750 \times 0.2658 = 3920 \text{ LB/"}$$

$$M.S = \frac{3920}{3250} - 1 = \underline{\underline{+0.20}} \longrightarrow \text{OK}$$

N_c GIVEN IS 3250 #/" . PER REF. LOAD CURVE

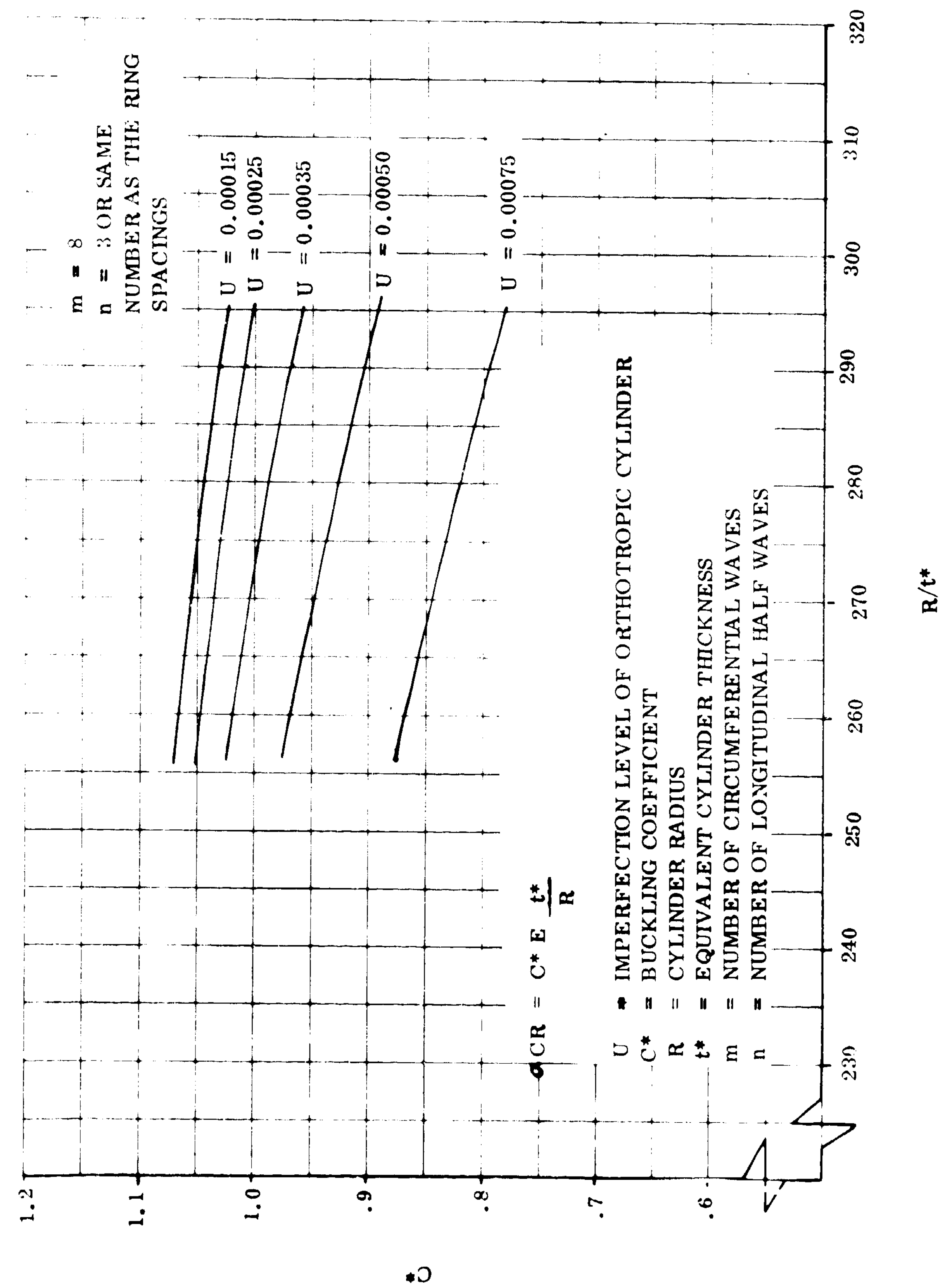


FIGURE 13: C* Vs R/t* CURVES FOR ORTHOTROPIC CYLINDRICAL CONFIGURATIONS OTHER THAN CORRUGATED SKIN CYLINDERS

B) GENERAL INSTABILITY INVESTIGATION

(MONOCOQUE CONSTRUCTION NO RINGS & STIFFENERS)

$$t^* = t_s = 0.22$$

$$R/t^* = 340/0.22 = 1535$$

$$C = 0.18$$

$$\sigma_{CR} = \frac{0.18 \times 10.4 \times 10^6}{1535} = 0.00122 \times 10^6$$

$$= 1220 \text{ PSI}$$

ACTUAL COMPRESSIVE STRESS

$$\sigma_c = 12.10 \text{ KSI} = 12,100 \text{ PSI}$$

MONOCQUE CONSTRUCTION NEEDS LARGER t_s VALUE.

C) INVESTIGATION OF LOCAL INSTABILITY STRESSES

a) SKIN-PANEL BUCKLING STRESS BETWEEN STIFFENERS

$$\sigma_{CR} = \frac{K \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$$= \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.22}{10}\right)^2$$

$$= 18500 \text{ PSI}$$

$$M.S = \frac{18500}{12100} - 1 = \underline{+0.53}$$

b) INTERFRAME BUCKLING STRESSES

(i) APPLICATION OF EULER'S FORMULA

$$N_{CR} = \frac{\pi^2 E I}{L^2}$$

$$= \frac{9.85 \times 10.4 \times 10^6 \times 0.09762}{64.5^2}$$

$$= 2420 \text{ LB/in}$$

SHy

(ii) APPLICATION OF INTERFRAME BUCKLING STRESS EQUATION

$$N_{CR} = \frac{K \pi^2 E \quad t_1^*}{12(1-\nu^2) \quad L_R^2}$$

▷ D5-13272 & NASA-TN-3783

$$t_1^* = \sqrt[4]{12 \times 0.09762 \times 0.22} = 0.71$$

$$t_1^{*3} = 0.36$$

$$Z_L = \frac{L_R^2}{R t_1^*} (1-\nu^2)^{1/2} = \frac{4150}{340 \times 0.71} \times 0.945 = 16.4$$

FROM BUCKLING COEFFICIENT CHART FIG 6 TN-3783

FOR $R/t_1^* = 340/0.71 = 480 \approx 500$

$K_c = 4.5$ MIN.

$$N_{CR} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6 \times 0.36}{10.7 \times 4150}$$

$$= 3740 \text{ LB}/''$$

$$MS = \frac{3740}{3250} - 1 = \underline{\underline{+0.15}} \longrightarrow$$

OK

IF RING SPACING IS @ 70" ±

$$N_{CR} = 3740 \times 4150/4900 = 3,170 \text{ LB}/''$$

$$MS = \frac{3170}{3200} - 1 \approx \underline{\underline{0.0}} \longrightarrow$$

SHY A BIT

c) CRIPPLING STRESS IN STIFFENER ELEMENT IS NOT A PROBLEM

(D) INVESTIGATION OF LH_2 TANK SIDE WALL FOR TENSION LOAD CAPABILITY

MAX N_t LOAD OCCURS FOR THE OPERATIONAL MODE OF CORE + 8 SRM + INJECTION

MAX N_t = 11000 LB/"

t_a = 0.2658 " (EQUIVALENT SMEARED THICKNESS)

$$\sigma_t = \frac{11000}{0.2658} = 41500 \text{ PSI}$$

$$M.S = \frac{62000}{41500} - 1 = \underline{+0.49} \longrightarrow$$

I.F USING SKIN ALONE FOR N_t LOAD

$$\sigma_t = \frac{11000}{0.22} = 50{,}000 \text{ PSI}$$

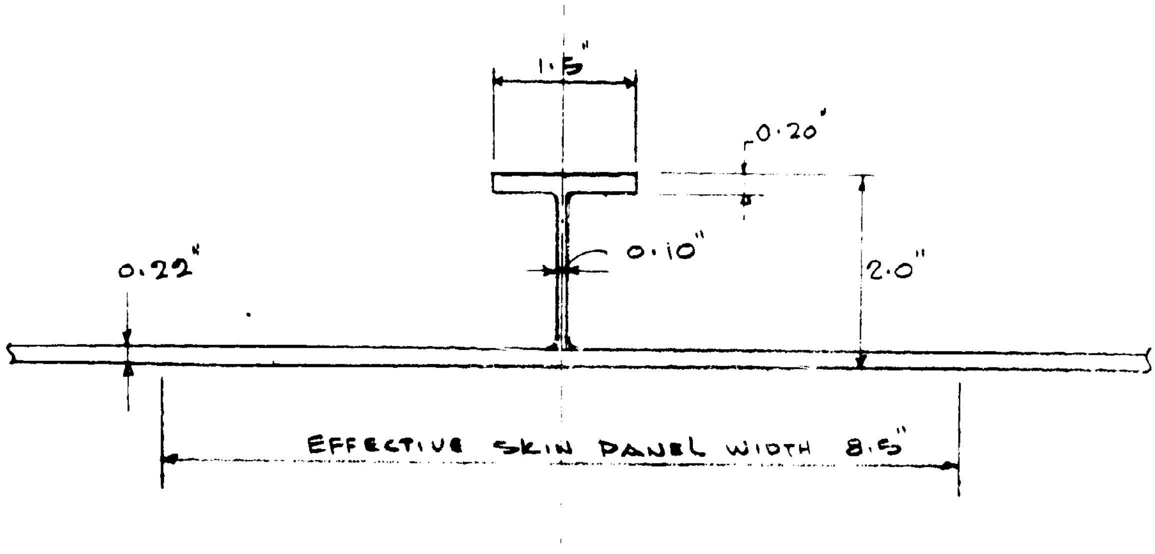
$$M S = \frac{62000}{50{,}000} - 1 = \underline{+0.24} \longrightarrow$$

OK

SUPERSEDED

SIZING OF FWD END SECTION OF LH_2 TANK

1ST TRIAL



ASSUME STRESS LEVEL AROUND

$$f_c = 20{,}000 \text{ PSI}$$

$$b_{EFF} = 1.7\,t\sqrt{\frac{E}{f_c}} = 1.7 \times 0.22\sqrt{\frac{10.4\times10^6}{2.0\times10^4}}$$

$$= 1.7 \times 0.22 \times 22.8 = 8.5"$$

	A	Y	AY	AY^2	I_o
$A_1 = 8.5 \times 0.22 =$	1.870	0.110	0.2060	0.02265	$\frac{1}{12}\,8.5\times0.22^3 = 0.00755$
$A_2 = 1.58 \times 0.10 =$	0.158	1.010	0.1595	0.16100	$\frac{1}{12}\,0.1\times1.58^3 = 0.03290$
$A_3 = 1.5 \times 0.20 =$	0.300	1.90	0.5700	1.08000	$\frac{1}{12}\,1.5\times0.2^3 = 0.00099$
	2.328		0.9355	1.26365	0.04144

$$\bar{Y} = \frac{0.9355}{2.328} = 0.402"$$

$$I_c = 1.264 + 0.04144 - 2.328 \times \overset{0.374}{0.402^2} = 0.9314$$

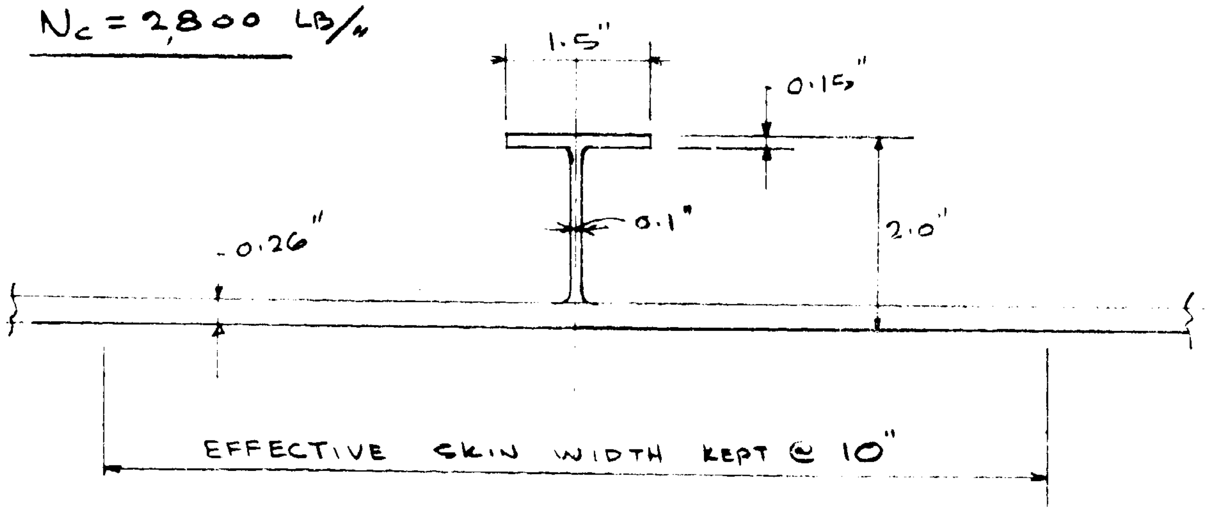
$$I_s = 0.9314 / 8.5 = 0.1096 \quad \text{IN}^4/"$$

$$\rho = \sqrt{\frac{I_c}{A}} = \sqrt{\frac{0.9314}{2.328}} = 0.630$$

SIZING OF AFT END SECTION OF LH_2 TANK

SKIN - STIFFENER SECTION @ STA 501 ±

$N_c = 2{,}800$ LB/IN



SECTION 2-2

	A	y	AY	Ay^2	I_o
$A_1 = 10 \times 0.26 =$	2.600	0.130	0.338	0.0440	0.01470
$A_2 = 1.59 \times 0.10 =$	0.159	1.1145	0.182	0.2060	0.03290
$A_3 = 1.5 \times 0.15 =$	0.225	1.9250	0.433	0.8350	0.00042
	2.984 □"		0.953	1.0850	0.04802

$$\bar{Y} = \frac{0.953}{2.984} = 0.319$$

$$I_c = 1.085 + 0.048 - 2.984 \times 0.319^2 = 0.829$$

$$I_S = 0.829/10 = 0.0829$$

$$t_a = 0.2984$$

ACTUAL COMPRESSIVE STRESS

$$\sigma_c = \frac{2800}{0.2984} = \underline{9{,}380} \text{ PSI}$$

A) INVESTIGATION OF GENERAL INSTABILITY STRESSES FOR AFT LH_2 TANK WALL SECTION

USING APPROXIMATE STRESS EQUATION

$$\sigma_{CR} = C^* E \frac{t^*}{R}$$ ▷ D5-13272

$$t^* = \sqrt[4]{12 \times 0.0829 \left(\underset{0.0384}{\frac{2.5}{65}} + 0.26 \right)} = 0.738$$

$$R/t^* = 340/0.738 = 462$$

$$C^* \approx 0.645$$

$$\sigma_{CR} = \frac{0.645 \times 10.4 \times 10^6}{462} = 14500 \text{ PSI}$$

$$M.S = \frac{14500}{9380} - 1 = \underline{+0.55}$$ →

B) INVESTIGATION OF INTERFRAME BUCKLING STRESS

$$N_{CR} = \frac{K \pi^2 E \, t_1^{*3}}{12(1-\nu^2) L_R^2}$$

$$t_1^* = \sqrt[4]{12 \times I_s \times t_s}$$

$$= \sqrt[4]{12 \times 0.0829 \times 0.26} = 0.713$$

$$t_1^{*3} = 0.362$$

$$Z_L = \frac{4150}{340 \times 0.71} \times 0.945 = 16.4$$

$K_c \approx 4.5$ FROM FIG 6, TN-3783

$$N_{CR} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6}{10.7 \times 4150} \times 0.362 = 3750 \text{ LB/IN}$$

$$M.S = \frac{3750}{2800} - 1 = \underline{+0.34}$$ →

MARGIN OF SAFETY APPEARS EXCESSIVE, HOWEVER THE PEAKING EFFECT AT UPPER END OF THRUST STRUCTURE MAY STILL HAVE SOME INFLUENCE AT THE STATION INVESTIGATED. HENCE THE LOWER END SECTION OF LH_2 WALL MAY BE OK.

INVESTIGATION OF GENERAL INSTABILITY STRESS
BY APPLYING THE EXACT STRESS EQUATION
REFERENCE 3, D5-13272

GIVEN DATA

$L = 903''$

$R = 340''$ $\qquad R^2 = 115600$

$A_s = 0.2658 \, \square'' / ''$

$t_s = 0.22$

$p = 10''$

$t_a = 0.2658''$

$I_s = 0.09762$

$A_R = 2.50 \, \square''$

$I_R = 150 \text{ IN}^4$

$L_R = 64.5$

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s\right)} = \sqrt[4]{12 \times 0.09762 \left(\frac{2.5}{64.5} + 0.22\right)} = 0.741$$

$$R/t^* = \frac{340}{0.741} = 458$$

ASSUME NODE PT @ EVERY OTHER RING

$n = 7$ (BASED ON NODE PT ASSUMPTION)

$m = 8$ (BASED ON TEST DATA GUIDE)

$$\gamma = \frac{t^* R^2}{I_s} = \frac{0.741 \times 115600}{0.09762} = 8.78 \times 10^5$$

$$\psi = \frac{2\pi n R}{L} = \frac{6.28 \times 7 \times 340}{903} = 16.55$$

$\psi^2 = 275$

$\psi^4 = 75600$

$$\psi^2 \gamma = 275 \times 8.78 \times 10^5 = 2.41 \times 10^8$$

ASSUME $\quad U = 0.00025$

$$\rho = U \times \left(\frac{R}{t^*}\right)^2 = 2.5\times10^{-4} \times 2.1\times10^{5} = 52.5$$

$$K = 1 + \frac{2\rho}{m^{1.5}n^{0.5}D} = 1 + \frac{2\times52.5}{8^{1.5}7^{0.5}D} = 1 + \frac{1.75}{D} = 1 + \frac{B_1}{D}$$

$$B_1 = 1.75$$

$$\phi = \frac{4R^4}{I_s t^*} = \frac{4\times1.335\times10^{10}}{0.09762\times0.741} = 7.385\times10^{11}$$

$$\phi - 8\Gamma\left(\frac{R}{t^*}\right)^2 = -7.385\times10^{11}$$

$$H_x = \frac{E t_a}{1-\nu^2} = \frac{E\times0.2658}{0.891} = 0.298\,E$$

$$H_\theta = \frac{E A_R}{L_R} + E t_s = E\times0.0388 + 0.22\,E = 0.2588\,E$$

$$\frac{H_x}{H_\theta} = 1.15$$

$$D_x = E I_s = 0.09762\,E$$

$$D_\theta = \frac{E t_s^3}{12(1-\nu^2)} + E\frac{I_R}{L_R} = \frac{E\times0.22^3}{10.7} + E\times\frac{150}{64.5}$$

$$= 0.000995\,E + 2.326\,E = 2.327\,E$$

$$D_t \approx 0$$

$$\xi = \frac{m^4}{\psi^2} + \frac{H_x}{H_\theta}\psi^2 + 2(1+\nu)m^2 = \overset{15}{\frac{4100}{275}} + \overset{316}{1.15\times275} + \overset{170}{2.66\times64} = 501$$

$$\xi^2 = 251000$$

$$b = \psi^4 + \frac{m^4}{D_x}\times3D_\theta + \frac{R^2t^*E}{\xi^2 D_x}\left\{m^4 + 2(1+\nu)m^2\psi^2 + \psi^4\frac{H_x}{H_\theta}\right\}$$

$$= 75600 + \underset{293,500}{\frac{4100\times3\times2.327}{0.09762}} + \overset{349}{\frac{115600\times0.741}{251000\times0.09762}}\left\{4100 + \overset{46500}{2.66\times64\times275} + \overset{87051}{1.15\times75600}\right\}$$

$$= 8.491\times10^5$$

$$A_1 = \frac{\psi^2 \gamma}{[\phi - 8\gamma(\frac{R}{t_0})^2]} = \frac{2.41 \times 10^8}{-7.385 \times 10^{11}} = -0.3265 \times 10^{-3}$$

$$C_1 = \frac{b}{[\phi - 8\gamma(\frac{R}{t_0})^2]} = \frac{8.491 \times 10^5}{-7.385 \times 10^{11}} = -1.15 \times 10^{-6}$$

$$D = \frac{B_1}{2} - \frac{2C_1}{A_1^2 B_1} = \frac{1.75}{2} + \frac{2 \times 1.15 \times 10^{-6}}{0.107 \times 10^{-6} \times 1.75}$$

$$D = 0.875 + 12.27 = 13.145$$

$$D^2 = 172.7910$$

$$B_1 D = 23.0038$$

$$D^2 + B_1 D = 195.7948$$

$$A_1(D^2 + B_1 D) = -63.92700 \times 10^{-3}$$

$$A_1^2(D^2 + B_1 D)^2 = 4086.66133 \times 10^{-6}$$

$$-4C_1 D^2 = 794.83860 \times 10^{-6}$$

$$4881.49993$$

$$\sqrt{4881.49993 \times 10^{-6}} = 69.86773 \times 10^{-3}$$

$$63.92700 \times 10^{-3}$$

$$5.94073 \times 10^{-3}$$

$$S = \frac{1}{2}\, 5.94073 \times 10^{-3}$$

$$= 2.97036 \times 10^{-3}$$

$$\sigma_{CR} = S \times E = 2.97036 \times 10^{-3} \times 10.4 \times 10^6$$

$$= 30891 \text{ PSI}$$

$$N_{CR} = 30891 \times 0.2658 = 8150 \text{ LB/IN}$$

GENERAL INSTABILITY IS NOT A PROBLEM

IF $U = 0.0005$ WHICH IS A COMMON IMPERFECTION IN TANK CONSTRUCTION

$\rho = 105$

$B_1 = 3.5$

$$D = 1.75 + \frac{2.3}{0.107 \times 3.5} = 7.90$$

$$D^2 = 62.3$$

$$B_1 D = +)\ 27.66$$

$$89.96$$

$$A_1 (D^2 + B_1 D) = -29.35 \times 10^{-3}$$

$$A_1^2 (D^2 + B_1 D)^2 = 862 \times 10^{-6}$$

$$-4C_1 D^2 = 286 \times 10^{-6}$$

$$1148 \times 10^{-6}$$

$$S = \frac{1}{2} \left\{ -A_1 (D^2 + B_1 D) + \sqrt{A_1^2 (D^2 + B_1 D)^2 - 4C_1 D^2} \right\}$$

$$= \frac{1}{2} \{ -29.35 + 33.86 \} \times 10^{-3}$$

$$= \tfrac{1}{2} [4.51 \times 10^{-3}] = 2.255 \times 10^{-3}$$

PREDICTED $\sigma_{cr} = 23{,}400$ PSI

$C^* = 1.03$

ACTUAL $\sigma_c = 12{,}100$ PSI

$$M.S = \frac{23400}{12100} - 1 = \underline{+0.93} \longrightarrow$$

NO GENERAL INSTABILITY FAILURE IS EXPECTED

INTERFRAME BUCKLING GOVERNS DESIGN

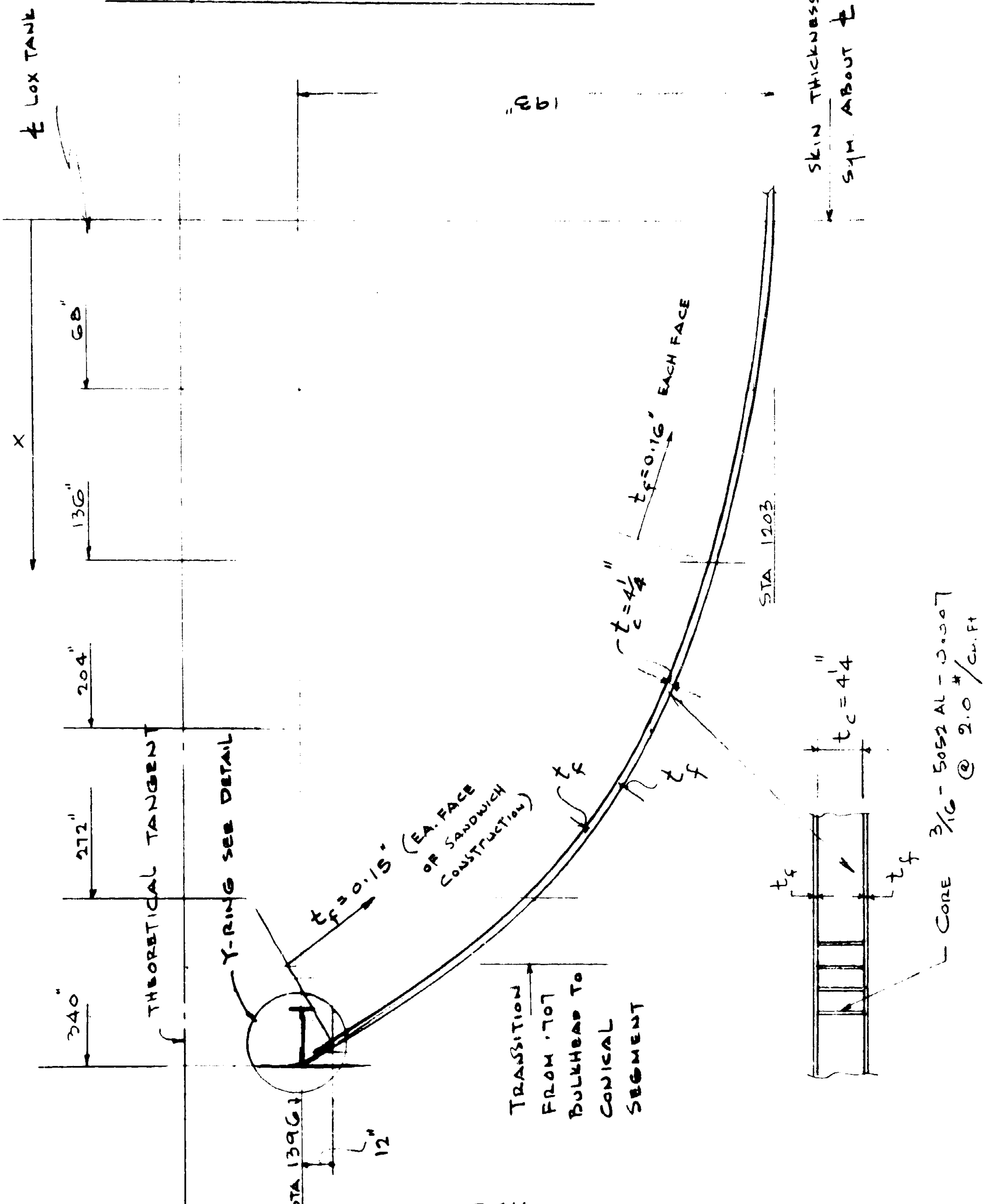
B-2.8

MLLV SINGLE STAGE CORE VEHICLE
ANALYSIS OF COMMON BULKHEAD
SANDWICH CONSTRUCTION

Design For
Max Positive Pressure
Max p = 76 psi @ Apex

Max Negative Pressure
Max -p = 21.7 psi @ Apex

ANALYSIS OF COMMON BULKHEAD



ANALYSIS OF COMMON BULKHEAD

ASSUMPTIONS :

a) MATERIAL TO BE 2219-T87 ALUMINUM

b) SANDWICH CONSTRUCTION FOR POSSIBLE EXTERNAL NEGATIVE PRESSURE WHEN LOX IS CONSUMED FIRST.

c) MATERIAL PROPERTIES IS AS FOLLOWS :

$$f_{tu} = 63000 \text{ psi}$$
$$f_{ty} = 50000 \text{ psi}$$
$$E = 10.5 \times 10^6 \text{ psi}$$
$$G = 3.9 \times 10^6$$
$$E_c =$$
$$G_c =$$
$$\nu = 0.33$$

DESIGN CONDITION (I)

DESIGN AGAINST THE MAX DIFFERENCE OF PRESSURIZATION BETWEEN LOX AND LH_2 TANK

a) LOCATION AT APEX OF COMMON BULKHEAD

$$x = 0 \quad y \approx 240$$

$$\Delta p = (1.4 \times 74 - 1.0 \times 28) = 103.5 - 28 = 75.5 \quad \text{SAY } 76 \text{ PSI}$$

SIZE OF SANDWICH FACINGS TO RESIST MAX. INTERNAL PRESSURE

$$r_2 = r_1 \approx 480''$$

$$N_\phi = N_\theta = \frac{pa^2}{2b} \times \frac{1}{B.F} \qquad B.F = 0.95$$

$$= \frac{76 \times 340^2}{2 \times 240 \times 0.95} = \frac{76 \times 115\,600}{456} = 19300 \text{ LB}$$

ASSUME EACH FACE OF SANDWICH SKIN TAKES EQUAL SHARE OF MEMBRANE FORCES THEN

$$t_T = \frac{19300}{63000} = 0.306''$$

EACH FACE OF SKIN THICKNESS IS

$$t_f = 0.153'' \quad \text{SAY} \quad 0.155''$$

b) AT

$x \approx 272''$
$y \approx 142''$
$r_2 \approx 402.5$
$r_1 \approx 270$

JUNCTION OF CONICAL PORTION WITH CURVILINEAR PORTION

$$\Delta p = (1.4 \times 62 - 1.0 \times 27.5) = 87 - 27.5 = 59.5 \text{ PSI}$$

SAY 60 PSI

(i) USING CURVILINEAR RADII

MERIDIANAL MEMBRANE FORCE

$$N_\phi = \frac{p r_2}{2} = \frac{60 \times 402.5}{2} = 30 \times 402.5 = 12100\,\#/''$$

$$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right) = 60\,(402.5 - 300) = 60 \times 102.5 = 6150\,\#/''$$

$$t_f = 12{,}100 / 63000 \times 2 = 0.096'' \quad \text{SAY} \quad 0.1''$$

(ii) USING CONICAL STRESS FORMULA
FOR SECTION BEYOND TRANSITION PT.

$$N_\phi = \frac{272 \times 60}{2 \times \cos 30^\circ} = \frac{272 \times 30}{0.866} = 9450\,\#/''$$

$$N_\theta = 2 \times 9{,}450 = 18{,}900 \text{ LB}/''$$

$$t_T = \frac{18{,}900}{63000} = 0.30''$$

USE $t_f = 0.155''$, THE SAME AS APEX PORTION

(C) CALCULATE THICKNESS REQUIREMENT FOR LOCATION

$X = 136$

$y = 217''$

$r_2 = 472$

$r_1 = 436$

$\Delta p = (1.4 \times 70 - 1 \times 27.5) = 98 - 27.5 = 70.5$ PSI

$N_\phi = \frac{p \times r_2}{2} = \frac{70.5 \times 472}{2} = 16650$ LB/"

$t_f = \frac{16650}{2 \times 63000} = 0.132''$

$N_\theta = p\left(r_2 - \frac{r_2^2}{2r_1}\right) = 70.5\left(472 - \frac{222000}{872}\right) = 15350\#/"$

N_ϕ GOVERNS DESIGN

(d) AT $X = 334''$ WELD JT. OF Y-RING TO CONICAL END OF BULKHEAD

$\Delta P = (52 \times 1.4 - 1 \times 27.5) = 45.5$ PSI SAY 46

$N_\theta = \frac{46 \times 334}{\cos 30^\circ} = 17750$ LB/"

$t_f = \frac{17750}{2 \times 63000} = 0.141''$

ANALYSIS OF COMMON BULKHEAD FOR MAX NEGATIVE PRESSURE

GIVEN MIN. ULAGE PRESSURE IN LOX TANK

$p_u = 17.5$ PSI (ASSUME IN LOX)

MAX ULAGE PRESSURE IN LH_2 TANK

$p_u = 28$ PSI

$$-\Delta p_{MAX} = -(28 \times 1.4 - 1.0 \times 17.5) = -2\ldots$$

INVESTIGATION OF COMPRESSIVE STRESS CAPABILITY OF COMMON BULKHEAD AGAINT NEGATIVE PRESSURE

USING V. SMITH UNPUBLISHED CHART FOR SANDWICH BULKHEAD UNDER EXTERNAL PRESSURE (BOEING SEATTLE)

USING MAX THICKNESS AT APEX FOR DESIGN

a) ASSUME $t_c = 3''$

$t_1 = 0.155$

$t_2 = 0.155$

$$t^* = 1.73(3 + 0.31) = 5.71$$

$$R \approx 480$$

$$a \approx 340$$

$$\lambda = \left[12(1-\nu^2)\right]^{1/4} \frac{a}{\sqrt{R t^*}}$$

$$= \frac{1.815 \times 340}{\sqrt{480 \times 5.71}} = 11.8$$

$$E = 10.5 \times 10^6$$

LET $Z = \dfrac{E_1 t_1 + E_2 t_2}{2 G_c K}$

$= \dfrac{10.5 \times 10^6 \times 0.310}{2 G_c \times 480}$

ASSUME $G_c = 14.3 \times 10^3$

USE 60 % CORRECTION FACTOR FOR CORE DEPTH

$G_c = 14.3 \times 10^3 \times 0.6$

$= 8.6 \times 10^3$

$Z = \dfrac{10.5 \times \cancel{10^6}^{\,3} \times 0.310}{2 \times 8.6 \times 10^3 \times 480} = \dfrac{10500 \times 0.31}{17.2 \times 480} = 0.394$

FROM CHART (V. SMITH) @ 99 % PROBABILITY
95 % CONFIDENCE

BUCKLING PARAMETER $P_{CR} = 300 = \dfrac{(1-\nu^2)(a^4)}{t^{*3} E (2t_f)} \tau_{CR}$

$\tau_{CR} = \dfrac{300 \times 5.71^3 \times 10.5 \times 10^6 \times 2 \times 0.155}{0.891 \times 340^2 \cdot 340^2}$

$= \dfrac{300 \times 185.5 \times 10.5 \times 0.31 \times 10^9}{11.9 \times 10^9} = 15.3$ PSI

SH4

b) TRY $t_c = 4.0$

$t_1 = 0.155$

$t_2 = 0.155$

$t^* = 1.73\,(4 + 0.32) = 7.47$

$R \approx 480$

$a \approx 340$

$$\lambda = \frac{1.815 \times a}{\sqrt{R\, t^*}} = \frac{1.815 \times 340}{\sqrt{480 \times 7.47}} = 10.3$$

$$Z = \frac{10.5 \times 10^6 \times 0.320}{2 \times G_c \times R} = \frac{10.5 \times 10^6 \times 0.32}{2 \times 10 \times 10^3 \times 480} = 0.35$$

$G_c = 14.3 \times 10^3 \times 0.70 = 10 \times 10^3$

FROM V. SMITH BUCKLING PARAMETER CHART
@ 99 % PROBABILITY
95 % CONFIDENCE

FOR $\lambda = 10.3$

$Z = 0.35$

$P_{CR} = 175$

$$q_{CR} = \frac{175 \times 7.47^3 \times 10.5 \times 10^6 \times 2 \times 0.16}{0.891 \times 338^4}$$

$$= \frac{175 \times 417 \times 10.5 \times 10^6 \times 0.32}{0.891 \times 13 \times 10^9} = 21.2 \text{ PSI}$$

11.6

REQUIRED $q_{CR} = 21.7$ PSI

SHY A LITTLE BIT

TRY $t = 4.25''$

$t_1 = 0.16$

$t_2 = 0.16$

$t^* = 1.73\,(4.25 + 0.32) = 7.9$

$R \approx 480$

$a \approx 338$

$$\lambda = \frac{1.85 \times 338}{480 \times 7.905} =$$

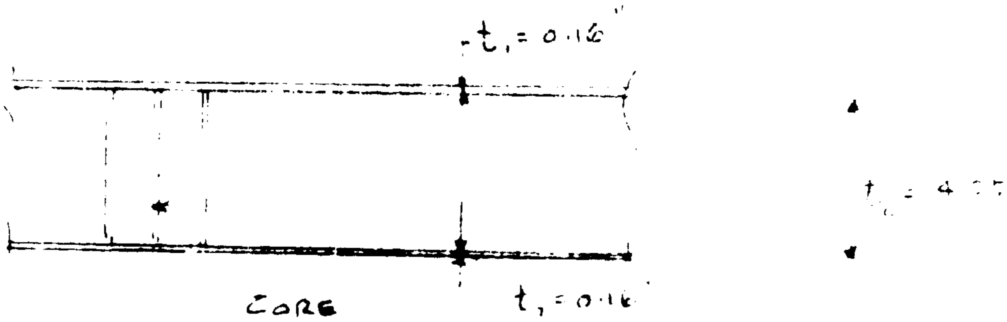
$$Z = \frac{0.5 \times 10^6 \times 0.32}{2 \times G_c \times R} = \quad = 0.35$$

$P_{CR} = 155$

$$\tau_{CR} = \frac{155 \times 7.905^3 \times 10.5 \times 10^6 \times 0.35}{0.891 \times 13 \times 10^9} = 22.3 \text{ PSI}$$

$$M.S = \frac{22.3}{21.7} - 1 = \underline{+0.03}$$

THE FINAL SANDWICH SECTION SHALL BE



CORE

3/16 5052 - 0.007 (2.0 #/C.F

[illegible] EVALUATION OF SANDWICH [illegible]
COMPRESSIVE STRESS CAPABILITY [illegible]
DEVELOPMENT FROM D5-132[illegible]

$$I_s = 0.16 \times 2 \times (2.205^2) = 0.3[illegible]$$

$$t^* = \sqrt{12 I_s / (2 \times t_f)} = \sqrt{12 \times 0.3[illegible]} [illegible]$$

$$R/t^* = \frac{480}{1.65} = 291$$

$$\sigma_{cr} = 0.6 \times E \times \frac{t^*}{R} \quad [illegible]$$

$$= \frac{0.6 \times 10.5 \times 10^6}{291} = 0.0[illegible] = 21,700 \text{ psi}$$

ACTUAL COMPRESSIVE STRESS DUE TO [illegible]
LOAD

$$\sigma_\theta = \sigma_a = \frac{p\,a^2}{0.5 \times 2\,b\,(2t_f)} = \frac{21.7 \times 340^2}{1.9 \times 2[illegible]} = 17200 \text{ psi}$$

$$M.S = \frac{21700}{17200} - 1 = \underline{\underline{+0.26}}$$

INVESTIGATION OF COMPRESSIVE [illegible]

FOR SHELL @ $X = 136''$

$R_2 \approx 466$ [illegible]

$t_1 = t_2 =$ [illegible]

ASSUME $t_c = 4.25$

$t^* = 1.73\,(4$ [illegible]

$$\lambda = \frac{1.815 \times 338}{\sqrt{466 \times 7.82}} = \text{[illegible]}$$

$$Z = \frac{10.5 \times 10^6 \times 0.27}{2 \times 10 \times 10^3 \times 466} = \text{[illegible]}$$

$P_{CR} = 161$ (V. [illegible])

$$q_{CR} = \frac{161 \times 7.82^3 \times 10.5 \times 10^6 \times 0.27}{0.891 \times 13 \times 10^4} = \text{[illegible] PSI}$$

FOR EXTERNAL LOAD CONDITION

IT IS SUGGESTED TO USE $t_c = 0.6$ [illegible]

$$q_{CR} = \frac{161 \times 7.82^3 \times 10.5 \times 10^6 \times 0.32}{0.891 \times 13 \times 10^4} = 22.3 \text{ PSI}$$

INVESTIGATION OF COMPRESSIVE STRESS [illegible]

FOR SHELL @ $X = 272$

$R_2 \approx 400$

ASSUME $t_1 = t_2 = 0.160$

$t^* = 1.73\,(4.25 \cdot 0.[illegible]$ [illegible]

$\lambda = \dfrac{1.815 \times 338}{\sqrt{400 \times 7.905}} =$ [illegible]

$Z = \dfrac{10.5 \times 10^6 \times 0.32}{2 \times 10 \times 10^3 \times 400} =$ [illegible]

$P_{CR} = 206$

$\sigma_{CR} = \dfrac{206 \times 7.905^3 \times 10.5 \times 10^6 \times 0.32}{0.891 \times 13 \times 10^9} = 29.3$ PSI

$M.S = \dfrac{29.3}{21.7} - 1 = +0.35$

$t_1 = t_2 = 0.15$ MAY BE USED

$\sigma_{CR} = 27.5$ PSI

$M.S = +0.26$

INVESTIGATION OF COMPRESSIVE STRESS CAPABILITY FOR CONICAL SHELL @ X = 334

$X = 334$

$R_2 = 386$

$t_1 = t_2 = 0.15$

$t^* = 1.73\ (4.55) = 7.86$

$t^*)^3 = 486$

$$\lambda = \frac{1.815 \times 339}{\sqrt{386 \times 7.86}} = 11.15$$

$$Z = \frac{10.5 \times 10^6 \times 0.30}{2 \times 10 \times 10^3 \times 386} = 0.409$$

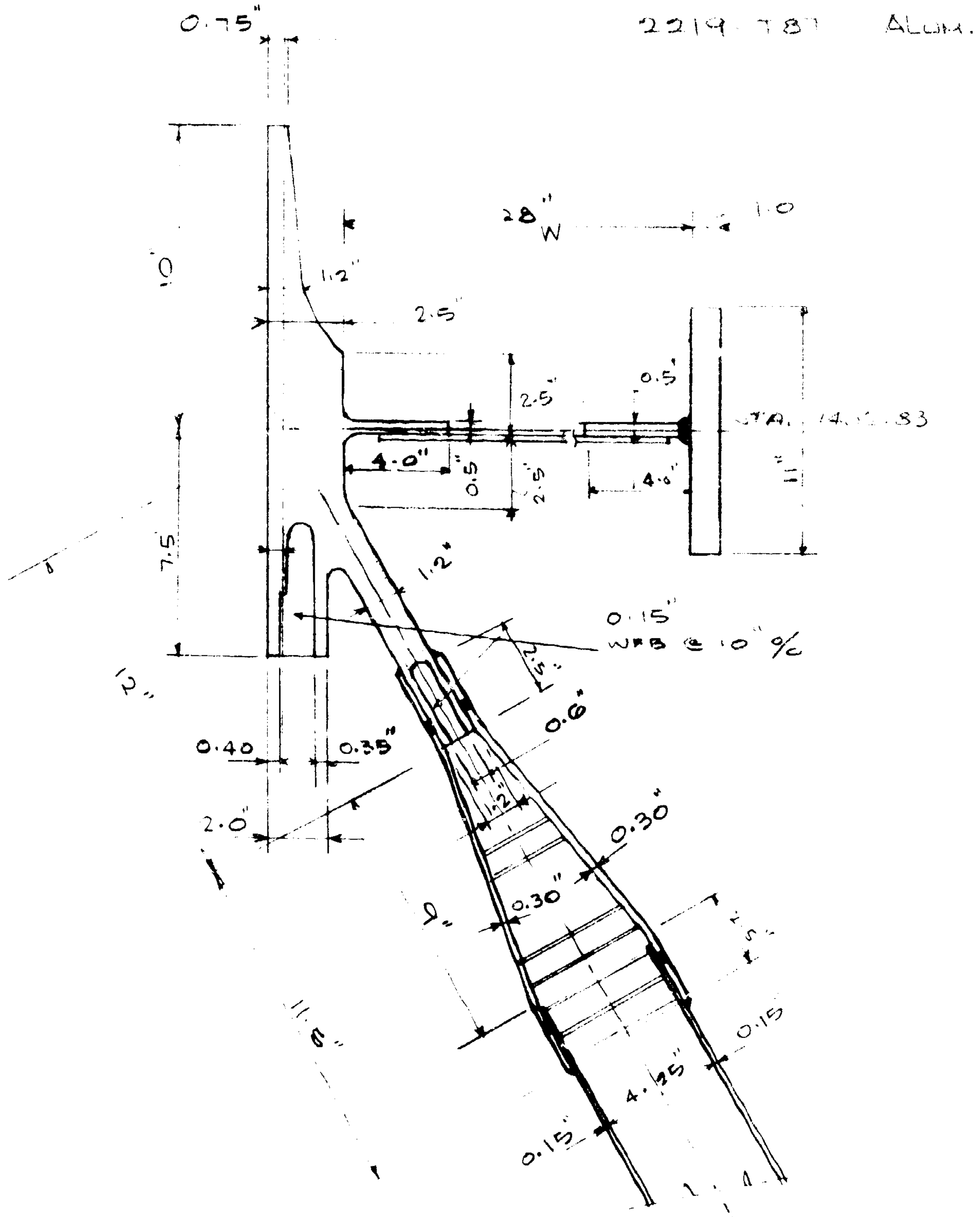
$$P_{CR} = \frac{220 \times 486 \times 10.5 \times 10^6 \times 0.30}{0.891 \times 13 \times 10^9} = 29.2$$

$$M.S = \frac{29.2}{21.7} - 1 = \underline{+0.345}$$

B-2.9

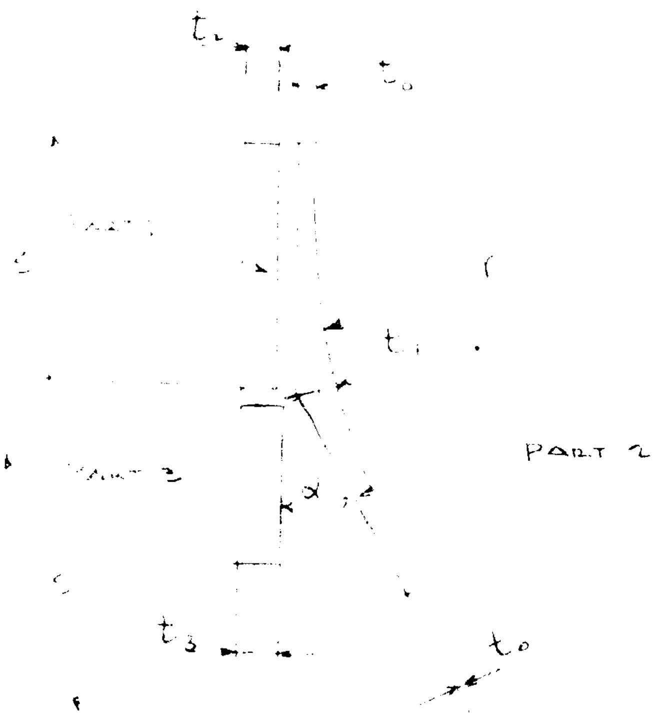
MLLV - SINGLE STAGE
CORE VEHICLE COMMON BULKHEAD
Y-RING ANALYSIS

COMMON BULKHEAD Y-RING ANALYSIS



COMMON BULKHEAD Y-RING DETAIL

USING APPROXIMATE METHOD [illegible]



F_w = [illegible]

$R =$ [illegible]

$\alpha = 30°$

$$t_0 = \frac{pR\,(D.F)}{F_{WELD}\cos\alpha} = \frac{(75-28)\times 340)\times 1.2}{34500\times 0.866} = \frac{47\times 340\times 1.2}{34500\times 0.866} = 0.64''$$

$$t_1 = t_0\left[1 + \frac{\{1+9.6\alpha\,(R/t_0)^{1/2}\}^{1/2}}{4}\right]$$

$$= t_0\left[1 + \frac{\{1+9.6\times\frac{\pi}{6}(23.1)\}^{1/2}}{4}\right] = 2.36''$$

$$r = \frac{t_1\cos\frac{\alpha}{2} - t_0}{1-\cos\frac{\alpha}{2}} = \frac{2.36\times 0.966 - 0.64}{1-0.9659} = 48''$$

$$S = (r+t_0)\tan\frac{\alpha}{2} = (48+0.64)\times 0.2679 = 13''\ \text{(USE 12'')}$$

THICKNESS OF TANK WALL

$$t = \frac{68\times 340}{63000} = 0.37''$$

$$t_2 = \bar{t} + t_o = 0.37 + 0.[illegible] = 1.0$$

$$t_3 = 0.22 + t_o = 0.22 + 0.61 = 0.83$$

MAX COMPRESSIVE STRESS CAPABILITY

$$R/t = 340/1.0 = 340$$

[illegible] MAX $\sigma_{cr} = CE\, t/R = 0.28 \times 10.5 \times 10^6 / 340 = 8630$

$$N_C = 8630 \times 1.0 = 8630 \text{ LB/}''$$

IF THICKNESS OF MONOCOQUE TANK IS 0.75

$$R/t = 340/0.75 = 453$$

USE PBY COEFF

$$C^* = 0.33 \qquad \omega = 0.0004$$

$$\sigma_{cr} = \frac{0.33 \times 10.5 \times 10^6}{453} = 7650 \text{ PSI}$$

$$N_{CR} = 7.650 \times 0.75 = \underline{5750} \text{ LB/}''$$

FOR DETAIL DISCONTINUITY ANALYSIS SEE LH_2 TANK LOWER BULKHEAD Y-RING ANALYSIS. SINCE MAX INTER. PRESSURE FOR LH_2 Y-RING IS 50 PSI (ULT), IT IS SLIGHTLY HIGHER THAN COMMON BULKHEAD Y-RING WITH ΔP @ 47 PSI. THE DESIGN MAY BE SIMILAR.

ANALYSIS OF ADD'L RING SECTION [illegible]

HORIZONTAL COMPONENT OF MERIDIANAL [illegible]

ASSUME $\Delta P = (57 \times 1.4 - 29 \ldots)$ [illegible]

$R_2 = \dfrac{300}{\cos \alpha}$ = [illegible]

MERIDIANAL TENSILE FORCE

$N_\phi = \dfrac{p R_2}{2}$ = [illegible]

HORIZONTAL COMPONENT

$H_\phi = N_\phi \sin 30^\circ$ = [illegible]

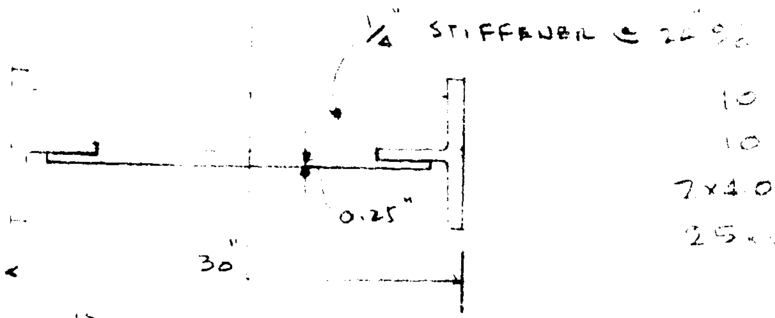
AREA OF RING REQ'D

$A_R = \dfrac{H_\phi \times R}{50{,}000} = \dfrac{4500 \times 330}{50{,}000}$ = 2 [illegible]

IN THE Y-RING SECTION

ASSUME 1" MATERIAL × 10" [illegible]

A PART OF THRUST RING REQ [illegible]



10 × 1.0 = [illegible]
10 × [illegible] = 10 [illegible]
7 × 4.0 [illegible] = 4.0
25 × 0.25 = 6.25
[illegible]

I_{Y-Y}

$I_1 = 10.0 \times 11.50^2 = 1320$

$I_2 = 10.0 \times 11.50^2 = 1320$

$I_3 = 8.0 \times 12.0^2 = 1150$

$I_4 = \frac{1}{12}\, 0.25 \times 25^3 = 326$

I_{Y-Y} 4116 IN^4

I_{x-x} IS

$$I_1 = 2 \times \frac{1}{12} 10 \times 10^3 = 2000/12 = 166.5 \text{ IN}^4$$

$$I_2 \approx 0$$

$$I_3 \approx 0$$

COMPRESSIVE CAPABILITY OF RING

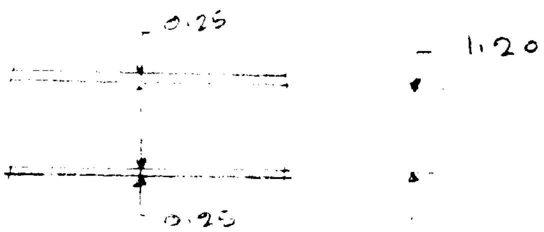
$$f_{CR} = \frac{(n^2-1) E I}{(1-\nu^2) R^3} = \frac{(9-1) \times 10.5 \times 10^6 \times 166.5}{3.45 \times 10^6 \times .91} = 4570 \text{ \#/in}$$

THE FURNISHED RING IS OK

$$M.S = \frac{4570}{4500} - 1 \approx 0$$

INVESTIGATION OF COMPRESSIVE CAPABILITY OF [illegible]

SECTION @ Y-RING AND CONICAL BULKHEAD [illegible]



$t_c = 0.12$

$t = 0.25$

$t_2 = 0.25$

$t^* = 1.73\,(1.20 + 0.50) = 1.73 \times 1.70 = 2.94$

$R = \dfrac{334}{\cos\alpha} = \dfrac{334}{0.866} = 386$

$a = 339$

$\lambda = \dfrac{1.815 \times 339}{\sqrt{386 \times 2.94}} = 18.25$

33.8

$E = 10.5$

$Z = \dfrac{10.5 \times 10^{6}\,(0.50)}{2 \times 14.3 \times 10^{3} \times 386} = \dfrac{10500 \times 0.50}{28.6 \times 386} = 0.478$

$P_{CR} = 1550$

$q_{CR} = \dfrac{1550 \times 2.94^{3} \times 10.5 \times 10^{6} \times 2 \times 0.25}{0.891 \times 13.2 \times 10^{4}}$

$= \dfrac{1.550 \times 25.2 \times 10.5 \times 10^{9} \times 0.5}{11.8 \times 10^{4}} = 17.5$ PSI

INCREASE $t_f = 0.3''$

$q_{CR} = 17.5 \times 0.6/0.5 = 21$ PSI

M.S ≈ 0

INVESTIGATION OF MONOCOQUE T-RING CONICAL SEGMENT FOR COMPRESSIVE STRESS CAPABILITY

$t = 1.2''$

$R = 386$

$l = 339$

$\Lambda = \frac{1.315 \times 339}{\sqrt{386 \times 1.2}} = 2[illegible]$

21.6

$P_{CR} = 0000$ @ 99% PROBABILITY 95% CONFIDENCE

$f_{CR} = \frac{P_{CR}\, E}{(1-\nu^2)\left(\frac{a}{t}\right)^4} = \frac{10000 \times 10^{3} \times 10.5 \times 10^{6}}{0.391 \times 3.4 \times 10^{9}} = 85$ PSI

IF 90% PROBABILITY & 95% CONFIDENCE IS USED

$P_{CR} = 14000$

$f_{CR} = 18.5 \times 1.4/10 = 26$ PSI

$MS = \frac{26}{21.7} - 1 = \underline{+0.20}$

B-2.10

MLLV SINGLE STAGE
LOX TANK SIDE WALL
ANALYSIS FOR
CORE ALONE, & CORE + 8 SRM + 3 MODULE INJECTION STAGE

MAX DESIGN CONDITIONS:

a) Max N_c = 6,000 Lb/In Core + 8 SRM + 3 Module Injection Stage

b) Max N_t = 16,000 Lb/In Core + 8 SRM + 3 Module Injection Stage

INVESTIGATION OF LOX TANK SIDE WALL FOR STABILITY STRESSES

MAX $N_C = 6{,}000$ LB/"

CORE + 8 SRM + 3 INJECTION STAGES

THIS IS A SHORT CYLINDER

(1) APPLYING NASA TN-3783 AND D5-13272 REF. 3

N_C LOAD EQUATION

$$N_{CR} = \frac{K_C \pi^2 E\, t_s^3}{12(1-\nu^2)\, L^2} \qquad L \approx 50$$

ASSUME $t_s = 0.55$"

$$Z_L = \frac{L^2}{Rt}(1-\nu^2)^{1/2}$$

$$= \frac{2900}{340 \times 0.55}\, 0.945 = 14.7$$

$$N_{CR} = \frac{4.75 \times 9.85 \times 10.4 \times 10^6 \times 0.165}{12(1-\nu^2) \times 2500}$$

$$= 0.003 \times 10^6 = 3000 \text{ \#/"}$$

THICKNESS IS INADEQUATE

INCREASE t_s TO 0.7 $\quad t_s^3 = 0.343$

$$N_{CR} = 3000 \times \frac{0.343}{0.165} = 6250 \text{ \#/"}$$

$$M.S = \frac{6250}{6000} - 1 = +0.04$$

NEED 0.7" MONOCOQUE SKIN

(2) USING LONG CYLINDER APPROACH

BUCKLING STRESS EQUATION D5-13272

$$\tau_{CR} = C^* E \frac{t^*}{R}$$

$$t^* = t_s = 0.7$$

$$R/t = 340/0.7 = 485$$

$$C^* \approx 0.30$$

$$\tau_{CR} = \frac{0.30 \times 10.4 \times 10^6}{485} = 0.00643 \times 10^6$$

$$N_{CR} = 6430 \times 0.7 = 4500 \text{ LB}/''$$

SHY

INCREASE t_s to 0.75"

$$R/t = 340/0.75 = 453$$

$$C^* = 0.32 \qquad \text{FOR } U = 0.00045$$

$$T_{CR} = \frac{0.32 \times 10.4 \times 10^6}{453} = 7350 \text{ PSI}$$

$$N_{CR} = 7350 \times 0.75 = 5500 \ \#/''$$

STILL SHY 10%, HOWEVER THIS IS A RATHER SHORT CYLINDER WALL. METHOD (1) INVESTIGATION SEEMS MORE LOGICAL THAN LONG CYLINDER APPROACH CONDUCTED ABOVE. HENCE 0.75" FOR LOX TANK SIDE WALL SHOULD BE ADEQUATE FOR MAX 6000 #/" AT FWD END.

INVESTIGATION OF LOX TANK WALL FOR MAX N_t LOAD

FOR 2219-T87 ALU ALLOY

$f_{tu} = 34500$ PSI WELDMENT STRENGTH

GIVEN MAX $N_t = 16000$ LB/IN

$$T_t = \frac{16000}{0.75} = 21300 \text{ PSI}$$

$$M.S = \frac{34500}{21300} - 1 = \underline{+0.62}$$

N_t LOAD IS ADEQUATE

INVESTIGATION OF PROOF TEST CONDITION

$$N_t = \frac{16000}{1.4} \times 1.1 = 12600 \text{ LB/IN}$$

$$T_t = \frac{12600}{0.75} = 16800 \text{ LB/IN}$$

$$M.S = \frac{16000}{16800} - 1 \simeq 0$$

$f_{ty} = 16{,}000$ PSI FOR WELDMENT ALLOWABLE

IF S-IC CRITERION IS FOLLOWED

F.S = 1.05 FOR PROOF TEST

$$N_t = \frac{16000}{1.4} \times 1.05 = 12000 \text{ LB/IN}$$

$$T_t = 12000/0.75 = 16000 \text{ PSI}$$

$$M.S = 0$$

B-2.11

MLLV CORE VEHICLE

ANALYSIS OF LOX TANK UPPER

BULKHEAD SHELL CONFIGURATION

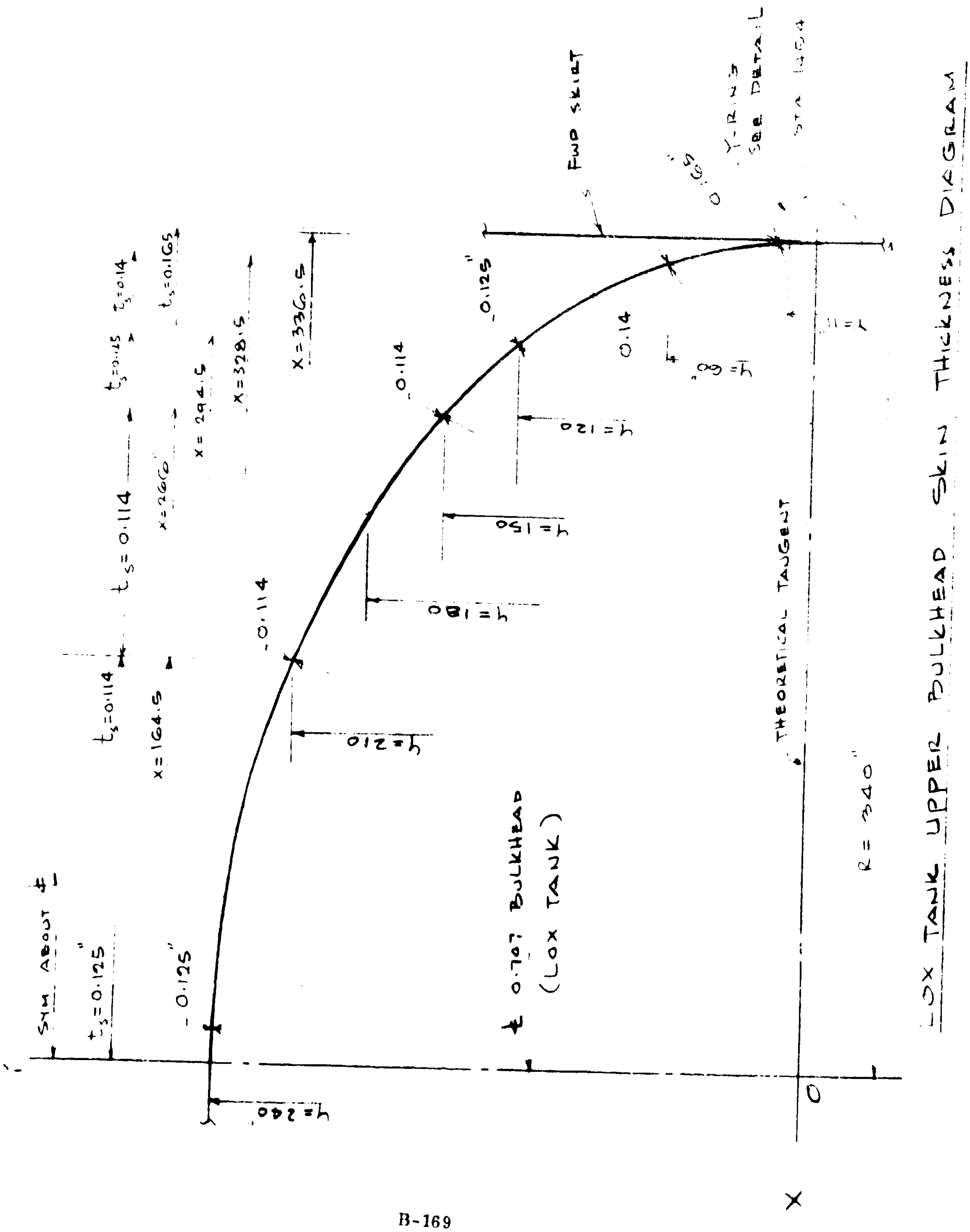
MATERIAL 2219-T87 FOR BULKHEAD CONSTRUCTION

WELD LAND STRESS PROPERTIES

f_{tu} = 16,000 psi

NON-WELD LAND AREA

f_{tu} = 63,000 psi


LOX TANK UPPER BULKHEAD SKIN THICKNESS DIAGRAM
FWD SKIRT
Y-RING SEE DETAIL
STA 1454
THEORETICAL TANGENT
R = 340"
0.707 BULKHEAD (LOX TANK)
SYM. ABOUT ℄
t_s = 0.125"
t_s = 0.114
t_s = 0.114
t_s = 0.125
t_s = 0.14
t_s = 0.165
x = 164.5
x = 266
x = 294.5
x = 328.5
x = 336.5
y = 240"
y = 210
y = 180
y = 150
y = 120
y = 60"
0.125"
0.114
0.114
0.14
0.125"
0.165"
O
X

SINGLE STAGE LOX TANK UPPER BULKHEAD ANALYSIS

ASSUMPTIONS :

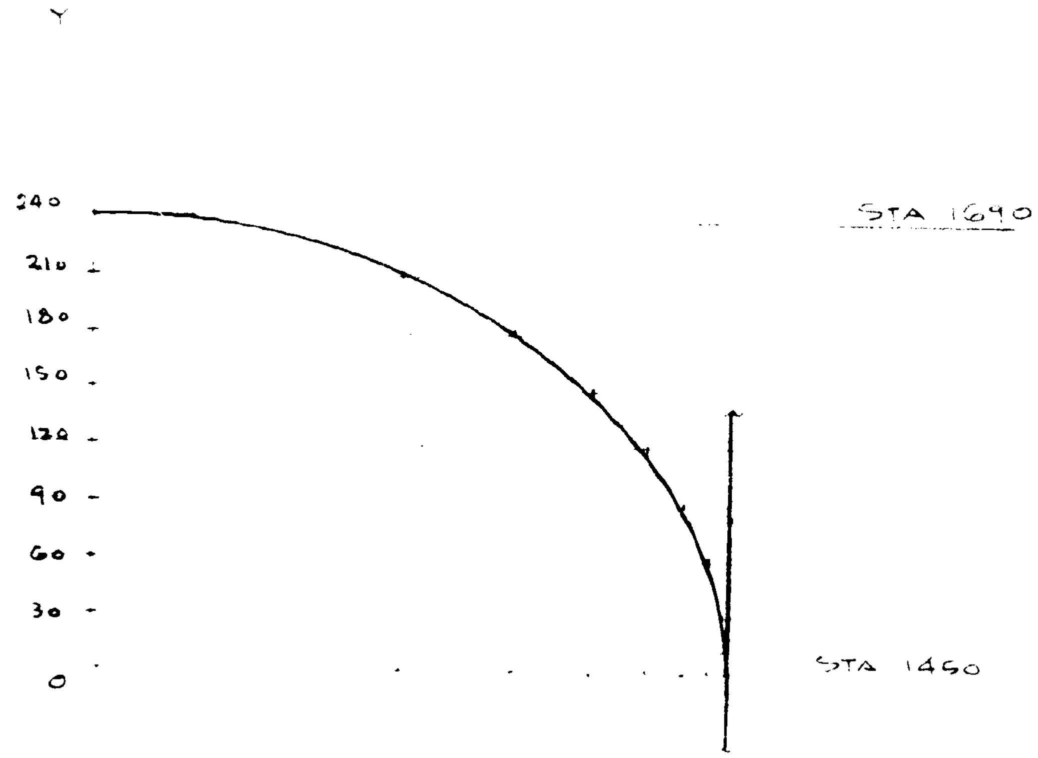
1. SIZING OF BULKHEAD SHELL BASED UPON PRESSURIZATION

AT STA	1630 - 1700	p_{ULT} = 30 PSI
AT STA	1600	p_{ULT} = 35 PSI
	1570	p_{ULT} = 40 PSI
	1540	p_{ULT} = 45 PSI
	1510	p_{ULT} = 50 PS
	1480	p_{ULT} = 55 PSI
	1450	p_{ULT} = 60 PSI

THEORETICAL TANGENT IS AT STA 1450 FOR A .70 BULKHEAD

GEOMETRY COMPUTATION FOR UPPER LOX BULKHEAD

ASSUME $y = 0$ AT THEORETICAL TANGENT



$$x = \frac{a}{b}\sqrt{b^2 - y^2}$$

$a = 340$
$b = 240$

FOR $y = 0$ $x = a = 340'$

$y = 30$ $x = 1.414\sqrt{57600 - 900} = 336.5$

$y = 60$ $x = 1.414\sqrt{57600 - 3600} = 328.5$

$y = 90$ $x = 1.414\sqrt{57600 - 8100} = 315.5$

$y = 120$ $x = 1.414\sqrt{57600 - 14400} = 294.5$

$y = 150$ $x = 1.414\sqrt{57600 - 22500}$ 265.5

$y = 180$ $x = 1.414\sqrt{57600 - 32400}$ 2[illegible]4 [illegible]

$y = 210$ $x = 1.414\sqrt{57600 - 44100} = 164.5$

$y = 240$ $x = 0$

COMPUTATIONS OF RADII AT VARIOUS PTS

a) $x = 0 \qquad y = 240$

$$r_2 = \frac{(a^4y^2 + b^4x^2)^{1/2}}{b^2} = \frac{a^2}{b^2}\,y = \left(\frac{340}{240}\right)^2 \times 240 = 480$$

$$r_1 = r_2^3\,\frac{b^2}{a^4} = \frac{480^3 \times (0.707)^2}{340^2} = 480$$

b) $x = 164.5 \qquad y = 210$

$$r_2 = \frac{(340^4 \times 210^2 + 0.25 \times 340^4 \times 164.5^2)^{1/2}}{0.5 \times 340^2} = \frac{340^2\,(210^2 + 0.25 \times 164.5^2)^{1/2}}{340^2 \times 0.5}$$

$$= 2\,(44100 + 6750)^{1/2} = 451$$

$$r_1 = 451^3 \times \frac{0.5 \times 340^2}{340^{\cancel{4}\,2}} = \frac{451^3 \times 0.5}{340^2} = 397$$

c) $x = 224.5 \qquad y = 180$

$$r_2 = \frac{\cancel{a^2}\,(y^2 + 0.25\,x^2)^{1/2}}{0.5 \times \cancel{a^2}} = 2\,(y^2 + 0.25\,x^2)^{1/2}$$

$$= 2\,(32400 + \overset{12570}{0.25 \times 50300})^{1/2} = 424$$

$$r_1 = \frac{424^3 \times 0.5}{340^2} = 329$$

d) $x = 265.5 \qquad y = 150$

$$r_2 = 2\,(22500 + \overset{17500}{0.25 \times 70000})^{1/2} = 400$$

$$r_1 = \frac{400^3 \times 0.5}{115\,600} = 277$$

e)

$x = 294.5$

$y = 120$

$r_2 = 2\left(14400 + 0.25 \times 86600\right)^{1/2} = 380''$

$r_1 = \dfrac{380^3 \times 0.5}{115600} = 237''$

f)

$x = 315.5$

$y = 90$

$r_2 = 2\left(8100 + 0.25 \times \overset{24800}{315.5^2}\right)^{1/2} = 363$

$r_1 = \dfrac{363^3 \times 0.5}{115600} = 207''$

g)

$x = 328.5$

$y = 60$

$r_2 = 2\left(3600 + 0.25 \times \overset{175}{328.5^2}\right)^{1/2}$

$= 350$

$r_1 = \dfrac{350^3 \times 0.5}{115600} = 184.5$

h)

$x = 336.5$

$y = 30$

$r_2 = 2\left(900 + 0.25 \times 336.5^2\right)^{1/2} = 343$

$r_1 = \dfrac{343^3 \times 0.5}{115600} = 175$

i)

$x = 340$

$y = 0$

$r_2 = 2\left(0 + 0.25 \times 340^2\right)^{1/2} = 340$

$r_1 = 170$

SIZING OF BULKHEAD SHELL THICKNESS

a) AT TOP OF BULKHEAD SHELL

$$N_\phi = N_\theta = \frac{pa^2}{2b} = \frac{30 \times 340^2}{2 \times 240} = \frac{115600}{16} = 7230 \ \#/''$$

$$t = \frac{7230}{0.95 \times 63000} = 0.121'' \qquad \text{USE} \quad \underline{t = 0.125}$$

@ WELD LAND

$$t = \frac{1.2 \times 7230}{16000 \times 0.95} = 0.571''$$

b) $\underline{y = 210, \ x = 164.5}$

$r_2 = 451$

$r_1 = 397$

$$N_\phi = \frac{pr_2}{2} = \frac{30 \times 451}{2} = 15 \times 451 = 6760 \ \text{LB}/''$$

$$t = \frac{6760}{0.95 \times 63000} = \underline{0.114}''$$

$$N_\theta = p\left\{r_2 - \frac{r_2^2}{2r_1}\right\}$$

$$= 30\{451 - 255\} = 30 \times 196 = 5890 \ \text{LB}/''$$

N_ϕ GOVERNS THICKNESS DESIGN

@ WELD LAND

$$t = \frac{1.2 \times 6760}{16000 \times 0.95} = 0.54''$$

c) $y = 180 \qquad x = 224.5$

$r_2 = 424$

$r_1 = 329$

$$N_\phi = \frac{p r_2}{2} = \frac{30 \times 424}{2} = 15 \times 424 = 6350 \text{ LB}$$

$$t = \frac{6350}{0.95 \times 63000} = \underline{0.106}$$

$$N_\theta = p \left\{ r_2 - \frac{r_2^2}{2r_1} \right\} = 30 \{ 424 - 274 \} = 4500$$

N_ϕ GOVERNS DESIGN

WELD LAND

$$t = \frac{1.2 \times 6350}{0.95 \times 16000} = 0.502''$$

d) $y = 150 \qquad x = 265.5$

$r_2 = 400$

$r_1 = 277$

$$N_\phi = \frac{35 \times 400}{2} = 7000 \text{ LB/IN}$$

$$t = \frac{7000}{63000} = \underline{0.112}$$

$$N_\theta = 35 \{ 400 - 289 \} = 35 \times 111 = 3890 \text{ LB/IN}$$

N_ϕ GOVERNS DESIGN

AT WELD LAND

$$t = \frac{1.2 \times 7000}{16000} = 0.525''$$

e) $y = 120$, $x = 294.5$

$r_2 = 380$

$r_1 = 237$

$p = 40$ PSI

$$N_\phi = \frac{p r_2}{2} = \frac{40 \times 380}{2} = 76000 \text{ LB}/''$$

$$t = \frac{76000}{63000} = \underline{0.121''}$$

$$N_\theta = 40 \{380 - 304\} = 40 \times 76$$

N_ϕ GOVERNS DESIGN

@ <u>WELD LAND</u> $t_w = \frac{1.2 \times 76000}{16000} = 0.57''$

f) $y = 90$ $x = 315.5$

$r_2 = 363$

$r_1 = 207$

$$N_\phi = \frac{p r_2}{2} = \frac{45 \times 363}{2} = 22.5 \times 363 = 8150 \text{ LB}/''$$

$$t = \frac{8150}{63000} = \underline{0.13''}$$

@ WELD LAND

$$t_w = \frac{1.2 \times 8150}{16000} = 0.612''$$

g) $y = 60$ $x = 328.5$

$r_2 = 350$ $r_1 = 184.5$

$$N_\phi = \frac{50 \times 350}{2} = 25 \times 350 = 8750 \text{ LB}/''$$

$$t = \frac{8750}{63000} = \underline{0.14''}$$

@ WELD LAND

$$t_w = \frac{1.2 \times 8750}{16000} = 0.66''$$

h)

$y = 30 \qquad x = 336.5$

$r_2 = 343$

$r_1 = 175$

$$N_\phi = \frac{55}{2} \times 343 = 9450$$

$$t = \frac{9450}{63000} = 0.15''$$

i)

$y = 0 \qquad x = 340$

$r_2 = 340$

$r_1 = 170$

$$N_\phi = 60 \times 340/_2 = 10{,}200 \quad \text{LB}/''$$

$$t = \frac{10{,}200}{63000} = 0.162''$$

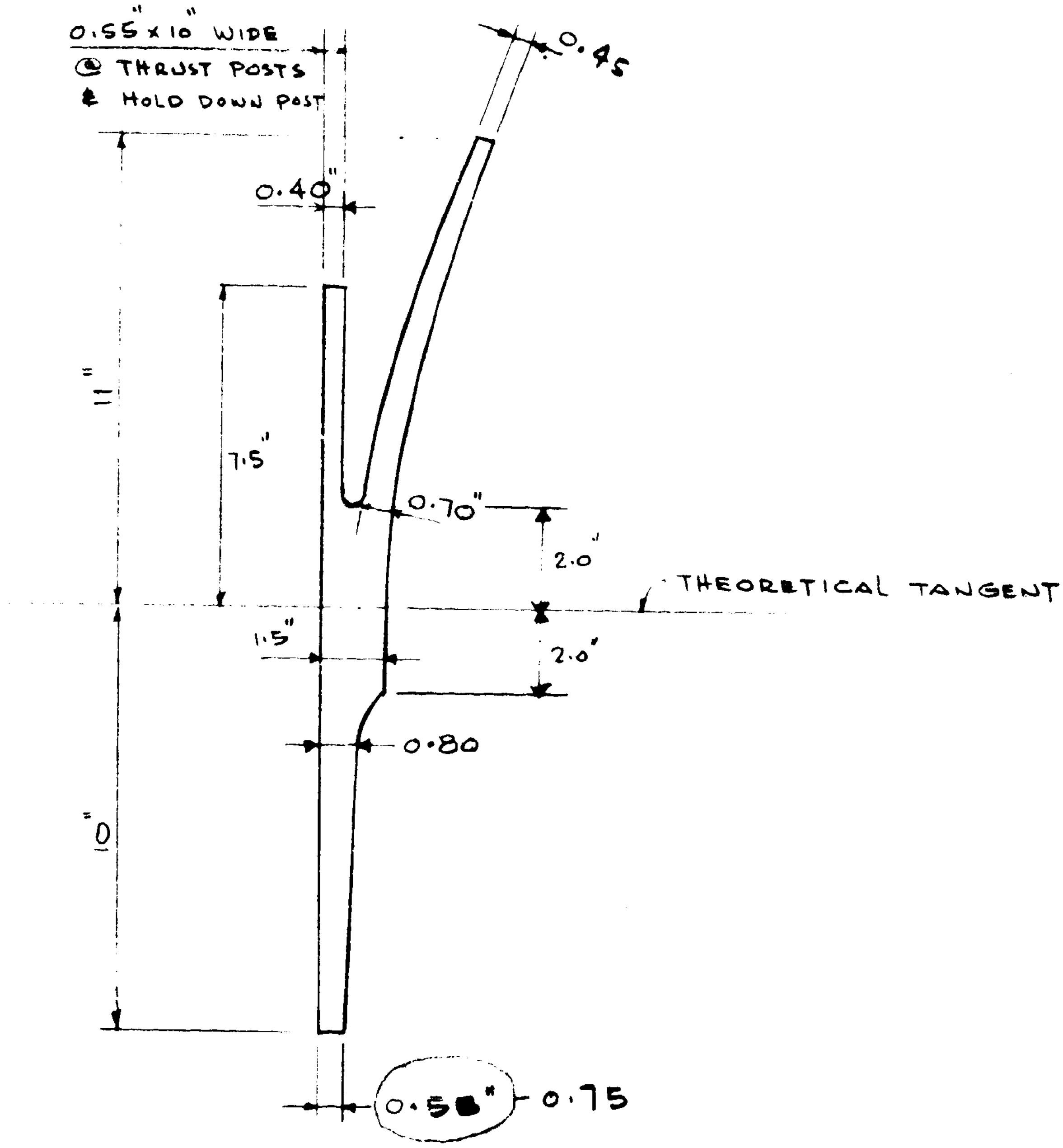
AT WELD LAND

$$t_w = \frac{1.2 \times 10{,}200}{16000} = \underline{\underline{0.765''}}$$

B-2.12

MLLV SINGLE STAGE
CORE VEHICLE
ANALYSIS OF LOX TANK UPPER BULKHEAD
Y-RING CONFIGURATION

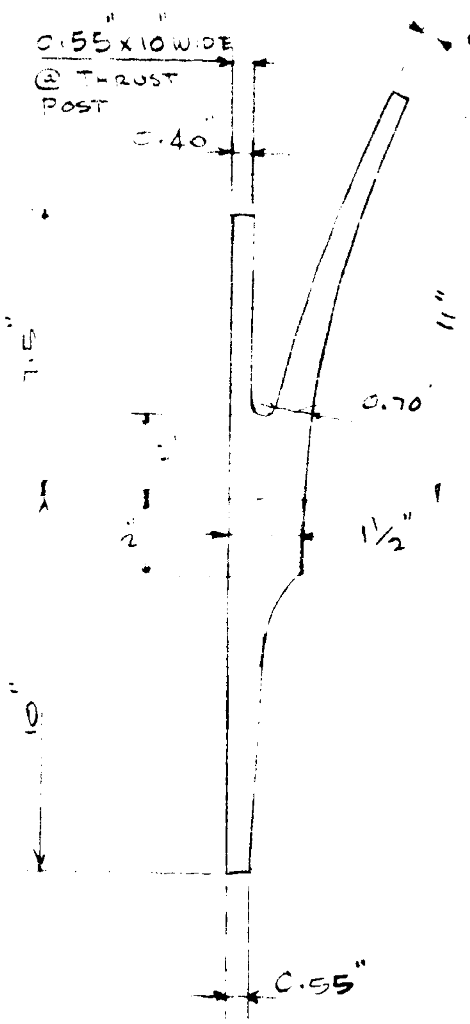
MATERIAL - 2219-T87

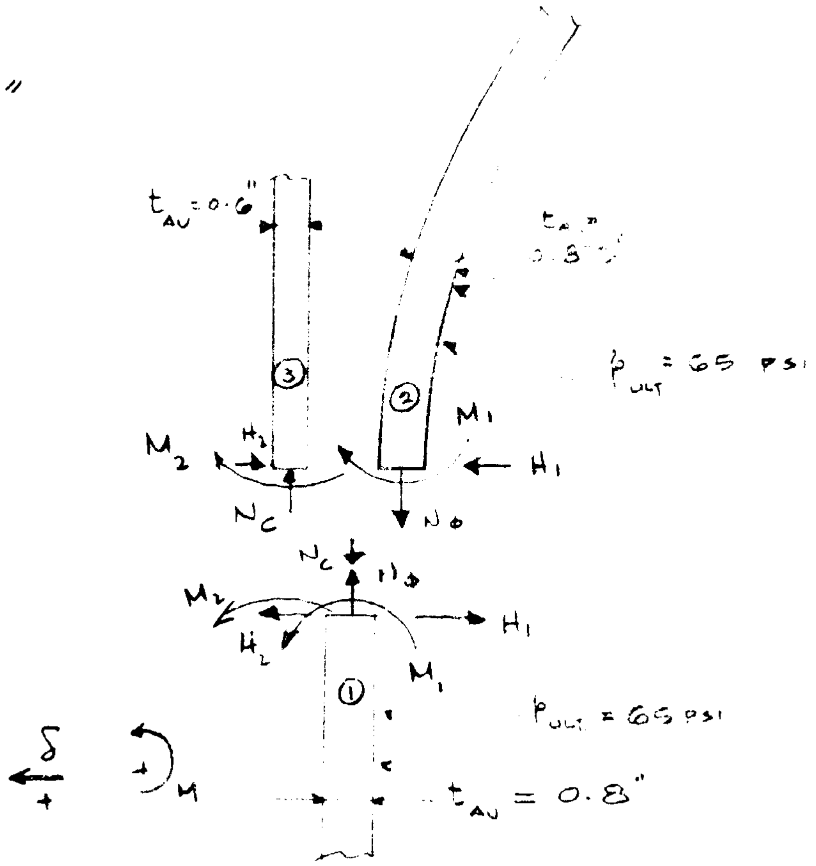


ASSUMED Y-RING SECTION
UPPER LOX BULKHEAD

MLLV CORE VEHICLE LOX TANK UPPER BULKHEAD

Y-RING ANALYSIS





SIMULATED SHELL ELEMENT (AV. THICKNESS) DISCONTINUITY FORCE DIAGRAM

ASSUME SHELL ①, ② & ③ ARE ALL LONG CYLINDER ELEMENTS

DISCONTINUITY FORCES ARE:

$H_1 = 191$ #/"

$H_2 = -65$ #/"

$M_1 = 223$ "-#/"

$M_2 = 225$ "-#/"

MIN. THICKNESS REQUIREMENT IN LOX TANK CYLINDER WALL.

$$p_{ULT} = 65 \text{ PSI}$$

$$t = \frac{65 \times 340}{63000} = 0.35''$$

COMPUTATION OF GEOMETRIC PARAMETERS

SHELL (1)

$$\lambda = \frac{1.279}{\sqrt{R\, t_{AV}}} = \frac{1.279}{\sqrt{340 \times 0.8}} = \frac{1.279}{16.5} = 0.0775$$

$$D = \frac{E \times 0.8^3}{12(1-\nu^2)} = 0.0479\, E$$

$$S_1 = \frac{pr}{2t} = \frac{65 \times 340}{2 \times 0.80} = \frac{22100}{1.6} = 13800 \text{ PSI}$$

$$S_2 = \frac{pr}{t} = \frac{65 \times 340}{0.8} = 27600 \text{ PSI}$$

SHELL (2)

$$\beta = 1.279 \sqrt{\frac{R_2}{t_{AV}}} = 1.279 \sqrt{\frac{340}{0.875}} = 25.2$$

$$K_1 = K_2 \approx 1$$

$$S_1 = \frac{p r_2}{2} = \frac{65 \times 340}{2} = 32.5 \times 340 = 11000 \text{ PSI}$$

$$S_2 = p \left[r_2 - \frac{r_2^2}{2 r_1} \right] = 0$$

SHELL (3)

$$\lambda = \frac{1.279}{\sqrt{R t}} = \frac{1.279}{\sqrt{340 \times 0.6}} = 0.0894$$

$$D = \frac{E \times 0.6^3}{12(1-\nu^2)} = 0.0202\, E$$

DEFLECTION OF SHELL (1) (BULKHEAD SHELL)

$$\delta_1^{p} = \frac{R}{E}(S_2 - \nu S_1) = \frac{340}{E}(27600 - 0.3\times 13800) = \frac{7.960\times 10^6}{E}$$

$$\bar{\delta}_1^{H_1} = -\frac{H_1}{2D\lambda^3} = -\frac{H_1}{2\times 0.0479E\times 4.65\times 10^{-4}} = -\frac{2.23\times 10^4 H_1}{E}$$

$$\bar{\delta}_1^{M_1} = \frac{M_1}{2D\lambda^2} = \frac{M_1}{2\times 0.0479E\times 6.0\times 10^{-3}} = \frac{1740 M_1}{E}$$

$$\bar{\delta}_1^{M_2} = \frac{1740 M_2}{E}$$

$$\delta_1^{H_2} = \frac{22500\ H_2}{E}$$

ROTATION OF SHELL (1)

$$\theta_1^{p} \approx 0$$

$$\theta_1^{H_1} = -\frac{H_1}{2D\lambda^2} = -\frac{H_1}{2\times 0.0479E\times 0.0775^2} = \frac{-1740\ H_1}{E}$$

$$\theta_1^{H_2} = +\frac{H_2}{2D\lambda^2} = \frac{1740\ H_2}{E}$$

$$\theta_1^{M_1} = \frac{M_1}{\lambda D} = \frac{M_1}{0.0775\times 0.0479E} = \frac{270\ M_1}{E}$$

$$\theta_1^{M_2} = \frac{M_2}{\lambda D} = \frac{270\ M_2}{E}$$

DEFLECTION OF SHELL (2)

$$\delta_2^{p} = \frac{R}{E}(S_2 - \nu S_1) = \frac{340}{E}(0 - 0.3\times 11000) = -\frac{1.12\times 10^6}{E}$$

$$\bar{\delta}_2^{M_1} = \frac{+M_1}{Et}\left(\frac{2\beta^2 \sin\phi}{k_1}\right) = \frac{M_1}{0.875E}\ \frac{2\times 25.2^2\times 1}{1} = \frac{1445 M_1}{E}$$

$$\delta_2^{H_1} = \frac{+H_1}{Et}(\beta R_2 \sin^2\phi)(k_2 + \frac{1}{k_1}) = \frac{H_1}{0.875E}(25.2\times 340)\times 2$$

$$= \frac{19600\ H_1}{E}$$

ROTATION OF SHELL (2)

$$\theta_2^{p} = 0$$

$$\theta_2^{M_1} = -\frac{M_1}{Et}\left(\frac{4\beta^3}{R_2 K_1}\right) = -\frac{M_1 \times 4 \times 25.2^3}{0.875 \times 340 \cdot E} = -\frac{217 M_1}{E}$$

$$\theta_2^{H_1} = -\frac{H_1}{Et}(2\beta^2 \sin\phi)\left(\frac{1}{K_1}\right)$$

$$= -\frac{H_1}{0.875E}(2 \times 633 \times 1) = -\frac{1447 H_1}{E}$$

DEFLECTION OF SHELL (3)

$$\delta_3^{p} = 0$$

$$\delta_3^{H_2} = -\frac{H_2}{2D\lambda^3} = -\frac{H_2}{2 \times 0.0202E \times 0.0894^3}$$

$$= \frac{-H_2}{0.0404E \times 7.14 \times 10^{-4}} = -\frac{34650 H_2}{E}$$

$$\delta_3^{M_2} = \frac{M_2}{2D\lambda^2} = \frac{M_2}{2 \times 0.0202E \times 7.99 \times 10^{-3}} = \frac{3090 M_2}{E}$$

ROTATION OF SHELL (3)

$$\theta_3^{p} = 0$$

$$\theta_3^{H_2} = +\frac{H_2}{2D\lambda^2} = \frac{3090 H_2}{E}$$

$$\theta_3^{M_2} = -\frac{M_2}{\lambda D} = -\frac{M_2}{0.0894 \times 0.0202E} = -\frac{554 M_2}{E}$$

SET UP COMPATIBLE EQUATIONS

$$\delta_1 = \delta_2$$

$$7.96\times10^6 - 22500H_1 + 1740M_1 + 1740M_2 + 22500H_2$$
$$= -1.12\times10^6 + 1445M_1 + 19600H_1$$

$$-42100H_1 + 22500H_2 + 295M_1 + 1740M_2 + 9.08\times10^6 = 0 \quad (1)$$

$$\theta_1 = \theta_2$$

$$-1740H_1 + 1740H_2 + 270M_1 + 270M_2 = -217M_1 - 1447H_1$$

$$-293H_1 + 1740H_2 + 487M_1 + 270M_2 = 0 \quad (2)$$

$$\delta_1 = \delta_3$$

$$7.96\times10^6 - 22500H_1 + 1740M_1 + 1740M_2 + 22500H_2$$
$$= -34650H_2 + 3090M_2$$

$$-22500H_1 + 57150H_2 + 1740M_1 - 1350M_2 + 7.96\times10^6 = 0 \quad (3)$$

$$\theta_1 = \theta_3$$

$$-1740H_1 + 1740H_2 + 270M_1 + 270M_2 = 3090H_2 - 554M_2$$

$$-1740H_1 - 1350H_2 + 270M_1 + 824M_2 = 0 \quad (4)$$

SOLVE THE FOLLOWING 4 SIMULTANEOUS EQUATIONS

$$-42100H_1 + 22500H_2 + 295M_1 + 1740M_2 + 9.08\times10^6 = 0 \quad (1)$$

$$-293H_1 + 1740H_2 + 487M_1 + 270M_2 = 0 \quad (2)$$

$$-23500H_1 + 57150H_2 + 1740M_1 - 1350M_2 + 7.96\times10^6 = 0 \quad (3)$$

$$-1740H_1 - 1350H_2 + 270M_1 + 824M_2 = 0 \quad (4)$$

$143.5\times(2)$ $$-42100H_1 + 250{,}000H_2 + 70000M_1 + 38800M_2 = 0 \quad (5)$$

$1.87\times(3)$ $$-42100H_1 + 107{,}000H_2 + 3255M_1 - 2525M_2 + 14.9\times10^6 = 0 \quad (6)$$

$24.2\times(4)$ $$-42100H_1 - 32{,}700H_2 + 6540M_1 + 19920M_2 = 0 \quad (7)$$

$$-42100H_1 + 22{,}500H_2 + 295M_1 + 1740M_2 + 9.08\times10^6 = 0 \quad (8)$$

(5) - (6) $$+143{,}000H_2 + 66745M_1 + 41325M_2 - 14.9\times10^6 = 0 \quad (9)$$

(6) - (7) $$139{,}700H_2 - 3285M_1 - 22445M_2 + 14.9\times10^6 = 0 \quad (10)$$

(7) - (8) $$-55{,}200H_2 + 6245M_1 + 18180M_2 - 9.08\times10^6 = 0 \quad (11)$$

$1.024\times(10)$ $$143{,}000H_2 - 3360M_1 - 23000M_2 + 15.26\times10^6 = 0 \quad (12)$$

$2.59\times(11)$ $$-143{,}000H_2 + 16180M_1 + 47050M_2 - 23.5\times10^6 = 0 \quad (13)$$

$$143{,}000H_2 + 66745M_1 + 41325M_2 - 14.9\times10^6 = 0 \quad (14)$$

(12) + (13) $$12820M_1 + 24050M_2 - 8.26\times10^6 = 0 \quad (15)$$

(13) + (14) $$82925M_1 + 88375M_2 - 38.42\times10^6 = 0 \quad (16)$$

$6.46\times(15)$ $$82925M_1 + 155200M_2 - 53.4\times10^6 = 0 \quad (17)$$

(16) - (17) $$-66825M_2 + 14.98\times10^6 = 0$$

$$M_2 = \frac{14.98\times10^6}{66825} = \underline{224.5}\ ''\text{-}\# \quad (18)$$

SUBSTITUTE (18) INTO (15)

$$12820M_1 + 5.4\times10^6 - 8.26\times10^6 = 0$$

$$M_1 = \frac{2.86\times10^6}{12820} = \underline{223}\ ''\text{-}\# \quad (19)$$

SUBSTITUTE (18) & (19) INTO (9)

$$143{,}000 H_2 + 66745 \times 223 + 41325 \times 224.5 - 14.9 \times 10^6 = 0$$

$$143{,}000 H_2 = -9.29 \times 10^6$$

$$H_2 = -64.8 \quad \text{LB}/'' \qquad (20)$$

SUBST. (18), (19), & (20) INTO (4)

$$-1740 H_1 + \overset{87400}{1350 \times 64.8} + \overset{60200}{270 \times 223} + \overset{185000}{824 \times 224.5} = 0$$

$$H_1 = \frac{332{,}600}{1740} = 191 \quad \text{LB}/''$$

CHECK EQ (1)

$$-42100 \times 1.1 - 22500 \times 64.8 + 295 \times 223 + 1740 \times 224.5 + 9.08 \times 10^6$$

$$-8.05 \times 10^7 - 1.457 \times 10^6 + 69700 + 391000 + 9.08 \times 10^6$$

$$-9.52 \times 10^6 + 9.53 \times 10^6 \approx 0 \quad \text{OK}$$

CHECK EQ. (2)

$$-293 \times 191 - 1740 \times 64.8 + 487 \times 223 + 270 \times 224.5$$

$$-56000 - 112700 + 108500 + 60600$$

$$-168700 + 169000 \approx 0 \quad \text{OK}$$

CHECK EQ (3)

$$-22500 \times 191 - 57150 \times 64.8 + 1740 \times 223 - 1350 \times 224.5 + 7.96 \times 10^6 =$$

$$-4300000 - 3700000 - 303000 + 388000 + 7.96 \times 10^6$$

$$-4.3 \times 10^6 - 3.7 \times 10^6 - 0.303 \times 10^6 + 0.388 \times 10^6 + 7.96 \times 10^6$$

$$-8.303 \times 10^6 + 8.35 \times 10^6 \approx 0 \quad \text{OK}$$

SUPERSEDED D5-13463-8

SOLVE THE FOLLOWING 4 SIMULTANEOUS EQUATIONS

$$-42100 H_1 + 22500 H_2 + 295 M_1 + 1740 M_2 + \overset{9.08}{8.94} \times 10^6 = 0 \quad (1)$$

$$-293 H_1 + 1740 H_2 + 487 M_1 + 270 M_2 = 0 \quad (2)$$

$$-22500 H_1 + 57150 H_2 + 1740 M_1 - 1350 M_2 + \overset{7.96}{7.82} \times 10^6 = 0 \quad (3)$$

$$-1740 H_1 - 1350 H_2 + 270 M_1 + 824 M_2 = 0 \quad (4)$$

REWRITE THE ABOVE EQUATIONS AS

$$295 M_1 + 1740 M_2 - 42100 H_1 + 22500 H_2 + \overset{9.08}{8.94} \times 10^6 = 0 \quad (1)$$

$$487 M_1 + 270 M_2 - 293 H_1 + 1740 H_2 + 0 = 0 \quad (2)$$

$$1740 M_1 - 1350 M_2 - 22500 H_1 + 57150 H_2 + \overset{7.96}{\cancel{7}.82} \times 10^6 = 0 \quad (3)$$

$$270 M_1 + 824 M_2 - 1740 H_1 - 1350 H_2 = 0 \quad (4)$$

5.9 × (1) $\quad 1740 M_1 + 10260 M_2 - 248000 H_1 + 132900 H_2 + 52.8 \times 10^6 = 0 \quad (5)$

3.57 × (2) $\quad 1740 M_1 + 965 M_2 - 1046 H_1 + 6215 H_2 = 0 \quad (6)$

$\quad 1740 M_1 - 1350 M_2 - 22500 H_1 + 57150 H_2 + 7.82 \times 10^6 = 0 \quad (7)$

6.43 × (4) $\quad 1740 M_1 + 5300 M_2 - 11200 H_1 - 8700 H_2 = 0 \quad (8)$

(5) − (6) $\quad 9295 M_2 - 246,955 H_1 + 126,685 H_2 + 52.8 \times 10^6 = 0 \quad (9)$

(6) − (7) $\quad 2315 M_2 + 21,455 H_1 - 50,935 H_2 - 7.82 \times 10^6 = 0 \quad (10)$

(7) − (8) $\quad -6650 M_2 - 11,300 H_1 + 65,850 H_2 + 7.82 \times 10^6 = 0 \quad (11)$

4.015 × (10) $\quad 9295 M_2 + 86,150 H_1 - 204000 H_2 - 31.4 \times 10^6 = 0 \quad (12)$

1.396 × (11) $\quad -9295 M_2 - 15,800 H_1 + 92,000 H_2 + 10.92 \times 10^6 = 0 \quad (13)$

$\quad 9295 M_2 - 246,955 H_1 + 126,685 H_2 + 52.8 \times 10^6 = 0 \quad (9)$

(12) + (13) $\quad 70,350 H_1 - 112,000 H_2 - 20.48 \times 10^6 = 0 \quad (14)$

(13) + (9) $\quad -262,755 H_1 + 218,685 H_2 + 63.72 \times 10^6 = 0 \quad (15)$

3.73 × (14) $\quad +262,755 H_1 - 418,000 H_2 - 76.5 \times 10^6 = 0 \quad (16)$

(15) + (16) $\quad -199,315 H_2 - 12.78 \times 10^6 = 0 \quad (17)$

$$H_2 = \frac{-12.78 \times 10^6}{199315} = \underline{\underline{-64.15}} \text{ LB}/'' \quad (18)$$

SUPERSEDED D5-13463-8

SUBSTITUTE (18) INTO (14)

$$70350 H_1 + \overset{7.19 \times 10^6}{112{,}000 \times 64.15} - 20.48 \times 10^6 = 0$$

$$H_1 = \frac{13.29 \times 10^6}{70350} = \underline{\underline{188}} \text{ LB/"} \quad (19)$$

SUBSTITUTE (18) & (19) INTO (9)

$$9295 M_2 - 46.4 \times 10^6 - \overset{8.13 \times 10^6}{126{,}855 \times 64.15} + 52.8 \times 10^6 = 0$$

$$M_2 = \frac{1.73 \times 10^6}{9295} = \underline{187} \text{ "-\#} \quad (20)$$

SUBSTITUTE (18), (19) & (20) INTO (4)

$$270 M_1 + 824 \times 187 - 1740 \times 188 + 1350 \times 64.15 = 0$$

$$M_1 = \frac{86500}{270} = \underline{\underline{321}} \text{ "-\#} \quad (21)$$

CHECK EQ. (1)

$$-42100 \times 188 - 22500 \times 64.15 + 295 \times 321 + 1740 \times 187 + 8.94 \times 10^6$$

$$-7.9 \times 10^6 - 1.455 \times 10^6 + .0946 \times 10^6 + 0.325 \times 10^6 + 8.94 \times 10^6 = 0$$

$$-9.355 \times 10^6 + 9.3596 \times 10^6 \approx 0 \quad \text{OK}$$

CHECK EQ. (2)

$$-293 \times 188 - 1740 \times 64.15 + 487 \times 321 + 270 \times 187 = 0$$

$$-55200 - 111600 + 156500 + 50500 =$$

$$-167000 + 207000 \not\approx 0$$

CHECK EQ (3)

$$-22500 \times 188 - 57150 \times 64.15 + 1740 \times 321 - 1350 \times 187 + 7.82 \times 10^6$$

$$-4.24 \times 10^6 - 3.68 \times 10^6 - 0.253 \times 10^6 + (0.559 + 7.82) \times 10^6$$

$$-8.173 \times 10^6 + 8.379 \times 10^6 \not\approx 0$$

INVESTIGATION OF STRESSES IN SHELL ①

GIVEN $\Sigma M = (223 + 225) = 448 \text{ "-\#/"}$

$\Sigma H = 191 + 65 = 265 \text{ \#/"}$

FOR $t = 0.8''$ AT NECK PORTION

a) MERIDIANAL BENDING STRESS

$$\sigma_b = \frac{6 \times 448}{0.64} = 4200 \text{ PSI}$$

b) MEMBRANE MERIDINAL STRESS

$$\sigma_d = \frac{65 \times 340}{2 \times 0.80} = 13850 \text{ PSI}$$

COMBINED STRESS IS

$$\Sigma(\sigma_b + \sigma_d) = 18050 \text{ PSI}$$

HOOP STRESS INVESTIGATION IN SHELL ①

AT THEORETICAL TANGENT LINE

$t = 1.5''$

$$\lambda = \frac{1.279}{\sqrt{340 \times 1.5}} = \frac{1.279}{22.6} = 0.0565$$

a) MEMBRANE HOOP STRESS

$p = 60$ PSI

$$\sigma_2 = \frac{pr}{t} = \frac{65 \times 340}{1.50} = 14750 \text{ PSI}$$

TENSION

b) DIRECT HOOP STRESS FROM MOMENT

$$\sigma_2' = \frac{2M}{t}\lambda^2 R = \frac{2 \times 448}{1.5} \times 3.2 \times 10^{-3} \times 340 = 650 \text{ PSI}$$

c) DIRECT HOOP STRESS FROM SHEAR ΣH

$$\sigma_2'' = -\frac{2H}{t} \times R = -\frac{2 \times 265}{1.5} \times 0.0565 \times 340$$

$$= -6800 \text{ PSI}$$

d) POISSON BENDING STRESS

$$\sigma_3''' = 0.3 \times 4200 = 1260 \text{ PSI}$$

COMBINED HOOP STRESS

$$\Sigma \sigma_2 = 14{,}750 + 650 - 6800 - 1260 = 7340 \text{ PSI}$$

TENSION I.F.

$$\Sigma \sigma_2 = 14{,}750 + 650 + 1260 - 6800 = 9{,}860 \text{ PSI}$$

TENSION O.F.

CONCLUSION: BOTH MERIDIANAL & HOOP STRESS IN SHELL ① ARE NOT CRITICAL.

INVESTIGATION OF MERIDIANAL STRESS AT 10" AWAY FROM THEORETICAL TANGENT @ SHELL (T)

ASSUME λ VALUE BASED ON $t_{av} = 0.65$

$$\lambda = \frac{1.279}{\sqrt{340 \times 0.65}} = \frac{1.279}{14.9} = 0.086$$

$$\lambda x = 0.086 \times 10 = 0.86$$

MOMENT DECAY COEFF $A_{\lambda x} \approx 0.65$

$$M = 0.65 \times 448 = 291 \text{ ''-\#}$$

a) MERIDIANAL BENDING STRESS

$$\sigma_b = \frac{6 \times 291}{0.36} = 4900 \text{ PSI}$$

b) MEMBRANE MERIDIANAL STRESS

$$\sigma_d = \frac{65 \times 340}{2 \times 0.6} = 18,400 \text{ PSI}$$

COMBINED STRESS

$$\Sigma \sigma = 23,300 \text{ PSI}$$

ALLOWABLE F_{tu} @ WELD JT = 34,500 PSI

$$M.S = \frac{34,500}{23,300} - 1 = +0.480 \longrightarrow$$

M.S. IS TOO CONSERVATIVE

USE $t = 0.55$ INSTEAD OF 0.6" @ WELD JT.

$$M.S = +0.33 \longrightarrow$$

FOR t = 0.55"

MISMATCH BENDING MOM. WAS NOT CONSIDERED

HOOP STRESS INVESTIGATION @ WELD JT SHELL (1)

a) MEMBRANE HOOP STRESS

$$\sigma_2 = \frac{65 \times 340}{0.6} = 36{,}900 \text{ PSI TENSILE}$$

b) DIRECT HOOP STRESS FROM M

$$\sigma_2' = \frac{2M}{t} \lambda^2 R = \frac{2 \times 291}{0.6} \times 7.4 \times 10^{-3} \times 340 = 2{,}440 \text{ PSI TENSILE}$$

c) DIRECT HOOP STRESS FROM H

$$\sigma_2'' = -\frac{2H}{t} \lambda R = -\frac{2 \times 265 \times 0.6}{0.6} \times 0.086 \times 340$$

$$= -15{,}500 \text{ PSI (COMPR. STRESS)}$$

d) POISSON BENDING STRESS

$$\sigma_2''' = 0.3 \times 7000 = 2100 \text{ PSI}$$

COMBINED HOOP STRESS @ WELDED JT STRESS

$$\Sigma \sigma_2 = 36{,}900 + 2440 - 15{,}500 + 2100 = 25{,}940 \text{ PSI TENSILE I.F}$$

$$\Sigma \sigma_2 = 36{,}900 + 2440 - 15{,}500 - 2100 = 21740 \text{ TENSILE O.F.}$$

$$M.S = \frac{34500}{25940} - 1 = \underline{+0.33} \longrightarrow$$

$$M.S = \underline{+0.29} \longrightarrow \text{ FOR } \underline{t = 0.55''} \text{ AT WELD JT}$$

INVESTIGATION OF STRESSES @ SHELL ②

STRESS AT WELD JT.

$M_1 = 223$ "-#/" $\qquad t_{AV} \approx 0.6$

$$\lambda = \frac{1.279}{\sqrt{340 \times 0.6}} = 0.0893$$

$$\lambda x = 11 \times 0.0893 \approx 1.0$$

$A_{\lambda x} \approx 0.60$ (MOMENT DECAY COEFF HETENYI TABLE)

$M = 0.60 \times 223 = 134$ "-#

a) MERIDIANAL BENDING STRESS

$$\sigma_b = \frac{6 \times 134}{0.45^2} = 3960 \text{ PSI}$$

b) MEMBRANE MERIDIANAL STRESS

$$\sigma_d = \frac{60 \times 340}{2 \times 0.45} = 22,700 \text{ PSI}$$

$$\Sigma \sigma = 26,660 \text{ PSI}$$

$$M.S = \frac{34500}{26,660} - 1 = +\underline{0.295}$$

MISMATCH ECCENTRIC MOMENT WAS NOT CONSIDERED

INVESTIGATION OF CRITICAL STRESS CONDITION AT WELD JT. OF SHELL ②

ASSUME $t_{AV} = 0.60$

$$\beta = 1.279\sqrt{\frac{340}{0.6}} = 30.5$$

HOOP STRESS INVESTIGATION

GIVEN $M = 0.6 \times 223 = 134$ "-#/"

$H = 0.6 \times 191 = 115$ #/"

HOOP STRESS CALCULATION @ $y = 11''$

$$x = 1.414\sqrt{57600 - 121} = 339$$

$$r_2 = 2(121 + 0.25 \times 115000)^{1/2} = 340.122$$

$$r_1 = \frac{340^3 \times 0.5}{115600} = 170.186$$

$$\sigma_\theta = 60\{340.122 - 339.87\} = 0.252 \times 60 = 15 \text{ \#/''}$$

NEGLIGIBLE

a) MEMBRANE HOOP STRESS

$$\sigma_2 \approx 0$$

b) HOOP STRESS DUE TO M

$$\sigma_2' = \frac{M}{tR_2}\frac{2 \times \beta^2}{K_1} = \frac{134}{0.45 \times 340} \, 2 \times 30.5^2/1 = 1630 \text{ PSI}$$

TENSILE

c) HOOP STRESS DUE TO H

$$\sigma_2'' = \frac{115}{0.45} \times 2 \times 30.5 \times 1 = 15{,}650 \text{ PSI}$$

TENSILE

d) POISSON BENDING STRESS

$$\sigma_2''' = 0.3 \times 3960 = 1190 \text{ PSI}$$

HOOP STRESS IS NOT CRITICAL. HOWEVER

MISMATCH BENDING MAY BE SIGINIFICANT

HENCE $t = 0.45$ MAY BE A GOOD DESIGN

B-2.13

MLLV SINGLE STAGE

CORE VEHICLE FWD.

HOLD DOWN SKIRT

ANALYSIS

a) Fwd. Hold down Skirt Design

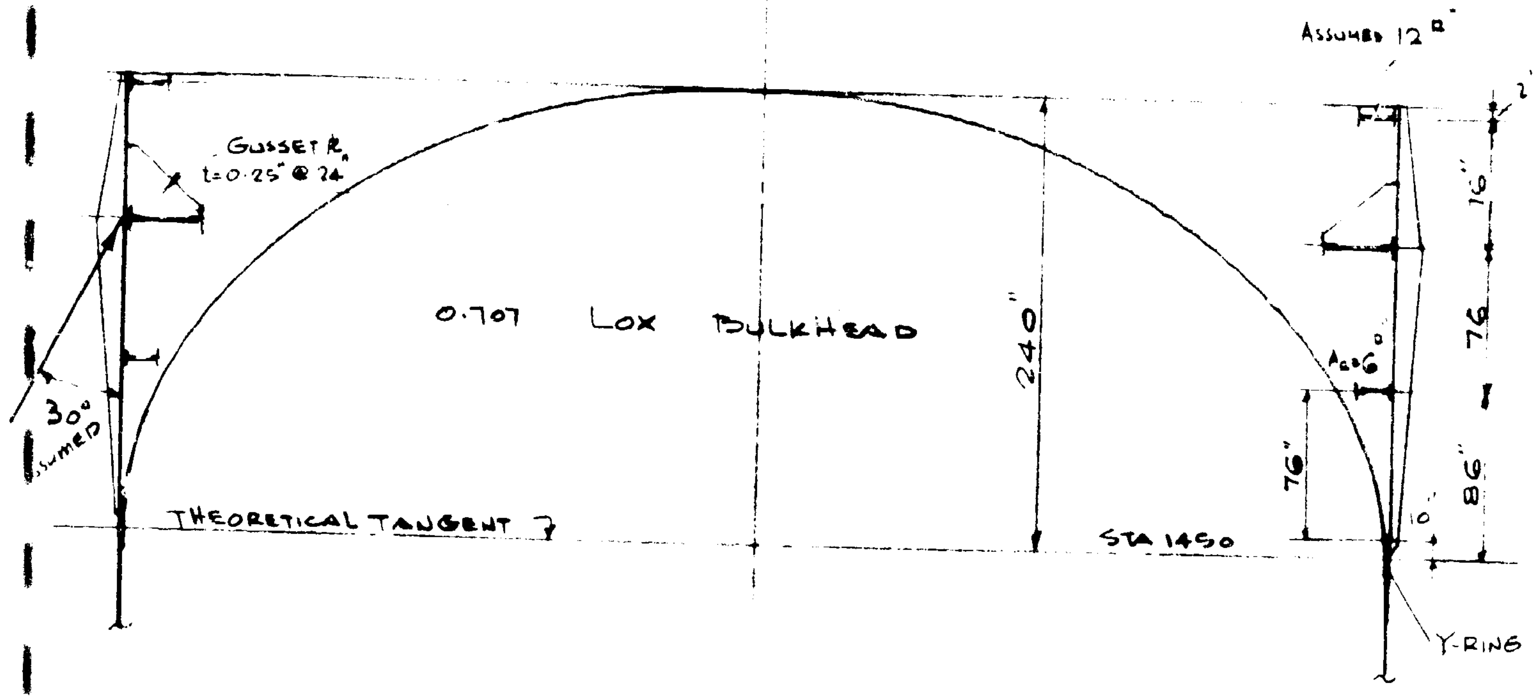
Min. M. S. = +0.09 (N_t governs design)

b) Fwd. Skirt Hold down Post Design

c) Hold down skirt thrust ring

d) Shear Lag Analysis

FWD HOLD DOWN SKIRT ANALYSIS   MLLV CORE VEHICLE ONLY

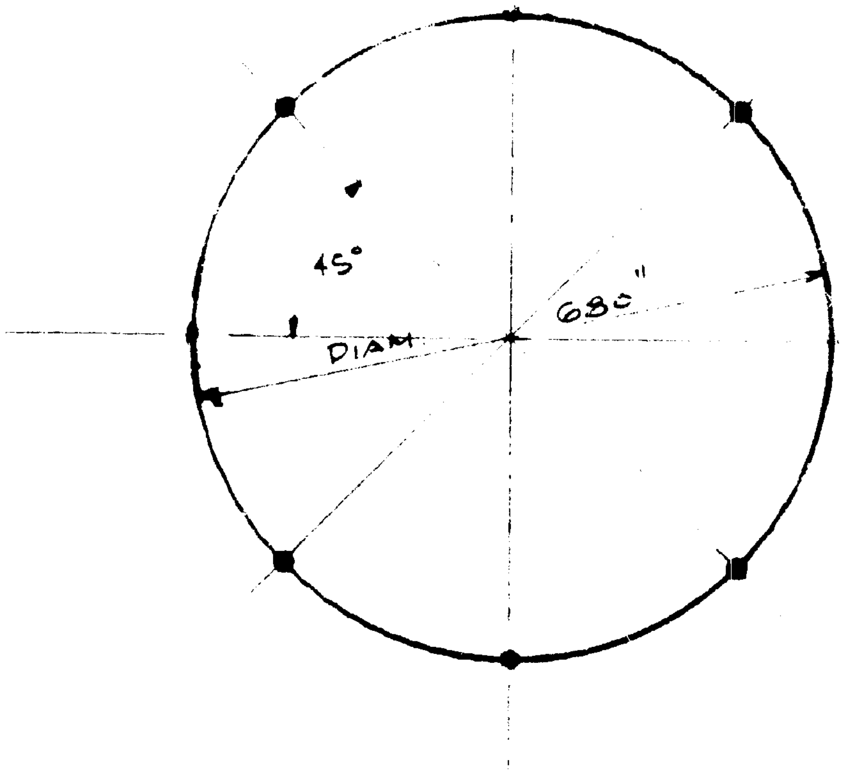


I FORWARD HOLD-DOWN SKIRT CONFIGURATION
CORE VEHICLE ONLY

CORE CUT OFF
N_c ULTIMATE (lb/in)

STA	FWD	AFT
1690	2343	2343
1454	2467	

HOLD DOWN POST LOCATION



ASSUMED HOLD DOWN POST LOCATION

FWD HOLD DOWN SKIRT CONFIGURATION DESIGN CONDITIONS:

1. FOR MAX REBOUND TENSION LOAD @ EACH HOLD DOWN POST

$$T_T = 2.205 \times 10^6 \times 1.4 = 3.09 \times 10^6 \text{ LB}$$

* $$N_t = \frac{3.09 \times 10^6}{230} = 0.01345 \times 10^6 = 13{,}450 \text{ LB/"}$$

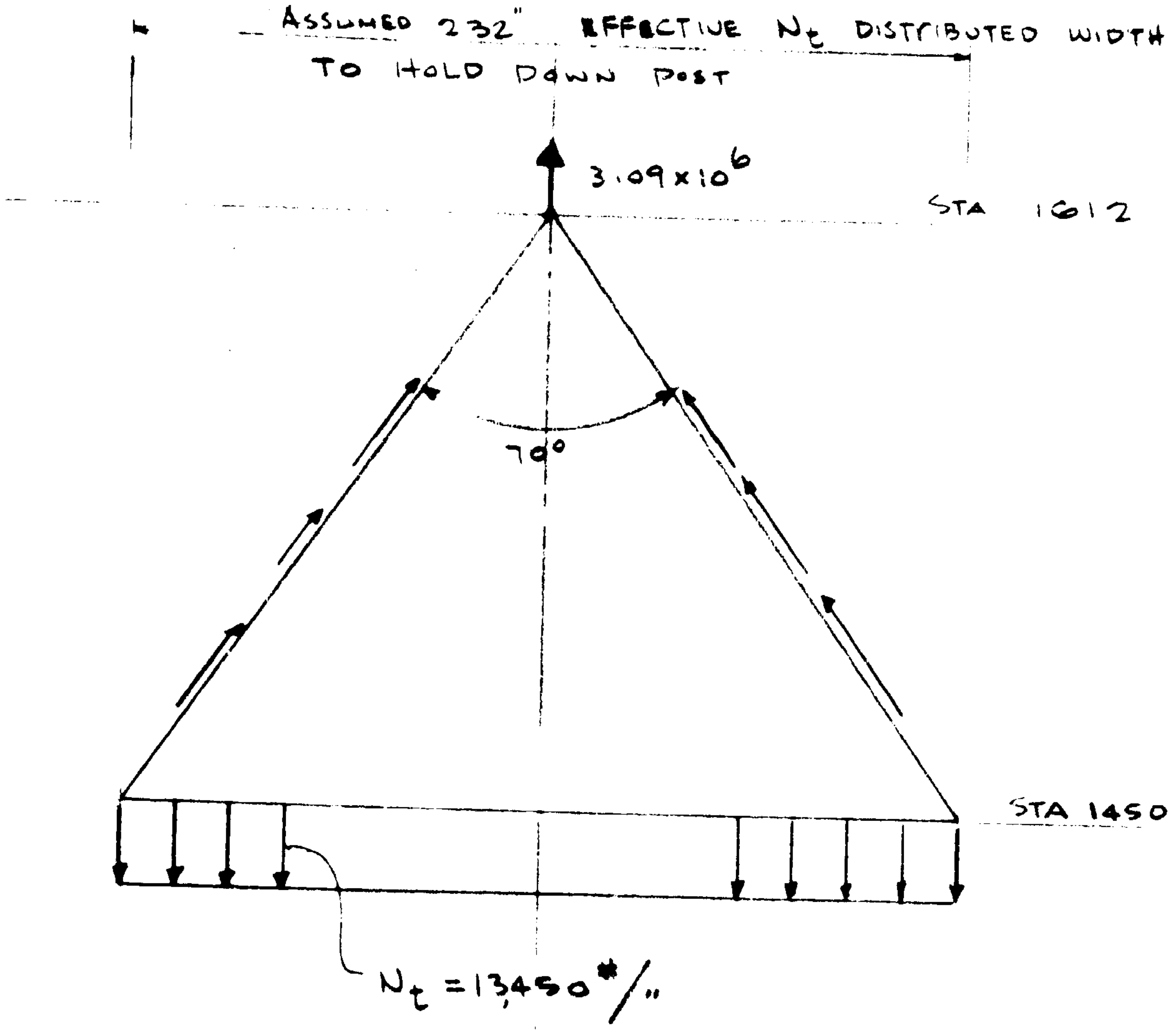
2. FOR MAX. COMPRESSIVE LOAD @ CUT-OFF

$$N_c = 2{,}500 \text{ LB/"}$$

* THIS N_t LOAD IS OBTAINED BY CONSIDERING REBOUND LOAD AS A PT. LOAD. RELIEF LOAD IS NEGLECTED.

APPROXIMATE SHEAR LAG PATH DUE TO HOLD DOWN LOAD CONITION CORE VEHICLE ONLY

ASSUME ONLY 4 HOLD-DOWN POSTS ASSEMBLY IN OPERATION

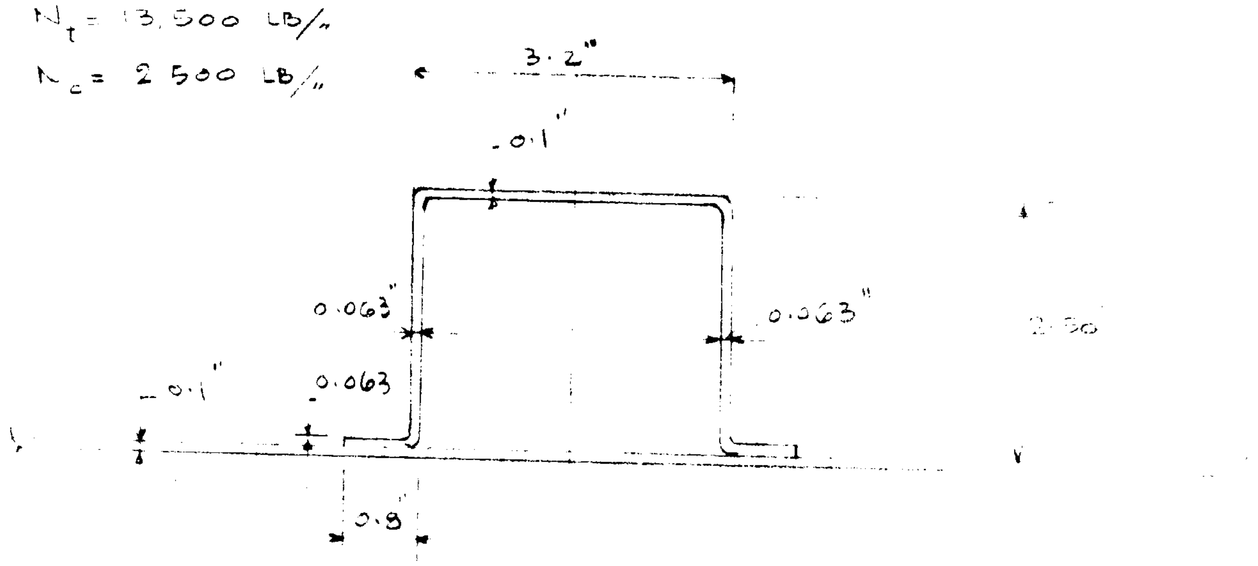


BENDING MOMENT CONTRIBUTION TO HOLDDOWN POST IS INSIGNIFICANT

SIZING OF FWD SKIRT SKIN-STIFFENER PANEL [illegible]

$N_t = 13{,}500$ LB/in

$N_c = 2500$ LB/in



8.0 EFFECTIVE PANEL WIDTH [illegible] N_c [illegible]

	A	Y	Ay	Ay^2	I_o
$A_1 = 8.0 \times .01 = $	0.800	0.0500	0.0400	0.0020	[illegible]
$A_2 = 1.6 \times 0.063 = $	0.101	0.1302	0.0132	0.00[illegible]7	
$A_3 = 2 \times 2.4 \times 0.063 = $	0.302	1.3000	0.3920	0.5100	[illegible]
$A_4 = 3.2 \times 0.10 = $	0.32[illegible]	2.5500	0.8150	2.0800	0.00026[illegible]
	1.523		1.2602	2.5937	0.14693[illegible]

$$\bar{y} = \frac{1.2602}{1.523} = 0.8275$$

$$I_c = 2.5937 + 0.146 - 1.523 \times 0.828^2 = 1.6977$$

$$I_s = 1.6977 / 8.0 = 0.2120$$

$$t_a = \frac{1.523}{8.0} = 0.1905$$

$$\rho = \sqrt{\frac{I_c}{A}} = \sqrt{\frac{1.6977}{1.523}} = 1.058$$

$$L/\rho = 76/1.058 = 71.8$$

DESIGN AXIAL COMPRESSIVE STRESS

$$f_c = \frac{8.0 \times 2500}{1.523} = \underline{13{,}150 \text{ PSI}}$$

(A) INVESTIGATION OF LOCAL INSTABILITY STRESSES

a) LOCAL SKIN PANEL BUCKLING

$$\tau_{CR} = \frac{K_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = \frac{4 \times 9.87 \times 10.4 \times 10^6}{10.7} \left(\frac{0.1}{4}\right)^2$$

$$= 38.2 \times 10^6 \times 6.25 \times 10^{-4} = 23850 \text{ PSI}$$

b) STIFFENER WEB BUCKLING STRESS

$$\tau_{CR} = \frac{K_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = \frac{4 \times 9.87 \times 10.4 \times 10^6}{10.7} \left(\frac{0.063}{2.5}\right)^2$$

$$= 38.2 \times 6.30 \times 10^2 = 24000 \text{ PSI}$$

c) STIFFENER FLANGE BUCKLING STRESS

$$\tau_{CR} = 38.2 \times 10^6 \times 9.8 \times 10^{-4} = 37400 \text{ PSI}$$

MIN MARGIN OF SAFETY FOR COMPRESSIVE N_c LOAD APPLIED TO LOCAL PANEL BUCKLING IS

$$M.S = \frac{23,850}{13,150} - 1 = \underline{\underline{+0.815}}$$

d) INTERFRAME BUCKLING STRESS EVALUATION

(i) APPLY CONSERVATIVE EULER'S FORMULA FOR LONG COLUMN ELEMENT

$L_R = 76$ $\quad L/\rho = 71 \pm$ (LONG COL.)

$$P_{CR} = \frac{\pi^2 E I}{L_R^2} = \frac{9.85 \times 10.5 \times 10^6 \times 1.6977}{5800}$$

$$= 0.0302 \times 10^6 = 30200 \text{ LB}$$

$$N_{CR} = 30200/8 = 3780 \text{ LB/IN}$$

$$M.S = 3780/2500 - 1 = \underline{+0.51}$$

APPLY THE FOLLOWING EQUATION FOR N_{CR}

$$N_{CR} = \frac{K_c \pi^2 E \, t_1^{*3}}{12(1-\nu^2) L_R^2}$$ D5-[illegible] & TN-[illegible]

$$Z_L = \frac{L_R^2}{R t_1^*}(1-\nu^2)^{1/2} = \frac{5800}{340 \times [illegible]} \times 0.[illegible] = [illegible]$$

$$t_1^* = \sqrt[4]{12 \times I_s \, t_s} = \sqrt[4]{12 \times [illegible]} = [illegible]$$

$$(t_1^*)^3 = 0.356$$

$K_c = 4.75$ NASA TN [illegible]

$$N_{CR} = \frac{4.75 \times 9.85 \times 10.4 \times 10^6 \times 0.356}{10.7 \times 5800} = 0.[illegible] \times 10^6$$

$$= 2850 \text{ LB/IN}$$

$$M.S. = \frac{2850}{2500} - 1 = \underline{+0.135}$$

B. INVESTIGATION OF GENERAL INSTABILITY

ASSUME $A_R = 6 \ \square''$

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$= \sqrt[4]{12 \times 0.212 \left(\frac{6}{76} + 0.10\right)} = 0.821$$

$$R/t^* = 340/0.821 = 413$$

$C^* \approx 0.75$ FOR $\nu = 0.00025$

$m = 8$

$n = 3$

$$T_{CR} = \frac{0.75 \times 10.4 \times 10^6}{413} = 18900 \text{ PSI}$$

$$M.S. = \frac{18900}{13,150} - 1 = \underline{+0.435}$$

RING AREA MAY BE REDUCED. HOWEVER SIZE OF TANK, 680" DIAM NEEDS HEAVIER RINGS

FOR MAINTAINING CIRCULARITY FROM GOOD ENGINEERING COMMONSENSE PT. OF VIEW RING LESS THAN 6 a MAY NOT BE ADEQUATE EVEN TIMOSHENKO'S RING CRITERION IS SATISFIED

(C) INVESTIGATION OF FWD HOLD DOWN SKIRT CAPABILITY TO SUPPORT N_t LOAD

GIVEN $N_t = 13,450$ LB/in

FOR THE WHOLE EFFECTIVE SKIN STRINGER PANEL

$$\Sigma N_t = 8 \times 13,450 = 107,500 \text{ LB}$$

$$\sigma_t = \frac{107,500}{1.523} = 70,500 \text{ PSI}$$

$$M.S = \frac{77000}{70.500} - 1 = \underline{\underline{+0.09}}$$

THIS INDICATES THAT HOLD DOWN SKIRT DESIGN IS GOVERNED BY N_t LOAD

IF INJECTION STAGE IS ACCOMPANIED WITH CORE VEHICLE IN SINGLE STAGE ORBIT, THEN

$$N_t = \frac{2.297 \times 10^6 \times 1.4}{232} = 13850 \text{ LB/in}$$

$$\Sigma N_t = 8 \times 13,850 = 111,000 \text{ LB}$$ PER SKIN STRINGER PANEL

$$\sigma_t = \frac{111,000}{1.523} = 72,750 \text{ PSI}$$

$$M.S = \frac{77000}{72750} - 1 = \underline{\underline{+0.06}}$$

OK

SIZING OF HOLD DOWN POST

MAX REBOUND LOAD IS

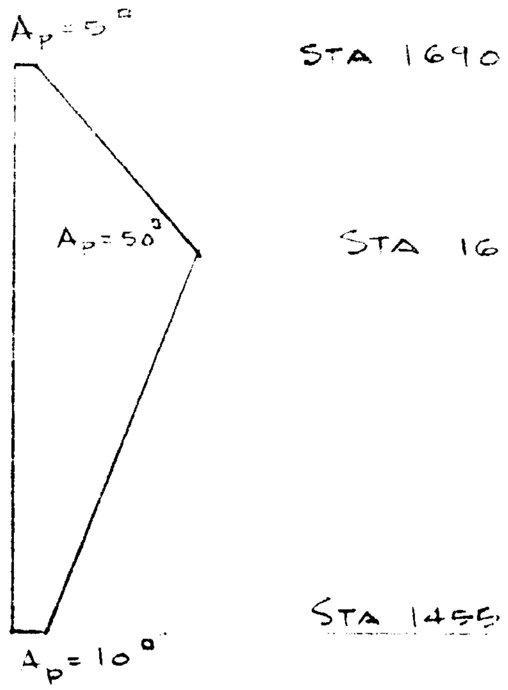
$$T_t = 3.09 \times 10^6 \text{ LB}$$

ASSUME DIE FORGED 7075-T6 ALUM MATERIAL

$$f_{tu} = 62000 \text{ PSI}$$

THE MAX POST AREA REQ'D IS

$$A_p = \frac{3.09 \times 10^6}{62000} = 50 \, \square''$$



FOR THE CASE OF SINGLE STAGE VEHICLE
(CORE + INJECTION STAGE

$$T_t = 3.235 \times 10^6$$

$$f_t = \frac{3.235 \times 10^6}{50} = 64500 \text{ PSI}$$

DIE FORGED ALU 7075-T6 ALLOY

$$f_{tu} = 69000 \text{ PSI MIN}$$

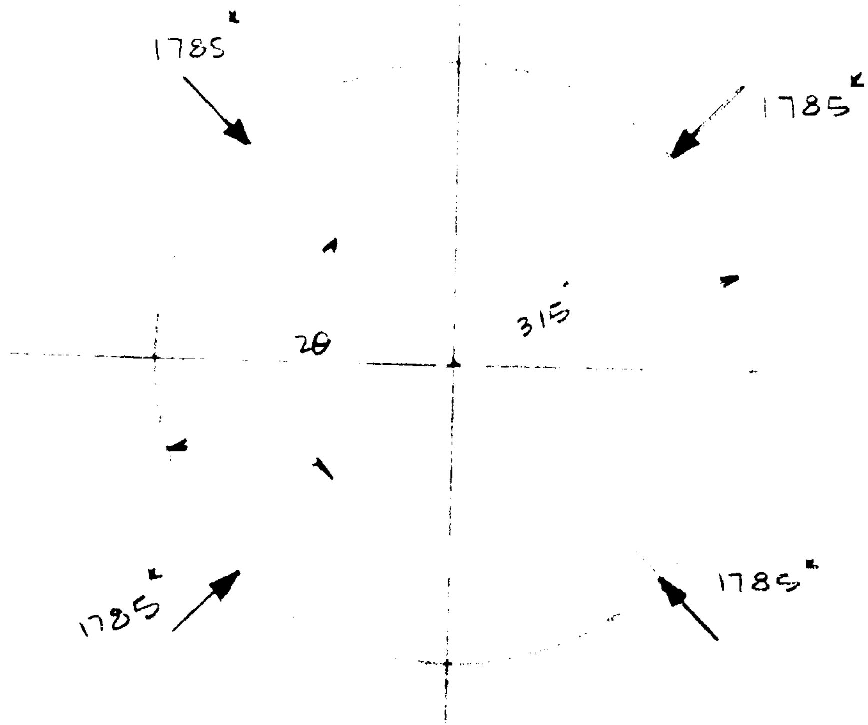
$$M.S. = \frac{69000}{64500} - 1 = \underline{+0.07} \longrightarrow \text{OK}$$

SIZING OF THRUST RING AT STA 1612

GIVEN $T_t = 3.09 \times 10^6$

$T_{t_H} = 3.09 \times 10^6 \times \tan 30^\circ = 3.09 \times 10^6 \times$ [illegible]

$= 1.785 \times 10^6$ lb   ASSUME 30° [illegible] FOR HOLD DOWN [illegible]



$2\theta = 90^\circ$

$\theta = \frac{\pi}{4}$

MAX BENDING MOMENT AT THE LOAD PT

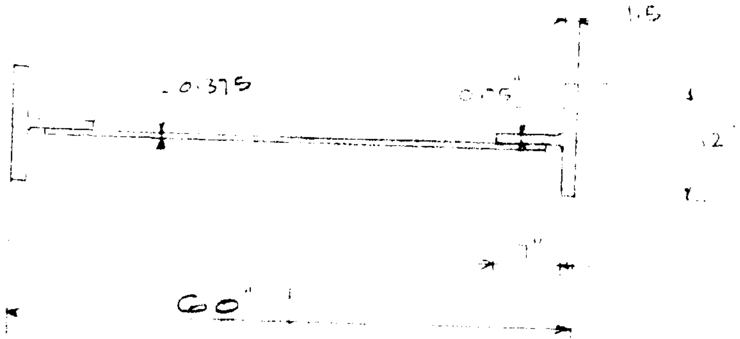
$$M = \frac{1}{2} P_r R \left(\frac{4}{\pi} - \cot 45^\circ \right)$$

$$= \frac{1}{2} 1785 \times 315 \, (1.2715 - 1)$$

$$= 76200 \text{ ''-kips}$$

$$C = \frac{1}{2} P_r \times \cot \theta = 892.5^k$$

NEED 60" DEPTH RING



$A_F = 12 \times 1.5 \times 2 = 36$

$A_W = 7 \times 2 \times 0.75 = 10.5$

$A_W = 54 \times 0.375 = 20.25$

$\Sigma A_R = 66.75 \ \square''$

$I_F = 36 \times 29.25^2 = 30800$

$I_W = 10.5 \times 25.0^2 = 6560$

$I_W = \frac{1}{12} 0.375 \times 54^3 = 4930$

$\Sigma I_R = 42290 \text{ IN}^4$

$$S = \frac{42,290}{30} = 1410 \text{ IN}^3$$

a. BENDING STRESS IN THE RING

$$\sigma_b = \frac{76200^{\text{IN-K}}}{1410} = 54,000 \text{ PSI}$$

b. AXIAL COMPRESSIVE STRESS IN THE RING

$$\sigma_a = \frac{892.5^k}{66.75} = 13350 \text{ PSI}$$

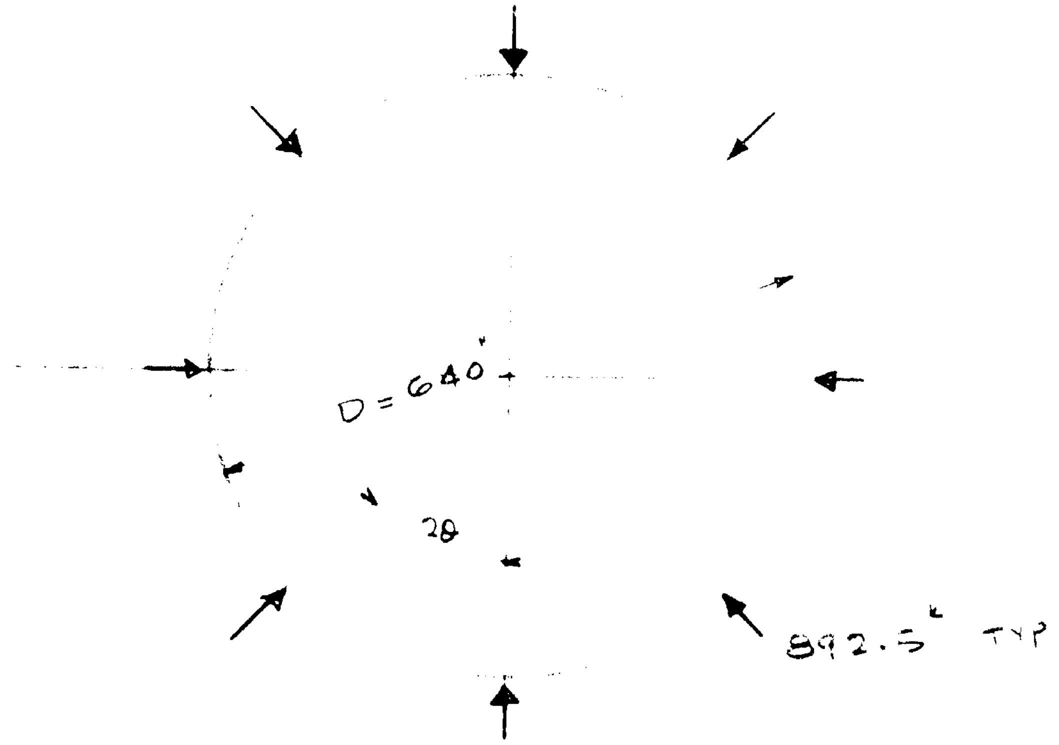
$$R_b = \frac{54000}{77000} = 0.702$$

$$R_a = \frac{13350}{69000} = \frac{0.194}{0.896}$$

$$M.S. = \frac{1}{0.896} - 1 = \underline{+0.115} \longrightarrow$$

IF 8 HOLD-DOWN POSTS ARE USED

HOLD DOWN ARM SKEW @ 30°



$\theta = \pi/8$

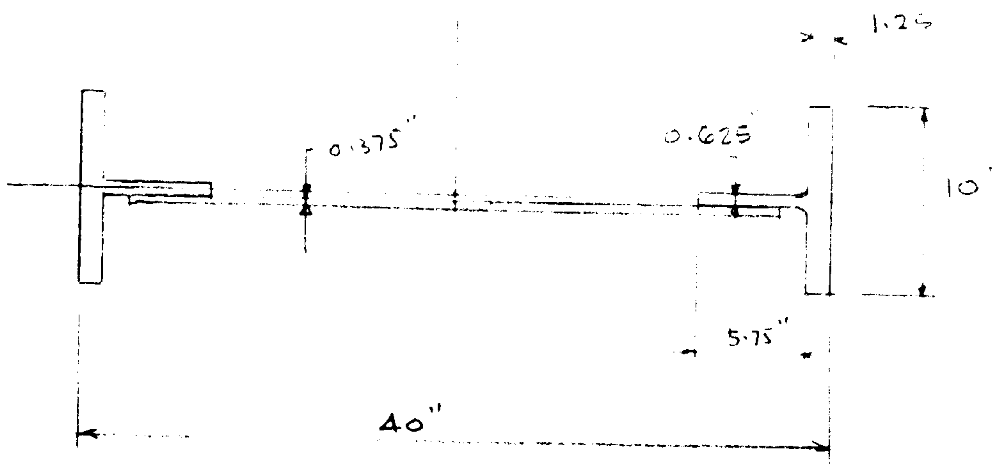
MAX BENDING MOMENT IS AT THE LOAD PT

$$M = \frac{1}{2}\, 892.5 \times 320 \left(\underbrace{\frac{8}{\pi} - \overset{2.4142}{\cot 22.5^\circ}}_{0.1323} \right)$$

$$= 160 \times 892.5 \times 0.1323 = 18{,}850 \text{ "-k}$$

$$C = \frac{1}{2} P_r \cot\theta = 892.5 \times 1.2071 = 1070^k$$

HOLD DOWN THRUST RING REQUIREMENT
FOR 8 HOLD DOWN POSTS



$A_F = 2 \times 10 \times 1.25 = 25 \; \square''$

$A_W = 2 \times 5.75 \times 0.625 = 7.2$

$A_W = 35 \times 0.375 = 13.1$

$45.3 \; \square''$

$I_F = 25 \times 19.375^2 = 9360$

$I_W = 7.2 \times 15.875^2 = 1815$

$I_W = \frac{1}{12} 0.375 \times 35^3 = 1350$

12525

$$S = \frac{12525}{20} = 627$$

$$\sigma_b = \frac{18850}{627} = 30000$$

$$\tau_d = \frac{1070}{45.3} = 23700$$

$$k_b = \frac{30000}{77000} = 0.39$$

$$k_d = \frac{23700}{69000} = 0.344$$

0.734

M.S = +0.36 →

$2645 \times \pi \times 640 = 53150$ cu in

$\Delta R_W = 5315$† LB NET SAVING

CHECK MAXIMUM BENDING MOMENT AT RING USING METHOD OF SUPERIMPOSING OF MOMENT INFLUENCE FROM NASA - STRUCTURES MANUAL FOR 4 HOLD DOWN POST CASE

$M_1 = +0.24 \times P_r R = 0.24 \times 1785 \times 315 = 35,000$

$M_2 = -0.10 \times P_r R =$

$M_3 = +0.08 \times P_r R =$ $\Big\}\; -0.11 \times 1785 \times 315 = -61900$

$M_4 = -0.09 \times P_r R =$

MAX $\Sigma M = +73100$ in-kip

THIS CHECKS WITH ROARK'S FORMULA CLOSELY

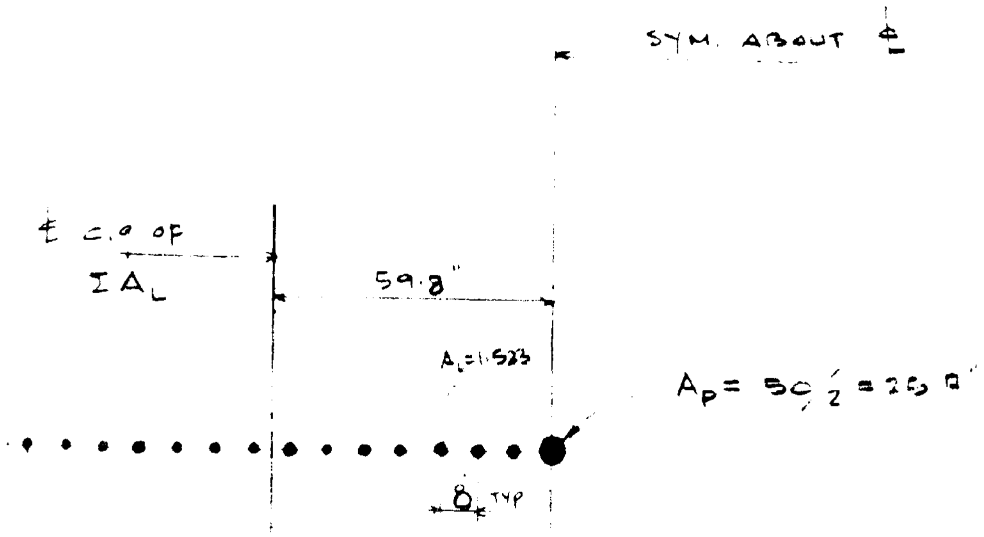
Assumption

IF THE HOLDDOWN ARM IS ASSUMED TO SKEW @ 0° ONLY

$T_H = 3.09 \times 10^6 \times \tan 0° = 0$ (RADIAL LOAD = 0)

THE THRUST RING AT STA 1630 WILL BE DESIGNED FOR STIFFNESS ONLY. IN THIS CASE RING SIZE MAY BE ASSUMED AS 12 D" WITH LOCAL REINFORCEMENT AT HOLD DOWN FITTING AREAS.

SHEAR LAG ANALYSIS OF HOLD DOWN SKIRT



C.g OF ΣA_L

M

$1.523 \times 1 \times 8$
$1.523 \times 2 \times 8$
$1.523 \times 3 \times 8$
$1.523 \times 4 \times 8$
$1.523 \times 5 \times 8$

$1.523 \times 14 \times 8$

$\Sigma A_L = 21.38$ $\quad \Sigma M: 1.523 \times 105 \times 8 = 1280$

$$b_c = \bar{x}_L = \frac{1280}{21.38} = 59.8"$$

THE SUBSTITUTED PANEL WIDTH

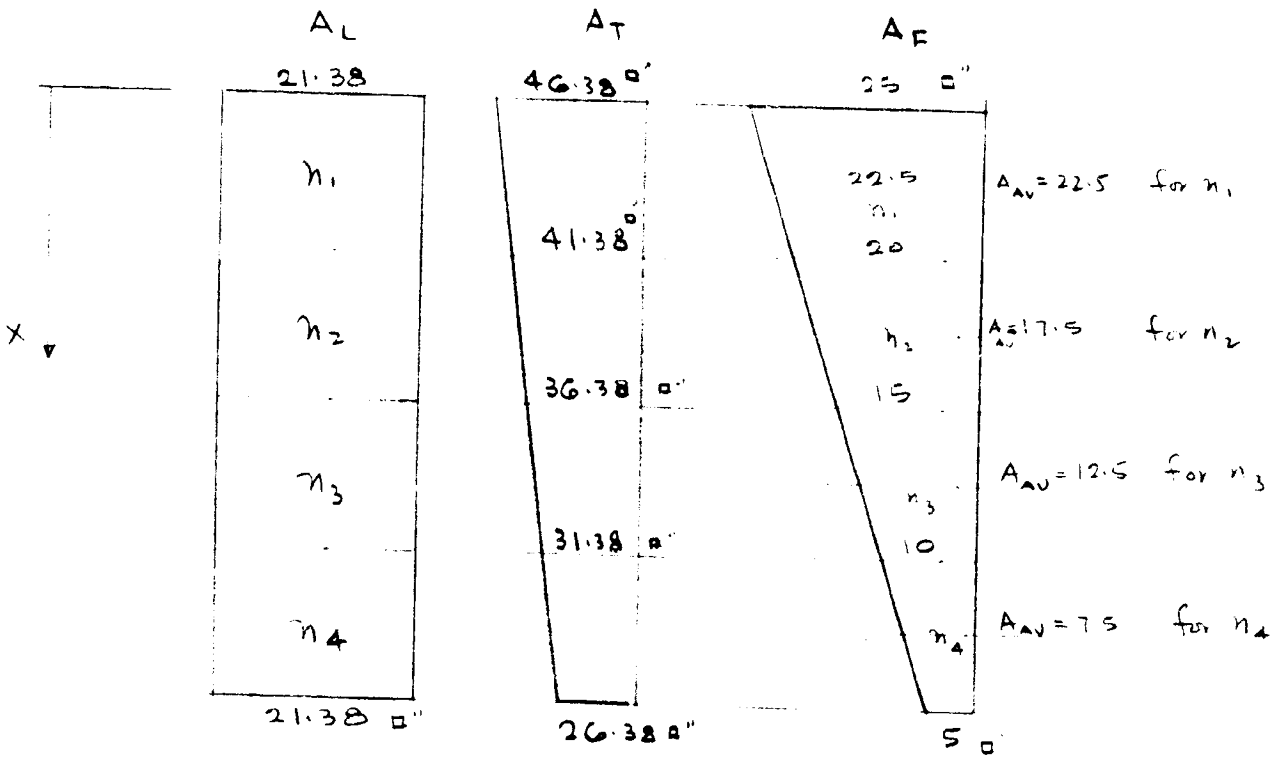
$$b_s = \left(0.65 + \frac{0.35}{n^2}\right) \bar{b}_c$$

$$= \left(0.65 + \frac{0.35}{196}\right) \times 59.8 = 39"$$

▷ P. KUHN
STRESS IN AIRCRAFT
& SHELLS

COMPUTATION OF SHEAR LAG PARAMETERS

$$k = \sqrt{\frac{Gt}{Eb_s}\left(\frac{1}{A_F} + \frac{1}{A_L}\right)} \qquad b_s = 39 \qquad t = 0.10$$



$$k_1 = \sqrt{\frac{3.9 \times 10^6 \times 0.1}{10.4 \times 10^6 \times 39}\left(\frac{1}{22.5} + \frac{1}{21.38}\right)} = 0.936 \times 10^{-2}$$

$$k_2 = \sqrt{9.6 \times 10^{-4}\left(\frac{1}{17.5} + 0.04675\right)} = 0.999 \times 10^{-2}$$

$$k_3 = \sqrt{9.6 \times 10^{-4}\left(\frac{1}{12.5} + 0.04675\right)} = 1.103 \times 10^{-2}$$

$$k_4 = \sqrt{9.6 \times 10^{-4}\left(0.18025\right)} = 1.318 \times 10^{-2}$$

COMPUTATION OF UNIT SHEAR DEFORMATIONS
p & q FOR UNIT FORCE

$$p_n = \frac{k_n}{G t_n \tanh k_n a_n}$$

$a_n = 40''$
$t_n = 0.1''$

$$q_n = \frac{k_n}{G t_n \sinh k_n a_n}$$

$$p_1 = \frac{0.936 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \tanh \underset{0.36}{0.375}} = 6.67 \times 10^{-8}$$

$$q_1 = \frac{0.936 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \sinh \underset{0.385}{0.375}} = 6.23 \times 10^{-8}$$

$$p_2 = \frac{0.999 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \tan \underset{0.38}{0.399}} = 6.75 \times 10^{-8}$$

$$q_2 = \frac{0.999 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \sinh \underset{0.41}{0.399}} = 6.22 \times 10^{-8}$$

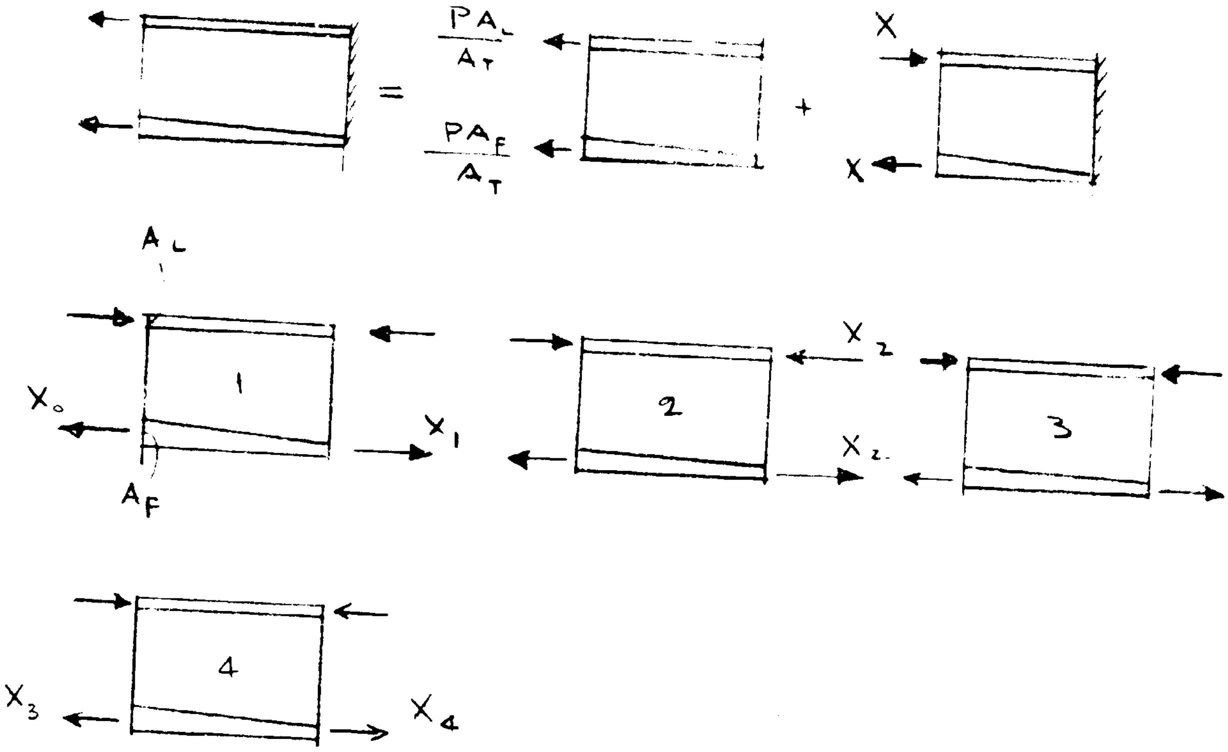
$$p_3 = \frac{1.103 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \tanh \underset{0.414}{0.442}} = 6.83 \times 10^{-8}$$

$$q_3 = \frac{1.103 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \sinh \underset{0.456}{0.442}} = 6.20 \times 10^{-8}$$

$$p_4 = \frac{1.318 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \tanh \underset{0.485}{0.527}} = 6.97 \times 10^{-8}$$

$$q_4 = \frac{1.318 \times 10^{-2}}{3.9 \times 10^6 \times 0.1 \sinh \underset{0.555}{0.527}} = 6.10 \times 10^{-8}$$

ELEMENTARY SHEAR STRAIN



SINCE SHEAR FLOW

$$\bar{q} = \frac{dF_L}{dx} = -P\frac{d}{dx}\left(\frac{A_L}{A_T}\right) = P\frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

&

SHEAR STRAIN

$$\bar{\gamma}_n = \frac{\bar{q}}{G t_n} = \frac{-P}{G t_n}\frac{d}{dx}\left(\frac{A_L}{A_T}\right)$$

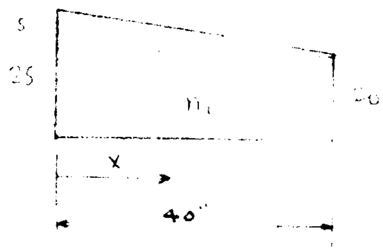
$$= \frac{P}{G t_n}\frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$P = \frac{3.09 \times 10^6}{2} = 1.545 \times 10^6 \text{ LBS / HALF FLANGE POST}$$

AT ELEMENT $n=1$ SHEAR STRAIN

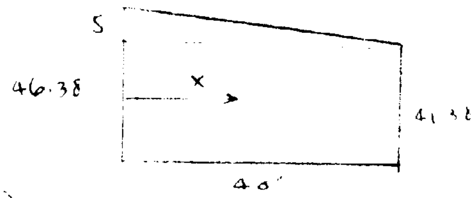
$$\bar{\gamma}_1 = \frac{P}{G t_n} \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$= \frac{1.545\times 10^6}{3.9\times 10^6 \times 0.1} \frac{d}{dx}\left(A_F/A_T\right)$$



$A_F = 25.0 - 0.125\,X$

$A_T = 46.38 - 0.125\,X$



$$\bar{\gamma}_1 = 3.97 \frac{d}{dx}\left(\frac{A_F}{A_T}\right)$$

$$= 3.97 \frac{(46.38-0.125x)(-0.125)-(25-0.125x)(-0.125)}{(46.38-0.125x)^2}$$

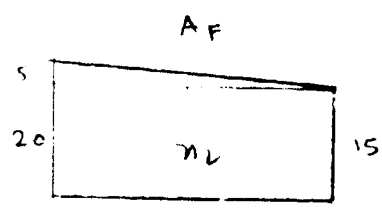
$$= 3.97 \; (-5.8 + 0.0155x) - [-3.12 + 0.0155x]$$

$$\bar{\gamma}_{1\,x=20} = 3.97 \frac{(-2.68)}{(43.88)^2} = -\frac{10.62}{1910} = \underline{-0.00556}$$

AT ELEMENT $n=2$ SHEAR STRAIN

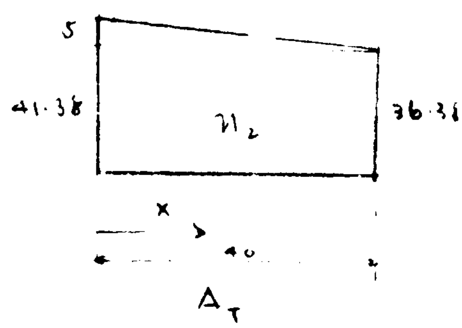
$A_F = 20 - 0.125\,X$

$A_T = 41.38 - 0.125\,X$



$$\bar{\gamma}_2 = 3.97 \frac{(41.38-0.125x)(-0.125)-[(20-0.125x)(-0.125)]}{(41.38-0.125x)^2}$$

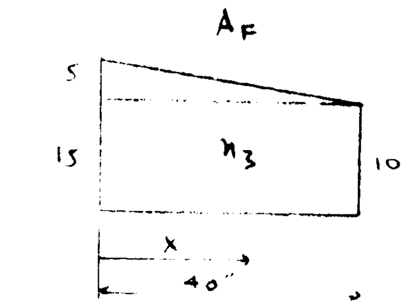
$$\bar{\gamma}_{2\,x\,10} = 3.97 \frac{(-5.16+2.5)}{(38.88)^2} = -0.00704$$



AT ELEMENT $n=3$ SHEAR STRAIN

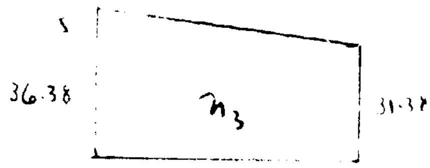
$$A_F = 15 - 0.125\,x$$

$$A_T = 36.38 - 0.125\,x$$



$$\bar{\Gamma}_3 = 3.97\,\frac{(36.38-0.125x)(-0.125) - \left[(15-0.125x)(-0.125)\right]}{(36.38-0.125x)^2}$$

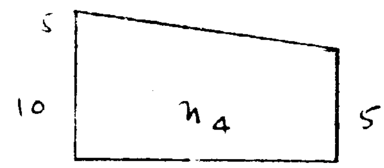
$$\bar{\Gamma}_{3\,(x=20)} = 3.97\,\frac{4.55 - 1.88}{1140} = 0.0093$$



AT ELEMENT $n=4$ SHEAR STRAIN

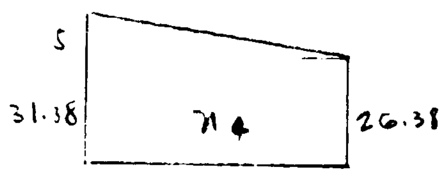
$$A_F = 10 - 0.125\,x$$

$$A_T = 31.38 - 0.125\,x$$



$$\bar{\Gamma}_4 = 3.97\,\frac{-3.92 + 1.25}{830}$$

$$\bar{\Gamma}_4 = 0.0128$$



APPLICATION OF THE RECURRENCE EQUATION FOR THE FOR THE RELATIONS OF THE FLANGE FORCE WITH RESPECT TO SHEAR FLOW & SHEAR STRAIN

$$\gamma_n X_{n-1} - (p_n + p_{n+1}) X_n + \gamma_{n+1} X_{n+1} = -\bar{r}_n + \bar{r}_{n+1}$$

FOR $n = 1$

$$\gamma_1 X_0 - (p_1 + p_2) X_1 + \gamma_2 X_2 = -\bar{r}_1 + \bar{r}_2$$

$$X_0 = P \frac{A_L}{A_T} = 1.545 \times 10^6 \frac{21.38}{46.38} = 0.71 \times 10^6$$

$$6.23 \times 10^{-8} \times 0.71 \times 10^6 - (6.67 + 6.75) \times 10^{-8} X_1 + 6.22 \times 10^{-8} X_2 = 0.00556 - 0.00704$$

$$4.42 \times 10^{-2} - 13.42 \times 10^{-8} X_1 + 6.22 \times 10^{-8} X_2 = -0.00148$$

$$-13.42 \times 10^{-8} X_1 + 6.22 \times 10^{-8} X_2 = -0.04568$$

$$-13.42 X_1 + 6.22 X_2 = -0.04568 \times 10^8$$

or $$-13.42 X_1 + 6.22 X_2 = -4.568 \times 10^6 \quad (1)$$

FOR $n = 2$

$$\gamma_2 X_1 - (p_2 + p_3) X_2 + \gamma_3 X_3 = -\bar{r}_2 + \bar{r}_3$$

$$6.22 \times 10^{-8} X_1 - 13.58 \times 10^{-8} X_2 + 6.20 \times 10^{-8} X_3 = -0.00226$$

$$6.22 X_1 - 13.58 X_2 + 6.20 X_3 = -0.226 \times 10^6 \quad (2)$$

FOR $n = 3$

$$\gamma_3 X_2 - (p_3 + p_4) X_3 + \cancel{\gamma_4} X_4 = -\bar{r}_3 + \bar{r}_4$$

$$6.20 \times 10^{-8} X_2 - 13.80 X_3 = -0.0035$$

$$6.20 X_2 - 13.80 X_3 = -0.35 \times 10^6 \quad (3)$$

SOLVE THE FOLLOWING 3 EQUATIONS

$$-13.42 X_1 + 6.22 X_2 = -4.568 \times 10^6 \quad (1)$$

$$6.22 X_1 - 13.58 X_2 + 6.20 X_3 = -0.226 \times 10^6 \quad (2)$$

$$6.20 X_2 - 13.80 X_3 = -0.35 \times 10^6 \quad (3)$$

$$X_3 = \frac{6.20 X_2 + 0.35 \times 10^6}{13.80}$$

$$X_3 = 0.448 X_2 + 0.0254 \times 10^6 \quad (4)$$

SUBSTITUTE (4) INTO (2)

$$6.22 X_1 - 13.58 X_2 + 6.20 (0.448 X_2 + 0.0254 \times 10^6) = -0.226 \times 10^6$$

$$6.22 X_1 - 13.58 X_2 + 2.78 X_2 = -0.226 \times 10^6 - 0.1575 \times 10^6$$

$$6.22 X_1 - 10.80 X_2 = -0.384 \times 10^6 \quad (5)$$

$$-13.42 X_1 + 6.22 X_2 = -4.568 \times 10^6 \quad (1)$$

$2.16 \times (5)$ $$+13.42 X_1 - 23.30 X_2 = -0.830 \times 10^6 \quad (6)$$

(1) + (6) $$-17.08 X_2 = -5.398 \times 10^6$$

$$X_2 = \underline{0.316 \times 10^6}$$

$$X_3 = 0.448 \times 0.316 \times 10^6 + 0.0254 \times 10^6$$

$$= 0.1415 \times 10^6 + 0.0254 \times 10^6$$

$$X_3 = \underline{0.1669 \times 10^6}$$

$$-13.42 X_1 + 6.22 \times 0.316 \times 10^6 = -4.568 \times 10^6$$

$$X_1 = \frac{6.532 \times 10^6}{13.42} = \underline{0.486 \times 10^6}$$

CHECK EQ (2) FOR SOLUTIONS :

$$6.22 \times 0.486 - 13.58 \times 0.316 + 6.20 \times 0.1669 = -0.226$$

$$3.02 - 4.290 + 1.033 = -0.226$$

$$-0.237 = -0.226$$

OK.

THE RESULTS OF TENSILE FLANGE FORCES ARE

$X_0 = 0.71 \times 10^6$ LBS

$X_1 = 0.486 \times 10^6$ LBS

$X_2 = 0.316 \times 10^6$ LBS

$X_3 = 0.167 \times 10^6$ LBS

$X_4 = 0$

COMPUTATION OF TENSILE STRESSES IN FLANGE, POST

$$\sigma_{F_n} = \frac{P}{A_{T_n}} + \frac{X_n}{A_{F_n}}$$

$x = 0$ $$\sigma_{F_0} = \frac{1.545 \times 10^6}{46.38} + \frac{0.71 \times 10^6}{25} = 33400 + 28400$$
$$= 61{,}800 \text{ PSI}$$

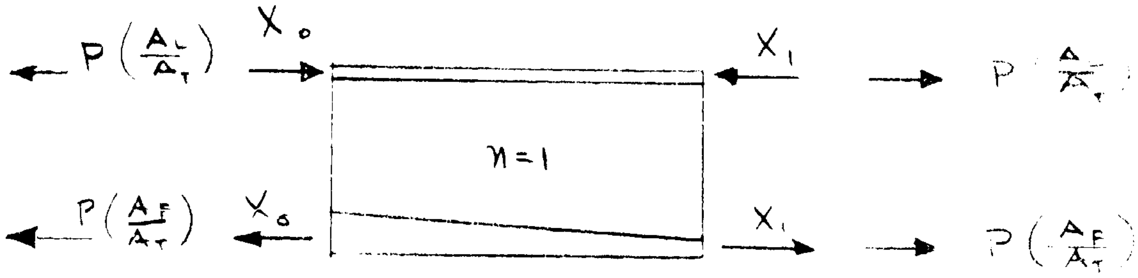
$x = 40''$ $$\sigma_{F_{40}} = \frac{1.545 \times 10^6}{41.38} + \frac{0.486 \times 10^6}{20} = 37400 + 24300$$
$$= 61{,}700 \text{ PSI}$$

$x = 80''$ $$\sigma_{F_{80}} = \frac{1.545 \times 10^6}{36.38} + \frac{0.316 \times 10^6}{15} = 42500 + 21000$$
$$= 63{,}500 \text{ PSI}$$

$x = 120$ $$\sigma_{F_{120}} = \frac{1.545 \times 10^6}{31.38} + \frac{0.167 \times 10^6}{10} = 49200 + 16700$$
$$= 65{,}900 \text{ PSI}$$

$x = 160$ $$\sigma_{F_{160}} = \frac{1.545 \times 10^6}{26.38} + 0 = 58{,}700 \text{ PSI}$$

COMPUTATION OF SHEAR STRAINS & SHEAR FLOW



FOR $X=0$ SHEAR STRAIN

$$\gamma_0 = p_1 X_0 - q_1 X_1 + \bar{\gamma}_1$$

$$= 6.67\times10^{-8}\times0.71\times10^{6} - 6.23\times10^{-8}\times0.486\times10^{6} + (-0.00556)$$

$$= 4.73\times10^{-2} - 3.03\times10^{-2} - 0.00556$$

$$= 0.01144$$

SHEAR FLOW

$$\text{MAX}\quad q_0 = G t_0 \gamma_0 = 3.9\times10^{6}\times0.1\times0.01144 = \underline{4460\ \text{P}/''}$$

CHECK SHEAR BUCKLING STRESS ALLOWABLE

$$F_{s_{cr}} = \frac{K_s \pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 \qquad \triangleright \text{ NASA TN-3783}$$

$K_s = 5.5$ $\quad b = 3.2''$ $\quad t_s = 0.$

$$F_{s_{cr}} = \frac{5.5\times9.85\times10.4\times10^{6}}{10.7}\left(\frac{0.1}{3.4}\right)^2 = 45400\ \text{PSI}$$

ACTUAL SHEAR STRESS FROM SHEAR FLOW @ EDGE OF POST IS

$$F_s = 4000/0.1 = 40000\ \text{PSI}$$

$$\text{M.S} = \frac{45400}{40000} - 1 = \underline{+0.135}$$

COMPUTATION OF PEAK DISTRIBUTION OF N_t LOAD @ Y-RING JUNCTION WITH LOX BULKHEAD

GIVEN POST AREA = 5 □"

σ_F = 58,700 PSI

ASSUME DISTRIBUTION OF LOAD OVER 10" %

$$N_t = \frac{58700 \times 5}{10} = 29300 \text{ LB}/''$$

THE Y-RING CONN. STUB THICKNESS REQUIRES

$$t = \frac{29300}{63000} = \underline{\underline{0.465''}}$$

0.55" FURNISHED @ Y-RING CONNECTION SHOULD BE ADEQUATE TO RESIST BOTH BENDING & DIRECT N_t STRESSES.

B-2.14

MLLV SINGLE STAGE
CORE VEHICLE PLUS INJECTION STAGE
HOLDDOWN SKIRT
ANALYSIS

N_c = 4,750 Lb/In (Ult.)

Max. N_t = 13,950 Lb/In (Ult.) (Based Upon the Effective Shear Lag Distributed Width)

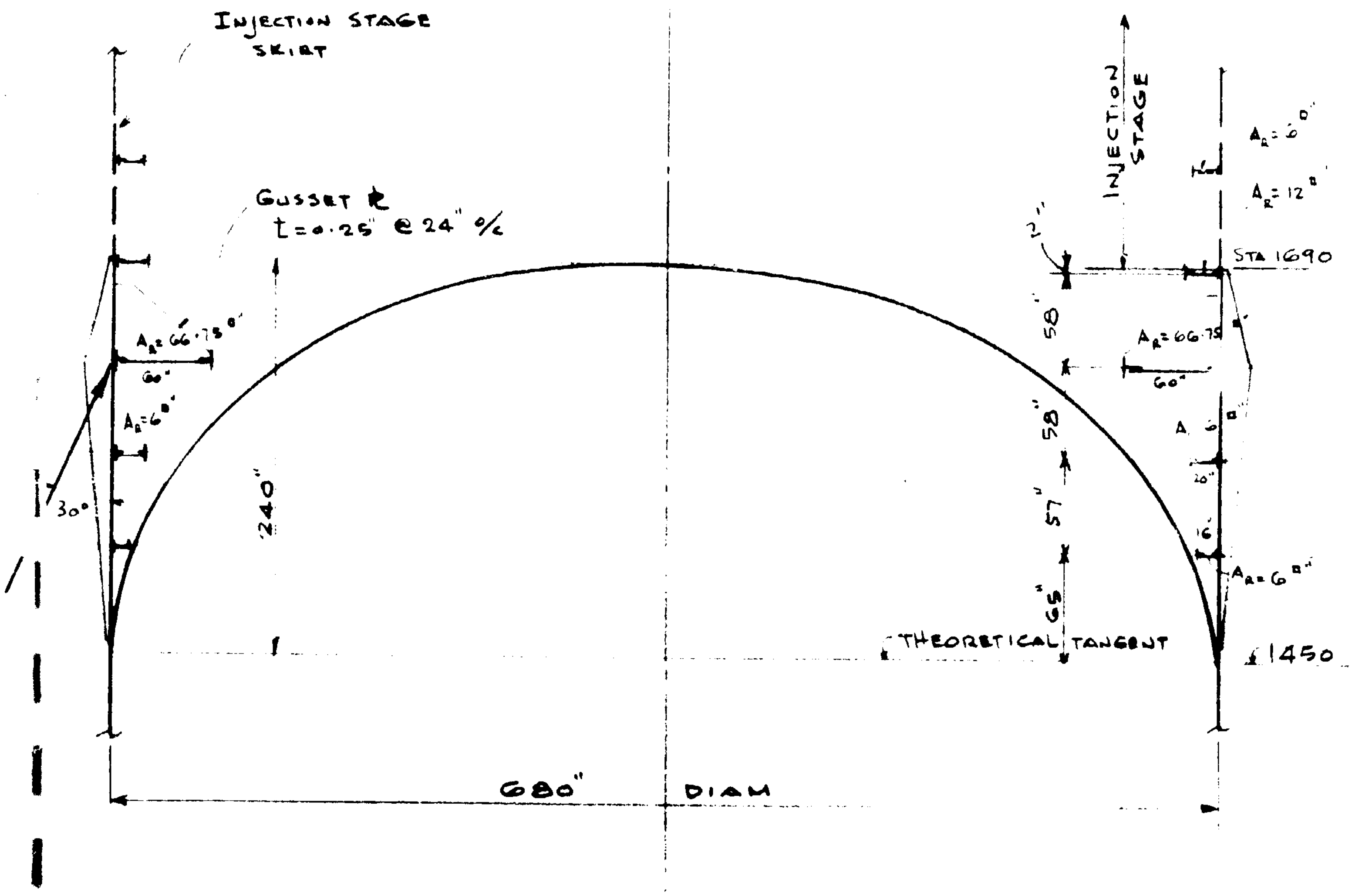
N_c Governs Forward Skirt Design

M.S. = 0

FWD HOLDDOWN SKIRT ANALYSIS

MLLV CORE VEHICLE AND INJECTION STAGE

HOLDDOWN POSTS & THRUST RING ARE ASSUMED TO BE THE SAME AS THE DESIGN FOR CORE VEHICLE ONLY

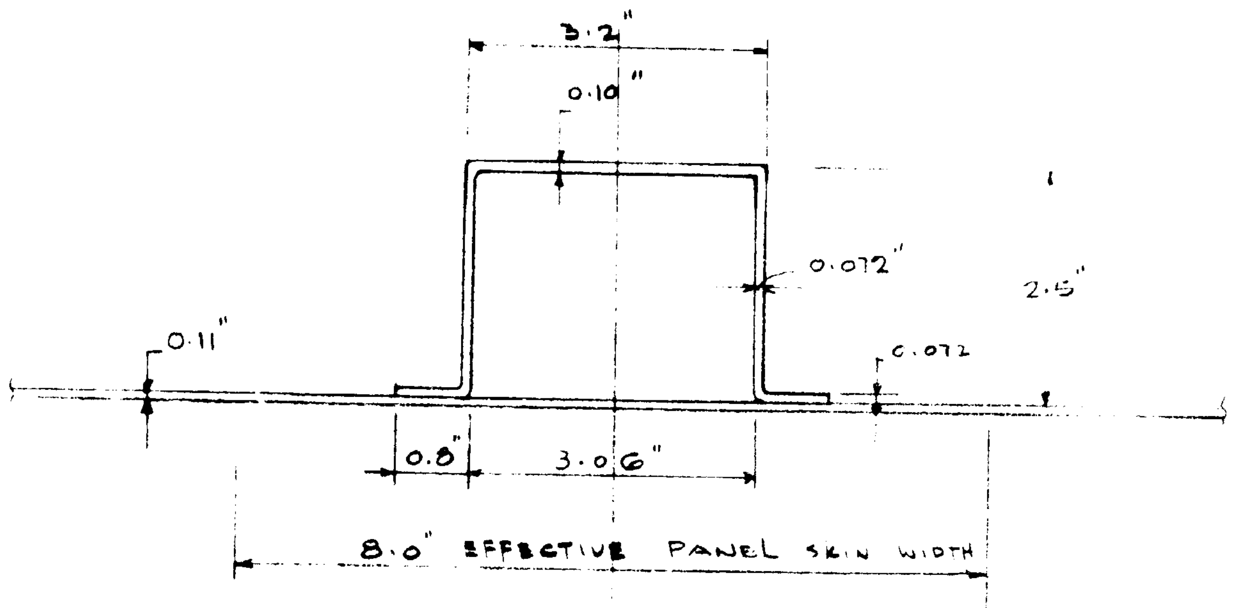


II FORWARD HOLDDOWN SKIRT CONFIGURATION.
CORE VEHICLE PLUS INJECTION STAGE

SIZING OF FWD SKIRT, SKIN - STIFFENER PANEL SECTION

FOR CUT-OFF COMPRESSIVE LOADS ON MLLV CORE + I.S.

$N_c = 4746$ LB/"



	A	Y	AY	AY^2	I_o
$A_1 = 8 \times 0.11$ =	0.880	0.055	0.0484	0.00266	0.00089
$A_2 = 1.6 \times 0.072$ =	0.115	0.146	0.0168	0.00245	0
$A_3 = 2.33 \times 2 \times 0.072$ =	0.336	1.347	0.4530	0.61000	0.15100
$A_4 = 3.20 \times 0.10$ =	0.320	2.555	0.8180	2.09000	0.00026
	1.651		1.3362	2.70511	0.15215

$$\bar{Y} = \frac{1.3362}{1.651} = 0.81$$

$$I_c = 2.7051 + 0.1522 - 1.651 \times 0.81^2 = 1.7673$$

$$I_s = 1.7673/8 = 0.2210$$

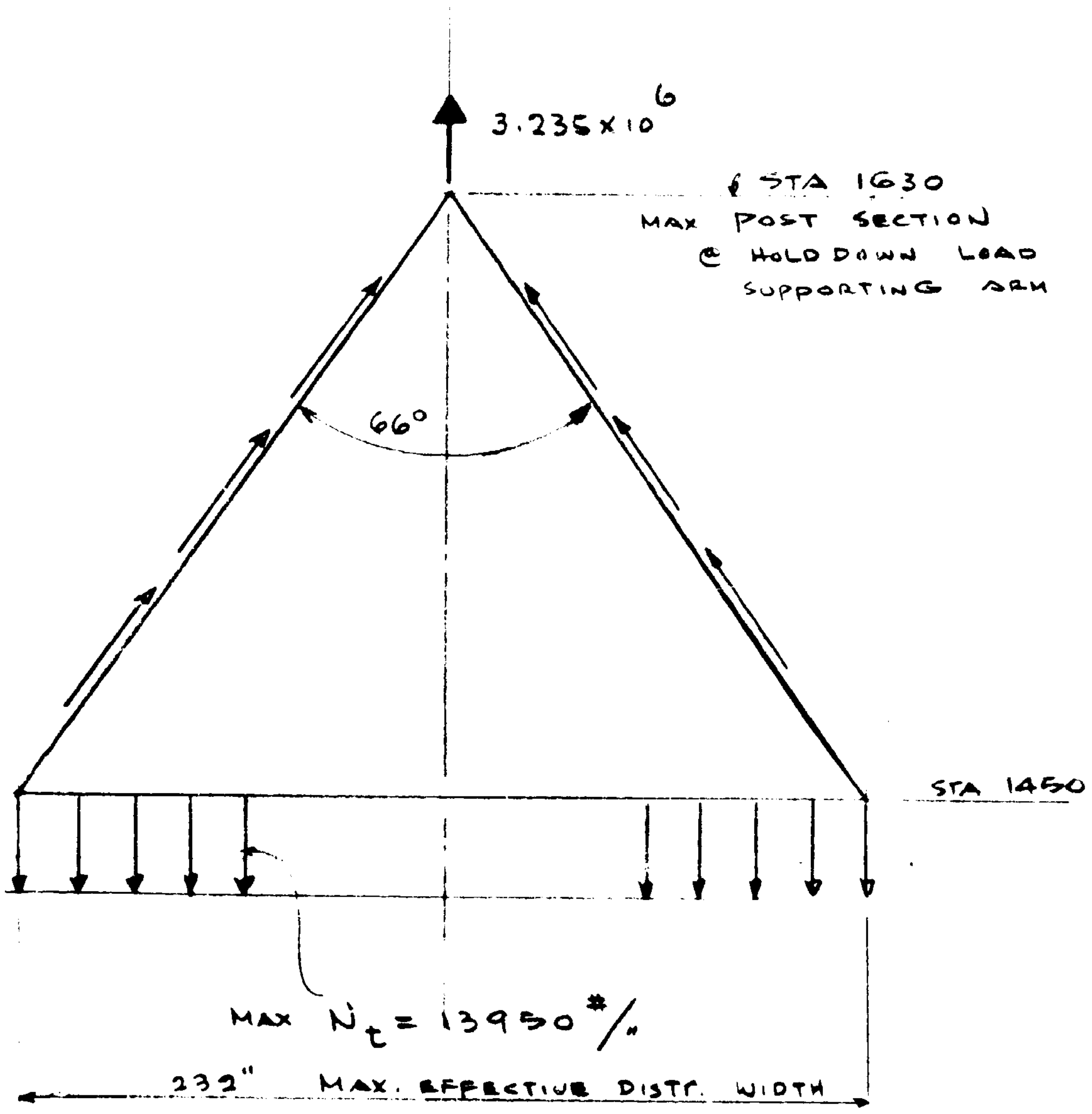
$$t_a = \frac{1.651}{8} = 0.2063$$

$$\rho = \sqrt{\frac{I_c}{A}} = \sqrt{\frac{1.7673}{1.651}} = 1.032$$

$$L/\rho = 76/1.032 = 73.5$$

APPROXIMATE SHEAR LAG PATH DUE TO HOLDDOWN LOAD CONDITION

CORE VEHICLE PLUS INJECTION STAGE ONLY



DIRECT COMPRESSIVE STRESS DUE TO N_c

$$f_c = \frac{8 \times 4750}{1.651} = 23{,}000 \text{ PSI}$$

DIRECT TENSILE STRESS DUE TO N_t

ASSUMED MAX HOLDDOWN REBOUND LOAD TO BE SUPPORTED BY 4 HOLDDOWN POSTS

GIVEN MAX TENSILE THRUST AT EA HOLDDOWN POST

$$T = 2.297 \times 10^6 \times 1.4 = 3.22 \times 10^6 \text{ LBS}$$

A'DL TENSILE LOAD DISTRIBUTED TO HOLD DOWN POST DUE TO BENDING MOMENT IS

$$\Delta T_M = \frac{23.2 \times 1.4 \times 10^6}{\pi \times 340^2} \times \frac{\cancel{2\pi \times 340}}{\cancel{4}\,2}$$

$$= \frac{32.4 \times 10^6}{\pi \times 680} = 0.0152 \times 10^6 \text{ / POST}$$

$$\Sigma T = T + \Delta T_m = 3.22 \times 10^6 + 0.0152 \times 10^6 = 3.235 \times 10^6$$

ASSUME SHEAR LAG EFFECTIVE DISTRIBUTION WIDTH OVER 66° ENVELOPE IS 232" ±

THE DESIGN N_t LOAD FOR HOLDDOWN SKIRT IS

$$N_t = \frac{3.235 \times 10^6}{232} = \underline{\underline{13950}} \text{ LB/''}$$

$$f_t = \frac{8 \times 13950}{1.651} = 67600 \text{ PSI}$$

$$M.S = \frac{77000}{67600} - 1 = \underline{\underline{+0.14}} \longrightarrow$$

THIS SKIRT IS OK FOR HOLDDOWN N_t LOAD

(A) INVESTIGATION OF LOCAL INSTABILITY STRESSES FOR $N_c = 4750$ LB/IN

a) LOCAL SKIN PANEL BUCKLING

$$\tau_{CR} = \frac{k_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.11}{4.0}\right)^2$$

$$= 29000 \text{ PSI}$$

$$M.S = \frac{29000}{23000} - 1 = +\underline{0.26}$$

b) STIFFENER WEB BUCKLING STRESS

$$\tau_{CR} = \frac{K_c \pi^2 E}{10.7} \left(\frac{t}{b}\right)^2 = \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.072}{2.50}\right)^2$$

$$= 31{,}500 \text{ PSI}$$

c) STIFFENER FLANGE BUCKLING STRESS

$$\tau_{CR} = 38.2 \times 10^6 \times 9.7 \times 10^{-4} = 37{,}000 \text{ PSI}$$

d) INTERFRAME BUCKLING STRESS INVESTIGATION

APPLICATION OF THE FOLLOWING EQUATION

$$N_{CR} = \frac{K_c \pi^2 E \, t_1^{*3}}{12(1-\nu^2) L_R^2}$$

▷ D5-132-2 OR TN-3783

$$Z_L = \frac{L_R^2}{R t_1^*} (1-\nu^2)^{1/2} = \frac{5760}{340 \times 0.735} \times 0.945 = 2.8$$

$k_c = 5$

$$t_1^* = \sqrt[4]{12 I_s t_s} = \sqrt[4]{12 \times 0.221 \times 0.11} = 0.735$$

$$t_1^{*3} = 0.397$$

$$N_{CR} = \frac{5 \times 9.85 \times 10.4 \times 10^6 \times 0.397}{10.7 \times 5750} = 3310 \text{ \#/IN}$$

SHY

REDUCE THE RING SPACING TO 60"

$$N_{CR} = \frac{K_c \pi^2 E t_1^{*3}}{12(1-\nu^2) L_R^2}$$

$$Z_L = \frac{3600}{340 \times 0.735} \times 0.945 = 13.6$$

$K_c = 4.5 \pm$ FROM TN-3783

$$N_{CR} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6 \times 0.397}{10.7 \times 3600} = 4750 \text{ LB/in}$$

$$M.S = \frac{4750}{4750} - 1 \approx 0$$

(B) INVESTIGATION OF GENERAL INSTABILITY STRESS

ASSUME $A_R = 6\ \square''$ $R = 340$

$L_R = 60$

$$t^* = \sqrt[4]{12 I_s \left(\frac{I_R}{L_R} + t_s\right)} = \sqrt[4]{12 \times 0.2210 \left(\frac{6}{60} + 0.11\right)}$$

$$= 0.868''$$

$$R/t^* = \frac{340}{0.868} = 392$$

FOR $\nu = 0.00025$

$m = 8$

$n = 3$

$C^* = 0.85$

$$\sigma_{CR} = C^* E \frac{t^*}{R}$$ ▷ D5-13272

$$= \frac{0.85 \times 10.4 \times 10^6}{392} = 23{,}200 \text{ PSI}$$

$$MS = \frac{23200}{23000} - 1 = \underline{\underline{+0.01}} \longrightarrow$$

CHECK SKIN THICKNESS FOR SHEAR BUCKLING STRESS

GIVEN APPROXIMATE SHEAR FLOW AT EDGE OF POST

$q_o = 4000$ LB/" (RESULT FROM SHEAR LAG ANALYSIS FOR CORE VEHICLE ONLY)

THEN

SHEAR FLOW FOR CORE & INJECTION STAGE MAY BE PROPORTIONED AS

$$q_o = 4000 \times \frac{3.235 \times 10^6}{3.09 \times 10^6} = 4190 \ ^\#/"$$

$$F_{s_{cr}} = \frac{K_s \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$ NASA TN-3783

ASSUME $b = 3.8"$ (CONSERVATIVE APPROACH)

$t_s = 0.11$

$$F_{s_{cr}} = \frac{5.5 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.11}{3.8}\right)^2$$

$$= 43{,}600 \text{ PSI}$$

ACTUAL SHEAR STRESS FROM SHEAR FLOW @ EDGE OF POST IS

$$F_s = 4190/0.11 = 38000$$

$$M.S = \frac{43{,}600}{38\,000} - 1 = \underline{+0.145}$$

B-2.15

MLLV CORE VEHICLE LOX FEED LINE ANALYSIS

1) Sized for Given Internal Pressure at Bottom of Line

2) Sized for Max Negative Pressure at Top of Line

Max $p = -21.7$ psi

SIZING OF LOX LINE

ASSUME 8" ID LOX LINE (24 ~ NO.)

EACH LINE IS CONNECTED TO ONE ENGINE

GIVEN MAX LIMIT PRESSURE AT BOTTOM OF LINE

@ MAX ACCELERATION $P_{LIMIT} = 176.3$

$$P_{ULT} = 176.3 \times 1.4 = 247 \text{ PSI}$$

$$t = \frac{p\,r}{\sigma_{tu}} = \frac{247 \times 4}{63000} = 0.0157$$

a) ASSUME MIN THICKNESS OF 0.05"

$$\sigma_{tu} = \frac{247 \times 4}{0.05} = 19800 \text{ PSI}$$

THIS IS THE STRESS DUE TO INTERNAL PRESSURE ONLY

b) SIZING OF LINE BY ASSUMING

INTERNAL PRESSURE $= 1.0 \times 17.5$

EXTERNAL PRESSURE $= 28 \times 1.4$

NET EXTERNAL PRESSURE

$$\Delta P_{ULT} = -(28 \times 1.4 - 1.0 \times 17.5) = -21.7 \text{ PSI}$$

APPLY ROARK'S FORMULA FOR LONG, THIN TUBE WITH EXTERNAL PRESSURE CASE 30 PAGE 318

$$\Delta P_{CR} = \frac{E}{4(1-\nu^2)} \times \frac{t^3}{r^3} = \frac{10.4 \times 10^6 \times 0.000125}{4 \times 64 \times 0.891}$$

$$= \frac{10.4 \times 10^6 \times 1.25 \times 10^{-4}}{4 \times 64 \times 0.891} = \frac{1300}{4 \times 64 \times 0.891} = 5.7 \text{ PSI}$$

NOT ENOUGH

TRY $t = 0.08''$

$t^3 = 0.000512$

$\Delta P_{CR} = 23.4$ PSI

$M.S = \frac{23.4}{21.7} - 1 = \underline{+0.08}$ →

PENDING INFORMATION OF MAX SURGED PRESSURE IN THE LOX LINE. THE LOX LINE IS SIZED FOR MAX NEGATIVE PRESSURE OF 21.7 PSI

LOX LINE WALL THICKNESS IS ASSUMED @ 0.08" FOR WT. ESTIMATE PENDING MAXIMUM SURGED PRESSURE & SUPPORT SYSTEM INFORMATION.

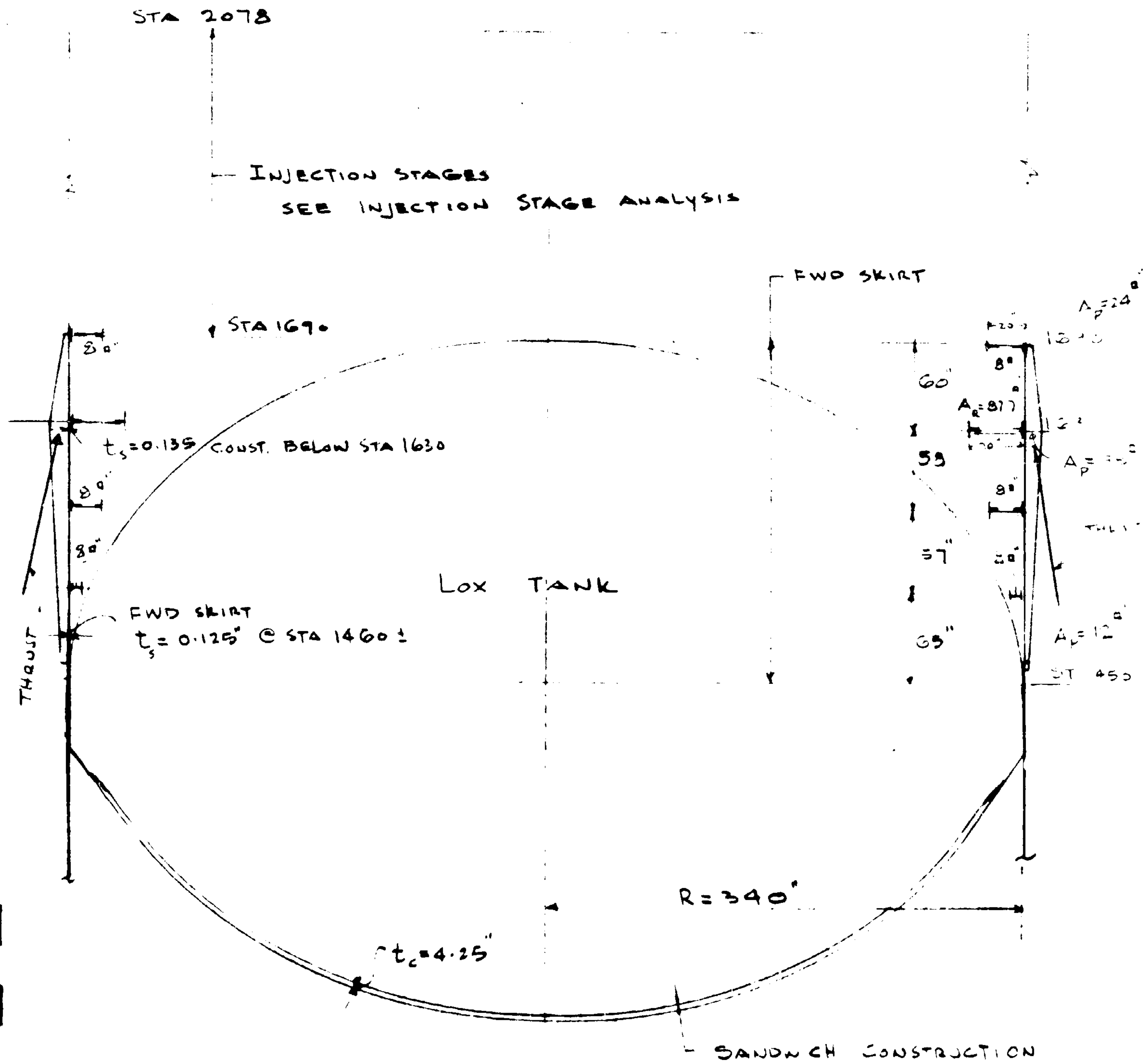
B-8

MAIN STAGE PLUS EIGHT STRAP-ON STAGES PLUS A THREE MODULE INJECTION STAGE

B-3.1

MLLV MAIN STAGE PLUS EIGHT STRAP-ON
STAGES PLUS A THREE MODULE INJECTION STAGE VEHICLE

MAIN STAGE FORWARD THRUST SKIRT



FORWARD SKIRT & LOX TANK CONFIGURATION
FOR 8 - SRM STRAP ON & 3-INJECTION STAGE

8-SRM STRAP ON PLUS 3-INJECTION STAGE

DESIGN OF FORWARD SKIRT BASED UPON THE FOLLOWING LOAD CONDITIONS:

CASE 1 CORE + 8-SRM + 3 INJECTION STAGE

a) FROM STA 1450 → STA 1630 & CORE CUT OFF

$(N_c)_{ULT} = 6000$ LB/" PER REF LOAD DIAGRAM

b) FROM STA 1630 → STA 1690 & MAX $q\alpha$

$(N_c)_{ULT} = 9300$ LB/" PER REF LOAD DIAGRAM

c) FROM STA 1450 → 1630 & MAX $q\alpha$

$(N_T)_{ULT} = 13{,}000$ LB/" TENSION IN SKIRT

d) @ SOLID MOTOR CUT OFF STA 1630 TO STA 1690

GIVEN THRUST LOAD (TOTAL 8-SRM)

3.2×10^6 LB FROM LOAD GROUP INFORM

$$T = \frac{8 \times 3.2 \times 10^6 \times 1.4}{2\pi \times 340} = 0.01675 \times 10^6$$

$$= 16750 \text{ LB/"} \uparrow$$

N_c DUE TO PAY LOAD AT STA 1690

7.97×10^6 LB FROM LOAD GROUP OF

$$N_c = \frac{7.97 \times 10^6 \times 1.4}{2\pi \times 340} = 5230 \text{ LB/"}$$

THE REMAINING NET THRUST AFTER DEDUCTING UNIT PAY LOAD PER INCH IS THE N_t LOAD TO PULL THE CORE STAGE BELOW STA 1630

$$N_t = 16750 - 5230 = 11520 \text{ LB/"} \downarrow$$

TENSION

LOAD CONDITION (b) & (c) MAY BE THE MOST CRITICAL CASE FOR FWD SKIRT DESIGN

CASE (a) SHALL BE USED TO INVESTIGATE STABILITY FOR SKIRT PORTION BETWEEN 1450 → 1630

SIZING OF THRUST POST AREA

@ CRITICAL MAX $\bar{q}\alpha$ CONDITION

$$C_o = \frac{2\pi R}{8} = \frac{2\pi \times 340}{8} = 267$$

DUE TO N_c LOAD THE POST AREA REQ'D TO SHEAR OFF MAX $\bar{q}\alpha$ THRUST INTO N_c PER INCH IS

$$A_{p_1} = \frac{9300 \times 267}{f_{cy}} = \frac{9300 \times 267}{58000} = 42.8 \text{ □}''$$

$f_{cy} = 58000$ FOR DIE-FORGED FITTING OF 7075-T6 ALU.

THE THRUST POST IS ALSO REQUIRED TO SHEAR OFF THE MAX $\bar{q}\alpha$ N_T LOAD BELOW STA 1630 INTO N_t (PER INCH)

$$A_{p_2} = \frac{13000 \times 267}{f_{tu}} = \frac{13000 \times 267}{62000} = 55 \text{ □}''$$

f_{tu} FOR DIE FORGED 7075-T6 ALU SECTION IS $f_{tu} = 62000$ PSI

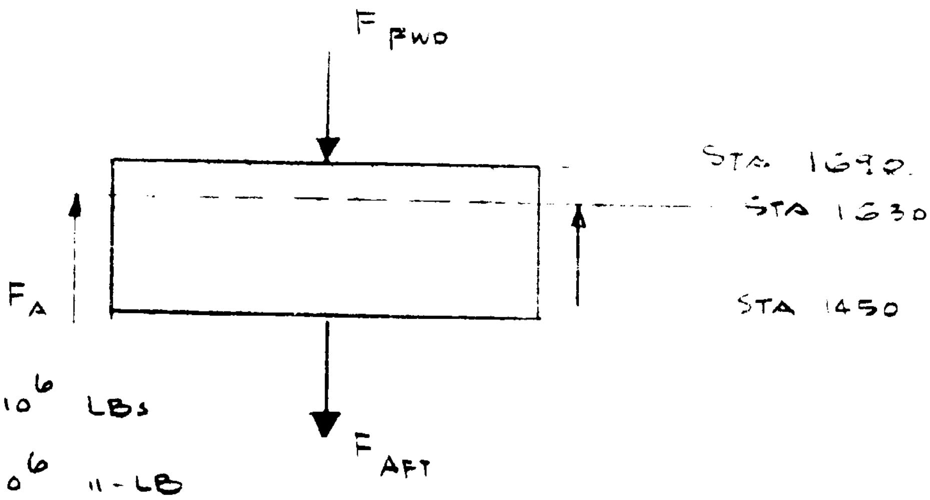
TOTAL MAX POST AREA AT STA 1630 IS

$$\Sigma A_p = A_{p_1} + A_{p_2} = 43 + 55 = 98 \text{ □}''$$

ASSUMED MIN. POST AREA 14 □'' AT STA 1810 & STA 1460 RESPECTIVELY

ANALYSIS OF ATTACHMENT SRM STRAP ON LOAD CONDITIONS FOR FWD SKIRT

FOR TWO MOST CRITICAL CONDITIONS ASSUME ATTACHMENT IS AT STA 1630



$F_A = 2.26\times10^6$ LBS

(MAX) $M = 14.5\times10^6$ IN-LB

CONDITION (1) $Q\alpha$ MAX

UNIFORM N_c LOAD (ULT) AT STA 1690 IS

$$N_c = \frac{5.265\times10^6}{\pi D}\times1.4$$

$$= \frac{5.265\times10^6}{2140}\times1.4 = 3450\ \#/''$$

ADD'L N_c DUE TO BENDING MOMENT

$$N_{c_M} = \frac{14.5\times10^6\times1.4}{\pi\times340^2} = 5540\ \#/''$$

$$\text{MAX } N_c = 3450 + 5540 \approx \underline{9000}\ \#/''$$

LOAD DATA INDICATES $N_c = 9300\ \#/''$

N_t LOAD BELOW STA 1630 (VERT LOAD ONLY)

$$N_t = \frac{11.378 \times 10^6 \times 1.4}{2140} = 7550 \text{ LB/''}$$

N_t LOAD DUE TO BENDING

$$N_{t_m} = \frac{14.5 \times 10^6 \times 1.4}{\pi \times 340^2} = \frac{5540}{\underline{\underline{13090}}} \text{ LB/''}$$

LOAD DATA INDICATES N_t = 13000 LB/''

THE FWD SKIRT DESIGN BASED UPON

N_c = 9300 #/'' ABOVE STA 1630

N_t = 13000 #/'' BELOW STA 1630

IS OK

CONDITION (II) SRM CUT OFF

GIVEN F_{FWD} LOAD $= 7.969 \times 10^6 \times 1.4 = 11.2 \times 10^6$

$$N_c = \frac{11.2 \times 10^6}{2140} = 5270 \ \#/''$$

NO BENDING MOMENT @ SRM CUT OFF

F_{AFT} LOAD $= 17.526 \times 10^6 \times 1.4 = 24.45 \times 10^6$

$$N_t = \frac{24.45 \times 10^6}{2140} = 11450 \ \text{LB}/''$$

COMPARE THE SKIRT LOAD MAGNITUDES FOR CONDITION I & II IT IS OBVIOUS THAT MAX $q\alpha$ IS THE CRITICAL DESIGN LOAD CONDITION FOR FWD SKIRT

CONDITION III CORE CUT OFF

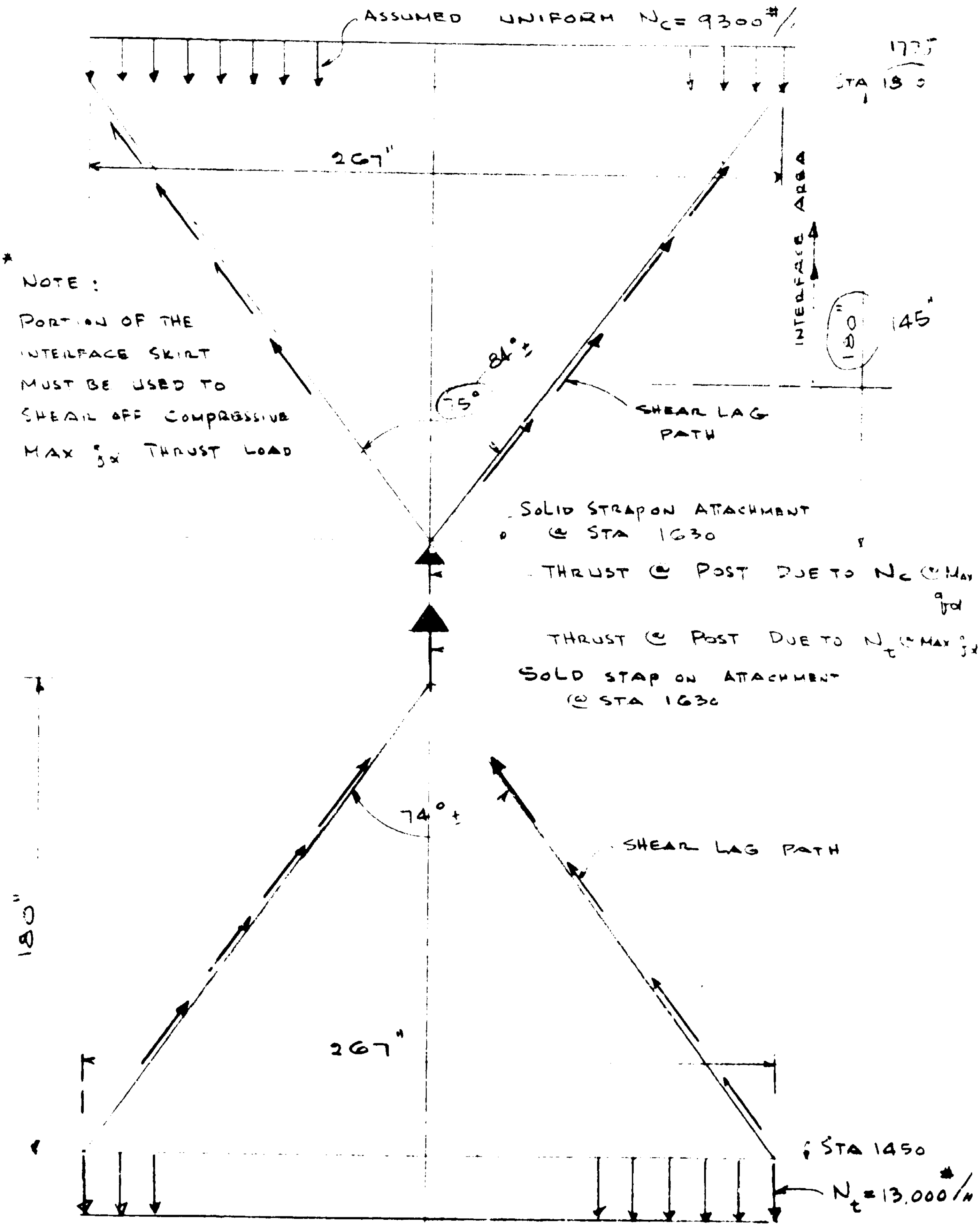
N_c LOAD BELOW STA 1630

$$N_c = \frac{9.0 \times 1.4 \times 10^6}{2140}$$

$$= 5900 \ \text{LB}/''$$

THIS MAY BE THE DESIGN CONDITION FOR FWD SKIRT BELOW STA 1630

APPROXIMATE SHEAR LAG PATH FOR MAX $\bar{q}\alpha$ LOADING



INVESTIGATION OF MAX THRUST LOAD @ MAX $\dot{\gamma}\alpha$ INCLUDING BENDING

GIVEN LONG. LOAD @ MAX $\dot{\gamma}\alpha$

$$T = 2.26 \times 10^6$$ FROM LOAD GROUP INF.

$$M = 14.5 \times 10^8 \text{ IN-LB}$$

$$N_C = N_T = \frac{14.5 \times 10^8}{\pi R^2} = \frac{14.5 \times 10^8}{\pi \times 115600}$$

$$= \frac{14.5 \times 10^8}{\pi \times 1.156 \times 10^5} = 4000 \text{ \#/IN}$$

ADDL THRUST DUE TO BENDING PER POST IS

$$\Delta T_M = 4000 \times 267 = 1.07 \times 10^6$$

TOTAL MAX THRUST DUE TO MAX $\dot{\gamma}\alpha$

$$T = (2.26 + 1.07) \times 10^6 = 3.33 \times 10^6$$

THE MAX THRUST DUE TO MAX $\dot{\gamma}\alpha$ IS

$$T = 3.33 \times 10^6 \times 1.4 = 4.67 \times 10^6 \text{ (ULT)}$$

ALTERNATIVE MAX THRUST POST AREA REQ'D

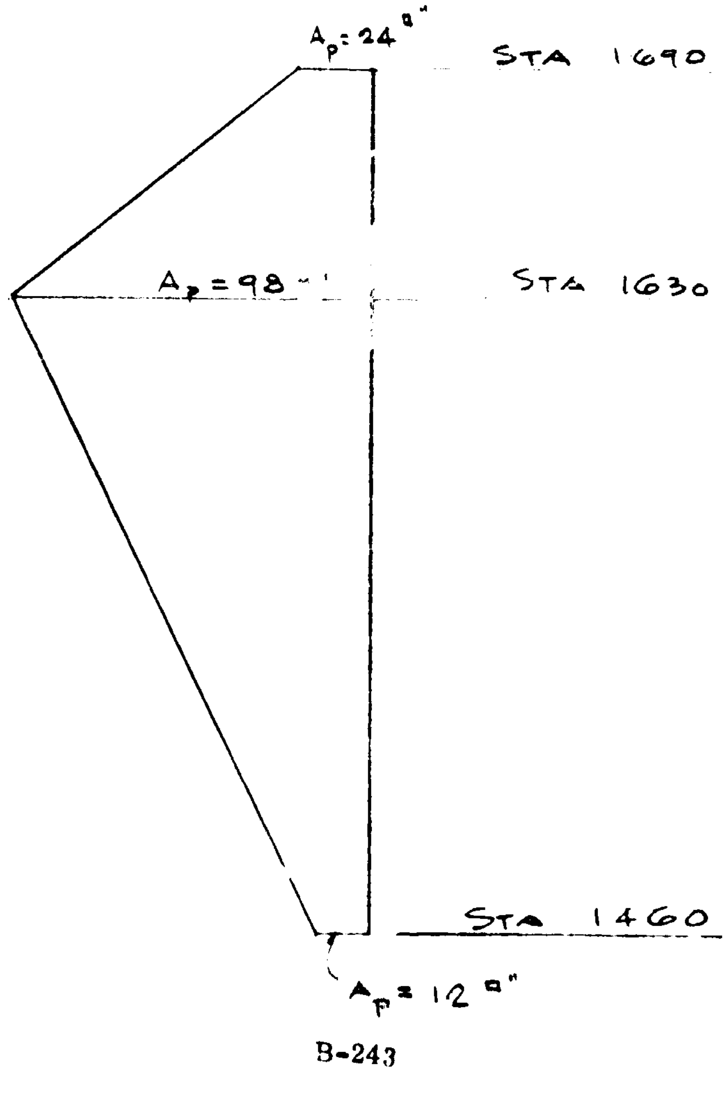
$$A_P = \frac{4.67 \times 10^6}{58000} = 81.0 \ \square''$$

HOWEVER DUE TO ECCENTRIC APPLICATION OF LOAD AT THRUST POST ATTACHMENT PT THE POST AREA OF 98 □" AS ANALYZED IN SH. #3 MAY BE REQ'D FOR CONSERVATIVE APPROACH IN PRELIMINARY STUDY.

SIZING OF THRUST POST BASED UPON THE APPLIED LOAD FOR CORE VEHICLE + 8 SRMS + 3 INJECTION STAGES

ASSUME STAGE SEPARATION OCCURS AT STA 1690
AND ASSUME 1/3 OF THE MAX $q\alpha$ THRUST LOAD IS TO BE SHEARED OUT BETWEEN STA 1630 & 1690
AND 2/3 OF MAX $q\alpha$ WOULD BE SHEARED OUT BETWEEN STA 1450 & STA 1630.
THIS IS ON THE ASSUMPTION THAT WT OF STAGE IS UNIFORM.

THE APPROXIMATE THRUST POST AREA DISTRIBUTION BASED ON SHEAR LAG PRINCIPLE IS SHOWN IN THE SKETCH BELOW



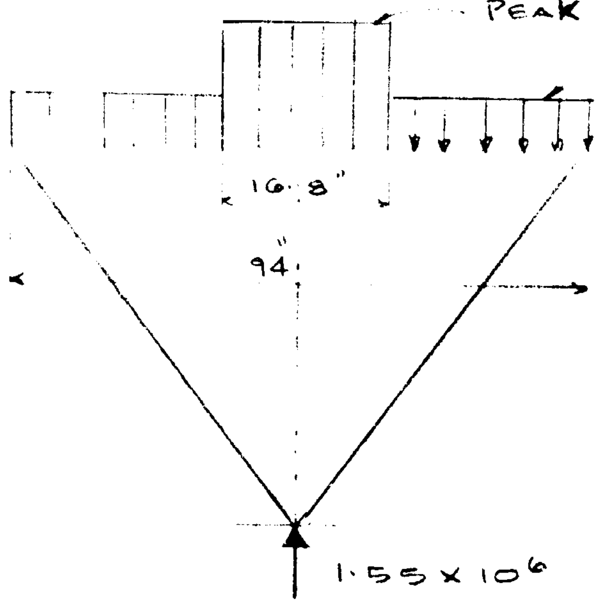
GIVEN MAX $\mathfrak{z}\alpha$ THRUST (UNIFORM WT OF STAGE IS NOT DEDUCTED

$$T_{max\ \mathfrak{z}\alpha} = 3.33 \times 10^6 \times 1.4 = 4.66 \times 10^6 \text{ LB}$$

$$\tfrac{1}{3}\, T_{MAX\ \mathfrak{z}\alpha} = \frac{4.66 \times 10^6}{3.0} = 1.55 \times 10^6 \text{ LBS}$$

$$\tfrac{2}{3}\, T_{MAX\ \mathfrak{z}\alpha} = 2 \times 1.55 \times 10^6 = 3.10 \times 10^6 \text{ LBS}$$

N_c LOAD DISTRIBUTION BASED UPON APPROXIMATE SHEAR LAG PRINCIPLE



THE TOP POST AREA AT STA 1690 $A_p \approx 20$ □"

$$\Sigma A_L = 10 \times 2.38 = 23.8$$

$$A_p = \frac{24}{47.8}$$

$$\sigma_c = \frac{1.55 \times 10^6}{47.8} = 32600 \text{ PSI}$$

CALCULATION OF PEAK LOAD AT TOP OF POST

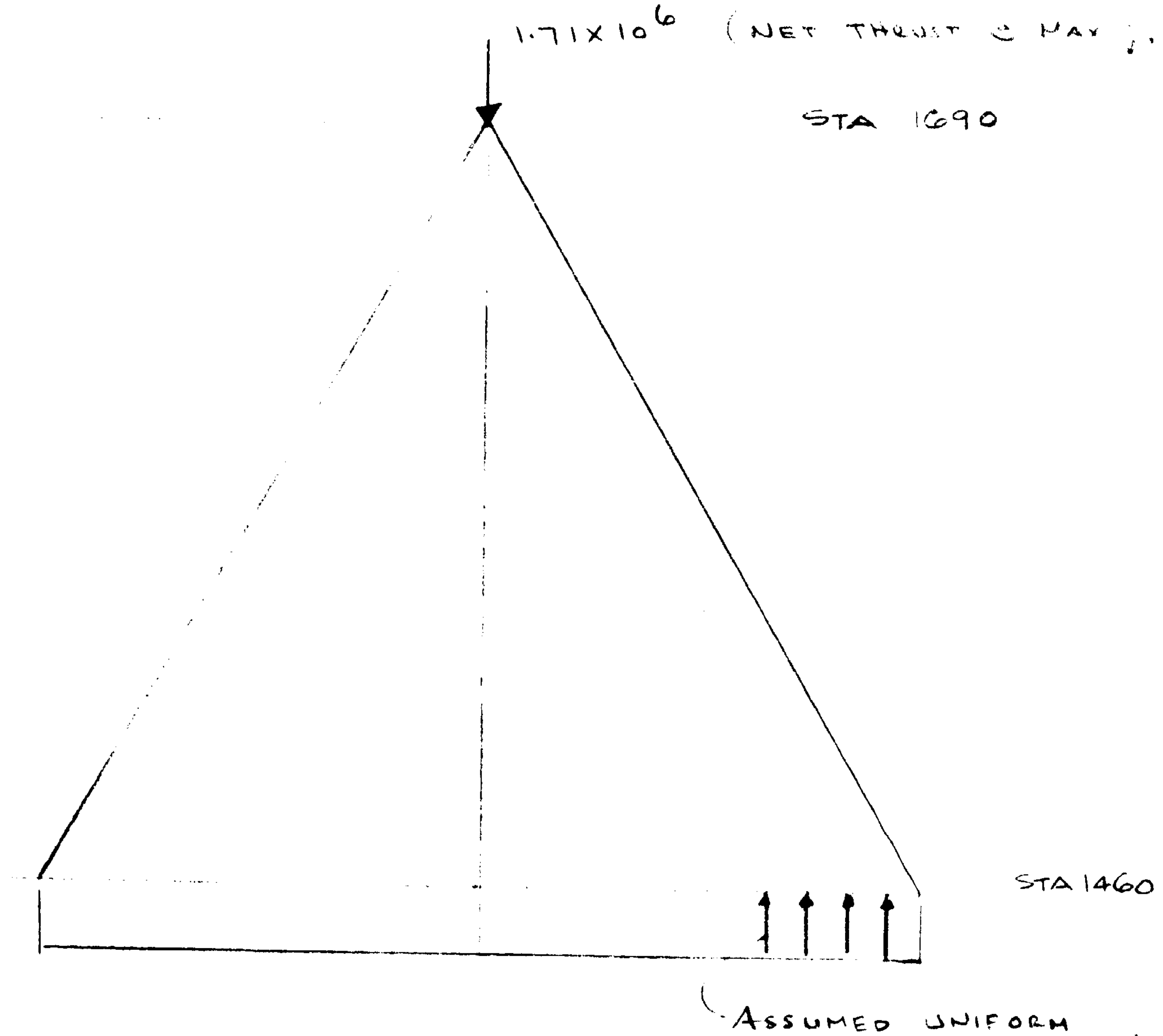
$$\text{MAX } N_c = \frac{32600 \times 24}{16.8} = 46500 \text{ LB}/''$$

$$\text{AV. } N_c = \frac{32,600 \times 2.38}{8.4} = 9300 \text{ LB}/''$$

FROM THE ABOVE ANALYSIS IT APPEARS THAT THRUST POST SHOULD BE EXTENDED BEYOND STA 1690, WELL INTO INJECTION STAGE. THIS CAN BE TAKEN CARE OF BY PROVIDING A TAPERED SPLICED THRUST POST SECTION BEYOND STA 1690 AND EXTENDED TO STA 1775 WITH TOP OF POST AREA EQUAL TO 4 □" ± ONLY BY DOING SO CAN UNIFORM N_c LOAD DISTRIBUTION BE ACCOMPLISED.

HOWEVER, ANOTHER REASONABLE ASSUMPTION CAN ALSO BE MADE BY ASSUMING THAT THE ENTIRE LENGTH OF FWD SKIRT BETWEEN STA 1690 AND 1460 IS THE EFFECTIVE ONE WAY SHEAR LAG PATH. THIS LATTER CASE WAS ASSUMED FOR THIS STUDY

N_c LOAD DISTRIBUTION FOR THE ENTIRE FWD SKIRT AS SHEAR LAG PATH BELOW STA 1690



ASSUME STAGE WT. TO BE CONCENTRATED LOAD @ EA. SOLID MOTOR

THE NET THRUST LOAD MAY BE APPROXIMATED AS

$$T_{\dot{\alpha}} = \left[3.33 \times 10^6 - \left(\frac{5.265 \times 10^6 + 11\ 578 \times 10^6}{8}\right)\right] \times 1.4$$

$$= 1.22 \times 10^6 \times 1.4 = 1.71 \times 10^6$$

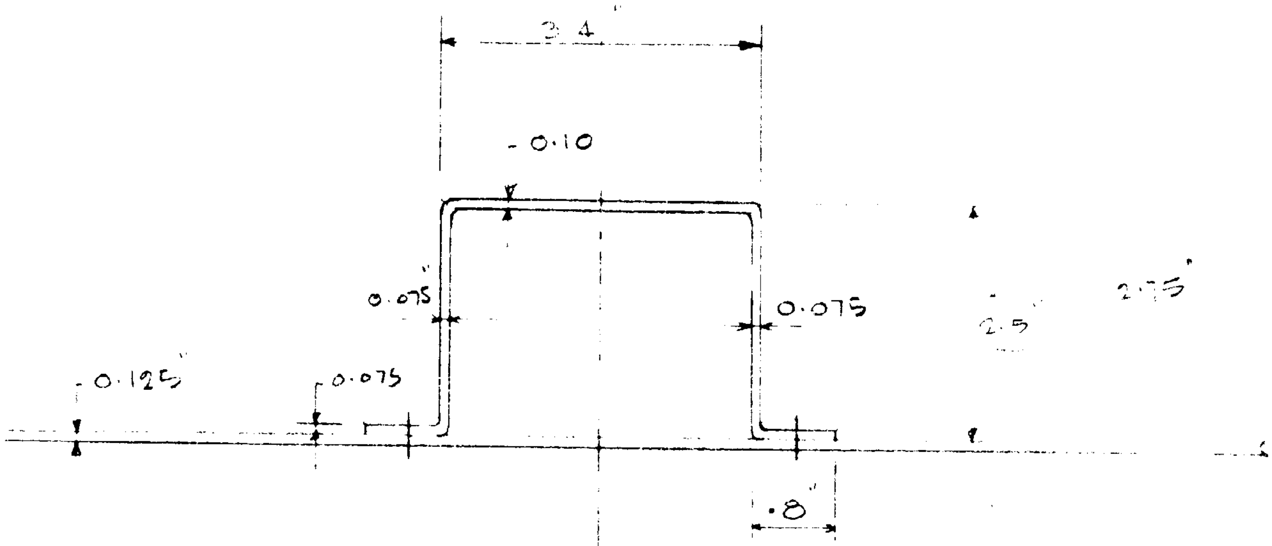
$$N_c = \frac{1.71 \times 10^6}{267} \approx 6400 \text{ LB}/\text{"}$$

FROM THE FOREGOING APPROXIMATE SHEAR LAG DISTRIBUTION THE APPARENT N_c DISTRIBUTION AT STA 1460 IS THE N_c LOAD DESIGNED FOR FWD SKIRT PORTION BETWEEN STA 1690 & 1460. HENCE THE SKIRT DESIGN WAS OK AND THE CONCEPT OF USING ENTIRE FWD SKIRT AS SHEAR LAG PATH MAY ALSO BE OK.

DESIGN OF SKIN STRINGER SECTION FOR EITHER

(1) $N_c = 6000$ LB/" @ CORE CUT-OFF BELOW STA 1630

(2) $N_t = 13000$ LB/" @ MAX f_x BELOW STA. 1630



EFFECTIVE SKIN PANEL WIDTH

$b = 8.4"$

STRINGER SECTION AT STA 1460

		A	y	Ay	Ay^2	I_o
$A_1 = 8.4 \times 0.125$	=	1.050	0.0625	0.0656	0.0041	0.00137
$A_2 = 1.6 \times 0.070$	=	0.112	0.1600	0.0179	0.0029	0
$A_3 = 2 \times 2.4 \times 0.070$ (0.075)	.	0.336	1.3250	0.4450	0.5900	0.1615
$A_4 = 3.4 \times 0.10$	=	0.340	2.5750	0.8750	2.2550	0.00028
		1.838		1.4035	2.8520	0.16315

$$\overline{Y} = \frac{1.4035}{1.838} = 0.765$$

$$I_c = 2.852 + 0.1632 - 1.838 \times 0.765^2 = 1.945 \text{ in}^4$$

$$I_s = \frac{1.945}{8.4} = 0.232$$

$$\rho = \sqrt{\frac{1.9450}{1.838}} = 1.03$$

$$t_a = \frac{1.838}{8.4} = \underline{\underline{0.219}}$$

(i) THE CRIPPLING STRESS OF STRINGER SECTION AS A WHOLE INCL. SKIN PANEL

$$\sigma_{cc} = \frac{1.05 \times 34000 + 0.34 \times 34400 + 0.336 \times 32400 + 0.112 \times 36600}{1.838}$$

$$= \frac{35700 + 11700 + 10900 + 4100}{1.838}$$

$$= \frac{62400}{1.838} = 34000 \quad \text{PSI}$$

$$\sigma_c = 27{,}400 \quad \text{PSI} \qquad \text{(ACTUAL COMPR. STRESS)}$$

$$M.S = \frac{34000}{27{,}400} - 1 = +\underline{0.24} \longrightarrow$$

(ii) INTERFRAME BUCKLING STRESS

$$t_1^* = \sqrt[4]{12 I_s t_s} \qquad \text{D5-13272}$$

$$t_1^* = \sqrt[4]{12 \times 0.232 \times 0.125} = \sqrt[4]{0.35} = 0.77$$

$$t_1^{*3} = 0.453$$

ASSUME $L_R = 60$

$$Z_L = \frac{L^2}{R t_1^*} (1-\nu^2)^{1/2} \qquad \text{TN-3783 \& D5-13272}$$

$$= \frac{3600}{340 \times 0.77} \times 0.945 = 13$$

FOR $R/t_1^* = 340/0.77 = 440$

$$K_c = 5.0 \qquad \text{TN-3783}$$

DESIGN CONDITION (1) INVESTIGATION OF THE MAX COMPRESSIVE STRESS CAPABILITY OF STRINGER SECTION BELOW STA 1630.

A) LOCAL BUCKLING STRESS INVESTIGATION

a) SKIN PANEL $b = 4.2''$

$$\sigma_{CR} = \frac{k_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

▷ D5-13272 & NASA STRUCTURES MANUAL

$$= \frac{4.0 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.125}{4.2}\right)^2 = 34000 \text{ PSI}$$

ACTUAL COMPR STRESS FOR STRINGER SECTION

$$\sigma_c = \frac{6000 \times 8.4}{1.838} = 27400 \text{ PSI}$$

$$M.S = \frac{34000}{27400} - 1 = \underline{+0.24} \longrightarrow$$

b) FLANGE OF STIFFENER

$$\sigma_{CR} = \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.10}{3.33}\right)^2 = 34{,}400 \text{ PSI}$$

$$M.S = \frac{34{,}400}{27{,}400} - 1 = \underline{+0.25} \longrightarrow$$

c) WEB OF STIFFENER

$$\sigma_{CR} = \frac{4 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.07}{2.4}\right)^2 = 32400 \text{ PSI}$$

d) CONNECTION FLANGE OF STIFFENER

$$\sigma_{CR} = \frac{0.5 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.07}{0.8}\right)^2 = 36600 \text{ PSI}$$

$$N_{CR} = \frac{K_c \pi^2 E \; t_1^{*3}}{12(1-\nu^2)\; L_R^2}$$ D5-13272 & TN-3783

$$= \frac{5.0 \times 9.85 \times 10.4 \times 10^6 \times 0.453}{10.7 \times 3600}$$

$$= 47.8 \times 10^6 \times 0.000126$$

$$= 47.8 \times 1.26 \times 10^2 = 6{,}030 \text{ LB}/''$$

$$M.S = \frac{6030}{6000} - 1 \approx 0$$

USING JOHNSON EULER'S EQUATION

FOR $L/\rho = 60/1.03 = 58.3$

$$\sigma_{CR} \approx 27000 \text{ PSI}$$

$$M.S \approx 0$$

IF L_R IS REDUCED TO 57''

$L/\rho = 55$. FOR $\sigma_{cc} = 34000$

$$N_{CR} = 6030 \times 3600/3250 = 6660$$

$$M.S = \frac{6660}{6000} - 1 = +\underline{0.11} \longrightarrow$$

(B) INVESTIGATION OF GENERAL INSTABILITY STRESS

ASSUME $A_R = 8.0 \ \square''$

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s \right)}$$

$$= \sqrt[4]{12 \times 0.232 \left(\frac{8}{60} + 0.125 \right)} = 0.918''$$

$$R/t^* = 340/0.918 = 371$$

EXTRAPOLATION FROM THE ATTACHED BUCKLING COEFFICIENT CHART ATTACHED. REF. D5-13272 FOR THEORY

FOR ASSUMED $m = 8$

$n = 3$

$\sqcup = 0.00025$

$$C^* \approx 0.9$$

$$\tau_{CR} = C^* E \frac{t^*}{R}$$

$$= \frac{0.9 \times 10.4 \times 10^6}{371} = 25300 \text{ PSI}$$

GENERAL INSTABILITY APPEARS SHY

INCREASE THE STRINGER WEB TO 2.65" HIGH

	A	y	Ay	Ay^2	I_o
$A_1 =$	1.050	0.0625	0.0656	0.0041	0.00137
$A_2 =$	0.120	0.1630	0.0196	0.0032	0
$A_3 =$	0.398	1.450	0.5760	0.8350	0.23100
$A_4 =$	0.340	2.825	0.9600	2.7100	0.00028
	1.908		1.6212	3.5523	0.23270

$$\bar{y} = \frac{1.621}{1.908} = 0.85$$

$$I_c = 3.552 + 0.233 - 1.908 \times 0.85^2 = 2.415$$

$$I_s = 2.415/8.4 = \underline{0.288}$$

$$t_a = 1.908/8.4 = 0.227$$

THEN

$$t^* = \sqrt[4]{12 \times 0.288 \times 0.2585} = \sqrt[4]{0.394} = 0.972$$

$$R/t^* = 340/0.972 = 350$$

EXTRAPOLATE THE BUCKLING COEFF CURVE OF $U = 0.00026$

$$C^* \approx 0.925$$

$$\sigma_{CR} = \frac{0.925 \times 10.4 \times 10^6}{350} = 27{,}600 \text{ PSI}$$

ACTUAL COMPR. STRESS

$$\sigma_c = \frac{6000 \times 8.4}{1.908} = 26{,}400 \text{ PSI}$$

$$M.S = \frac{27{,}600}{26{,}400} - 1 = \underline{+0.045} \longrightarrow$$

OK FOR GENERAL INSTABILITY

(2) SIZING OF STRINGER SECTION FOR

N_t = 13000 LB/" BELOW SRM ATTACHMENT PT.

STA 1630

ASSUME STRINGE SECTION INCLUDING SKIN

$A = 1.908 \text{ in}^2$

FOR STRINGER SPACING @ 8.4"

TOTAL TENSION LOAD IN ONE PANEL

IS $\Sigma N_t = 8.4 \times 13000 = 109200$ LB

$$\sigma_t = \frac{109,200}{1.908} = 57,100 \text{ PSI}$$

GIVEN ALLOWABLE $f_{tu} = 77000$ FOR 7075-T6 ALU

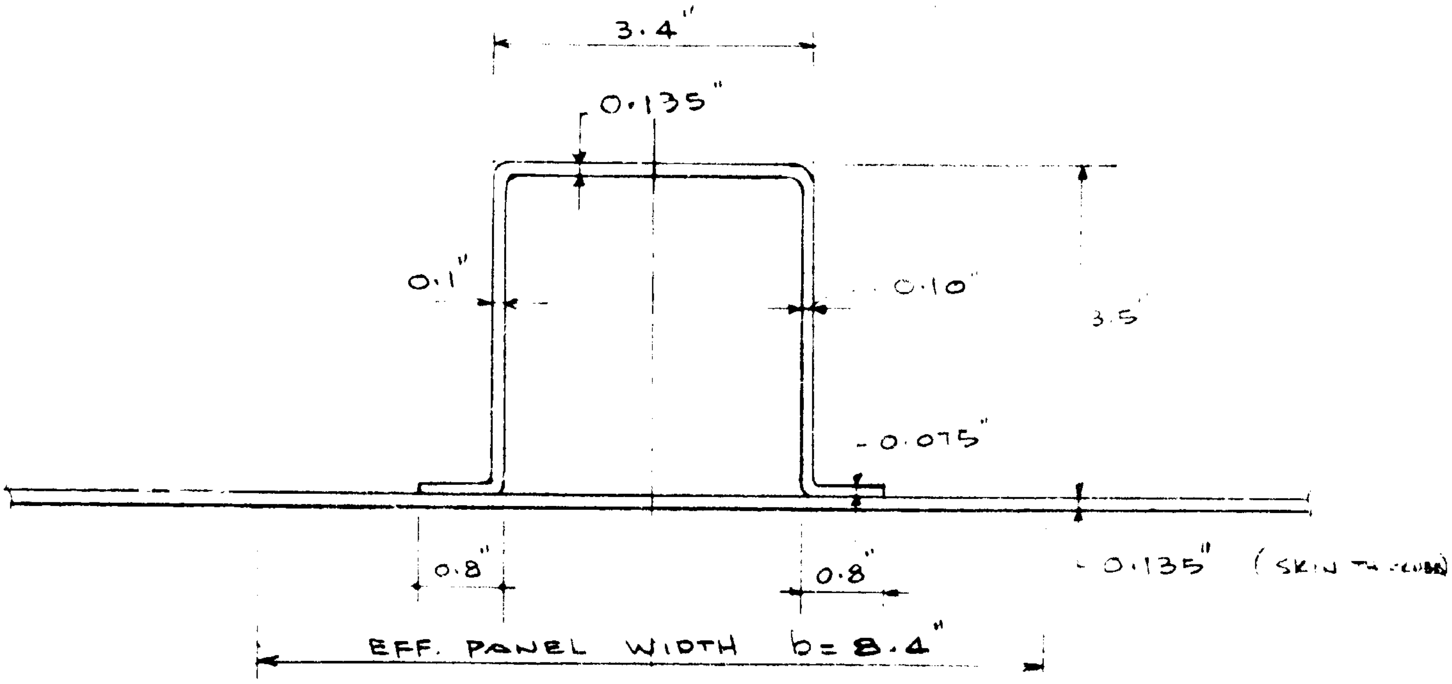
$$M.S = \frac{77000}{57100} - 1 = +0.34$$

COMPRESSIVE STRESS GOVERNS THE DESIGN

SIZING OF SKIN STRINGER SECTION

FOR MAX N_c = 9300 LB/" ABOVE SRM.

ATTACHMENT, BETWEEN STA. 1630 & 1690



MAX STRINGER SECTION BETWEEN STA 1630 & 1690

EFF. WIDTH $b_{eff} = 1.7 \times 0.135 \times 18.1 = 4.15"$

$2b_{eff} = 8.3 \approx 8.4$ AS SHOWN

	A	y	Ay	Ay^2	I_o
$A_1 = 8.4 \times 0.135 =$	1.135	0.0675	0.0766	0.00516	0.00172
$A_2 = 1.6 \times 0.075 =$	0.120	0.1730	0.0208	0.00360	0
$A_3 = 6.7 \times 0.100 =$	0.670	1.310	1.2120	2.19500	0.62500
$A_4 = 3.4 \times 0.135 =$	0.459	3.560	1.6350	5.81000	0.00070
	2.384		2.9444	8.01376	0.62742

$$\bar{Y} = \frac{2.9444}{2.384} = 1.234$$

$$I_c = Ay^2 + I_o - A\bar{Y}^2 = 8.014 + 0.627 - 2.384 \times 1.234^2 = 5.011 \text{ in}^4$$

(3.63)

$$I_s = 5.011/8.4 = 0.597 \text{ in}^4/"$$

$$t_a = 2.384/8.4 = 0.285$$

$$\rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{5.011}{2.384}} = 1.45$$

(A) GENERAL INSTABILITY ANALYSIS

(i) RING SIZE EVALUATION BASED UPON TIMOSHENKO'S CRITERION

GIVEN $a_x = 339$'

$I_s = 0.597$ IN^4/IN

$a_R = 330$"

$L_R = 60$"

$$A_R = \frac{4 \times \pi^2 I_s\, a_x\, a_R}{L_R^3}$$

$$= \frac{4 \times 9.85 \times 0.597 \times 339 \times 330}{3600 \times 60} = 12.3 \ \square"$$

(ii) USING SHANLEY'S CRITERION

$$I_R = \frac{0.785 \times R^4_{cyL} \times N_c}{10^3 \times 10.4 \times 10^6 \times L_R}$$

$$= \frac{0.785 \times 1.36 \times 10^{10} \times 9300}{10.4 \times 10^9 \times 60}$$

$$= \frac{0.785 \times 1.36 \times 93000}{10.4 \times 60} = 160 \ \text{IN}^4$$

ASSUME RING SIZE OF 8 □" (CHOOSE AREA BETWEEN (i)

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$= \sqrt[4]{12 \times 0.597 \left(\frac{8}{60} + 0.135\right)} = 1.177$$

0.2685

$$R/t^* = 340/1.177 = 289$$

GENERAL INSTABILITY STRESS EVALUATION

GIVEN $R/t^* = 289$

$\upsilon \approx 0.00025$ (ASSUMED)

$m \approx 8$ } ASSUMED

$n \approx 3$ }

FROM THE ATACHED BUCKLING COEFF. CHART PRODUCED BY USING THEORY FROM D5-13272

$$C^* \approx 0.975\ t$$

$$\sigma_{CR} = C^* E\, t^*/R$$

$$= \frac{0.975 \times 10.4 \times 10^6}{289} = 35000 \text{ PSI}$$

ACTUAL COMPR. STRESS

$$\sigma_c = \frac{9300 \times 8.4}{2.384} = 32700 \text{ PSI}$$

$$M.S = \frac{35000}{32700} - 1 = \underline{\underline{+0.07}} \longrightarrow$$

(B) LOCAL INSTABILITY INVESTIGATION (PANEL BUCKLING)

a) LOCAL SKIN PANEL BUCKLING

$$\sigma_{CR} = \frac{K_c \pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

▷ NASA - STRUCTURES MANUAL & D5-13272

$$= \frac{\overbrace{4 \times 9.85 \times 10.4 \times 10^6}^{38.2 \times 10^6}}{10.7} \left(\frac{0.135}{4.2}\right)^2$$

$$= 39{,}200 \text{ PSI}$$

$$M.S = \frac{39{,}200}{32{,}800} - 1 = \underline{+0.195}$$

b) LOCAL STIFFENER WEB BUCKLING

$$\sigma_{CR} = 38.2 \times 10^6 \left(\frac{0.1}{3.365}\right)^2 = 33700 \text{ PSI}$$

$$M.S = \frac{33{,}700}{32{,}800} - 1 = \underline{+0.025}$$

c) LOCAL STIFFENER FLANGE BUCKLING STRESS

$$\sigma_{CR} = 38.2 \times 10^6 \left(\frac{0.135}{3.4}\right)^2 = 59{,}500 \text{ PSI}$$

d) LOCAL STIFFENER CONNECTION LEG BUCKLING

$$\sigma_{CR} = 4.78 \times 10^6 \left(\frac{0.07}{0.80}\right)^2$$

$$= 4.78 \times 7.65 \times 10^3 = 36{,}600 \text{ PSI}$$

e) STIFFENER CRIPPLING STRESS INVESTIGATION

$$\sigma_{cc} = \frac{\Sigma \sigma_{ccN} \times b_n t_n}{\Sigma b_n t_n}$$

$$= \frac{1.135 \times 39,200 + 0.12 \times 36600 + 0.67 \times 33700 + 0.459 \times 59500}{2.384}$$

$$= \frac{44500 + 4390 + 22600 + 27300}{2.384}$$

$$= \frac{98790}{2.384} = 41400 \text{ PSI}$$

$$M.S = \frac{41400}{32800} - 1 = \underline{+0.26}$$

f) INTERFRAME BUCKLING

$$t_1^* = \sqrt[4]{12 I_s (t_s)} = 0.989''$$ ▷ D5-13272

$$N_{cr} = \frac{K_c \pi^2 E t_1^{*3}}{12(1-\nu^2) L_R^2}$$ ▷ D5-13272 & TN-3783

$$Z_L = \frac{L_R^2}{R t_1^*} (1-\nu^2)^{1/2}$$

$$= \frac{3600}{340 \times 0.989} \times 0.945 = 10.2$$

$K_c \approx 4.3$ FROM TN-3783

$t_1^{*3} = 0.963$

$$N_{CR} = \frac{4.3 \times 9.85 \times 10.4 \times 10^6}{10.7 \times 3600} \times 0.963$$

$$= 41 \times 10^6 \times \frac{0.963}{3600} = 110 \times 10^2 = 11000 \text{ LB/IN}$$

$$M.S = \frac{11000}{9300} - 1 = +0.18$$

INTERFRAME BUCKLING BY JOHNSON - EULER EQUATION

$$F_c = \sigma_{ac} - \frac{\sigma_{cc}^2 \times \left(\frac{L}{\rho}\right)^2}{4\pi^2 E}$$

$$= 41400 - \frac{41400^2 \times 41.5^2}{4 \times 9.85 \times 10.4 \times 10^6} = 34.500 \text{ PSI}$$

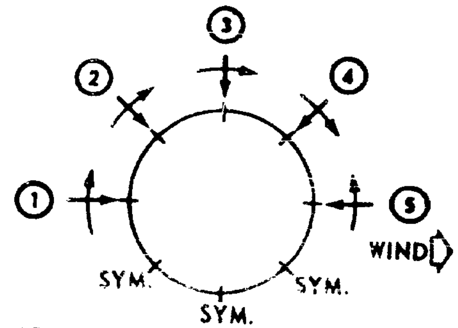
$$M.S = \frac{34500}{32800} - 1 = \underline{+0.05} \longrightarrow$$

THIS METHOD IGNORES THE EFFECT OF ELASTIC SKIN SUPPORT (CONSERVATIVE SIDE)

UPPER ATTACHMENT POINT - VEHICLE STATION 1630

LOADING CONDITION	F_A* (LBS)	NORMAL LOAD - (LBS)					TANGENTIAL LOAD - (LBS)				
		1	2	3	4	5	1	2	3	4	5
ON-PAD FUELED	1,081,043	0	0	0	0	0	0	0	0	0	0
THRUST BUILD-UP	1,081,043	0	0	0	0	0	0	0	0	0	0
LIFT-OFF	1,654,000	165,624	165,624	165,624	165,624	165,624	0	0	0	0	0
QαMAX.	2,255,421	202,000	370,161	1,105,000	649,801	164,000	0	-421,080	323,000	-654,101	0
SRM CUT-OFF	3,198,008	324,213	324,213	324,213	324,213	324,213	0	0	0	0	0

*FOR ONE (1) SRM



ARROW DIRECTIONS INDICATE ASSUMED POSITIVE DIRECTIONS FOR APPLIED LOADS

LOWER ATTACHMENT POINT - VEHICLE STATION 355

LOADING CONDITION	F_B (LBS.)	NORMAL LOAD - (LBS.)					TANGENTIAL LOAD - (LBS.)				
		1	2	3	4	5	1	2	3	4	5
ON-PAD, FUELED	0	0	0	0	0	0	0	0	0	0	0
THRUST BUILD-UP	0	0	0	0	0	0	0	0	0	0	0
LIFT-OFF	0	604,376	604,376	604,376	604,376	604,376	0	0	0	0	0
Qα MAX	0	332,000	706,925	436,000	375,161	540,000	0	165,882	122,000	165,780	0
SRM CUTOFF	0	149,178	149,178	149,178	149,178	149,178	0	0	0	0	

F_A = FORWARD AXIAL LOAD
F_B - AFT AXIAL LOAD

TABLE B-3.1-I SOLID MOTOR ATTACHMENT LOADS

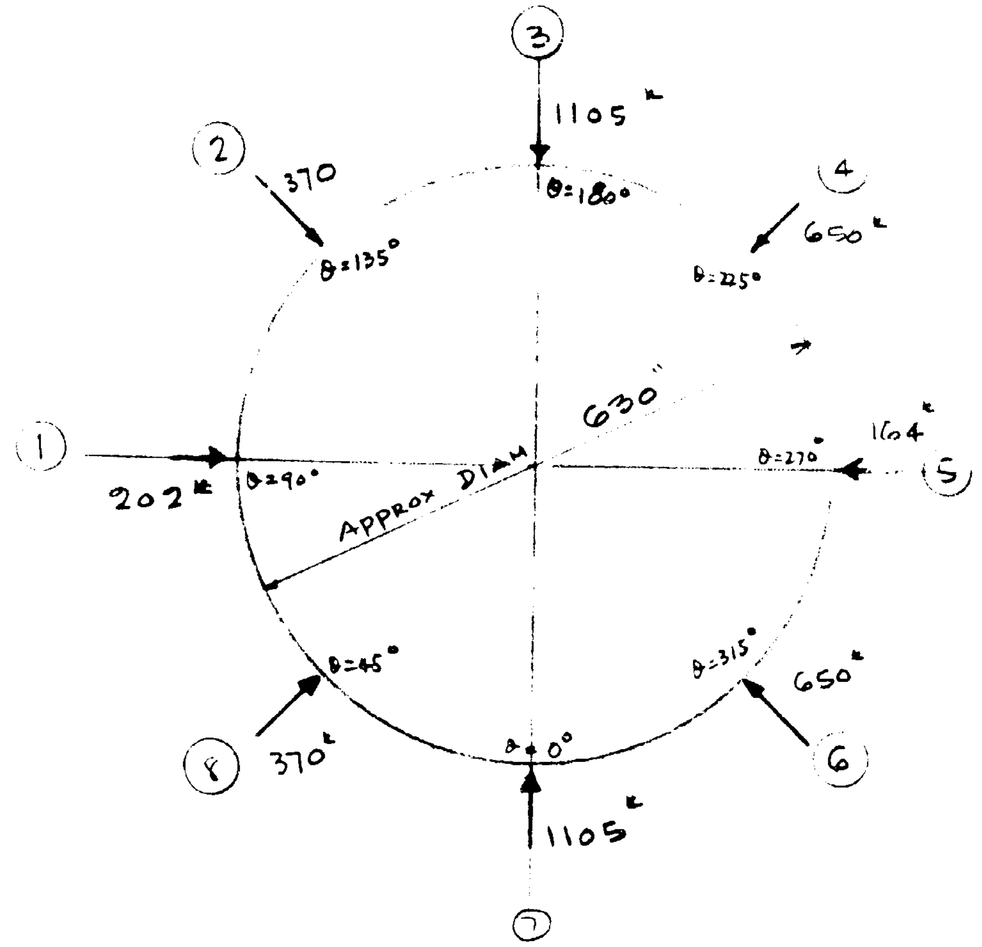
B-3.2

MLLV MAIN STAGE PLUS EIGHT STRAP-ON STAGES PLUS A THREE MODULE INJECTION STAGE VEHICLE

MAIN STAGE FORWARD THRUST RING

APPROXIMATE SIZING OF SRM FWD ATTACHMENT RING AT STA 1630

ASSUMPTION : FROM LOAD INFORMATION IT APPEARS THAT MAX $q\alpha$ CONDITION WILL BE THE MOST CRITICAL LOADING CASE TO DESIGN THE FWD ATTACHMENT RING

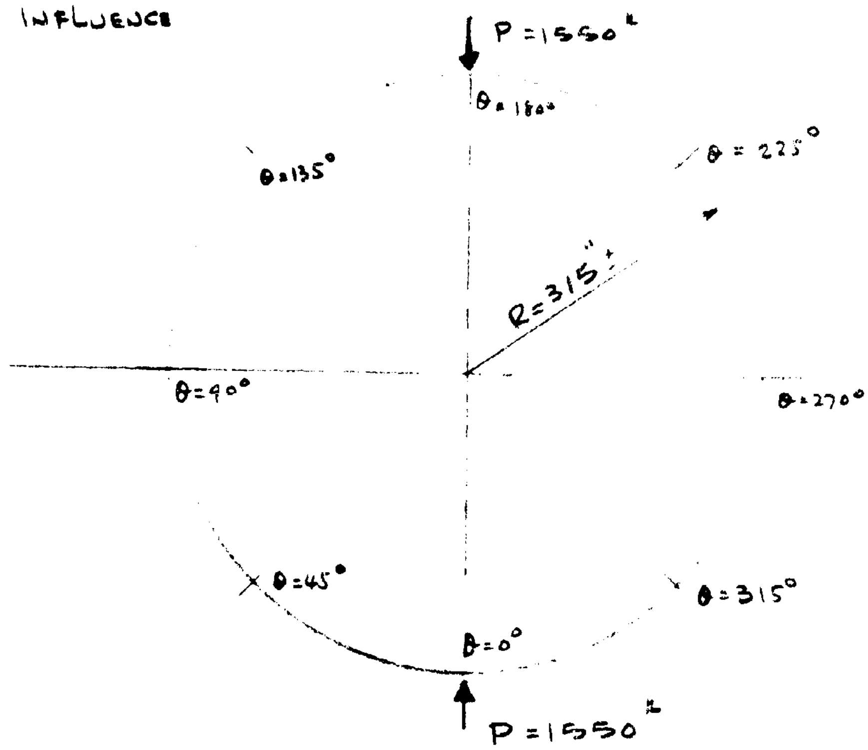


RADIAL LOAD GIVEN IS LIMIT MAX $q\alpha$ LOAD

BENDING MOMENT AT $\theta = 0°$ IS THE MOST CRITICAL DESIGN CASE

APPLYING F.S = 1.4 FOR ULTIMATE DESIGN

AND TREAT LOAD AS INDIVIDUAL CASE AND SUPERIMPOSING THE MAX INFLUENCE



$P = 1105 \times 1.4 = 1550^{K}$

LOADING CASE 1 — TWO RADIAL INWARD LOAD @ θ = 0° & 180°

$M = +0.318\, P_R\, R$ ▷ NASA STRUCTURES MANUAL

$= +0.318 \times 1550 \times 315$

$= +155,300$ "-K

$N = 0$

LOADING CASE 2 — ONE SINGLE RADIAL LOAD @ θ = 45°

@ $\theta = 0°$, $\phi = 315°$

$M = -0.05 \times 370 \times 1.4 \times 315 = -8130$ "-K

$N = -0.43 \times 370 \times 1.4 = -222^{K}$

LOADING CASE 3 — ONE SINGLE LOAD @ θ = 90°

@ $\theta = 0°$, $\phi = 270°$

$M = -0.09 \times 202 \times 1.4 \times 315 = -8050$ "-K

$N = -0.25 \times 202 \times 1.4 = -71^{K}$

LOADING CASE 4 ONE SINGLE LOAD AT $\theta = 135°$

@ $\theta = 0°$
or $\phi = 225°$

$M = +0.012 \times 370 \times 1.4 \times 315 = +1960$ "-k

$N = +0.075 \times 370 \times 1.4 = +39^k$

LOADING CASE 5 ONE SINGLE LOAD AT $\theta = 225°$

@ $\theta = 0°$
or $\phi = 135°$

$M = +0.012 \times 650 \times 1.4 \times 315 = +3430$ "-k

$N = +0.075 \times 650 \times 1.4 = 68^k$

LOADING CASE 6 ONE SINGLE LOAD @ $\theta = 270°$

@ $\theta = 0°$
$\phi = 90°$

$M = -0.09 \times 164 \times 1.4 \times 315 = -6500$ "-k

$N = -0.25 \times 164 \times 1.4 = -58^k$

LOADING CASE 7 ONE SINGLE LOAD @ $\theta = 315°$

@ $\theta = 0°$
$\phi = 45°$

$M = -0.05 \times 650 \times 1.4 \times 315 = -14350$ "-k

$N = -0.43 \times 650 \times 1.4 = -392^k$

SUMMATION OF MOMENTS FROM LOADING CASES 1 TO 7 RADIAL LOAD ONLY

$$\Sigma M = +155{,}500 - 8130 - 8050 + 1960 + 3430 - 6500 - 14{,}350$$

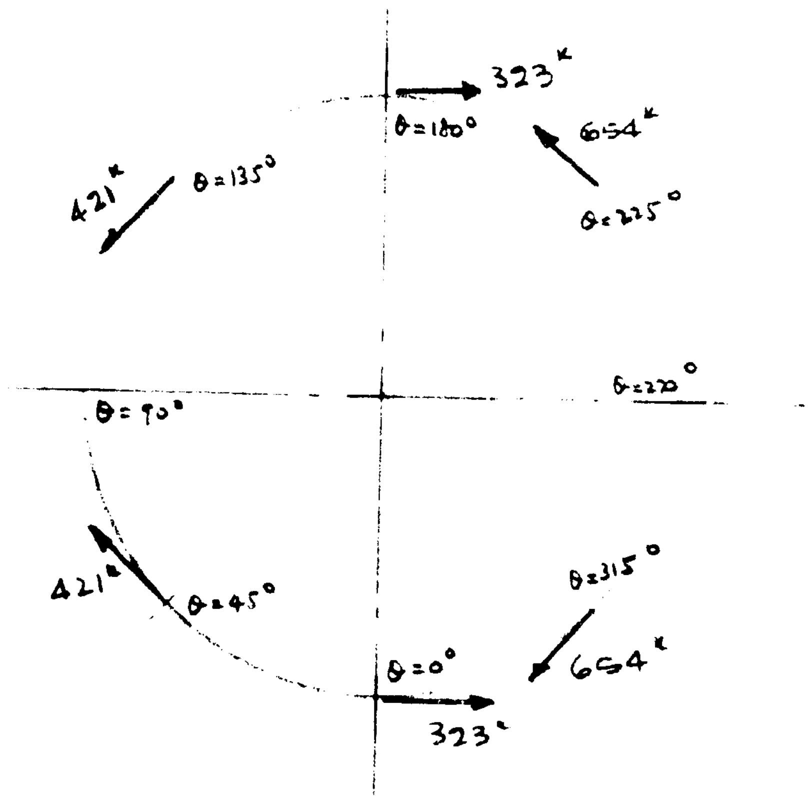
$$= \underline{\underline{+123{,}860}} \text{ ''-k}$$

SUMMATION OF NORMAL AXIAL LOAD FROM LOADING CASES 1 TO 7

$$\Sigma N = 0 - 222 - 71 + 39 + 68 - 58 - 392$$

$$= \underline{\underline{-636^{k}}}$$

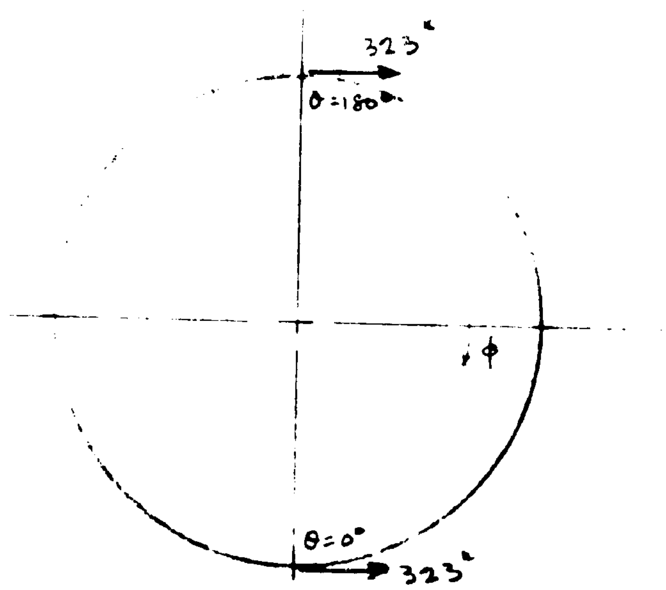
UPPER ATTACHMENT RING SUBJECTED TO TANGENTIAL LOAD



THE LOAD GIVEN IS LIMIT MAX j'd LOAD

SEPERATE THE ABOVE LOAD INTO THE FOLLOWING LOADING CONDITIONS AND SUPERIMPOSING THE RESULT

LOADING CONDITION #1



LOADING CASE 1

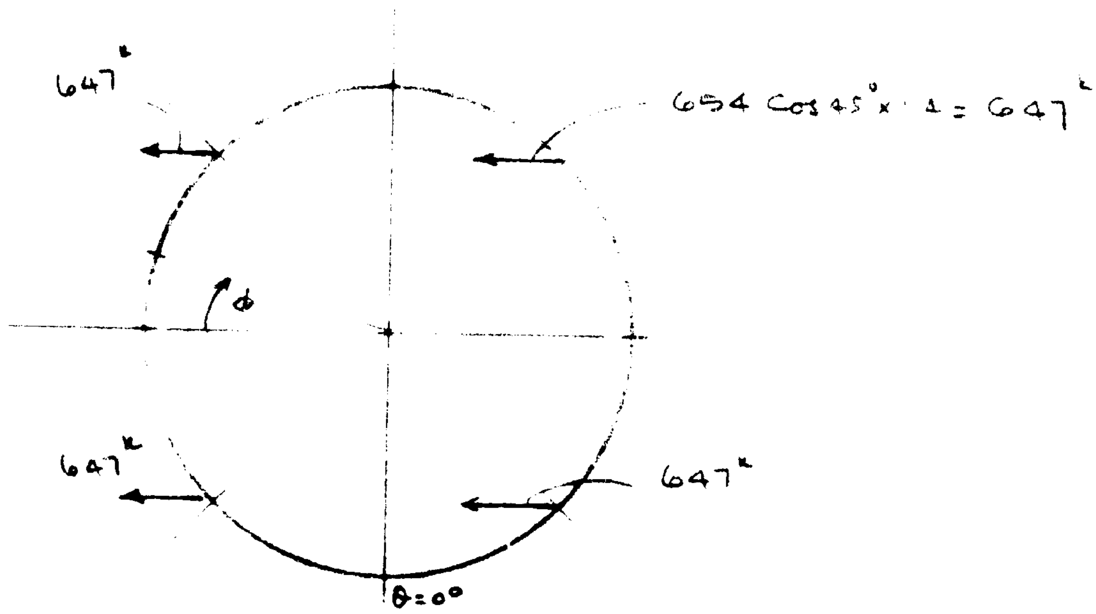
FOR LOAD @ $\theta = 0^\circ$ & $\theta = 180^\circ$

@ $\phi = 90^\circ$

$M = 0$

$N = 0.5\,P = -0.5 \times 323 \times 1.4 = -226^k$

LOADING CASE # 2

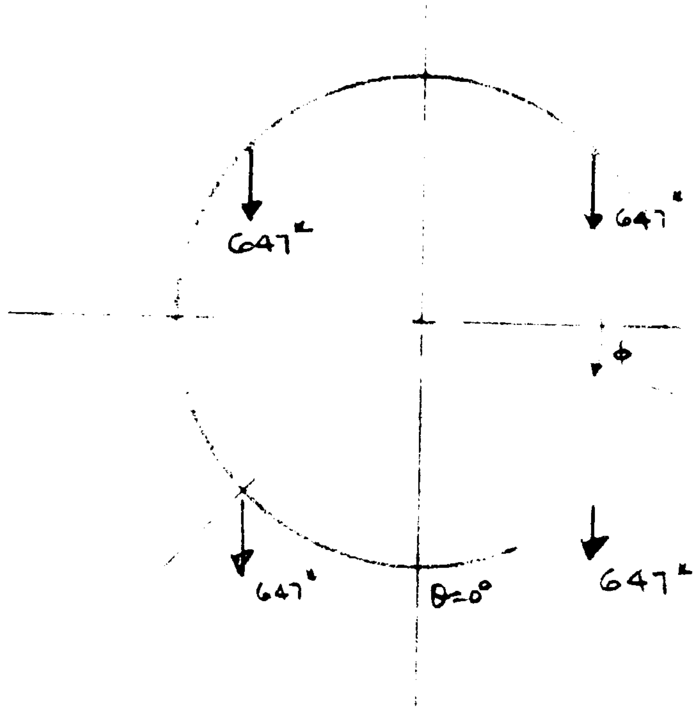


ASSUME ON CONSERVATIVE SIDE USE EQUAL MAX LOAD COMPONENT

AT $\phi = 270^\circ$ $M = 0$

ie $\theta = 0^\circ$ $N = 0$

LOADING CASE #3



FOR $\phi = 0°$

@ $\theta=0°$ $\quad M = +0.071 \times 647 \times 315 = 14500^{\text{ft-k}}$

$N = +0.64 \times 647 = 414^{k}$

SUMMATION OF MOMENTS FROM LOADING CASES ① TO #③

$\Sigma M = 0 + 0 + \underline{14500}^{\text{ft-k}}$

SUMMATION OF AXIAL FORCES FROM LOADING CASES ① TO #③

$\Sigma N = -226 + 0 + 414 = \underline{+188}^{k}$

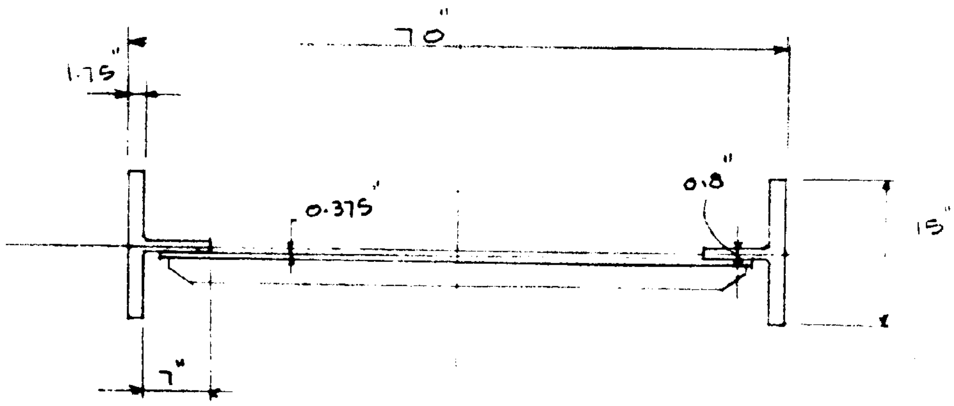
COMBINATION OF BOTH RADIAL AND TANGENTIAL LOADING CASES GIVES

MAX BENDING MOMENT AT $\theta = 0°$

$$\Sigma M = 123{,}860 + 14500 = \underline{\underline{138{,}360}} \text{ in-k}$$

$$\Sigma N = -636 + 188 = \underline{\underline{-448}}^{k}$$

DESIGN OF RING SECTION   FWD ATTACHMENT RING



$A_F = 2 \times 15 \times 1.75 = 52.5$

$A_W = 2 \times 7 \times 0.80 = 11.2$

$A_W = 64 \times 0.375 = 24.0$

$87.7 \ \square$

$I_1 = 52.5 \times 34.125^2 = 61500$

$I_2 = 11.2 \times 29.75^2 = 9900$

$I_3 = \frac{1}{12} 0.375 \times 64^3 = 8200$

79600 IN^4

$$S = \frac{79600}{35} = 2270 \text{ IN}^3$$

STRESS INVESTIGATION

a BENDING STRESS (ASSUME 7075-T6 ALUMINUM)

$M = 138,360$ in-k

$$\sigma_b = \frac{138,360^{\text{in-k}}}{2270} = 61000 \text{ PSI}$$

b AXIAL STRESS

$$\sigma_a = \frac{448}{87.7} = 5,150 \text{ PSI}$$

$F_{cy} = 69,000$ PSI FOR 7075-T6 EXTRUSION

$$R_b = \frac{61000}{69000} = 0.8850$$

$$R_a = \frac{5150}{69000} = \frac{0.0745}{0.9595}$$

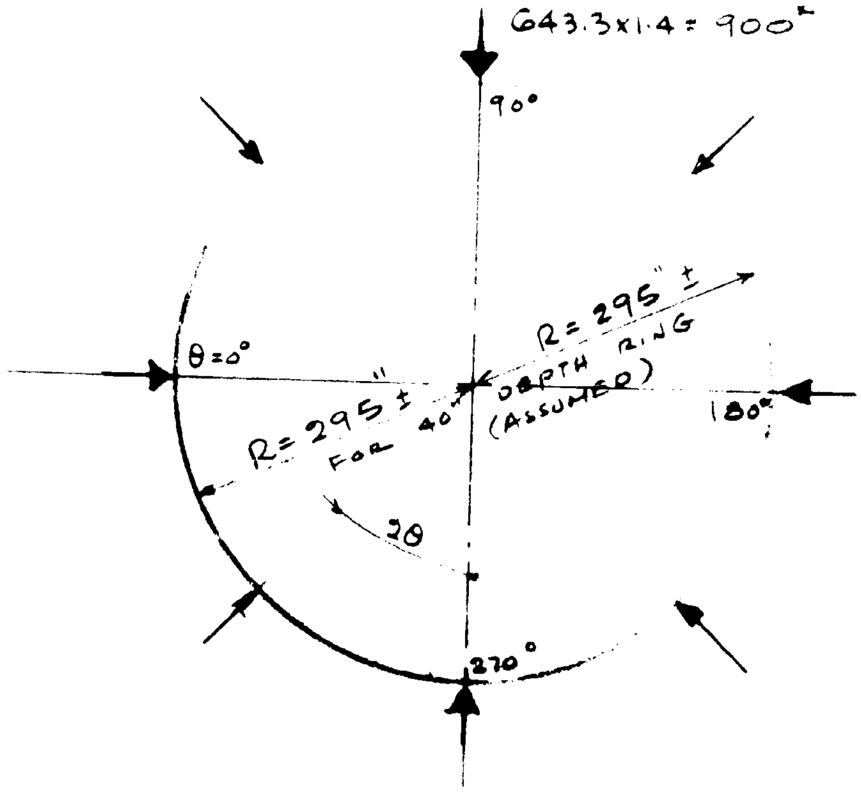
$$M.S. = \frac{1}{0.9595} - 1 = \underline{+0.042}$$

B-3.3

MLLV MAIN STAGE PLUS EIGHT STP -ON
STAGES PLUS A THREE MODUL
INJECTION STAGE VEHICLE

MAIN STAGE AFT THRUST RING

SIZING OF AFT ATTACHMENT RING BASED UPON LIFT OFF LOAD CONDITION STA 355



ULTIMATE LIFT OFF LOAD DIAGRAM

$2\theta = \pi/4 \qquad \theta = \pi/8$

ASSUME BENDING MOMENT AT EACH LOAD PT. IS "+"

$$\text{MAX} \quad M_{\theta=0^\circ} = \frac{1}{2} P_r R \left(\frac{1}{\theta} - \cot\theta \right)$$

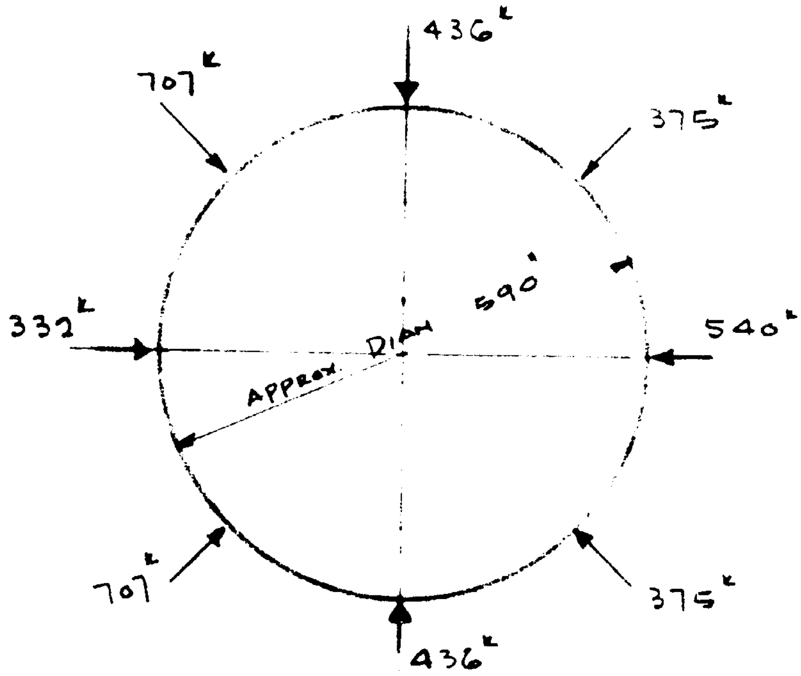
$$= \frac{1}{2} 900 \times 295 \left(\frac{8}{\pi} - \overset{2.4142}{\cot \pi/8} \right)$$

$$= 450 \times 295 \times 0.13427 = 17820^{\text{''-kips}}$$

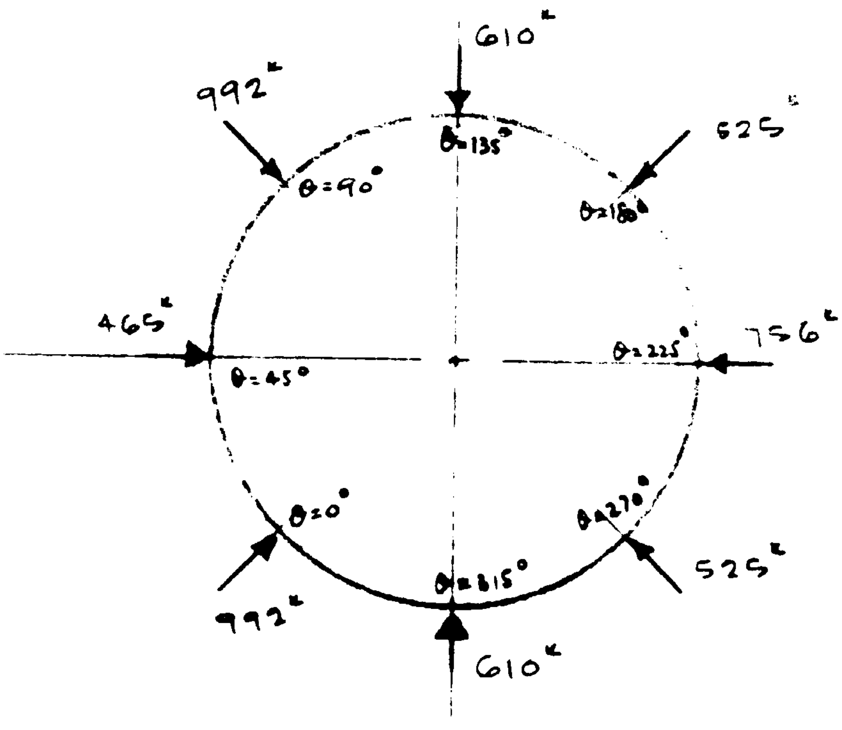
THIS LOAD CASE IS NOT THE CRITICAL CONDITION

SIZING OF AFT ATTACHMENT RING AT AFT SKIRT

VEHICLE STA 355 FOR MAX $q\alpha$ LOADING CONDITION



LIMIT MAX $q\alpha$ LOAD DIAGRAM PER LOAD GROUP OUPUT



ULTIMATE MAX $q\alpha$ LOAD DIAGRAM

FOR MAX 7d LOAD AS SHOWN

MAXIMUM MOMENT APPEARS AT 0° & 90° LOCATION BY SUPERINPOSING OF MOMENT INFLUENCE DUE TO OTHER LOAD WE HAVE

MOMENT AT LOCATION $\theta = 0$ AS FOLLOWS.

LOCATION OF LOAD	MOMENT INFLUENCE @ $\theta = 0°$	AXIAL FORCE INF.
$P_{0°} = 992$	$M_{0°} = +0.24 \times 992 \times 295 = 70300$ "-k	$N = -0.25 \times 992 = -248^k$
$P_{45°} = 465$	$M_{0°} = -0.045 \times 465 \times 295 = -6160$ "-k	$N = -0.43 \times 465 = -200$
$P_{90°} = 992$	$M_{0°} = -0.09 \times 992 \times 295 = -26300$ "-k	$N = -0.25 \times 992 = -248$
$P_{135°} = 610$	$M_{0°} = +0.016 \times 610 \times 295 = +2980$ "-k	$N = +0.075 \times 610 = +46$
$P_{180°} = 525$	$M_{0°} = +0.08 \times 525 \times 295 = +12400$ "-k	$N = +0.24 \times 525 = +130$
$P_{225°} = 756$	$M_{0°} = +0.016 \times 756 \times 295 = +3570$ "-k	$N = +0.075 \times 756 = +57$
$P_{270°} = 525$	$M_{0°} = -0.09 \times 525 \times 295 = -13900$ "-k	$N = -0.25 \times 525 = -131$
$P_{315°} = 610$	$M_{0°} = -0.05 \times 610 \times 295 = -9000$ "-k	$N = -0.43 \times 610 = -262$

$$\Sigma M = +89250 - 55360 = +33,890 \text{ ''-k}$$

$$\Sigma N = -948^k$$

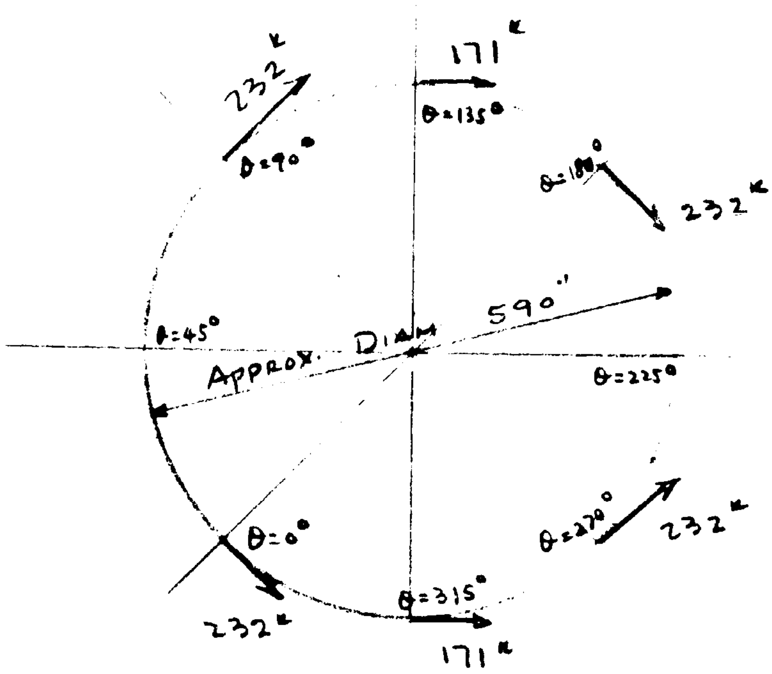
MOMENT AT LOCATION $\theta = 45°$

LOCATION OF LOAD	MOMENT INFLUENCE @ $\theta = 45°$	AXIAL FORCE
$P_{45°} = 465$	$M_{45°} = +0.24 \times 465 \times 295 = +33000$	
$P_{0°} = 992$	$M_{45°} = -0.05 \times 992 \times 295 = -14650$	
$P_{135°} = 610$	$M_{45°} = -0.09 \times 610 \times 295 = -16200$	
$P_{180} = 525$	$M_{45°} = +0.016 \times 525 \times 295 = +2480$	
$P_{225°} = 756$	$M_{45°} = +0.08 \times 756 \times 295 = +17900$	
$P_{270°} = 525$	$M_{45°} = +0.016 \times 525 \times 295 = +2480$	
$P_{315} = 610$	$M_{45°} = -0.09 \times 610 \times 295 = -16200$	
$P_{0°} = 992$	$M_{45°} = -0.05 \times 992 \times 295 = -14650$	

$$\Sigma M = -61700 + 55860 = -5840 \text{ ''-K}$$

THIS IS NOT THE CRITICAL MOMENT CASE

CALCULATION OF BENDING MOMENT DUE TO TANGENTIAL LOAD REF. ▷ NASA STRUCTURES MANUAL



ULTIMATE TANGENTIAL LOAD DIAGRAM

MOMENT INFLUENCES DUE TO TANGENTIAL LOADS AT $\theta = 0°$ ARE AS FOLLOWS :

a) FOR LOAD AT $\theta = 0°$ & $180°$

$$M_{\substack{\theta=0° \\ \phi=90°}} = 0$$

b) FOR LOADS AT $\theta = 90°$ & $270°$

$$M_{\substack{\theta=0° \\ \phi=180°}} = -0.09 \times 232 \times 295 = -6{,}160 \text{ ''-k}$$

c) FOR LOADS AT $\theta = 135°$ & $315°$

$$M_{\substack{\theta=0° \\ \phi=135°}} = +0.06 \times 171 \times 295 = +3030 \text{ ''-k}$$

SUMMATION OF MOMENT AT $\theta = 0°$

$$M = -6160 + 3030 = -3{,}130 \text{ in-k}$$

<u>AXIAL FORCE CALCULATION</u>

a) FOR LOAD AT $\theta = 0°$ & $180°$

$$N_{\theta=0°} = \pm 0.5 \times 232 = \pm 116^{k}$$

b) FOR LOAD AT $\theta = 90°$ & $270°$

$$N_{\theta=0°} = -0.16 \times 232 = -37$$

c) FOR LOAD AT $\theta = 135°$ & $315°$

$$N_{\theta=0°} = +0.075 \times 171 = +13^{k}$$

$$\text{MAX } \Sigma N = -116 - 37 + 13 = -140^{k}$$

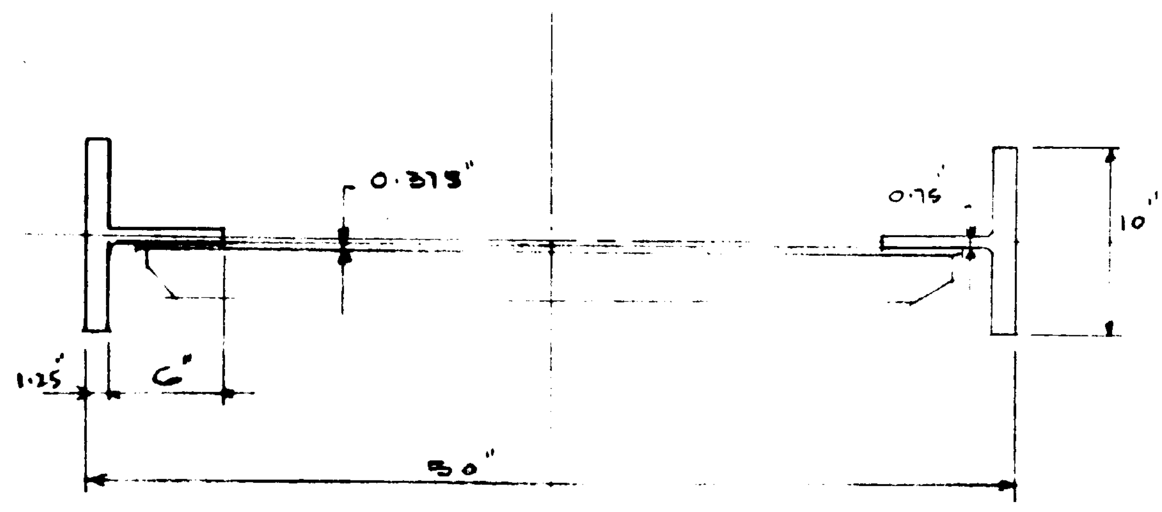
COMBINATION OF BOTH RADIAL LOAD AND TANGENTIAL LOADING CASES

$$\Sigma M = 33890 - 3130 = +30{,}760 \ ^{\text{in-k}}$$

$$\Sigma N = -948 - 140 = -1088 \ ^{k}$$

SIZING OF RING (AFT ATTACHMENT RING)

ASSUME 50" RING



$A_F = 2 \times 10 \times 1.25 = 25 \ \square''$

$A_W = 12 \times 0.75 = 9$

$A_W = 44 \times 0.375 = 16.6$

$\Sigma A = 50.6 \ \square''$

$I_F = 25 \times 24.388^2 = 15000 \ IN^4$

$I_W = 9 \times 20.75^2 = 3920$

$I_W = \frac{1}{12} 0.375 \times 44^3 = 2680$

$\Sigma I_c = 21{,}600 \ IN^4$

$$S = \frac{21{,}600}{25} = 865 \ IN^3$$

INVESTIGATION OF STRESSES IN RING

a) BENDING STRESS

GIVEN $\Sigma M = 31{,}000^{\text{"-K}}$

$$\sigma_b = \frac{31000}{865} = 35{,}800 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_a = \frac{1088}{50.5} = 21{,}600 \text{ PSI}$$

$$R_b = \frac{35{,}800}{69000} = 0.52$$

$$R_a = \frac{21600}{69000} = \frac{0.314}{0.834}$$

$$M.S = \frac{1}{0.834} - 1 = \underline{+0.20}$$

B-4

INJECTION STAGE STRESS ANALYSIS

B-4.1

INJECTION STAGE LOX TANK DESIGN

MLLV

INJECTION STAGE

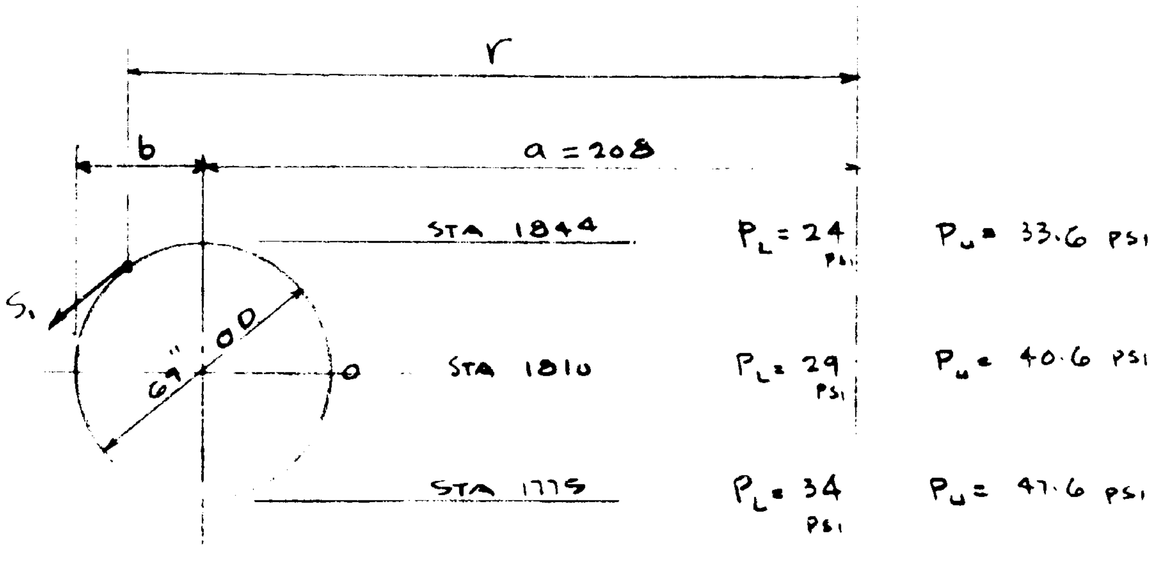
TANKS LOX TANK

GIVEN ULLAGE PRESSURE IN LOX TANK

$p_L = 24$ PSI AT TOP OF TORUS TANK

$P_L = 24 + 3.4 \times 2.8 = 33.5$ PSI ℄ BOTTOM OF TANK

$P_L = 24 + 0.041 \times 34.5 \times 3.4 = 29$ PSI @ MIDDLE OF TANK



APPLICATION OF ROARK'S STRESS & STRAIN FORMULA
TABLE XIII CASE 20

ASSUME CONSTANT THICKNESS FOR TANK SKIN

$$S_1 = \frac{p\,b}{t}\left(\frac{r+a}{2r}\right)$$

$$S_2 = \frac{p\,b}{2t}$$

MAX $S_1 = \dfrac{p\,b}{t}\left(\dfrac{2a-b}{2a-2b}\right)$ @ o @ STA 1810

MLLV

INJECTION STAGE

AT STA. 1775

$$r = a$$

$$S_1 = \frac{pb}{t}\left(\frac{a+a}{2a}\right) = \frac{pb}{t}$$

$$\text{OR } t = \frac{pb}{S_1} = \frac{47.6 \times 34.5}{63000} = 0.026$$

$$S_2 = \frac{pb}{2t} = \frac{47.6 \times 34.5}{0.052} = 31{,}500 \text{ psi}$$

AT STA 1810

$$p_u = 41 \text{ psi}$$
$$a = 208.0 \pm$$

$$r = a - b = 208.0 - 34.5 = 173.5$$

$$S_1 = \frac{pb}{t}\left(\frac{2a-b}{2a-2b}\right) = \frac{40.6 \times 34.5}{0.026}\left(\frac{\overset{381.5}{416-34.5}}{\underset{347}{416-69}}\right)$$

$$= 54000 \times \frac{381.5}{347.0} = 59500 \text{ psi}$$

$$S_2 = \frac{pb}{2t} = 27{,}200 \text{ psi}$$

AT STA 1810

$$p_u = 41 \text{ psi}$$

$$r = a + b = 242.5$$

$$S_1 = \frac{pb}{t}\left(\frac{2a+b}{2a+2b}\right)$$

$$= \frac{41 \times 34.5}{0.026}\left(\frac{\overset{450.5}{416+34.5}}{\underset{485}{416+69}}\right) = 50{,}300 \text{ psi}$$

$$S_2 = \frac{pb}{2t} = \frac{41 \times 34.5}{0.052} = 27200 \text{ psi}$$

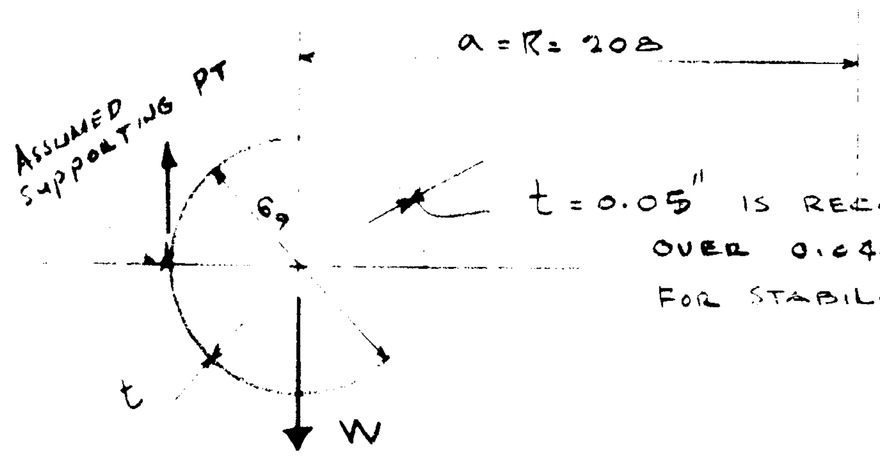
AT STA 1844

$\Gamma = a$ $p = 34$ PSI

$$S_1 = \frac{pb}{t} = \frac{34 \times 34.5}{0.026} = 45200 \text{ PSI}$$

$$S_2 = 45200 \text{ PSI}$$

ROTATION & SUBSEQUENT STRESS (BENDING DISTRIBUTION)



t = 0.05" IS RECOMMENDED OVER 0.0442 DESIGN THICKNESS FOR STABILITY

$$\text{VOLUME} = \pi D \times \frac{\pi d^2}{4}$$

$$= \frac{\pi^2 D d^2}{4} = \frac{\pi^2 \times 416 \times 69^2}{4} = \frac{9.85 \times 416 \times 4790}{4}$$

$$= 4.71 \times 10^6 \text{ IN}^3$$

$$\text{VOLUME LESS } 3\% = 4.569 \times 10^6 \text{ IN}^3$$

$$\text{WT} = \rho V = 0.041 \times 4.569 \times 10^6 = 0.1875 \times 10^6 \text{ LB}$$

$$W = 187{,}500 \text{ LBS}$$

$$M = \frac{W \times b}{\pi \times 2(R+b)} = \frac{187{,}500 \times 34.5}{2\pi \times 242.5} = 4250 \text{ ''-\#/''}$$

ROTATION ANGLE

$$\theta = MR^2/EI$$

▷ TIMOSHENKO STRENGTH OF MATERIALS VOL I

MLLV INJECTION STAGE

LOX TANK

$$\theta = \frac{MR^2}{E \times \pi r^3 t}$$

$$\sigma = \frac{E\theta Y}{R} = E\left(\frac{MR^2}{\pi E r^3 t}\right)\frac{r}{R} = \frac{MR}{\pi r^2 t}$$

THE THICKNESS REQUIREMENT DUE TO COMBINED PRESSURE AND BENDING

$$t = \frac{1}{F_{tu}}\left(pb + \frac{MR\,g'_s \times 1.4}{\pi r^2}\right)$$

ASSUME g FACTOR FOR BENDING IS ALSO 3.4

$$M = 4250 \times 1.4 \times 3.4 = 20200 \text{ in-\#}$$

AT STA 1775

$$t = \frac{1}{63000}\left(\overset{1660}{48 \times 34.5} + \overset{1124}{\frac{20200 \times 208}{3.14 \times 34.5^2}}\right) = 0.0442$$

MINIMUM STRESS SHOULD OCCUR AT STA 1844

$$\sigma_c = \frac{1124}{0.0442} = 25,400 \text{ PSI}$$

$$\sigma_t = \frac{24 \times 1.4 \times 34.5}{0.0442} = \overset{26200}{\cancel{33000}} \text{ PSI}$$

COMBINED STRESS

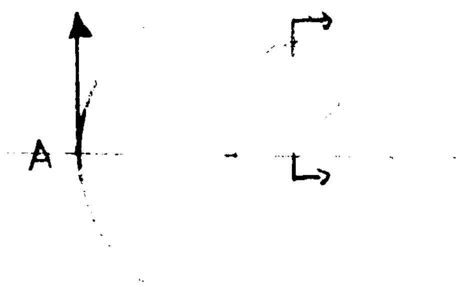
$$\Sigma\sigma = \sigma_t - \sigma_c = \overset{26200}{\cancel{33000}} - 25,400 = \overset{800}{\cancel{7,600}} \text{ PSI}$$

TENSILE STRESS

MLLV

INJECTION STAGE LOX TANK

IN ORDER TO PROVIDE ONLY ONE SHEAR SUPPORT AT PT A @ 8 PLACES AROUND THE TORUS CIRCUMFERENCE.

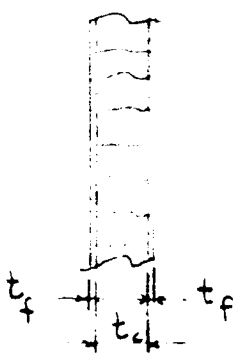


TWO CONCEPTS OF SHEAR WEB CAN BE EMPLOYED

(1) SANDWICH WEB PANEL

(2) RING REINFORCEMENT

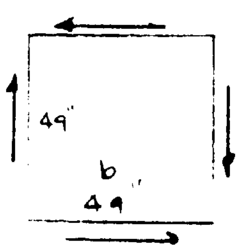
FOR BETTER RIGIDITY SANDWICH WEB PANEL @ EACH SUPPORTING LOCATION IS RECOMMENDED



FOR SIMPLIFIED DESIGN APPROACH ASSUME THE WEB PANEL IS AN INSCRIBED SQUARE PANEL OF 49" x 49"

GIVEN TOTAL WT. OF LOX TANK

$W = 187{,}500$ LBS



ASSUME G FACTOR IS 3.4

$W_u = 187{,}500 \times 1.4 \times 3.4 = 895000^{\#}$

THE TOTAL SHEAR AT EACH WEB PANEL IS
(ASSUMED IN 8 PLACES)

$$V_u = \frac{895000}{8} = 112000 \text{ LB ULT}$$

$$2t_f = \frac{V}{\tau_s b} = \frac{112000}{36000 \times 49} = 0.064''$$ ▷

$$\tau_f = \frac{K\pi^2 E_f t_c t_t}{4\lambda_f b^2} \qquad K = 5.35 + 4\left(b/a\right)^2$$
$$= 9.35$$

$$t_c(t_c + 2t_f) = \frac{4\lambda_f \times b^2 \tau_f}{K\pi^2 E_f} \qquad \lambda_f = 0.891$$

$$\tau_f \approx 36000 \text{ PSI}$$

$$t_c(t_c + 0.064) = \frac{0.891 \times 4 \times 49^2 \times 36000}{9.35 \times 9.85 \times 10.4 \times 10^6}$$

$$t_c^2 + 0.064\, t_c = \frac{3.56 \times 2410 \times 36000}{92.1 \times 10.4 \times 10^6}$$

$$= \frac{3.56 \times 24.1 \times 10^6 \times 3.6}{92.1 \times 10.4 \times 10^6} = 0.323$$

$$t_c^2 + 0.064\, t_c - 0.323 = 0$$

$$t_c = \frac{-0.064 \pm \sqrt{0.0041 + 4 \times 1 \times 0.323}}{2} = \frac{-0.064 \pm 1.135}{2}$$

$$= 0.6''$$

▷ HEXCEL, "HONEYCOMB SANDWICH DESIGN" BROCHURE "E"

MLLV

INJECTION STAGE WEB PANEL

$$VG_c = \frac{\pi^2 t_c E t_f}{2\lambda b^2}$$ REF ▷3

$$= \frac{9.85 \times 0.6 \times 10.4 \times 10^6 \times 0.032}{2 \times 0.891 \times 49^2}$$

$$= \frac{1.97 \times 10^6}{49 \times 98 \times 0.891} = \frac{0.0226 \times 10^6}{49} = 0.000461 \times 10^6$$

$$= 462$$

FROM CURVE FIG 3-4 REF ▷3

FOR $VG_c = 462$

FOR $G_c = 45000$

NEED 1/4 - 5052 - 0.009 @ 4.3#/CU FT

MIN. $G_c = 48000$ PSI

$$\therefore \quad V = \frac{462}{45000} = 0.0103$$

FOR SIMPLY SUPPORTED EDGE

FOR $V = 0.0103$

$b/a = 1$

$K_m = 9$ $\qquad$ $k_{m_0} = 9.2$

$$K = K_F + K_m$$

$$K_F = \frac{t^2}{3h^2} K_{m_0} = \frac{0.032^2 \times 9.2}{3 \times 0.632^2} = 0.00785$$

$$h = 0.6 + t_f = 0.632$$

▷3 MIL-HDBK-23, "COMPOSITE CONSTRUCTION FOR FLIGHT VEHICLE" PART III

MLLV

INJECTION STAGE WEB PANEL CONT'D

$$K = K_f + K_m$$

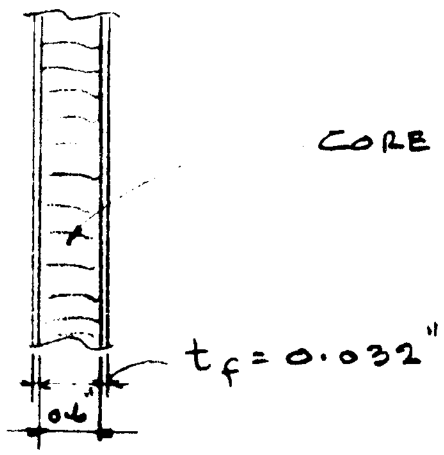
$$= 0.00785 + 9 = 9.00785$$

$$F_s = \frac{\pi^2 K E' h^2}{4 \lambda b^2}$$

$$= \frac{9.85 \times 9.01 \times 10.4 \times 10^6 \times 0.632^2}{4 \times 0.891 \times 49^2} = 0.0432 \times 10^6$$

$= 43200$ PSI OK THE SHEAR BUCKLING STRESS ALLOWABLE

THE FLAT SANDWICH PANEL SECTION IS ADEQUATE TO TRANSMIT THE SHEAR TO SUPPORT LOCATION



CORE IS 1/4 - 5052 - 0.0020 @ 4.3*/Cu Ft

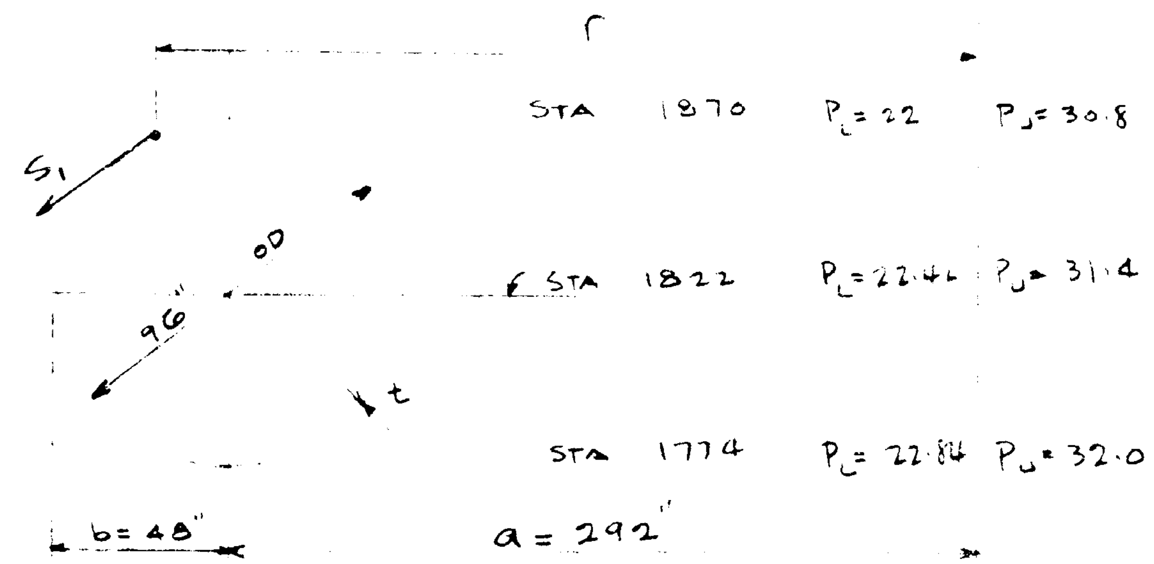
B-4.2

INJECTION STAGE LIQUID HYDROGEN TANK DESIGN

MLLV

INJECTION STAGE

LH_2 TANK



AT STA 1822 ℄ $r = a - b = 244$

$$t = \frac{pb}{S_1}\left(\frac{2a-b}{2a-2b}\right)$$

$$= \frac{31.4 \times 48}{63000}\left(\frac{\overset{536}{2\times292-48}}{\underset{488}{2\times292-96}}\right) = 0.0264''$$

SAY 0.027"

$$S_2 = \frac{pb}{2\times t} = \frac{31.4\times48}{\cancel{0.0264}\ 2\times0.027} = \cancel{56000}\ 28000 \text{ PSI}$$

AT STA 1810 ℄ $r = a + b$ $p = 31.4$

$$S_1 = \frac{pb}{t}\left(\frac{2a+b}{2a+2b}\right)$$

$$= \frac{31.4\times48}{0.027}\left(\frac{\overset{632}{584+48}}{\underset{680}{584+96}}\right) = 51800 \text{ PSI}$$

$$S_2 = \frac{pb}{2t} = \frac{31.4 \times 48}{2 \times 0.027} = 27,600 \text{ psi}$$

AT STA 1870

$r = a$

$p = 30.8$ psi

$$S_2 = S_1 = \frac{pb}{t} = \frac{30.8 \times 48}{0.027} = 54800 \text{ psi}$$

AT STA 1774

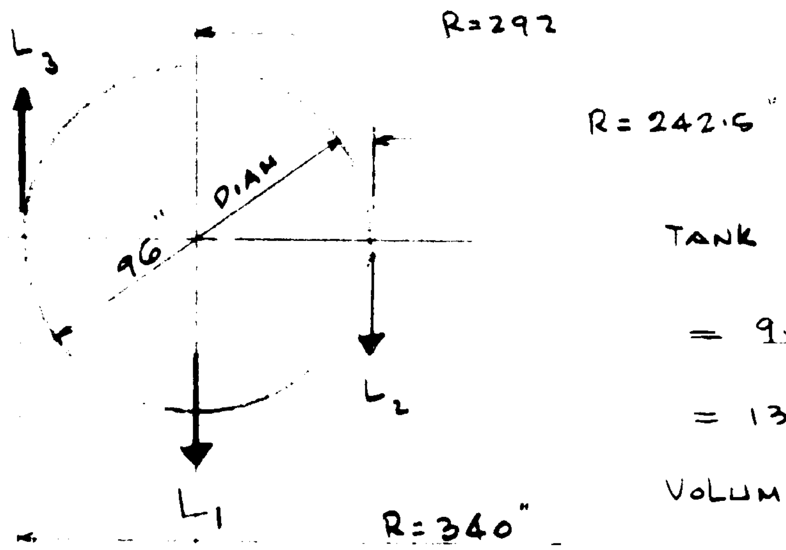
$r = a = 292$

$p = 32.0$ psi

$$S_1 = \frac{pb}{t}\left(\frac{2a+b}{2a+2b}\right)$$

$$S_1 = \frac{32 \times 48}{0.027}\left(\frac{\overset{632}{2 \times 292 + 48}}{\underset{680}{2 \times 292 + 96}}\right) = 52900 \text{ psi}$$

STRESSES FROM ROTATION (BENDING DISTRIBUTION)



$$\text{TANK VOL} = \frac{\pi^2 \times 292 \times 2 \times 96^2}{4}$$

$$= \frac{9.85 \times 584 \times 9230}{4}$$

$$= 13.3 \times 10^6 \text{ IN}^3$$

VOLUME LESS 3%

$$= 12.402 \times 10^6 \text{ IN}^3$$

$$LH_2 \text{ WT} = 12.902 \times 10^6 \times 4.41/1728$$

$$= 33000 \text{ LBS.}$$

$$L_2 = \frac{187,500}{2\pi \times 242.5} = 123 \text{ \#/in}$$

$$L_1 = \frac{33000}{2\pi \times 292} = 18 \text{ \#/in}$$

$$L_3 = \frac{187,500 + 33000}{2\pi \times 340} = 103 \text{ \#/''}$$

MOMENT ABOUT ℄ TANK

$$M = 123 \times 48 + 103 \times 48 = 5900 + 4950 = 10,850 \text{ ''-\#/''}$$

$$t = \frac{1}{F_{tu}} \left(p_u b + \frac{M \times 1.4 \times R \times g's}{\pi r^2} \right)$$

$$= \frac{1}{63000} \left(\overset{1535}{32 \times 48} + \frac{\overset{2020}{10850 \times 1.4 \times 292 \times 3.4}}{\pi \times 49^2} \right)$$

$$= 0.0565'' \quad \text{SAY} \quad 0.057''$$

INVESTIGATION OF COMPRESSIVE STRESS

$$\sigma_T^{\,p} = \frac{pb}{t} = \frac{30.8 \times 48}{0.057} = 26,000 \text{ PSI}$$

$$\sigma_c^{\,B} = \frac{MRg'.S.F.}{\pi r^2 t} = \frac{10850 \times 3.4 \times 1.4 \times 292}{\underset{2300}{\pi \times 48^2 \times 0.057}}$$

$$= 36600 \text{ PSI}$$

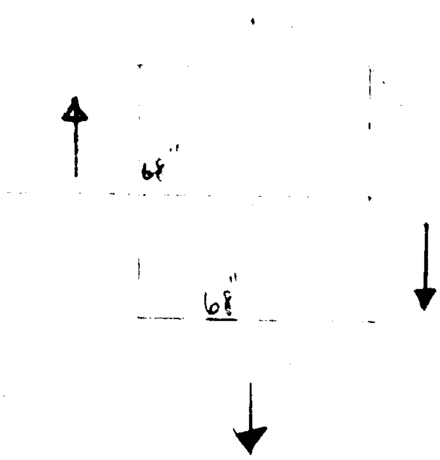
$$\sigma_c^{\,B} - \sigma_T^{\,p} = 36600 - 26,000 = 10,600 \text{ PSI}$$

COMPR STRESS

MLLV

INJECTION STAGE LH$_2$ TANK

SHEAR WEB REINFORCEMENT ASSUMED @ 3 PLACES



MAX SHEAR

$$V = \frac{187{,}500 + 33000}{8} \times 3.4 \times 1.4$$

$$= 131{,}000^{\#} \text{ ULT}$$

$$2t_f = \frac{V}{\tau_s b} = \frac{131{,}000}{36000 \times 68}$$

$$2t_f = 0.054$$

$$t_f = 0.027 \text{ IN}$$

CALCULATION OF CORE DEPTH REQUIREMENT

ASSUME

$$t_c(t_c + 2t_f) = \frac{0.8911 \times 4 \times 68^2 \times 3600\overset{4630}{0}}{9.35 \times \pi^2 \times 10.4 \times 10^6} = \frac{0.62 \times 10^6}{10^6}$$

$$t_c^2 + t_c \cdot 2t_f = 0.62$$

$$t_c^2 + 0.054\,t_c - 0.62 = 0$$

$$t_c = \frac{-0.054 \pm \sqrt{0.0029 + 4 \times 0.62}}{2} = \underline{\underline{0.76"}}$$

MLLV

INJECTION STAGE

SHEAR WEB. SHEAR MODULUS CALCULATION

$$VG_c = \frac{\pi^2 t_c E' t}{2\lambda b^2} = \frac{\pi^2 \times 0.76 \times 10.4 \times 10^6 \times 0.027}{2 \times 0.891 \times 68^2}$$

$$= \frac{0.0174 \times 10^6}{68} = 256$$

FROM CURVE 3-4 REF ▷

$VG_c = 256$ $G_c \approx 25000$

NEED $3/8$ - 5052 - 0.002 @ 3.0 #/CU FT

$G_c = 31,200$ PSI.

$$V = \frac{256}{31.200} = 0.0082$$

FOR SIMPLY SUPPORTED EDGE

FOR $V = 0.0082$

$b/a = 1$

$K_m = 9.1$ $K_{m_o} = 9.25$ FIGURE 3-5 REF. ▷

$K = K_F + K_m$

$$K_F = \frac{t^2}{3h^2} K_{m_o} = \frac{0.027^2 \times 9.25}{3 \times 0.79^2} = 0.0036$$

$h = 0.76 + t_f = 0.76 + 0.027 = 0.79$

$K = 0.0036 + 9.1 = 9.104$

THE SHEAR BUCKLING STRESS ALLOWABLE

$$F_s = \frac{\pi^2 k E h^2}{4 \lambda b^2}$$

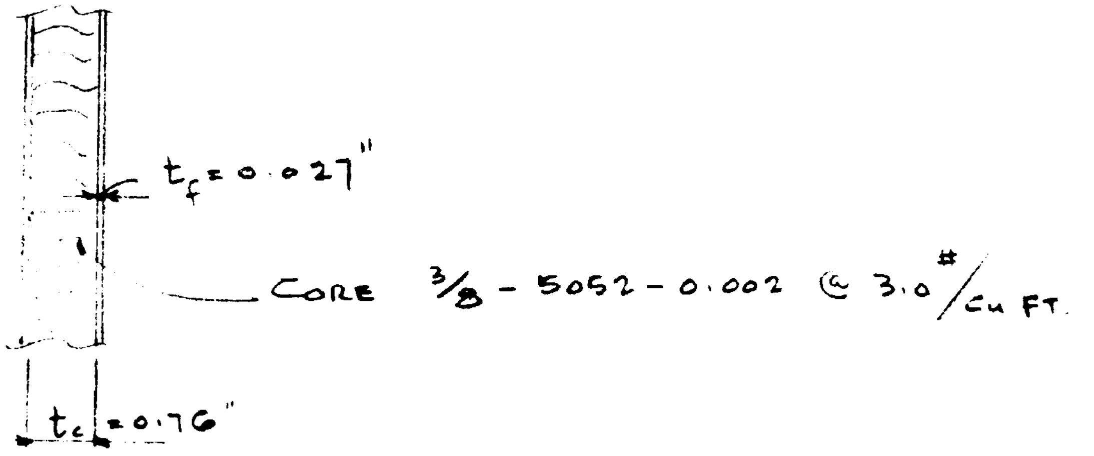
$$= \frac{9.85 \times 9.104 \times 10.4 \times 10^6 \times 0.79^2}{4 \times 0.891 \times 68^2}$$

$$= 36{,}400 \text{ PSI} \qquad \text{OK}$$

ASSUMED $\tau_s = 36{,}000$ PSI

$M.S \approx 0$

THE DESIGNED FLAT PANEL IS



INVESIGATION OF COMPRESSIVE STRESS CAPABILITY OF TORUS TANKS

a) LOX TANK

THE COMBINED MERIDIANAL STRESSES DUE TO INTERNAL PRESSURE & BENDING IS A NET TENSILE STRESS. HENCE THE SKIN DESIGNED FOR INTERNAL PRESSURE IS ADEQUATE.

b) LH_2 TANK

THE COMBINED MERIDIANAL STRESS DUE TO BOTH BENDING & INTERNAL PRESSURE IS A NET COMPRESSIVE STRESS WITH THE FOLLOWING MAGNITUDE

$$\sigma_c = 36600 - \overset{13000}{\cancel{25800}} = \overset{23,600}{\cancel{10,800}} \text{ PSI}$$

(i) USING MONOCOQUE APPROACH

ASSUME THE CRITICAL BUCKLING STRESS TO EQUAL TO THAT FOR A CYLINDER WITH A LENGTH EQUAL TO DISTANCE BETWEEN WEB PANEL. A LONG CYLINDER APPROACH

INCREASE THE SKIN THICKNESS FROM 0.057 TO 0.1"

AND APPLY THE CRITICAL BUCKLING STRESS DUE TO BENDING

$$\sigma_{b_{cr}} = 1.3\, C\, E\, t/R$$

FOR $R/t = 48/0.1 = 480$

FROM PBY'S MONOCOQUE COEFFICIENT CURVE

FOR $R/t = 480$

$\omega = 0.00050$

$C = 3.0$

$$\sigma_{b_{cr}} = \frac{1.3 \times 0.3 \times 10.4 \times 10^6}{480}$$

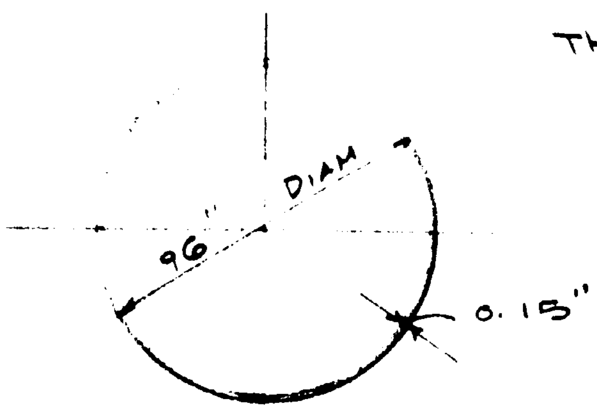
$= 8470$ PSI NOT ENOUGH

TRY TO INCREASE THE SKIN TO 0.125"

$$R/t = \frac{480}{0.125} = 384$$

$$\sigma_{b_{cr}} = \frac{1.3 \times 0.35 \times 10.4 \times 10^6}{380} = 12500 \text{ PSI}$$

$$MS = \frac{12500}{10800} - 1 = \underline{0.15} \longrightarrow \text{OK}$$



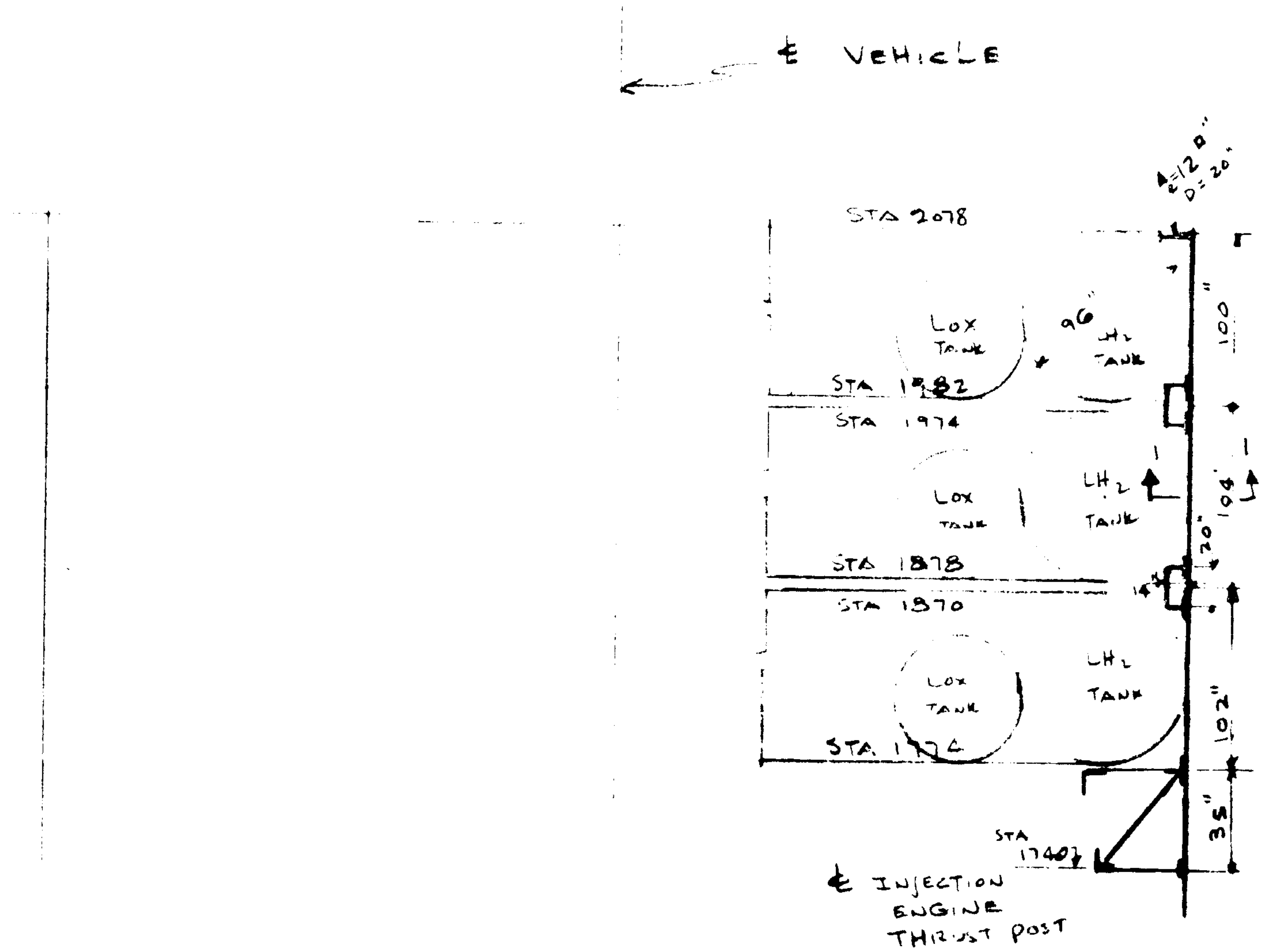
THE REVISED TANK SKIN TO SUPPORT NET COMPR. STRESS DUE TO BENDING IS $t_s = 0.125"$

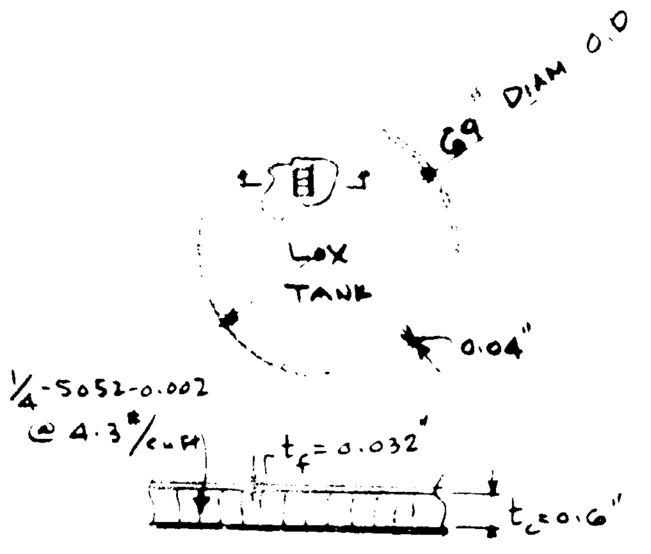
FOR ADD'L STABILITY $t_s = 0.15"$ IS RECOMMENDED AS MONOCOQUE CONSTRUCTION

B-4.3

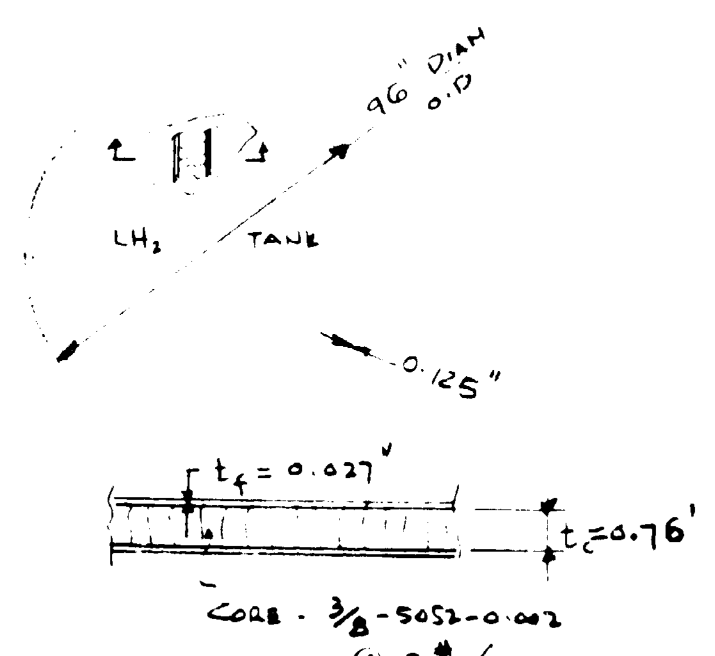
INJECTION STAGE SIDE WALL ANALYSIS

MLLV INJECTION STAGE SECTION





STIFFENED WEB PANEL
SANDWICH CONSTRUCTION
LOX TANK 8 REQ'D

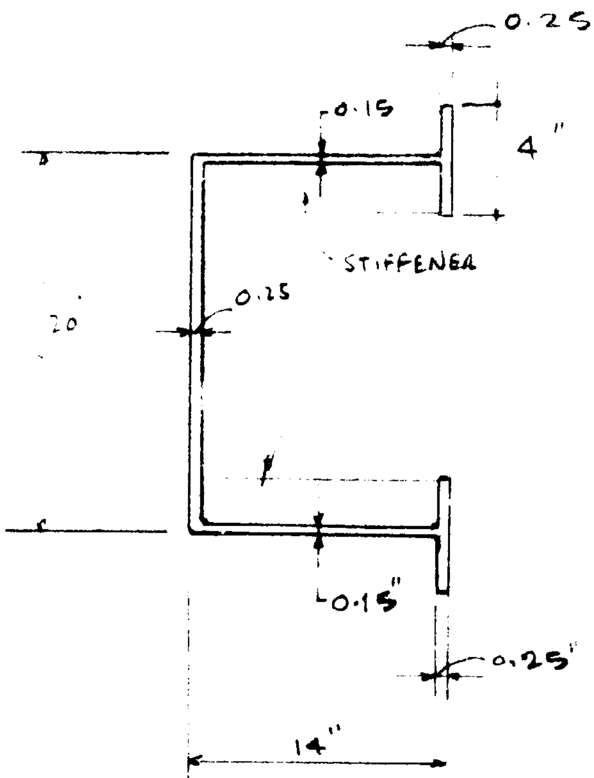


LH_2 WEB PANEL
SANDWICH CONSTRUCTION (8 REQ'D)

MLLV

INJECTION STAGE

INTERMEDIATE RING SIZING



$A_1 = 20 \times 0.25 = 5.0$

$A_2 = 2 \times 13.375 \times 0.15 = 4.0$

$A_3 = 2 \times 4 \times 0.25 = 2.0$

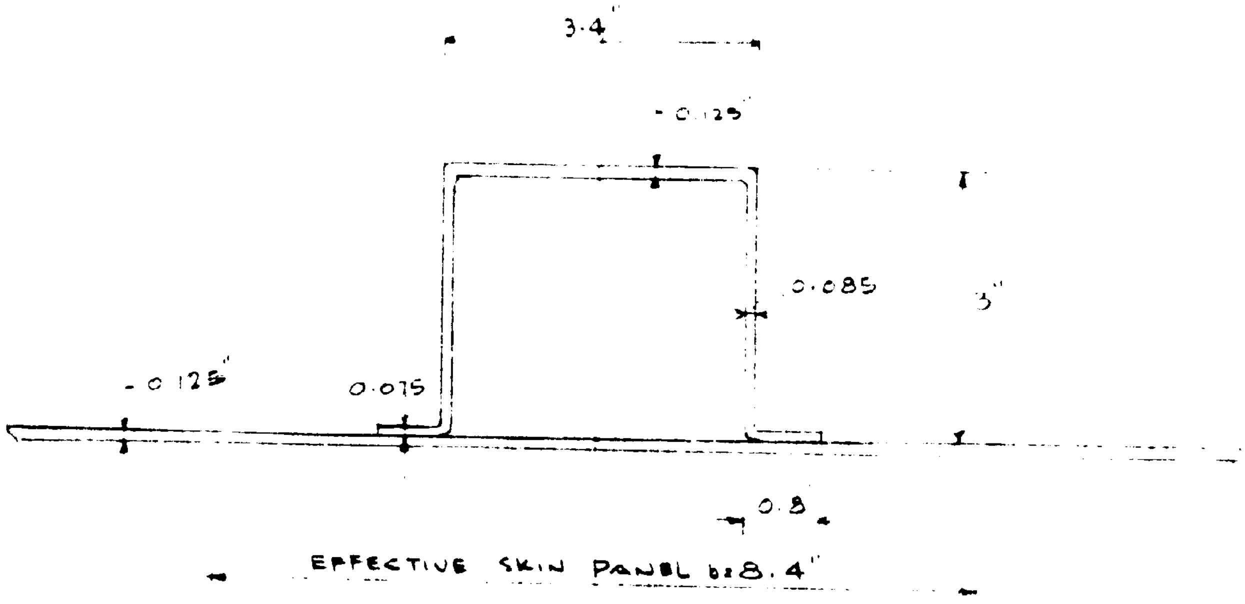
$11.0 \square''$

U-SHAPED RING IS RECOMMENDED TO REDUCE THE UNSUPPORTED SKIRT LENGTH TO SATISFY LOCAL INTERFRAME BUCKLING CRITERION

MLLV INJECTION STAGE WALL SECTION DESIGN

DESIGN OF SKIN-STRINGER SECTION FOR A

N_c = 7300 LB/" (ULT) AT STA 2080 (INJECTION STAGE)



STRINGER SECTION AT STATION 2080:

	A	y	Ay	Ay²	I₀
$A_1 = 0.125 \times 8.4$ =	1.0500	0.0625	0.0656	0.0041	0.00137
$A_2 = 1.43 \times 0.075$ =	0.1075	0.1630	0.0175	0.0029	–
$A_3 = 2 \times 2.875 \times 0.085$ =	0.4900	1.6400	0.8040	1.3200	0.3360
$A_4 = 3.4 \times 0.125$ =	0.4250	3.0620	1.3000	3.9800	0.0006
	2.0725		2.1871	5.3070	0.3403

$$\bar{y} = \frac{2.1871}{2.0725} = 1.054$$

$$I_c = 5.307 + 0.3403 - 2.0725 \times 1.054^2 = 3.357 \text{ in}^4$$

$$I_s = 3.357/8.4 = 0.4 \text{ in}^4/"$$

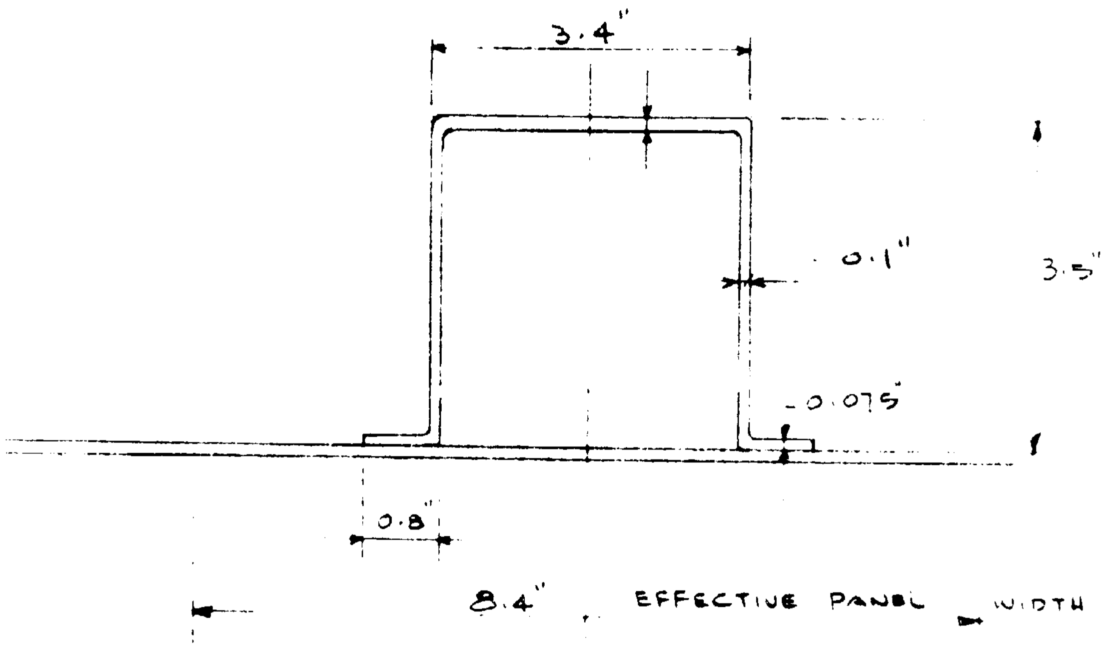
$$t_a = 2.0725/8.4 = 0.2470 \text{ in}$$

THIS SECTION IS SHY FOR INTERFRAME BUCKLING WITH RING SPACING OF 100" ±
HENCE HEAVIER WALL SECTION IS NEEDED
SEE NEXT SHEET

MLLV INJECTION STAGE WALL SECTION DESIGN

DESIGN OF SKIN-STRINGER SECTION FOR AN ULTIMATE

N_c = 9300 LB/" (MIN.) BETWEEN STA 1774 & STA 870



SECTION 1-1

$A = 2.384 \square''$

$I_s = 0.597 \text{ in}^4/''$

$t_a = 0.285'$

$\rho = 1.43$

$A_R = 10 \square'$ (INTERMEDIATE RING)

$L_R = 80'' \pm$

THIS IS THE SAME SECTION AS FWD SKIRT FOR 8-SRMS STRAP-ON CASE

BECAUSE OF LOCATION OF LH_2 TANK THE RING SPACING IS MADE MUC WIDER THAN FWD SKIRT.

GENERAL INSTABILITY INVESTIGATION

GIVEN $N_c = 9300$ #/IN MAX (ULT.)

$I_s = 0.597$

$t_a = 0.285$

$A_R = 10.0$

$L_R = 80$

$t_s = 0.135$

$$t^* = \sqrt[4]{12 I_s \left(\frac{A_R}{L_R} + t_s\right)}$$ REF D5-13272

$$= \sqrt[4]{12 \times 0.597 \left(\frac{10}{80} + 0.135\right)} = 1.1685''$$

0.260

$$R/t^* = \frac{340}{1.1685} = 291$$

$C^* \approx 1.0$ FROM THEORITICAL BULKHEAD

$$\sigma_{CR} = C^* E \frac{t^*}{R} = 1.0 \times 10.4 \times 10^6 \times \frac{1.169}{340} = 35800 \text{ PSI}$$

ACTUAL COMPRESSIVE STRESS

$$\sigma_c = \frac{9300}{0.285} = 32{,}700 \text{ PSI}$$

$$M.S = \frac{35800}{32700} - 1 = \underline{+0.095}$$

INVESTIGATION OF LOCAL INSTABILITY STRESSES

1) INTERFRAME BUCKLING BETWEEN RINGS

BECAUSE OF THE SIZE OF LH_2 TANK THE INTERMEDIATE RING IS ASSUMED TO HAVE A MAX SPACING OF 104"

$I_s = 0.597$
$t_s = 0.135$
$L_R = 104$"

$$t_1^* = \sqrt[4]{12 I_s t_s}$$

$$= \sqrt[4]{12 \times 0.597 \times 0.135}$$

$$= \sqrt[4]{0.966} = 0.992$$

$$t_1^{*3} = 0.975$$

$$Z_L = \frac{L^2}{R t_1^*} (1-\nu^2)^{1/2} = \frac{10800}{340 \times 0.992} \times 0.945 = 30.3$$

FOR $R/t_1^* = 340/0.992 = 343$

$K_c = 7.5$

$$N_{cR} = \frac{K_c \pi^2 E \times (t_1^*)^3}{12(1-\nu^2) L^2} = \frac{7.5 \times 9.85 \times 10.4 \times 10^6}{10.7} \left(\frac{0.975}{10800}\right)$$

$$= 6510\ \#/''$$

IF U SHAPED RING IS USED THE UNSUPPORTED SKIRT LENGTH BETWEEN RINGS WILL BE 80"

THEN $N_{cR} = 6510 \times \frac{10800}{7050} \times \frac{7.0}{7.5} = 9350\ \#/''$

$K_c \approx 7.0$

$L_R^2 = 7050$

LOCAL INSTABILITY (INTERFRAME BUCKLING INVESTIGATION)
BETWEEN STATION 2078 & STA 1982

$N_c = 7300$ LB/"

$L_R = 88$ (UNSUPPORTED SKIRT LENGTH)

$t_1^* = 0.992$

$(t_1^*)^3 = 0.975$

$Z_L = \frac{7720}{340 \times 0.992} \times 0.945 = 21.6$

$K = 6.5$

$N_{CR} = \frac{K \pi^2 E}{12(1-\nu^2)} \frac{(t_1^*)^3}{L^2} = \frac{6.5 \times 9.85 \times 10.4 \times 10^6}{10.7 \times 7720} \times 0.975$

$= 7880$

$MS = \frac{7880}{7300} - 1 = +0.08$

BETWEEN STA 1974 & STA 1878

$N_c = 8450$

$L_R = 84"$

$K = 6.5$

$N_{CR} = \frac{6.5 \times 9.85 \times 10.4 \times 10^6}{10.7 \times 7050} \times 0.975 = 8600$ #/"

$MS = \frac{8600}{8450} - 1 = +0.015$

BETWEEN STA 1870 & 1774

$N_c = 8950$ LB/" ULT

$N_{CR} = 8600 \times \frac{7050}{6400} = 9500$ #/"

$MS = \frac{9500}{8950} - 1 = +0.06$

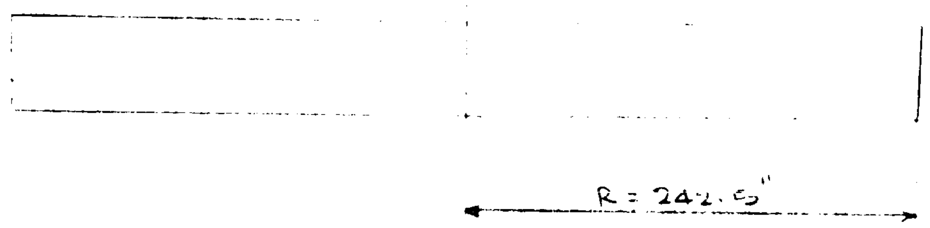
B-4.4

INJECTION STAGE HANGER SUPPORT BETWEEN TANKS

MLLV

INJECTION STAGE

CYLINDRICAL SKIRT — LOX TANK HANGER



ULT $N_t = \dfrac{\text{WT OF LOX} \times g\text{'s}}{2\pi R}$

$= \dfrac{187{,}500 \times 3.4 \times 1.4}{2\pi \times 242.5} = 587\ \#/''$

ASSUME HANGER IS IN CYLINDRICAL FORM

ASSUME 6AL - 4V

$F_{tu} = 157000$ PSI

$E_t = 16.0 \times 10^6$ PSI

$\nu = 0.30$

$\rho = 0.160\ \#/\text{cu in}^3$

$t = \dfrac{587}{157000} = 0.00374''$

ASSUME 2219 - T87 MATERIAL

$f_{tu} = 63000$

$t = \dfrac{587}{63000} = 0.0093''$

SAY $t = 0.01''$ HOWEVER

MIN $t = 0.05''$ SHOULD BE USED FOR RIGIDITY

INJECTION STAGE THRUST STRUCTURE

BASED UPON SHEAR LAG PRINCIPLE

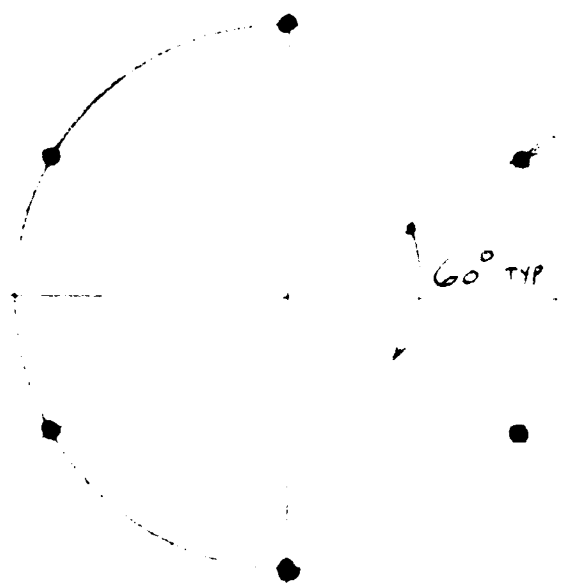
SINCE WE HAVE 6 INJECTION ENGINES

EACH ENGINE HAS A THRUST LOAD

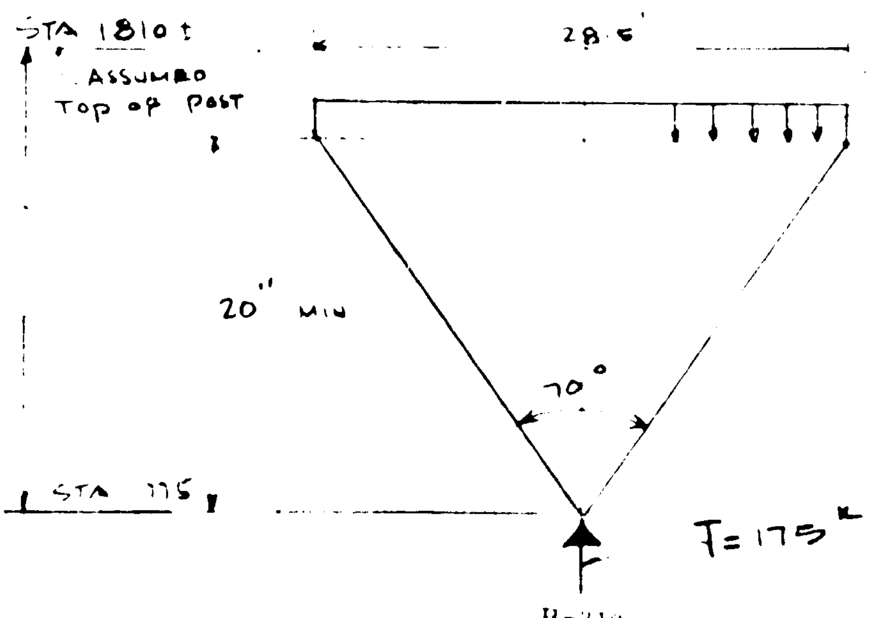
$T = 125 \times 1.4 = 175^{k}$ ULT THRUST

SIX ENGINES ARE ASSUMED TO BE LOCATED

℄ 60° APART



THE MAXIMUM N_c LOAD DISTRIBUTION

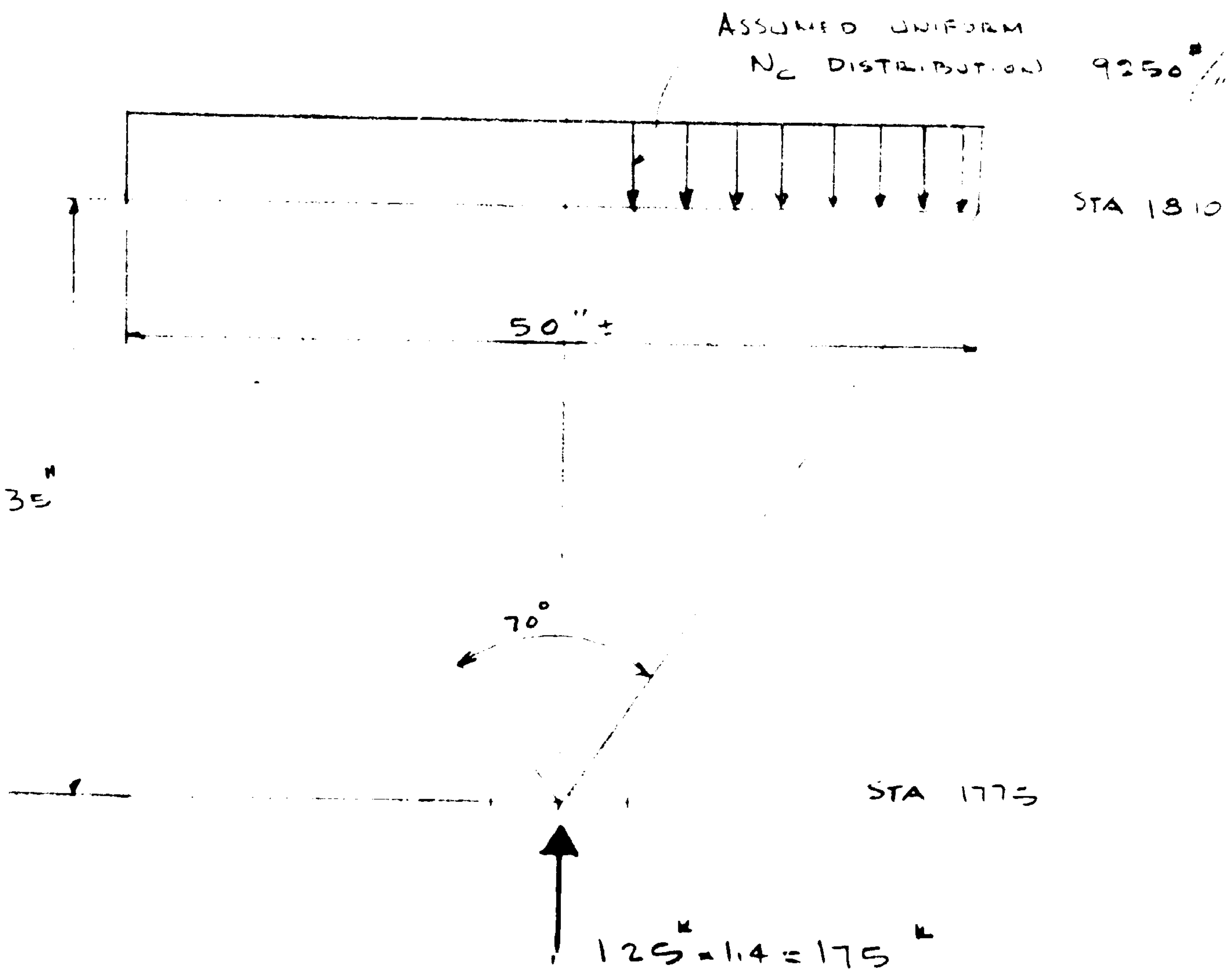


$N_c = \frac{175000}{28.5}$

$6150\ \#/in$

(FOR 20" SHEAR IN SKIRT

BASED UPON SHEAR LAG PRINCIPLE



$$N_c = \frac{175000}{50} = 3500\ \#/''$$

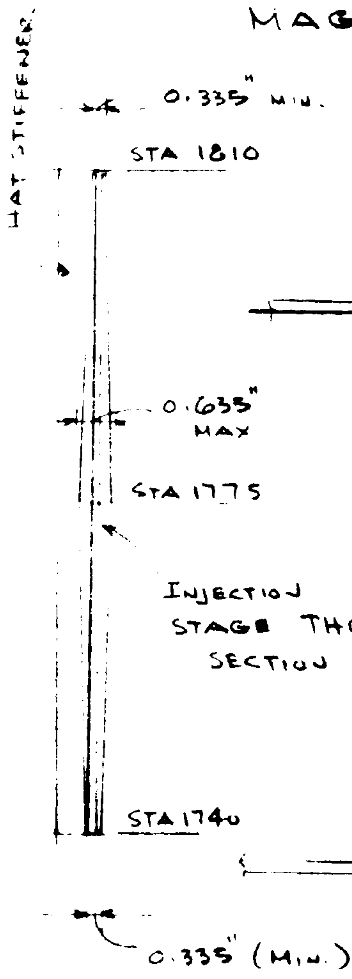
B-4.5

INJECTION STAGE THRUST STRUCTURE

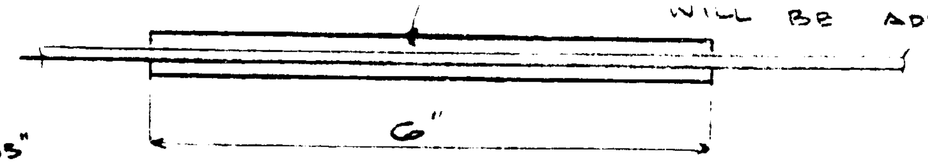
THE THRUST POST AREA REQ'D

$$A_p = \frac{175000}{68000} = 2.58 \ \square'' \ \text{MAX}$$

SINCE AREA REQUIRED IS A SMALL MAGUITUDE



DOUBLER 0.25" × 6" @ EA SIDE OF FWD SKIRT WILL BE ADEQUATE

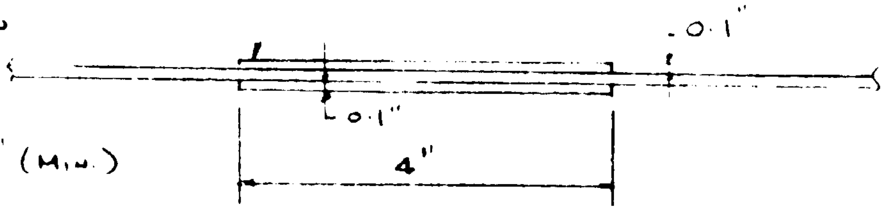


THRUST POST (6 REQ'D)

AREA REQ'D AT STA 1775

INJECTION STAGE THRUST POST SECTION

DOUBLER 4×0.1 @ EA. SIDE OF F'WD SKIRT



THRUST POST (6 REQ'D)

AREA PROVIDED AT STATION 1810 ±
& ALSO AT STA 1740

THE STRESS LEVEL DUE TO INJECTION STAGE THRUST IS

$$T_c = \frac{175000}{\underset{\text{DOUBLERS}}{(2 \times 6 \times 0.25} + \underset{\text{SKIN}}{6 \times 0.135)}}$$

$$= \frac{175000}{(3 + 0.81)}$$

$$= \frac{175000}{3.81} = 45900 \text{ PSI} \quad \text{AT}$$

MAX SECTION OF THRUST POST

CHECK N_c PEAK DISTRIBUTION AT TOP OF POST, STA 1810.

THE AREA PROVIDED AT TOP OF POST

$$\Sigma A = 8.4 \times 0.135 + 2 \times 4 \times 0.1$$

$$= 1.135 + 0.8 = 1.935 \ \square''$$

THEORETICAL UNIFORM N_c LOAD AT STA 1810 IS

$$N_c = \frac{175000}{53} = 3300 \text{ LB}/''$$

WHICH IS WELL BELOW THE MAXIMUM DESIGN CAPABILITY OF $N_c = 9300$ LB/'' FOR FWD SKIRT HENCE THE THRUST POST PROVIDED FOR INJECTION STAGE IS ON CONSERVATIVE SIDE

INVESTIGATION OF STRESS LEVEL AT TOP OF POST

THE EFFECTIVE (SKIN + STRINGER) THICKNESS

$$t_a = 0.285'' \quad \text{WITHOUT DOUBLER}$$

$$t_a = 0.285 + \frac{0.8}{8.4} = 0.38''$$

WITH UNIFORM $N_c = 3300$ LB/" @ STA 810

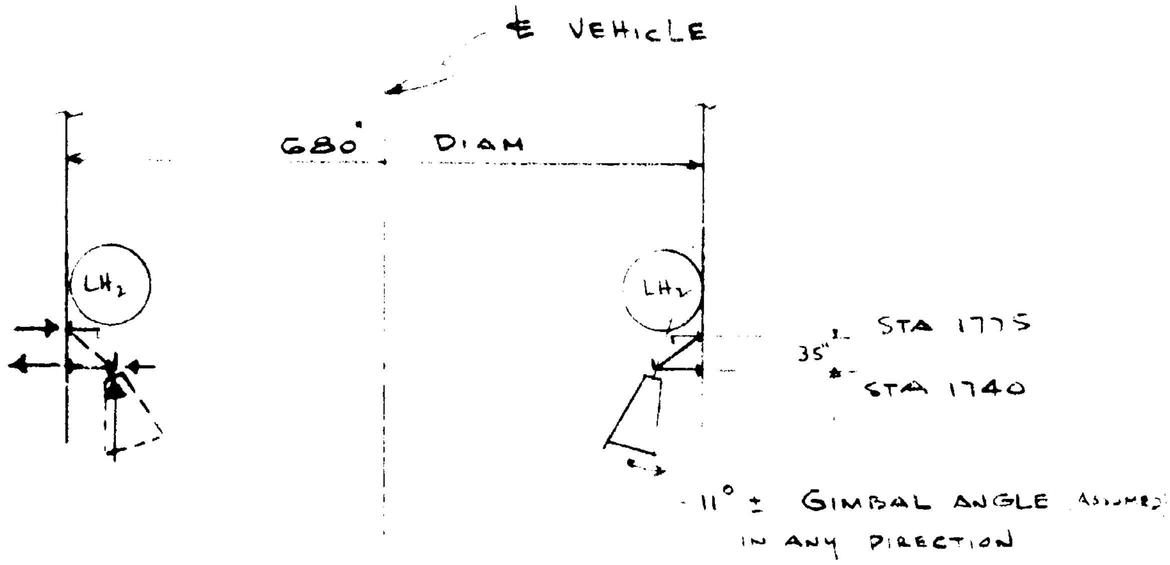
$$\sigma_c = \frac{3300}{0.285} = 11600 \text{ LB/□"}$$

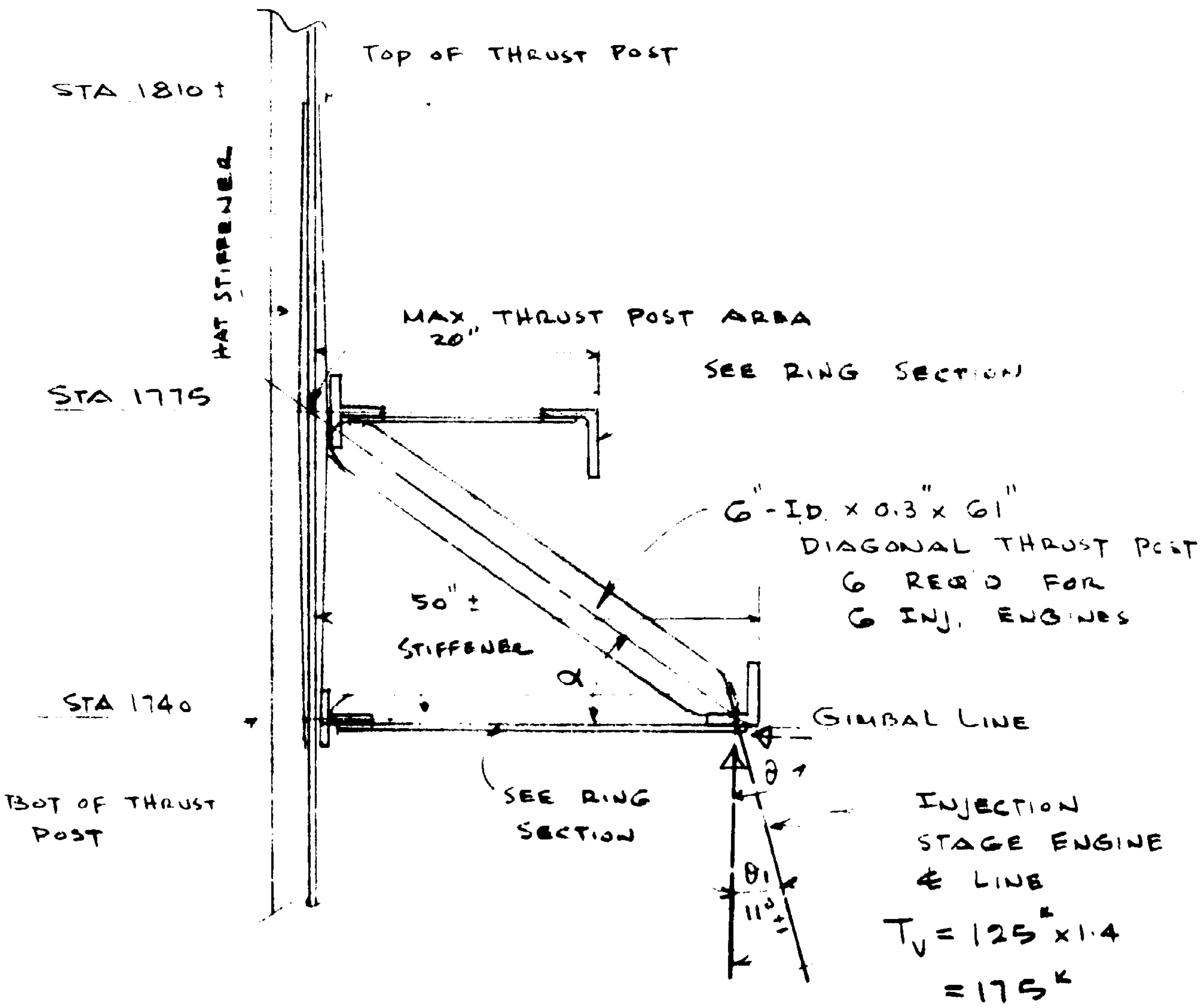
THE PEAK N_c AT POST AREA (DOUBLERS ARE PROVIDED)

$$N_c = 11600 \times 0.38 = \underline{\underline{4400}} \text{ LB/"}$$

MLLV

INJECTION STAGE THRUST STRUCTURE ANALYSIS





ASSUME ℄ ENGINE GIMBAL ANGLE θ_1 IS 11°

$$T_U = 175/\cos\theta_1 = 175/\cos 11° = 175/0.9816$$

$$= 178^k$$

GIMBAL ANGLE

$$T_H = 178 \sin\theta_1 = 178 \times 0.1908 = 34^k$$

$$T_V = 175^k$$

THE INJECTION ENGINE THRUST SUPPORTED BY THE THRUST POST (DIAGONAL) IS

$$T_d = 175/\cos\theta$$

$$l_d = \sqrt{35^2 + 50^2} = \sqrt{1225 + 2500} = 61.0$$

$$\cos\alpha = \frac{50}{61.0} = 0.820$$

$$\alpha = 34° \; 50'$$

$$\theta = 55° \; 10'$$

$$T_d = 175/\cos 55° 10' = 175/0.5712$$

$$= 306^k$$

THE HORIZONTAL THRUST

$T_H = 34^k$ (RADIAL LOAD @ LOWER RING)

$$T_H = 306 \sin\theta$$

$$= 306 \times \sin 55° 10' = 306 \times 0.8208 = 251^k$$

(HOR. COMP OF DIAGONAL THRUST)

SIZING OF DIAGONAL THRUST POST

GIVEN $T_d = 306^k$

ASSUME 7075-T6 ALUMINUM MATERIAL

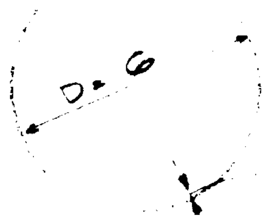
$F_{ty} = 68000\ \text{psi} \pm$

APPROX AREA REQUIRED

$$A_d = \frac{306000}{68000} = 4.5\ \square''$$

$$C = \pi D = 3.14 \times 6 = 18.85''$$

$$A = 18.85 \times 0.3 = 5.65\ \square''$$



t = 0.42'' (ASSUMED)

$L = 61.0$

$A = 4.5\ \square''$

$$I = \pi R^3 t = \pi \times 3^3 \times 0.3 = 27\pi \times 0.3 = 25.5\ \text{IN}^4$$

a) $$P_{CR} = \frac{\pi^2 E I}{L^2} = \frac{9.85 \times 10.4 \times 10^6 \times 25.5}{(61.0)^2}$$

$$= 0.631 \times 10^6$$

$$M.S = \frac{0.631 \times 10^6}{0.306 \times 10^6} - 1 = +1.06$$

b) USE Johnson-Euler EQUATION

$$\rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{25.5}{5.65}} = 2.12$$

$$L/\rho = \frac{61}{2.12} = 28.8$$

APPLY JOHNSON-EULER EQUATION FOR SHORT COLUMN APPROACH

$$F_c = F_{cc} - \frac{F_{cc}^2 \left(\frac{L}{\rho\sqrt{c}}\right)^2}{4\pi^2 E}$$

$$F_{cc} \approx F_{cy} = 68000 \qquad c \approx 1$$

$$F_c = 68000 - \frac{(68000)^2 \times (28.8)^2}{4 \times 9.85 \times 10.4 \times 10^6}$$

$$= 68000 - \frac{4.62 \times 10^9 \times 830}{410 \times 10^6}$$

$$= 68000 - 9350 = 58650 \text{ PSI}$$

SHY

ACTUAL STRESS

$$\sigma_c = \frac{306000}{5.65} = 54{,}300 \text{ PSI}$$

$$M.S = \frac{58650}{54300} - 1 = \underline{\underline{+0.08}} \longrightarrow$$

THE DESIGNED SECTION IS

$6''\phi^{ID} \times 0.30'' \times 61''$ LG

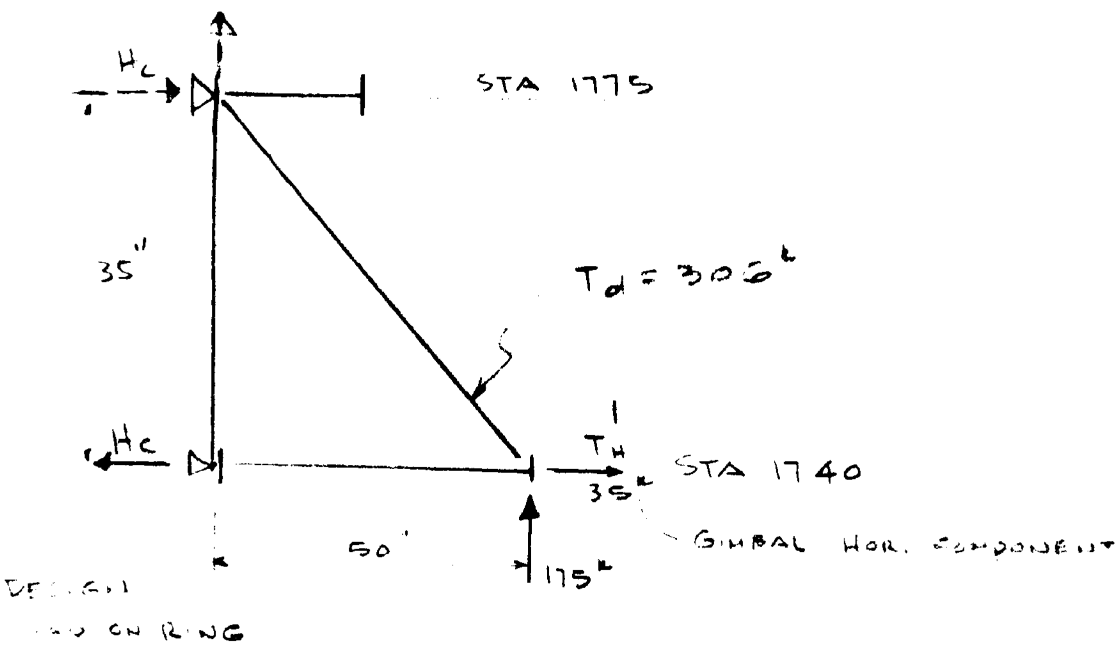
6 DIAGONAL THRUST POSTS ARE REQ'D FOR 6 INJECTION ENGINES

B-4.6

INJECTION STAGE THRUST RING ANALYSIS

DESIGN OF UPPER THRUST RING AT STA 1774

THIS RING SHOULD BE DESIGNED TO RESIST THE HORIZONTAL REACTION LOAD DUE TO THE TORQUE LOAD



THE HORIZONTAL REACTION

$$H_c = \frac{175 \times 50}{35} = 250^k$$

THE UPPER RING WILL BE DESIGNED FOR A HOR. RADIAL COMPONENT OF

$$\Sigma H = H_c = 250^k \quad \text{(OUTWARD)}$$

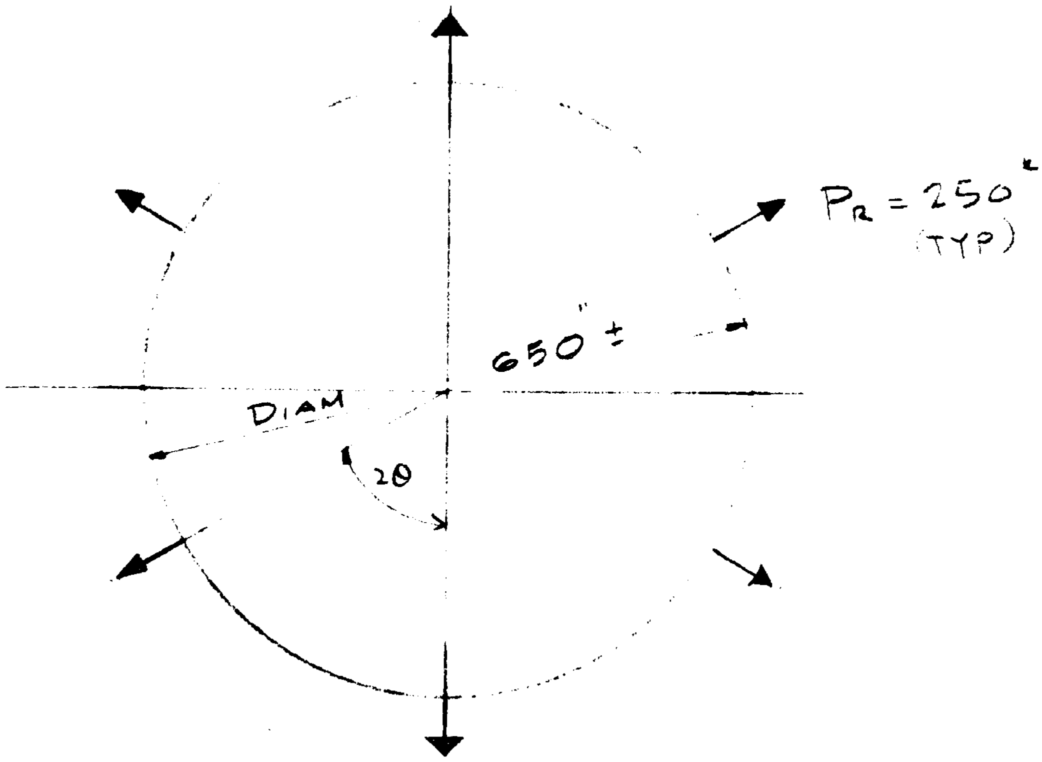
THE LOWER RING AT STA 1740 SHALL BE DESIGNED WITH THE FOLLOWING COMBINATION OF RADIAL THRUST LOAD

$$\Sigma H = T_H' + H_c = 35 + 250 = 285^k_{MAX} \quad \text{(INWARD)}$$

WHEN ENGINE IS VERTICAL

$$\Sigma H = 250^k$$

ASSUME A RING WITH 30" DEPTH (UPPER THRUST RING @ STA 1775)



$$2\theta = \pi/3 \quad ; \quad \theta = \pi/6$$

APPLY ROARK'S RING FORMULA

$$\text{MAX} \; -M = \frac{-1}{2} P_R R \left(\frac{1}{\theta} - \cot\theta \right)$$

$$= -\frac{1}{2}\, 250 \times 325 \left(\overset{1.91}{\frac{6}{\pi}} - \overset{1.7320}{\cot(\pi/6)} \right)$$

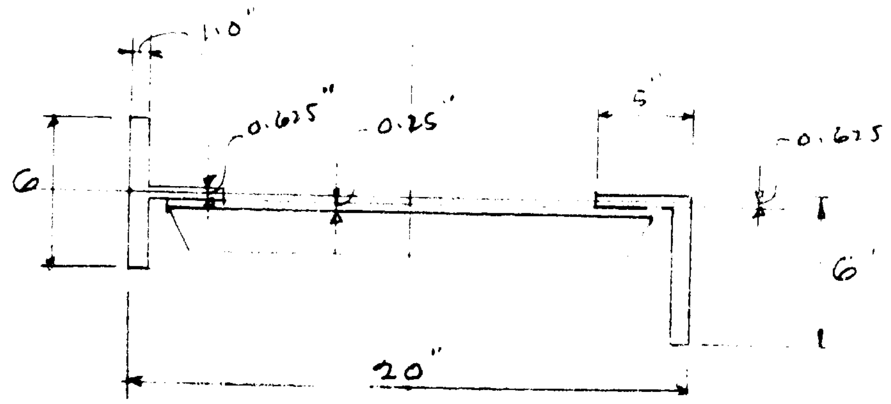
$$= -125 \times 325 \times 0.178 = -7250^{\text{"-K}}$$

AXIAL LOAD $N = \frac{1}{2} P_R \cot\theta$ AT LOAD PT

$$= \frac{1}{2}\, 250 \times 1.7320 = 217^{K}$$

SIZING OF RING SECTION @ STA 1775

M = 7250 "-K



$A_1 = 2 \times 6 \times 1.0 = 12.0$ $\qquad I_1 = 12.0 \times 9.5^2 = 1080$

$A_2 = 2 \times 4 \times 0.625 = 5.0$ $\qquad I_2 = 5.0 \times 7.0^2 = 245$

$A_3 = 15 \times 0.25 = 3.75$ $\qquad I_3 = \frac{1}{12} 0.25 \times 15.0^3 = 71$

$\Sigma A = 20.75 \square''$ $\qquad 1396$

$$S = \frac{1396}{10} = 139.6 \text{ IN}^3$$

a) BENDING STRESS

$$\sigma_b = \frac{7250000}{139.6} = 51{,}700 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_d = \frac{217000}{20.75} = 10{,}450 \text{ PSI}$$

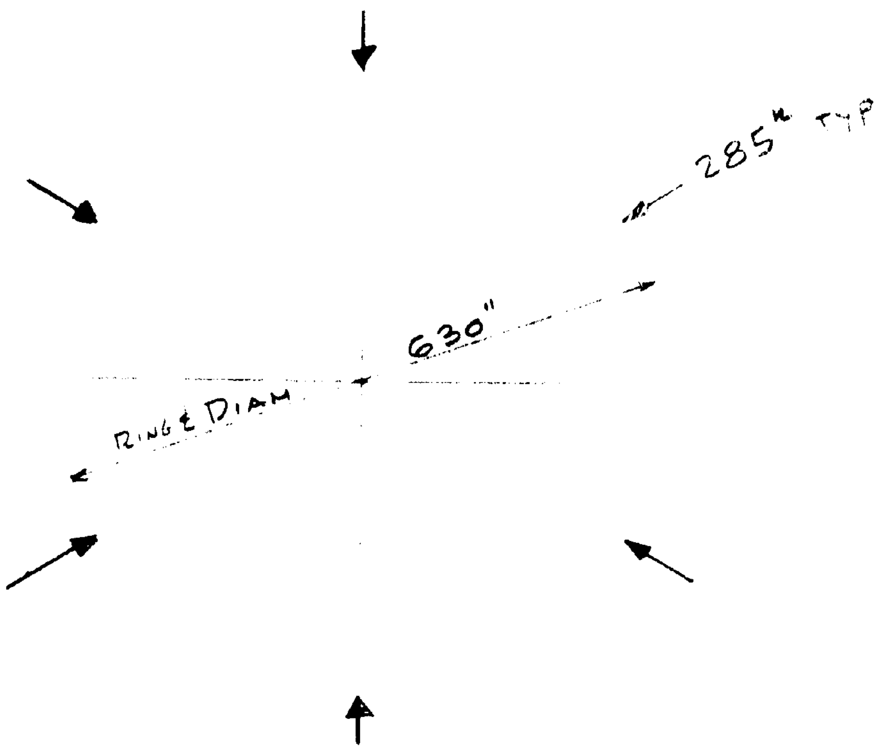
$$R_d = \frac{10450}{77000} = 0.136$$

$$R_b = \frac{51700}{77000} = 0.670$$

$$0.806$$

$$M.S = \frac{1}{0.806} - 1 = +0.24$$

DESIGN OF LOWER THRUST RING AT STA 1740



ASSUME ENGINE GIMBAL TOWARD ℄ OF VEHICLE

APPLIED THRUST $P_R = 35 + 250 = 285$ K

APPLYING ROARK'S RING FORMULA

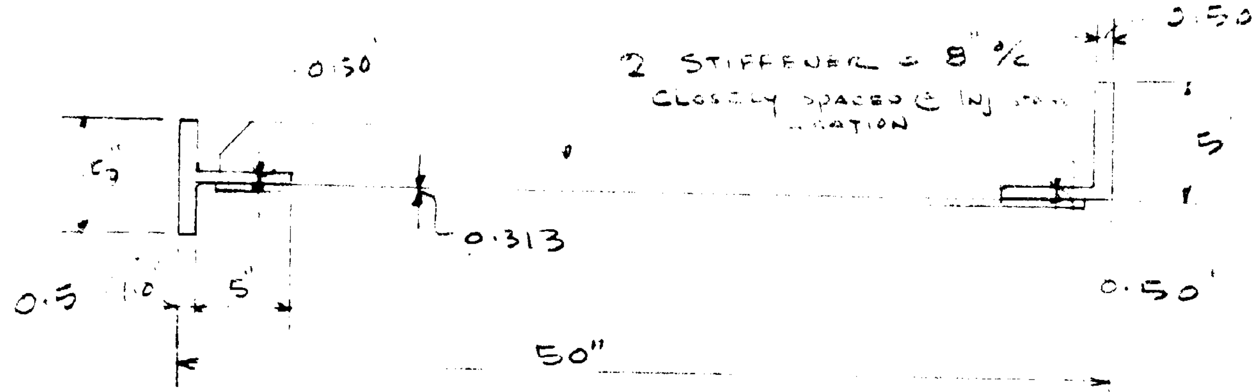
$$M = \frac{1}{2} P_R R \left(\frac{1}{\theta} - \cot\theta \right)$$

$$= \tfrac{1}{2}\, 285 \times 315 \times 0.1780 = 8{,}000 \text{ in-K}$$

$$N = \tfrac{1}{2} P_R \cot\theta = \tfrac{1}{2}\, 285 \times 1.732$$

$$= 248 \text{ K}$$

SIZING OF LOWER THRUST RING AT STA 1740



ASSUMPTION : GIMBAL LOAD IN THE HOR. TANGENTIAL DIRECTION WILL BE SUPPORTED BY

GIVEN $M = 8{,}000$ "-K

$N = 248$ K

$A_1 = 10 \times 0.50 = 5.0$

$A_2 = 10 \times 0.50 = 5.0$

$A_3 = 45 \times 0.313 = 14.10$

$\Sigma A = 24.10 \ \square''$

$I_1 = 5.0 \times 24.75^2 = 3050$

$I_2 = 5.0 \times 22.0^2 = 2420$

$I_3 = \frac{1}{12}\, 0.313 \times 45^3 = 2380$

$\Sigma I = 8{,}850 \text{ IN}^4$

$$S = \frac{8{,}850}{25} = 354 \text{ IN}^3$$

a) BENDING STRESS

$$\sigma_b = \frac{8000}{354} \times 10^3 = 22{,}700 \text{ PSI}$$

b) AXIAL STRESS

$$\sigma_a = \frac{248 \times 10^3}{24.1} = 10{,}300$$

$$MS = \frac{68000}{33000} - 1 = \underline{\underline{1.06}} \longrightarrow$$

THIS RING SUPPORTING ENGINE GIMBAL LOAD IS STIFFNESS GOVERNING RATHER THAN STRESS

B-5.1

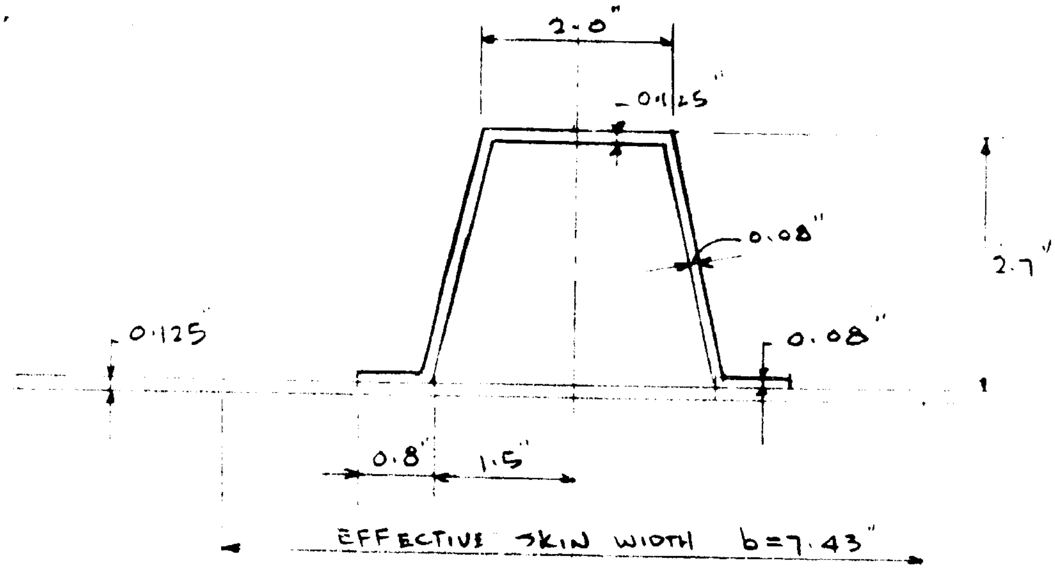
MLLV
BASE LINE CORE VEHICLE
PAYLOAD SENSITIVITY STUDY
AFT THRUST STRUCTURE ANALYSIS

Max. Ult. N_c = 7,400 Lb/In At Sta. 493 $\pm$

PAY LOAD SENSITIVITY

MLLV THRUST STRUCTURE (MULTI-CHAMBER CONFIG.)

$N_c = 7400$ #/" @ STA 493 ±



SLANTED LENGTH $= \sqrt{2.575^2 + 0.6^2} = \sqrt{6.25 + 0.36} = 2.65''$

	A	Y	AY	AY²	I_o
$A_1 = 2.0 \times 0.125$ =	0.250	2.763	0.691	1.9100	0.000325
$A_2 = 2 \times 2.65 \times 0.08$ =	0.424	1.413	0.600	0.8470	0.247000
$A_3 = 1.4 \times 0.08$ =	0.112	0.165	0.019	0.0031	≈ 0
$A_4 = 7.43 \times 0.125$ =	0.929	0.0625	0.058	0.0036	0.001210
	1.715		1.368	2.7640	0.24854

$$t_a = \frac{1.715}{7.43} = 0.231$$

$$Y = \frac{1.368}{1.715} = 0.797$$

$$\sigma_c = \frac{7400}{0.231} = 32000 \text{ psi}$$

$$I_c = 2.764 + 0.249 - 1.715 \times 0.797^2 = 1.923 \text{ IN}^4$$

$$I_s = \frac{1.923}{7.43} = 0.259 \text{ IN}^4/''$$

INVESTIGATION OF GENERAL INSTABILITY STRESS

GIVEN $t_s = 0.125''$

$t_a = 0.231''$

$I_s = 0.259$

$A_R = 8.0 \square''$

$L_R = 46''$

$$t^* = \sqrt[4]{12\, I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$t^* = \sqrt[4]{12 \times 0.259 \left(\frac{8}{46} + 0.125\right)}$$

.299

$$= 0.982$$

$$R/t^* = \frac{340}{0.982} = 347$$

USE APPROXIMATE BUCKLING COEFF $C^* = 1.15$

FOR THRUST STRUCTURE WITH $L/D = \frac{138}{340} = 0.405$

$$\sigma_{CR} = C^* E \frac{t^*}{R} \qquad \triangleright \text{ D5-13272}$$

$$\sigma_{CR} = \frac{1.15 \times 10.4 \times 10^6}{347} = 34{,}500 \text{ PSI}$$

$$N_{CR} = 34{,}500 \times t_a = 34{,}500 \times 0.231 = 7950\ \#/''$$

$$M.S = \frac{7950}{7400} - 1 = \underline{+0.07} \longrightarrow$$

INVESTIGATION OF GENERAL INSTABILITY STRESS BY USING THEORETICAL ANALYSIS BASED UPON REF D5-13272

$t_s = 0.125$ $\quad L_R = 46$ IN

$t_a = 0.231$ $\quad L = 140$ IN

$I_s = 0.259$

$A_R = 8.0$

$I_R \approx 600$ IN^4

$t^* = 0.982$

$R/t^* = 347$

ASSUMED $n = 3$

$m = 8$

$$\Gamma = \frac{t^* R^2}{I_s} = \frac{0.982 \times 115600}{0.259} = 438000 = 4.38 \times 10^5$$

$$\psi = \frac{2\pi n R}{L} = \frac{2\pi \times 3 \times 340}{140} = 45.7$$

$$\psi^2 = 2090$$

$$\psi^4 = 4.36 \times 10^6$$

$$\psi^2 \Gamma = 2.09 \times 10^3 \times 4.38 \times 10^5 = 9.15 \times 10^8$$

$$U = 0.00025 \quad \text{(ASSUMED)}$$

$$\rho = U \times \left(\frac{R}{t^*}\right)^2 = 0.00025 \times 120000 = 30$$

$$K = 1 + \frac{2\rho}{m^{1.5} n^{0.5} D} = 1 + \frac{60}{22.6 \times 1.732 D} = 1 + \frac{1.532}{D}$$

$$B_1 = 1.532$$

$$\Phi = \frac{4R^4}{I_s t^*} = \frac{4 \times 1.336 \times 10^{10}}{0.259 \times 0.982} = 2.1 \times 10^{11}$$

$$\Phi - 8\Gamma \left(\frac{R}{t^*}\right)^2 = -2.1 \times 10^{11}$$

$$H_x = \frac{E \times 0.231}{0.891} = 0.259\,E$$

$$H_\theta = E\frac{A_R}{L_R} + E\,t_s = 0.299\,E$$

$$\frac{H_x}{H_\theta} = 0.867$$

$$D_x = E I_s = E \times 0.259 = 0.259\,E$$

$$D_\theta = \frac{E I_R}{L_R} = E \times \frac{600}{46} = 13\,E$$

$$D_t \approx 0$$

$$\xi = \frac{m^4}{\phi^2} + \frac{H_x}{H_\theta}\phi^2 + 2(1+\nu)m^2 = \frac{\overset{2}{4100}}{2090} + \overset{.815}{0.867 \times 2090} + \overset{\sim 0}{2.66 \times 64} = 1937$$

$$\xi^2 = 3.95 \times 10^6$$

$$b = \phi^4 + \frac{m^2}{D_x}(3 D_\theta m^2) + \frac{R^2 t^* E}{\xi^2 D_x}\left\{ m^4 + 2(1+\nu)m^2\phi^2 + \phi^4\frac{H_x}{H_\theta} \right\}$$

$$= 4.36 \times 10^6 + \frac{4100 \times 3 \times 13}{0.259} + \overset{0.111}{\frac{115600 \times 0.982}{3.95 \times 10^6 \times 0.259}} - \overset{356000}{\left\{ 4100 + 2.66 \times 64 \times 2090 + 4.36 \times 10^6 \times 0.867 \right\}}$$

$$= 4.36 \times 10^6 + 0.618 \times 10^6 + 0.459 \times 10^6 = 5.437 \times 10^6$$

$$A_1 = \frac{\phi^2 \gamma}{\Phi - 8\gamma\left(\frac{R}{t^*}\right)^2} = \frac{9.15 \times 10^8}{-2.1 \times 10^{11}} = -4.36 \times 10^{-3}$$

$$C_1 = \frac{b}{\Phi - 8\gamma\left(\frac{R}{t^*}\right)^2} = \frac{5.437 \times 10^6}{-2.1 \times 10^{11}} = -25.9 \times 10^{-6}$$

$$D = \frac{B_1}{2} - \frac{2C_1}{A_1^2 B_1} = \overset{0.766}{\frac{1.532}{2}} + \overset{1.772}{\frac{2 \times 25.9 \times 10^{-6}}{19.08 \times 1.532}} = 2.538$$

$$D = 2.538$$

$$D^2 = 6.44144$$

$$B_1 D = 3.88822$$

$$10.32966$$

$$A_1(D^2 + B_1 D) = -4.36 \times 10^{-3} \times 10.32966 = -45.03732 \times 10^{-3}$$

$$A_1^2 (D^2 + B_1 D)^2 = 2028.36019 \times 10^{-6}$$

$$-4C_1 D^2 = 667.33318 \times 10^{-6}$$

$$2695.69337 \times 10^{-6}$$

$$\sqrt{A_1^2 (D^2 + B_1 D)^2 - 4C_1 D^2} = 51.92007 \times 10^{-3}$$

$$45.03732 \times 10^{-3}$$

$$6.88275 \times 10^{-3}$$

$$S = \frac{1}{2} \, 6.88275 \times 10^{-3} = 3.44142 \times 10^{-3}$$

$$\sigma_{CR} = SE = 3.44142 \times 10.4 \times 10^{6} \times 10^{-3}$$

$$= 35.7908 \times 10^{3} = 35{,}790 \text{ PSI}$$

$$M.S = \frac{35790}{32034} - 1 = \underline{+0.11} \longrightarrow$$

$$C^* = \frac{35790 \times 347}{10.4 \times 10^6} = \frac{1.13113 \times 10^7}{1.04 \times 10^7}$$

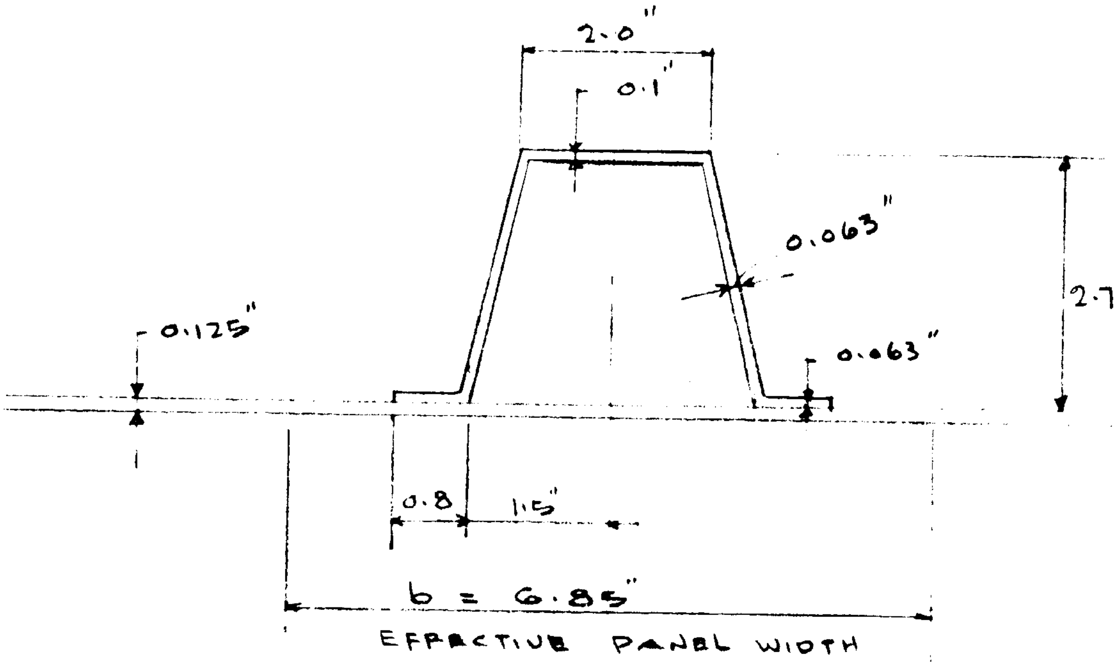
$$C^* = 1.26 \pm$$

THIS INDICATES THE $C^* = 1.15$ USED FOR APPROXIMATE CALCULATION IS A LITLE ON CONSERVATIVE SIDE

PAY LOAD SENSITIVITY STUDY BASE LINE CORE

MLLV THRUST STRUCTURE (MULTI-CHAMBER ENGINE)

$N_c = 6900$ #/" @ STA 355



$A_1 = 6.85 \times 0.125 = 0.8560$

$A_2 = 1.4 \times 0.063 = 0.0881$

$A_3 = 2.67 \times 2 \times 0.063 = 0.3360$

$A_4 = 2 \times 0.1 = 0.2000$

$\qquad 1.4801$

$$t_a = \frac{1.4801}{6.85} = 0.216$$

AV. $$\sigma_c = \frac{6900 \times 6.85}{1.4801} = 31{,}900 \text{ PSI}$$

B-5.2

MLLV
BASE LINE CORE VEHICLE
PAYLOAD SENSITIVITY STUDY
LH_2 TANK WALL STRUCTURAL ANALYSIS

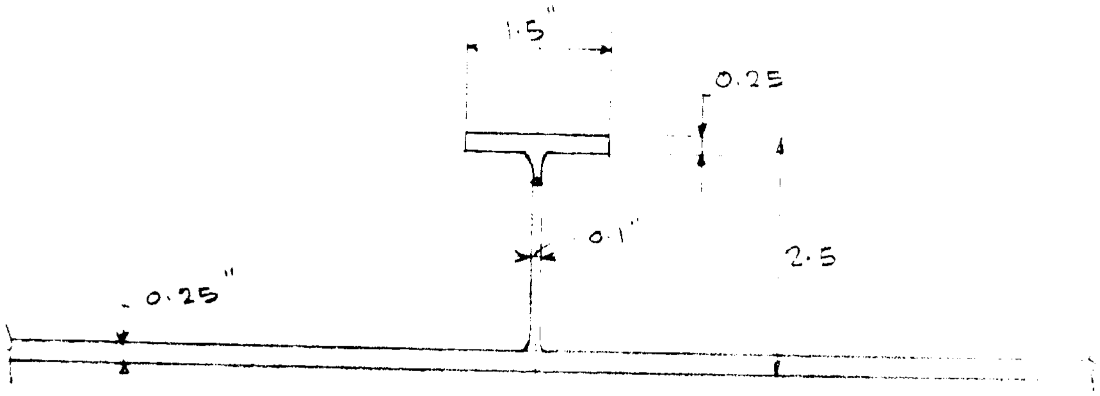
Max. Ult. N_c = 6,100 Lb/In At Sta. 1,390±

N_c = 3,200 Lb/In At Sta. 500±

LH_2 TANK

MLLV PAYLOAD SENSITIVITY STUDY

MAX N_c = 6100 LB/in STA 1390



EFFECTIVE SKIN PANEL WIDTH = 10"

A	y	Ay	Ay^2	I_o
$A_1 = 10 \times 0.25 = .50$	0.125	0.312	0.039	$\frac{1}{12}\,10 \times 0.25^3 = 0.0130$
$A_2 = 2.0 \times 0.1 = 0.20$	1.250	0.250	0.312	$\frac{1}{12}\,0.1 \times 2.0^3 = 0.0666$
$A_3 = 1.5 \times 0.25 = 0.38$	2.375	0.903	2.150	$\frac{1}{12}\,1.5 \times 0.25^3 = 0.00195$
3.08		1.465	2.501	0.08155

$$\bar{Y} = \frac{1.465}{3.08} = 0.477$$

$$I_c = 2.501 + 0.0816 - 3.08 \times 0.477^2 = 1.881$$

$$I_s = \frac{1.881}{10} = 0.188$$

$$t_a = \frac{3.08}{10} = 0.308$$

EFF. WIDTH FOR SKIN-STIFFENER PANEL

$$b_{eff} = 1.7 \times 0.25 \times \sqrt{\frac{10.4 \times 10^6}{19750}} = 9.75 \approx 10"$$

MLLV LH_2 TANK

INVESTIGATION OF LOCAL INSTABILITY
(INTERFRAME BUCKLING)

ASSUME $L_R = 60''$

$$t_1^* = \sqrt[4]{12 I_s t_s}$$

$$= \sqrt[4]{12 \times 0.189 \times 0.25} = \sqrt[4]{5.65/_{0}} = 0.863$$

$$t_1^{*3} = 0.656$$

$$Z_L = \frac{L_R^2}{R t_1^*} (1-\nu)^{1/2} = \frac{3600}{340 \times 0.863} \times 0.945 = 11.5$$

$K_c \approx 4.5$ FROM TN-3783 (NASA TECH NOTES)

$$N_{CR} = \frac{K_c \pi^2 E \, t_1^{*3}}{12(1-\nu^2) L_R^2} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6 \times 0.656}{10.7 \times 3600}$$

$= 7850$ LB/"

$$M.S = \frac{7850}{6100} - 1 = +0.2850$$

IF RING SPACING IS KEPT @ 64.5"

$K_c \approx 4.5$

$$N_{CR} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6 \times 0.656}{10.7 \times 4160} = 6800 \text{ \#/"}$$

$$MS = \frac{6800}{6100} - 1 = \underline{+0.11}$$

$L_R = 64.5''$ OK

MLLV LH$_2$ TANK

2) INVESTIGATION OF GENERAL INSTABILITY

$A_R = 2.5 \ \square''$

$L_R = 64.5 \ \square''$

$I_s = 0.188$

$t_s = 0.250$ $\quad t_a = 0.308$

$$t^* = \sqrt[4]{12 \times 0.188 \times \left(\frac{2.5}{64.5} + 0.250\right)} = 0.898$$

0.289

$$R/t^* = \frac{340}{0.898} = 378$$

USING THE ATTACHMENT CHART OF BUCKLING COEFFICIENT AS USED FOR CORE VEHICLE INVESTIGATION

FOR $n = 3$

$m = 8$

$U = 0.00025$

$C^* \approx 0.70$

$$\tau_{cr} = C^* E \, t^*/R = \frac{0.72 \times 10.4 \times 10^6}{378} = 19{,}850 \ \#/\square''$$

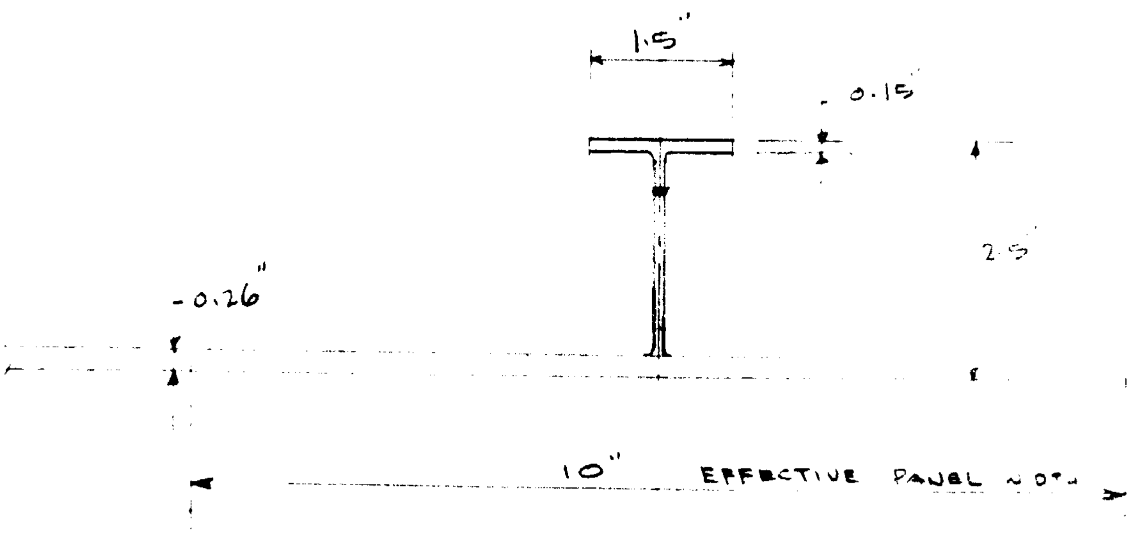
$$N_{cr} = 19850 \times t_a = 19{,}850 \times 0.308 = 6110 \ \#/''$$

$$M.S = \frac{6110}{6100} - 1 \approx 0 \longrightarrow$$

LH2 TANK

V-LV PAYLOAD SENSITIVITY STUDY

$N_c = 3200$ LB/" @ STA 500 ±



$A_{SKIN} = 10 \times 0.26 = 2.6$ □"

$A_W = 2.09 \times 0.1 = 0.209$

$A_F = 1.5 \times 0.15 = 0.225$

3.034 □"

BASED ON THE N_c LOAD GIVEN AT STA 500±
IT IS OBVIOUS THAT THE ABOVE PROPOSED
SECTION WILL BE ADEQUATE FOR N_c LOAD

THE OVER DESIGNED STIFFENER ELEMENT WILL
BE USED TO SUPPORT THE PEAK THRUST LOAD
AT LOWER BULKHEAD Y-RING.

B-5.3

MLLV
BASE LINE CORE VEHICLE
PAYLOAD SENSITIVITY STUDY
FORWARD SKIRT STRUCTURAL ANALYSIS

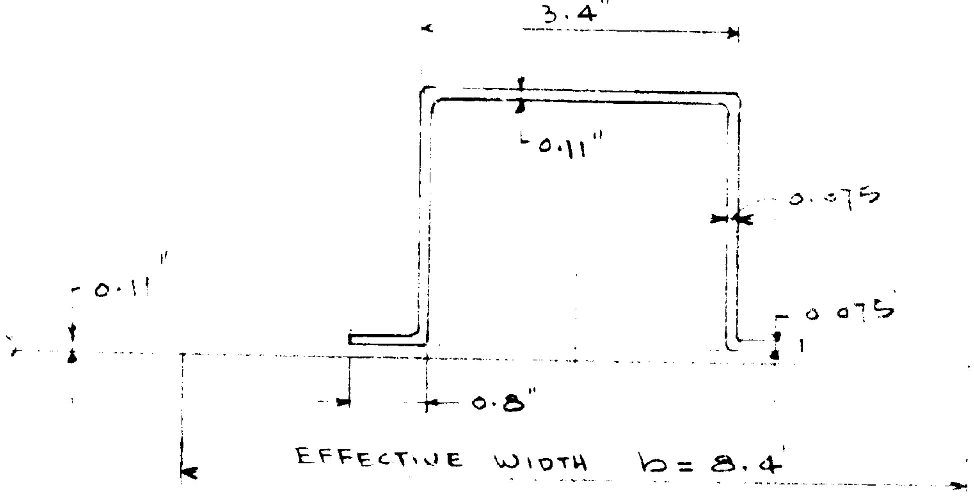
Max. Ult. N_c = 5,400 Lbs/In At Sta 1,460 $\pm$

MLLV

PAYLOAD SENSITIVITY STUDY - CORE VEHICLE AL BASELINE

FORWARD SKIRT

$N_c = 5400$ LB/" AT STA 1462



	A	Y	AY	AY²	I_o
$A_1 = 3.4 \times 0.11$	= 0.925	0.055	0.0510	0.002[illegible]	0.00111
$A_2 = 1.6 \times 0.075$	= 0.120	0.148	0.0178	0.00264	0
$A_3 = 2.565 \times 0.075 \times 2$	= 0.385	1.468	0.5650	0.83000	0.21100
$A_4 = 3.4 \times 0.110$	= 0.374	2.805	1.0500	2.95000	0.00038
	1.804		1.6838	3.78544	0.21249

$$Y = \frac{1.684}{1.804} = 0.934$$

$$I_c = 3.7854 + 0.2125 - 1.804 \times 0.934^2 = 2.428$$

$$I_s = \frac{2.428}{8.4} = 0.289$$

$$t_a = 1.804/_{8.4} = 0.215$$

$$\sigma_c = \frac{5400 \times 8}{1.804} = 24000 \text{ LB}/\square"$$

INVESTIGATION OF LOCAL BUCKLING STRESS

a) STIFFENER ELEMENT PANEL BUCKLING

HAT STIFFENER WEB BUCKLING

$$\tau_{CR} = \frac{4 \times \pi^2 E}{12(1-\nu^2)} \left(\frac{0.075}{2.70}\right)^2 = 24400 \text{ PSI}$$

ii $$\tau_{CR} = \frac{4 \times \pi^2 E}{12(1-\nu^2)} \left(\frac{0.11}{3.4}\right)^2 = 40200 \text{ PSI}$$

iii $$\tau_{CR} = \frac{0.5 \times \pi^2 E}{12(1-\nu^2)} \left(\frac{0.075}{0.8}\right)^2 = 42000 \text{ PSI}$$

$$M.S = \frac{29{,}400}{24{,}000} - 1 = \underline{+0.22}$$

b) INTERFRAME BUCKLING

$$t_1^* = \sqrt[4]{12 I_s t_s}$$

$$= \sqrt[4]{12 \times 0.289 \times 0.11} = 0.785$$

$$(t_1^*)^3 = 0.484$$

$$Z_L = \frac{3600}{340 \times 0.785} \times 0.945 = 12.7$$

$K_c = 4.5$ ▷ TN-3783

$$N_c = \frac{K_c \pi^2 E \times t_1^{*3}}{12(1-\nu^2) L_R^2} = \frac{4.5 \times 9.85 \times 10.4 \times 10^6 \times 0.484}{10.7 \times 3600}$$

$$= 5800 \text{ LB/IN}$$

$$MS = \frac{5800}{5400} - 1 = \underline{+0.07}$$

c) INVESTIGATION OF GENERAL INSTABILITY

$$t_s = 0.11$$
$$t_a = 0.215$$
$$A_R = 6.0 \ \square''$$
$$L_R = 60.0 \ \square''$$
$$I_s = 0.289$$

$$t^* = \sqrt[4]{12 \times I_s \left(\frac{A_R}{L_R} + t_s\right)}$$

$$= \sqrt[4]{12 \times 0.289 \left(0.10 + 0.11\right)} = 0.924$$

$$R/t^* = 340/0.924 = 368$$

$C^* \approx 0.85$ FROM BUCKLING COEFF. CURVE ATTACHED FOR LH_2 TANK DESIGN (EXTRAPOLATED)

$U = 0.00025$
$m = 8$
$n = 3$

$$\sigma_{CR} = 0.85 \times E \times \frac{t^*}{R}$$

$$= \frac{0.85 \times 10.4 \times 10^6}{368} = 24{,}000 \text{ PSI}$$

M.S ≈ 0 ⟶

GENERAL INSTABILITY GOVERNS DESIGN

END

DATE

FILMED

DEC 19 1969