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INVESTIGATION OF THE USE OF CARBON COMPOSITE MATERIALS FOR HELICOPTER TRANSMISSION HOUSING APPLICATIONS

By

Vance A. Chase

July 1973

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

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WHITTAKER CORPORATION
RESEARCH AND DEVELOPMENT DIVISION
SAN DIEGO, CALIFORNIA

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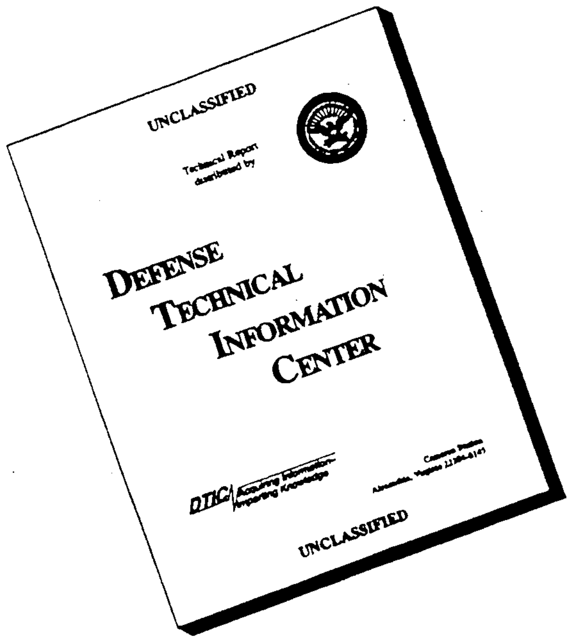

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The program reported herein was conducted to determine the feasibility of using advanced composite materials for a helicopter main transmission housing to provide increased stiffness, thereby reducing gear and bearing wear.

The report has been reviewed by this Directorate and is considered to be technically sound. It is published for the exchange of information and the stimulation of future research.

This program was conducted under the technical management of Mr. Robert L. Rodgers, Technology Applications Division.

Task 1F162208A17003
Contract DAAJ02-71-C-0059
USAAMRDL Technical Report 73-7
July 1973

INVESTIGATION OF THE USE OF CARBON COMPOSITE MATERIALS FOR HELICOPTER TRANSMISSION HOUSING APPLICATIONS

Final Report

by

Vance A. Chase

Prepared by

Whittaker Corporation
Research and Development Division
San Diego, California

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

SUMMARY

This program investigated the feasibility of applying advanced fiber-reinforced plastic composite materials to the UH-1 helicopter main transmission gear housing in order to increase stiffness of the structure to reduce gear and bearing wear. A design analysis was performed for the composite transmission housing based on carbon fiber (Modmor I) reinforced epoxy composite material

Two prototypes were fabricated and tested for stiffness in torsion and tension at ambient and elevated temperatures. Testing was also performed on a metal (magnesium) case in order to provide a basis for comparison. Prototype case S/N 1 showed a substantial increase in torsional stiffness but a reduction in tension stiffness over the metal case. A design modification resulted in changes in fiber orientation in the flange section and additional $\pm 45^{\circ}$ plies in the barrel section for prototype case S/N 2. Case S/N 2 was tested extensively, with deflection measurements being made at a number of intervals around the housing's circumference for both tension and torsional loading. Deflection of the composite case was found to vary dependent on the location. Deflection measurements ranged from a small fraction of those for the metal case to slightly greater.

FOREWORD

This report was prepared by Whittaker Research and Development Division, San Diego, California, under Contract DAAJ02-71-C-0059, for the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia. The program was performed under the technical direction of Mr. Robert Rodgers, Army project officer. This final report covers work performed during the period of June 1971 through September 1972.

Program management responsibilities were divided between Vance A. Chase and Audie L. Price. Other personnel contributing directly to the program included Mr. R. L. Van Auken, Engineering Laboratory Supervisor; Dr. K. L. Berg, Manager, Structural Development Engineering Department; Mr. R. N. Anderson, Designer; Mr. A. M. Thompson, Structural Analyst; Mr. D. J. Bridges, Fabricator; and Mr. Boris Levenetz, Manager, Advanced Composites Engineering Department.

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INTRODUCTION

The objective of this program was to determine the feasibility of applying advanced fiber-reinforced plastic composite materials to the UH-1 helicopter main transmission gear housing. Deflections of the present metal housing under load have been identified as a cause of accelerated gear and bearing wear. Reduction in the magnitude of these deflections by the utilization of high-modulus fiber-reinforced composite materials offers promise for prolonging the life of the transmission gears without increasing the weight of the system. A primary objective of this program was to alleviate this problem by designing a composite transmission housing having a 50% increase in stiffness over the present metal housing. The composite housing was also required to operate at temperatures up to 350°F and be compatible with Specification MIL-L-23699-B, Lubricating Oil, Aircraft Turbine Engine, Synthetic Base. Fabrication and structural testing of two prototype housings were required.

Advanced fiber-reinforced composite materials have demonstrated applicability to numerous aircraft structures with resulting reductions in weight and/or increases in performance. Many of these efforts have involved fairly simple structures in terms of analysis and fabrication complexity. The transmission housing investigated under this program is a complex structure due to cutouts, lubricant fittings and passages and internal structural elements. In addition, constraints were placed on the design of this composite structure by the necessity of interchangeability with the present metal housing and functionality in the present helicopter transmission system. These factors and the fact that the transmission housing is the structural link between the rotor and the aircraft make this program a significant step in the application of composite materials to aircraft structures.

The material selected for the transmission gear housing application was Narmco's 5208 prepreg, which is based on a high-temperature epoxy resin system and Modmor I carbon fibers. Modmor I fibers have a modulus of 55-65 million psi with a tensile strength of 200-300 ksi. This reinforcement provided high-modulus properties in the composite material, while maintaining a good level of strength. Selection of a high-temperature epoxy system was based on a requirement that the case be designed for operation at temperatures up to 350°F. U.S. Polymeric's EM7302 glass/epoxy bulk molding compound (BMC) was used for the bearing ring insert and bosses. Secondary bonding was accomplished using Hysol Dexter's EA-934 epoxy adhesive.

Due to the shape complexity and exploratory nature of the program, a hand layup, autoclave molding process was selected as the fabrication process for the composite housing shell and internal structure. The bearing support rings were fabricated from the epoxy/glass bulk molding compound by a compression molding process. Circumferential carbon reinforcement on the inner and outer diameters of the BMC bearing inserts was accomplished by filament winding of rings which were adhesively bonded to the BMC insert. The housing was laid up in epoxy/glass tooling from 3-inch-wide prepreg tape, tailored as necessary to fit the cutouts and contours. The circumferential flange reinforcements were prepared by filament winding of prepreg preform rings for inclusion in the layup.

Two prototype gear housing units were fabricated and tested for stiffness comparison with a production metallic housing.

TECHNICAL DISCUSSION

TRANSMISSION HOUSING DESIGN

Function of the Transmission Case

The UH-1 helicopter main transmission case (Bell part no. 204-040-353) is primarily a structural housing which forms part of the helicopter pylon support system (Figure 1). That is to say that all main rotor loads, both static and oscillatory, are transmitted through this case. The loads are introduced into the upper flange by the ring gear case directly above and are transmitted through the walls and flanges to the support case below. This support case is attached to the airframe via five (Figure 2) elastomeric bearings and a steel lift link.

The secondary function of the main case is to house and support the various main and accessory drive quills. The main input spiral bevel gears are housed in a quill which is inserted from the aft side of the case. There are four bearing reaction points for the input bevel pinion. It is supported by a triplex ball bearing near the outer proximity of the case and by a cylindrical roller bearing which is installed in a circular web supported member at the nose of the input pinion which is a part of the main case. A steering-wheel case which attaches to the top of the main case houses a duplex bearing which transmits the gear thrust and radial load through shear in the upper portion of the case. Finally, a cylindrical roller bearing providing radial load reaction is located in a ribbed bulkhead disc in the bottom of the main case. Both forward and laterally mounted accessory pads are provided for the respective drive quills.

The internal shape of the case is dependent on the geometry of the existing gears, shafts and flanges and limits the possibilities of geometry changes which are desirable in order to translate a metal design into a fibrous composite material design.

Figures 3 and 4 emphasize the complex shape of the existing magnesium casting.

General Concept and Approach

The requirement for interchangeability with the existing magnesium case imposes a severe restraint on the form design freedom, resulting in a relatively complex shape for a design in fibrous composite materials. Many different design approaches were considered involving a number of materials and tooling concepts before the present design was selected. The more important design considerations were:

1. Interchangeability with respect to external and internal attachment points to other gear system components.

2. Equivalent functions of the component with the gear system.

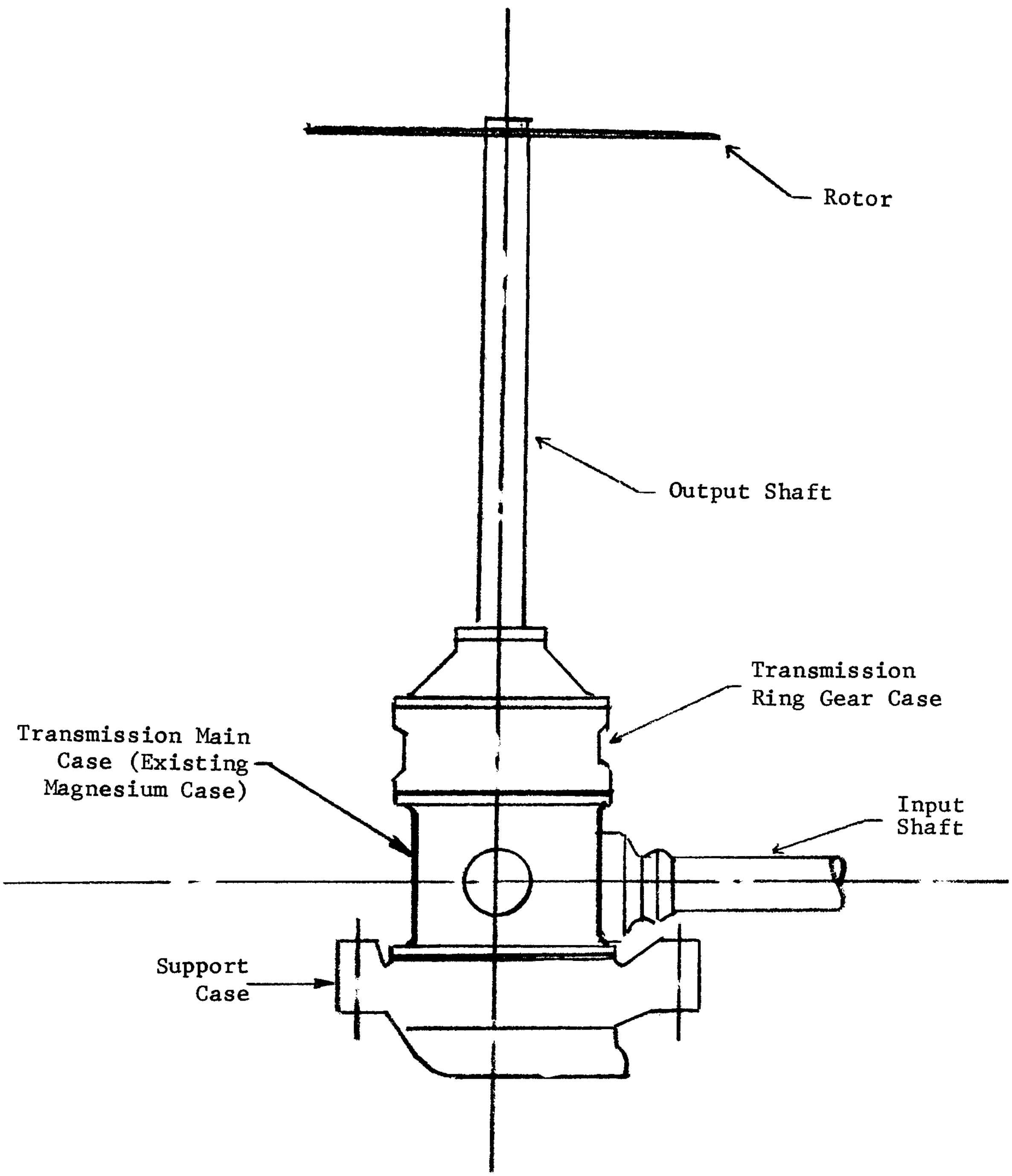


Figure 1. Location of the Transmission Case Within the Gear Case System.

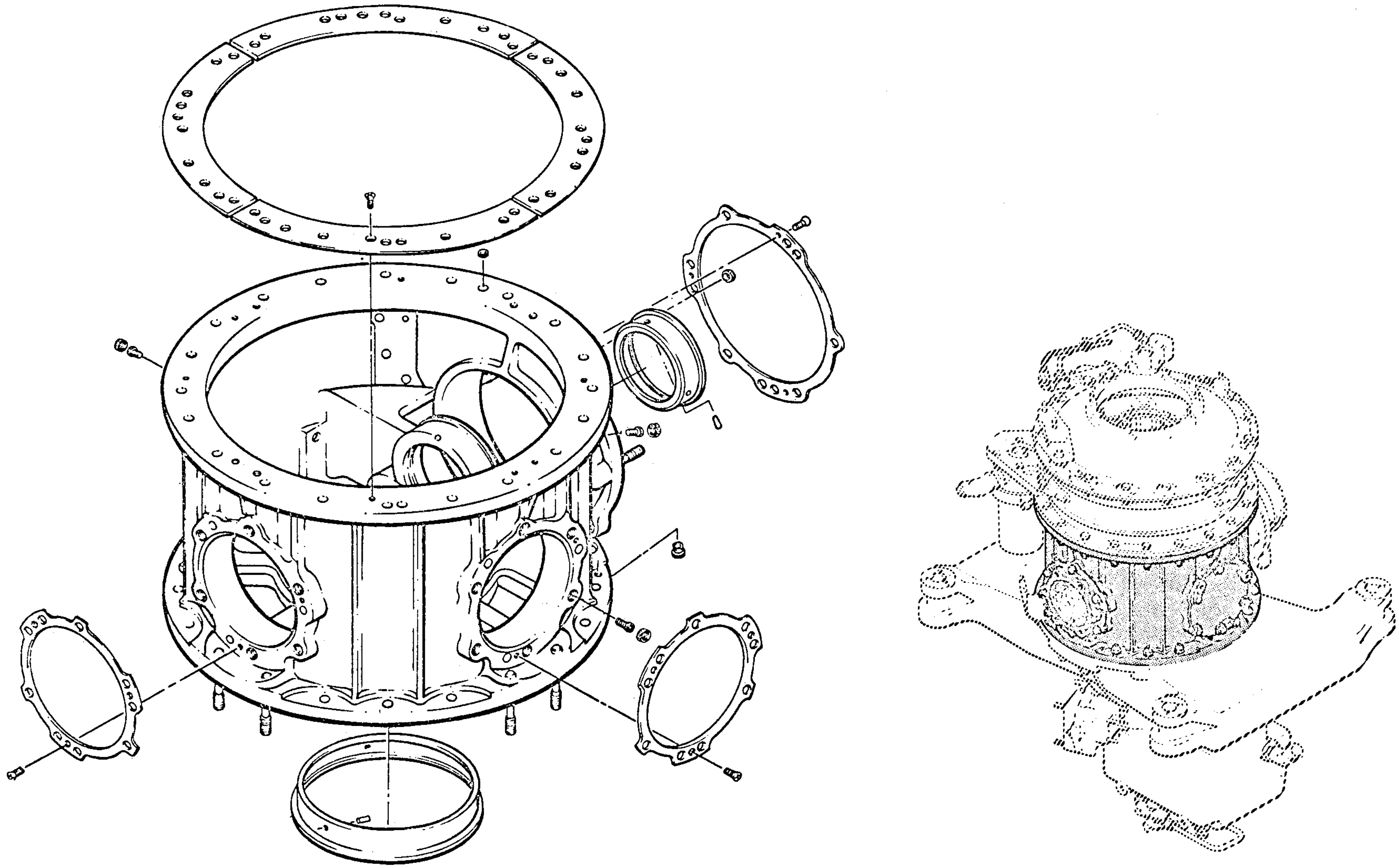


Figure 2. Case Assembly, Main (Existing Magnesium Case).

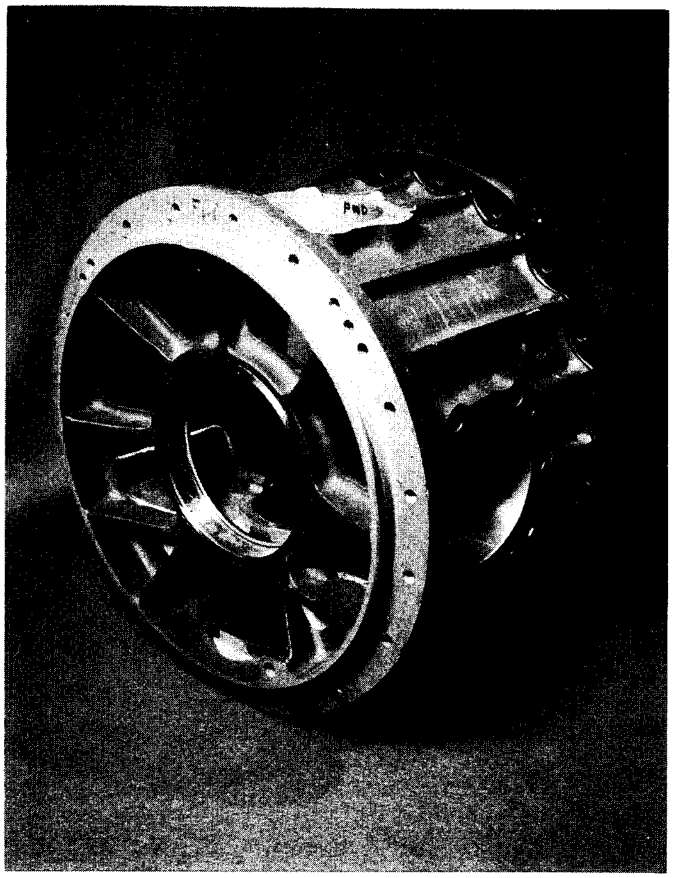


Figure 3. Base View of Magnesium Housing.

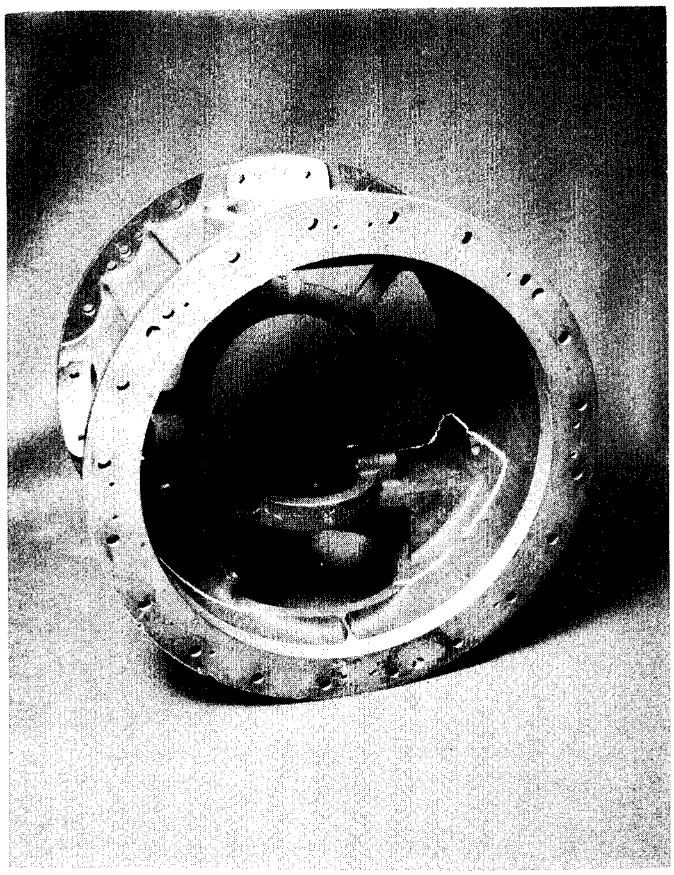


Figure 4. Top View of Magnesium Housing.

3. Structural reliability.

4. Provisions for high stiffness in strategic locations.

5. Internal configuration to promote oil circulation and lubrication.

6. Compatibility with chemical and temperature environments.

7. Utilization of reliable manufacturing processes.

Detail Design

The transmission case consists of a cylindrical section with integral end flanges. A base disc, resembling a wheel with spokes, is made separately and bonded to the lower end of the cylindrical section. Two auxiliary and one main bearing support rings penetrate the cylinder wall. The two composite rings for the auxiliary bearings are installed concurrently with the layup of the cylinder, and the main bearing ring is bonded in place after curing of the cylinder structure. An internal bearing support ring, in line with the main bearing, is supported by a web structure which is bonded to the cylinder and to the base disc. There are also several protrusions which serve to hold threaded inserts for attachment of oil lines. These protrusions are molded separately and are bonded to the case. The composite material transmission housing is shown in Figure 5.

The cylindrical section with the end flanges is built as one unit. The material is laid up on the inside surface of a segmented female mold and wrapped over the ends of the mold to form the flanges. The fibers are oriented circumferentially (hoop), axially (longitudinal or radial), or $\pm 45^\circ$ to the center axis. The orientation of each individual ply is shown in a diagram on drawing No. 4691 (Figure 6), which is the detail drawing of the housing shell. This layup schedule is strictly adhered to in the manufacturing process. Since the flanges are much thicker than the cylinder wall, a large number of the plies extend only partially into the cylindrical portion of the case. The hoop reinforcements in the flanges are filament wound to the shape of a flat washer and laid up on the flange as separate prepreg preforms. The two auxiliary bearing support rings are premanufactured and inserted in recesses in the shell layup tool. As the plies in the shell are laid up, they are folded inward at the intersection of the ring to conform to the outside contour of the ring. During the curing cycle the folded material is pressed against the bearing ring, thus joining the two parts together. This arrangement is possible only for the two auxiliary bearing rings because they protrude into the cylinder. The main bearing support ring protrudes out from the cylinder. Therefore, it cannot be installed in the same manner as described above. In this case the shell mold has a cutout slightly larger than the shape of the bearing ring. As the shell material is laid up, it is formed around the cutout, creating an eyelet-type flange. After curing of the shell, the inside surface of the cutout is machined to conform to the outside shape of the bearing ring. The bearing ring is then bonded in place with an

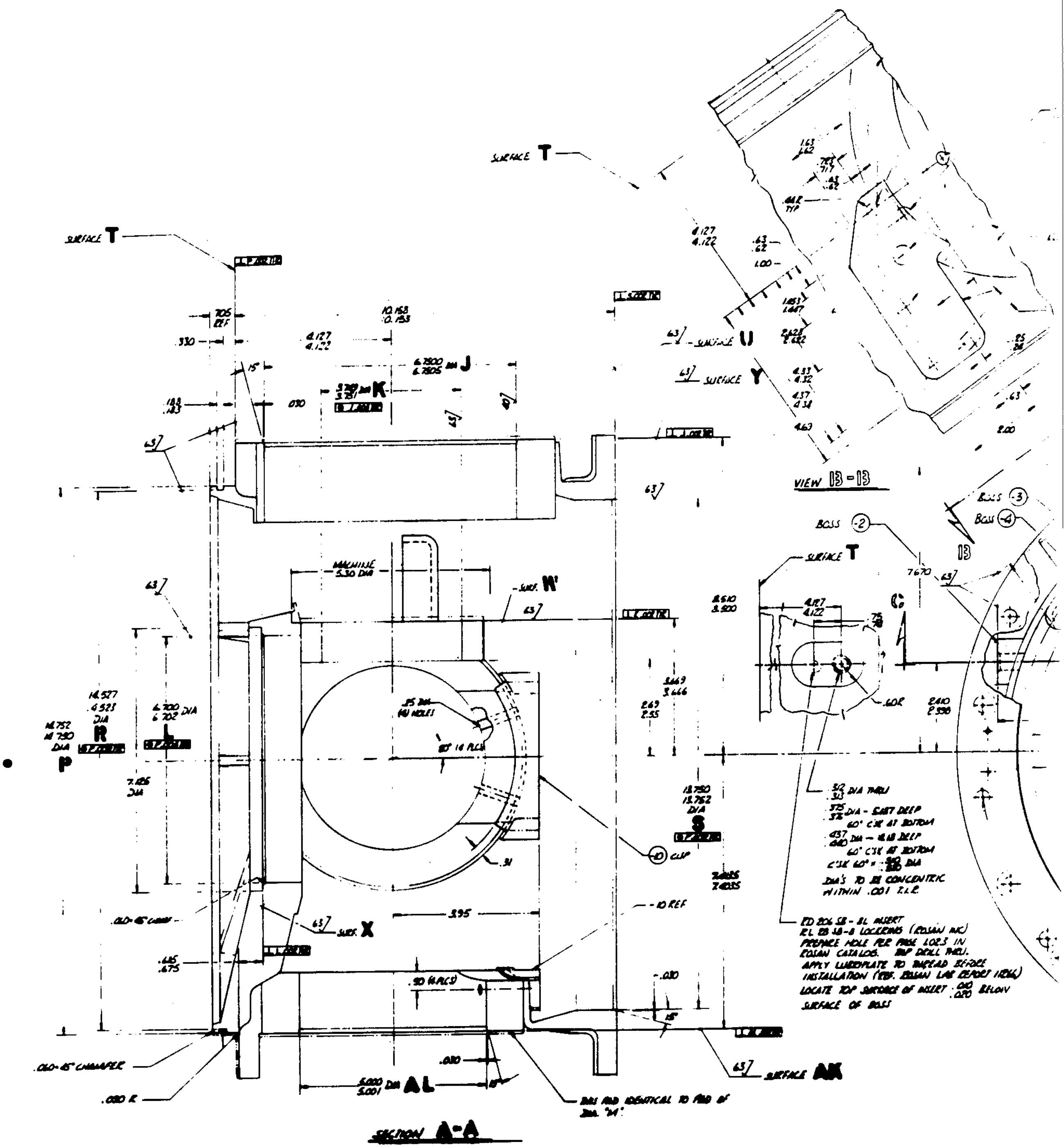
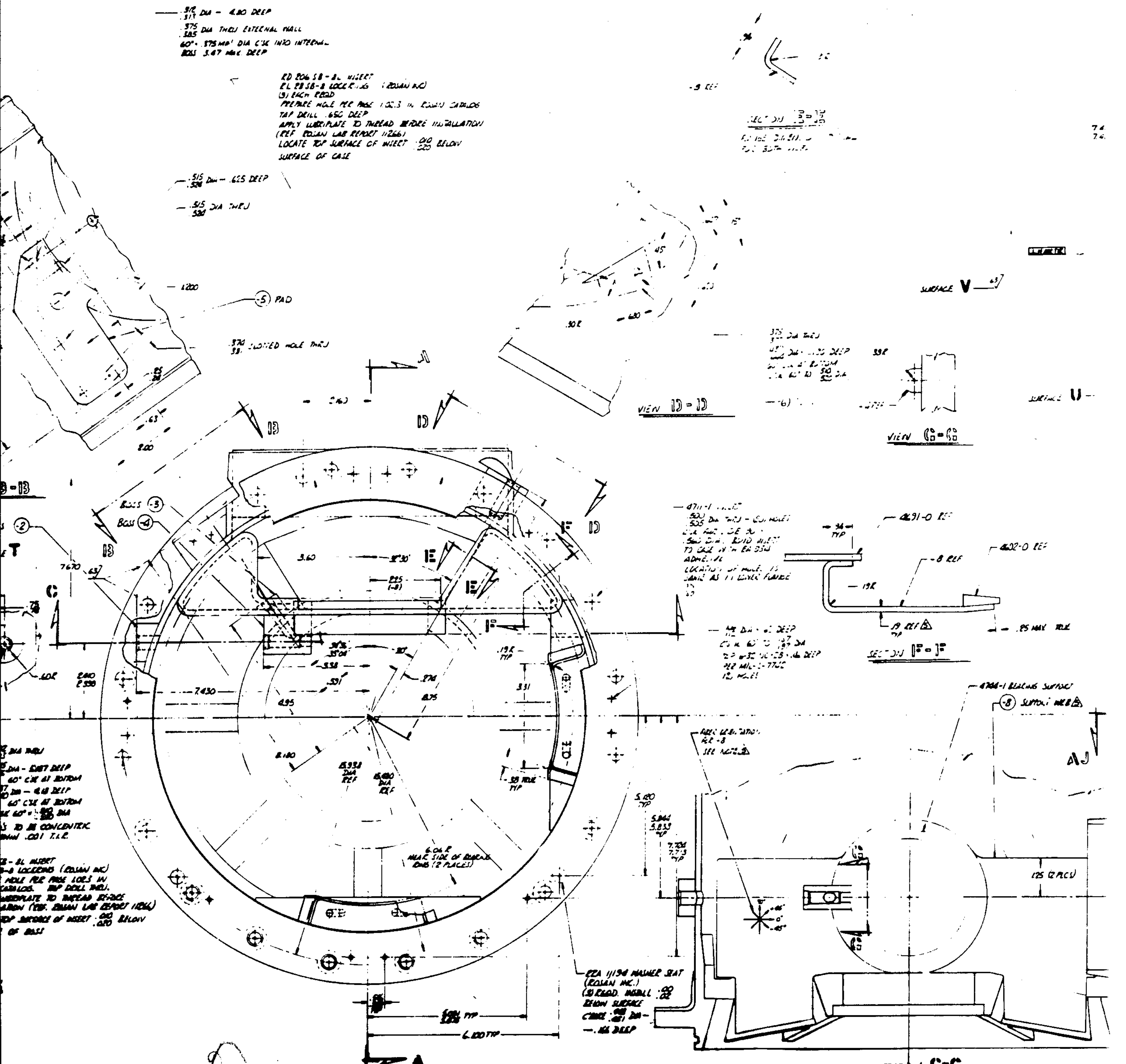
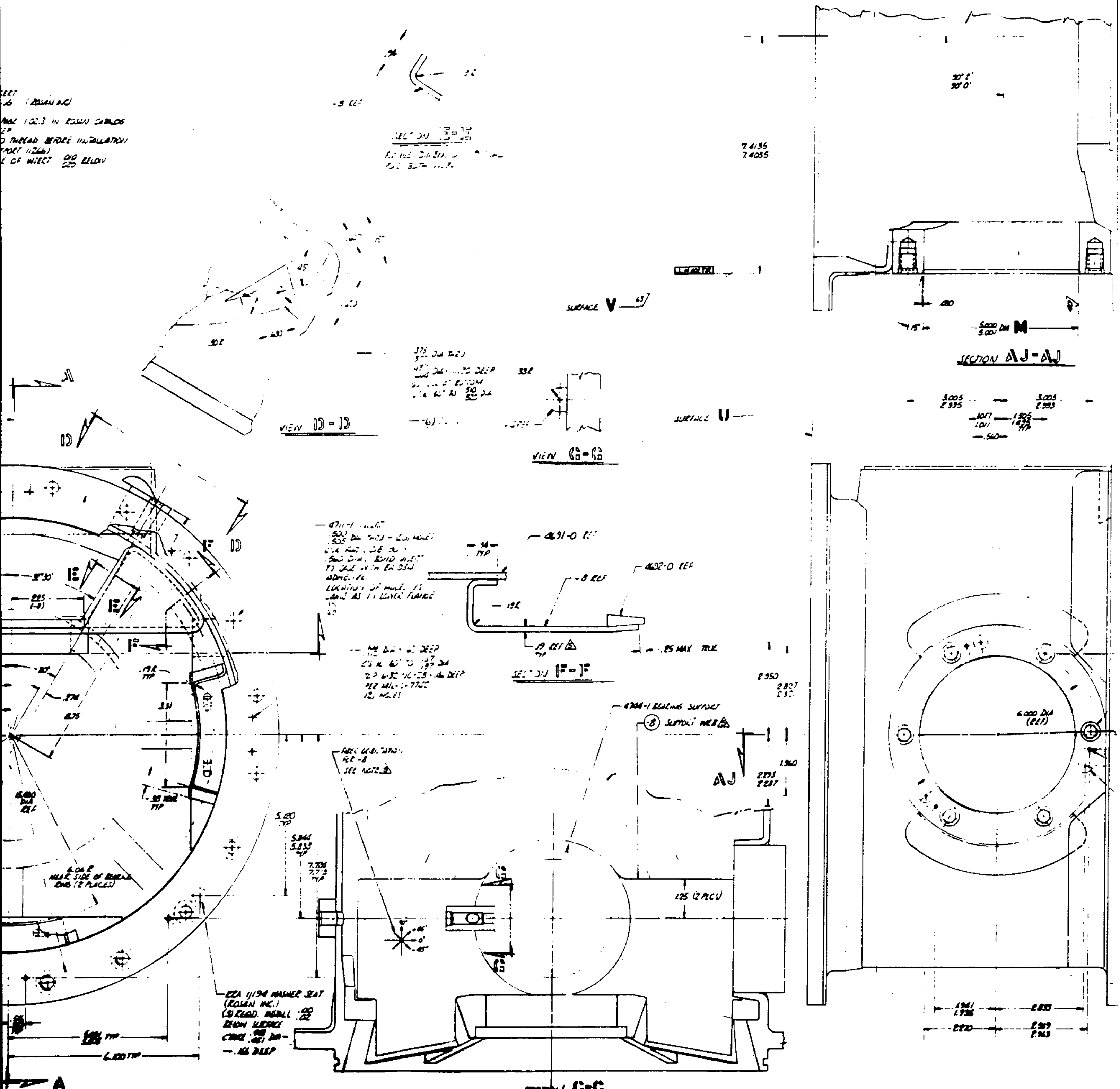


Figure 5. Housing Assembly - Helicopter Transmission, Composite Material (WRD Drawing No. 4690).

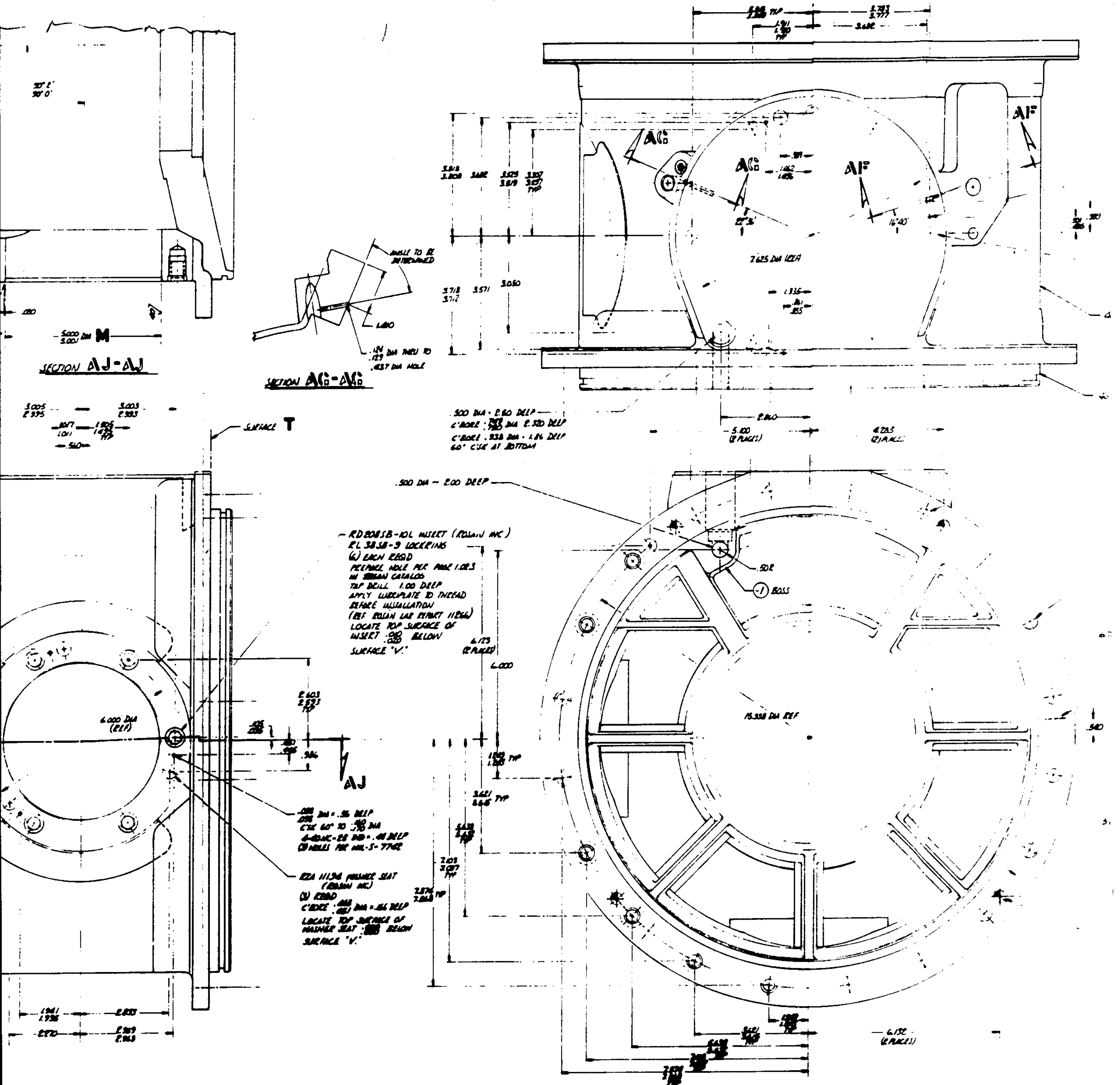


.312 .317 DIA - 4.80 DEEP
.375 .385 DIA THRU EXTERNAL WALL
60° x .575 MAX DIA C'SK INTO INTERNAL BOSS 3.47 MAX DEEP
RD 206 SB - 8L INSERT
RL 28 SB - 8 LOCKRING (ROSAN INC)
(3) EACH REQD
PREPARE HOLE PER PAGE 1 OF 3 IN ROSAN CATALOG
TAP DRILL .650 DEEP
APPLY LUBRIPLATE TO THREAD BEFORE INSTALLATION
(REF ROSAN LAB REPORT 11266)
LOCATE TOP SURFACE OF INSERT .010 .020 BELOW
SURFACE OF CASE
.515 .520 DIA - .625 DEEP
.515 .520 DIA THRU
(5) PAD
SLOTTED HOLE THRU
VIEW D - D
VIEW G - G
SURFACE V
SURFACE U
BOSS (3)
BOSS (4)
(2)
SECTION F - F
.19 REF
.95 MAX TOL
6.04 R
MAX SIDE OF BEARING RIBS (2 PLACES)
15.938 DIA REF
15.480 DIA REF
7.430
RZA 11134 WASHER SEAT
(ROSAN INC.)
(3) REQD. INSTALL .00 .02 BELOW SURFACE
6.100 TYP
A
AJ
(8) SUPPORT WEB
.125 (2 PLCS)
SECTION C-C

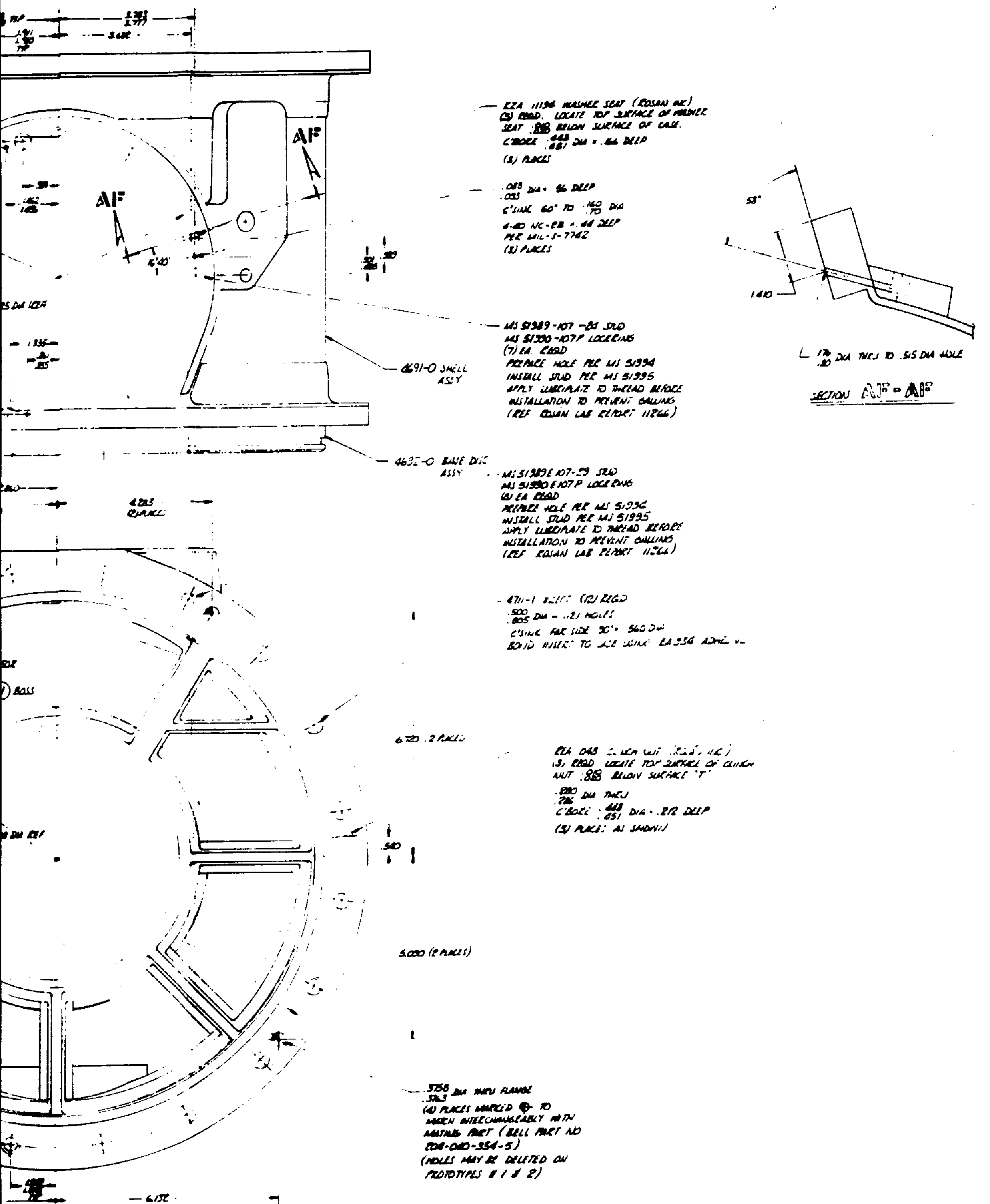


SECTION AJ-AJ
VIEW D-D
VIEW G-G
SECTION F-F
SECTION C-C
SURFACE V
SURFACE U
5.000 DIA M
6.000 DIA (REF)
4691-0 REF
4692-0 REF
-8 REF
.19 REF
.25 MAX. TRUE
4764-1 BEARING SUPPORT
-8 SUPPORT WEB
.125 (2 PLCS)
6.100 TYP
6.06 R NEAR SIDE OF BEARING BOSS (2 PLACES)
RZA 11194 WASHER SEAT (ROSAN INC.)
AJ
A

3



SECTION AJ-AJ
SECTION AG-AG
ANGLE TO BE DETERMINED
SURFACE T
7.625 DIA REF
.500 DIA ~ 2.00 DEEP
RD 808SB-10L INSERT (ROSAN INC)
RL 385B-9 LOCKRING
(6) EACH REQD
PREPARE HOLE PER PAGE 1.08.3 IN ROSAN CATALOG
TAP DRILL 1.00 DEEP
APPLY LUBRIPLATE TO THREAD BEFORE INSTALLATION
(REF ROSAN LAB REPORT 11266)
LOCATE TOP SURFACE OF INSERT BELOW SURFACE "V."
.50R
-1 BOSS
6.000 DIA (REF)
15.938 DIA REF
C'BORE .938 DIA - 1.86 DEEP
60° CSK AT BOTTOM
LOCATE TOP SURFACE OF WASHER SEAT BELOW SURFACE "V."



NOTES:

1. BOND 4632 BASE DISC TO 4691 SHELL WITH EA 9… ADHESIVE
2. TRIM 4744 INTERNAL BEARING SUPPORT [redacted] TO FIT CONTOUR OF 4632 DISC. BOND IN PLACE … EA 934 ADHESIVE.
3. PRE-MANUFACTURE ALL BOSSES AND PADS AND B… IN PLACE WITH EA 934 ADHESIVE
4. AXES OF DIAMETERS 'J', 'M' AND 'AL' SHALL INTER… AXIS OF DIA 'S' WITHIN .002 TIR
5. – B SHALL HAVE (6) PLIES IN EACH 0°, 90°, + AND −45° DIRECTION FOR A TOTAL OF (24) PLIES. USE TOOL PER DWG 4713 TO MAKE −3

5

E SEAT (ROSAN INC)
TOP SURFACE OF INSERT
SURFACE OF CASE
.66 DEEP

DIA
DEEP

1 STUD
LOCKING

E MS 51994
MS 51995
TO THREAD BEFORE
PREVENT GALLING
REPORT 11266)

STUD
LOCKING

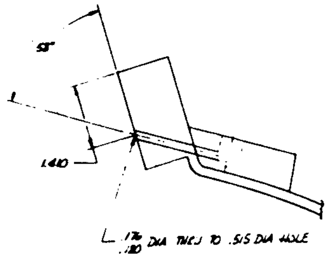
MS 51996
MS 51995
TO THREAD BEFORE
PREVENT GALLING
REPORT 11266)

REQD

ADHESIVE EA 934

CLINCH NUT (ROSAN INC)
LOCATE TOP SURFACE OF CLINCH
BELOW SURFACE 'T'

THRU
$\frac{.448}{.451}$ DIA × .212 DEEP
AS SHOWN



SECTION AF - AF

NOTES:

1. BOND 4632 BASE DISC TO 4631 SHELL WITH EA 934 ADHESIVE
2. TRIM 4744 INTERNAL BEARING SUPPORT [redacted] TO FIT CONTOUR OF 4632 DISC. BOND IN PLACE WITH EA 934 ADHESIVE.
3. PRE-MANUFACTURE ALL BOSSES AND PADS AND BOND IN PLACE WITH EA 934 ADHESIVE
4. AXES OF DIAMETERS 'J', 'M' AND 'AL' SHALL INTERSECT AXIS OF DIA 'S WITHIN .002 TIR
5. -8 SHALL HAVE (6) PLIES IN EACH 0°, 90°, +45° AND -45° DIRECTION FOR A TOTAL OF (24) PLIES. USE TOOL PER DWG 4713 TO MAKE -3

7	MS 51990-[illegible]	STUD LOCK RING	
7	MS 51990-[illegible]	STUD	
8	MS 51994	STUD LOCK RING	
8	MS 51994	STUD	
[illegible]	[illegible]	INSERT SEAT	(ROSAN INC, NEWPORT BEACH, CA)
3	[illegible]	CLINCH NUT	
[illegible]	[illegible]	LOCK RING	
4	[illegible]	LOCK RING	
[illegible]	[illegible]	INSERT	
4	[illegible]	INSERT	(ROSAN INC, NEWPORT BEACH, CA)
1	4744-1	BEARING SUPPORT	
[illegible]	4711-1	INSERT	
1	4632-0	BASE DISC ASSY	
1	4631-0	SHELL ASSY	
2	-10	CLIP	[illegible] / 5208
	-9		
1	-8	SUPPORT RING	
	-7		
1	-6	BOSS	
1	-5	PAD	
1	-4	BOSS	
1	-3	BOSS	
1	-2	BOSS	
1	-1	BOSS	[illegible] / 5208
	-01	[illegible] ASSY	

HOUSING ASSY - HELICOPTER
[illegible], [illegible] MANUAL

4690

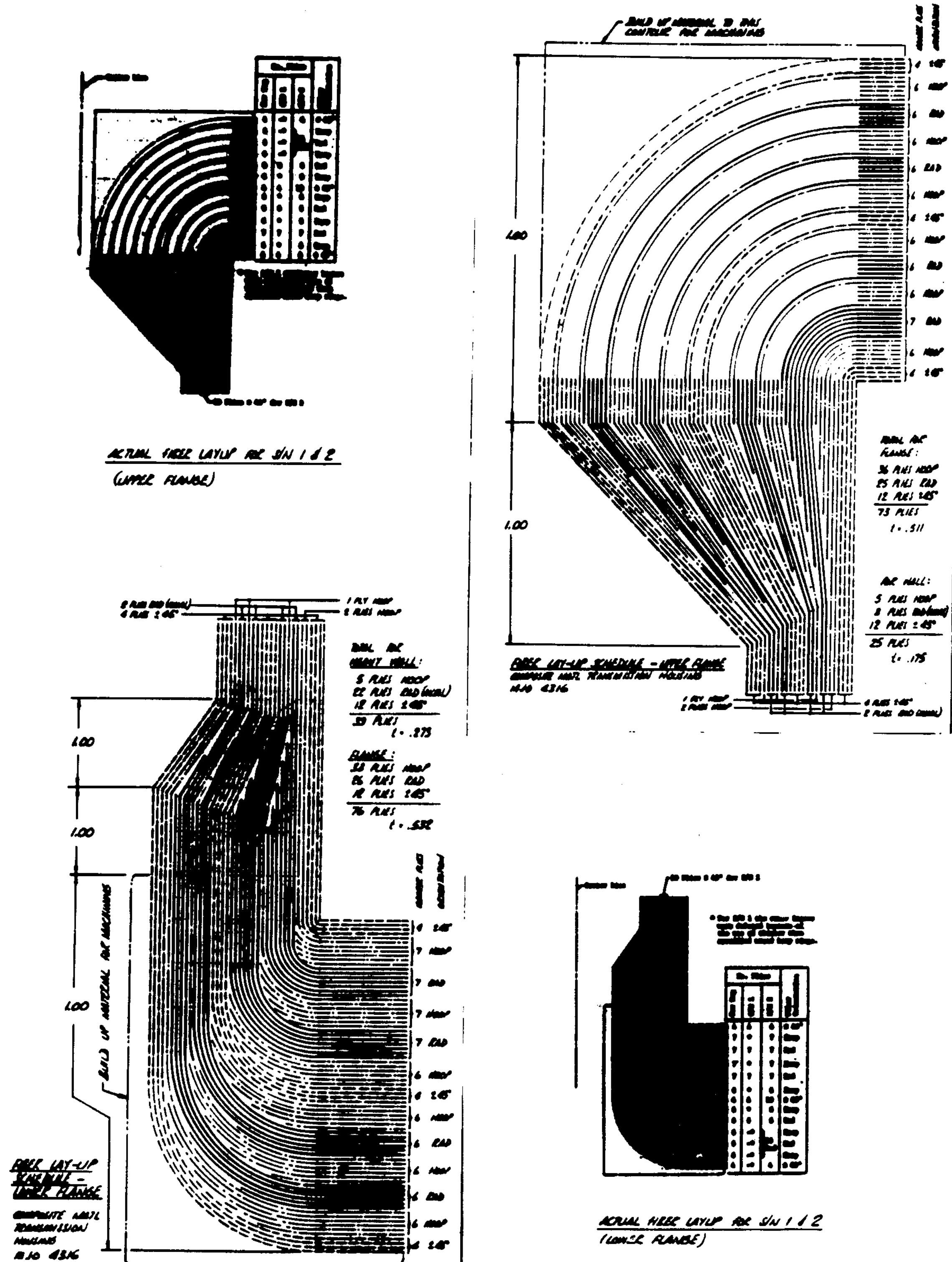
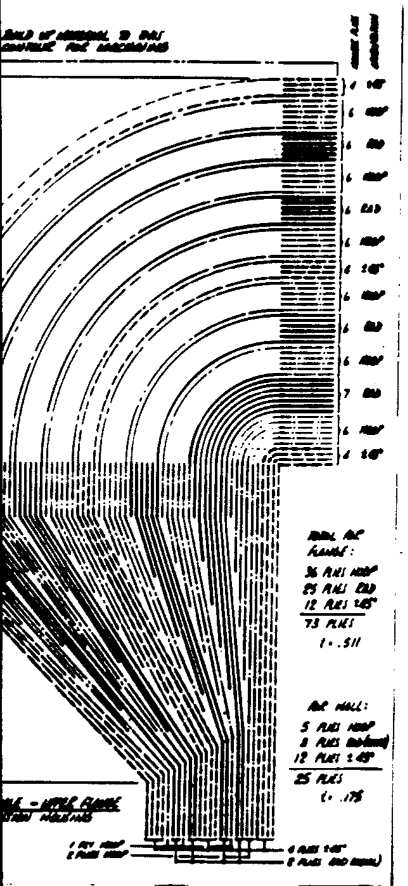
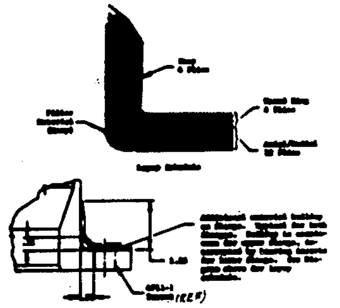
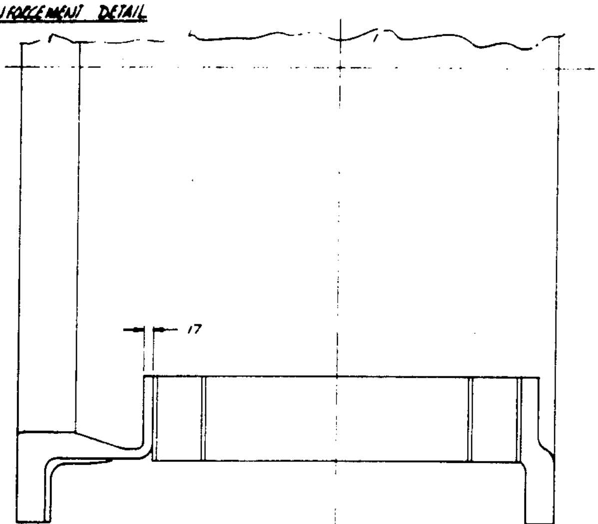


Figure 6. Shell Assembly - Helicopter Transmission Housing (WRD Drawing No. 4691).





FLANGE REINFORCEMENT DETAIL



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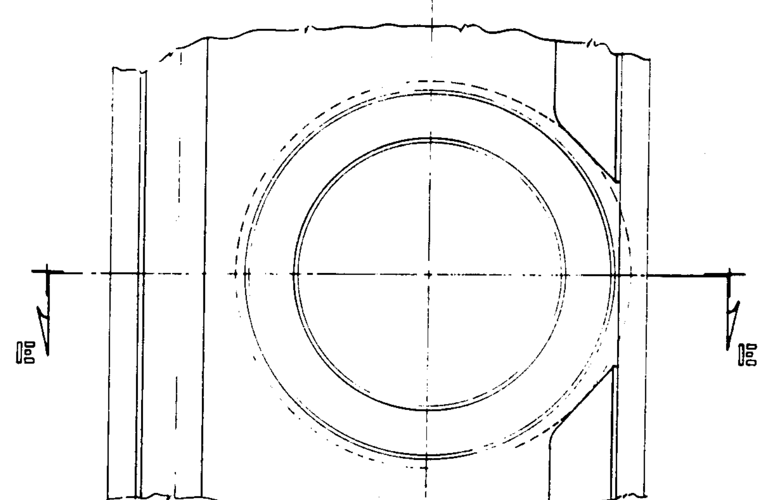
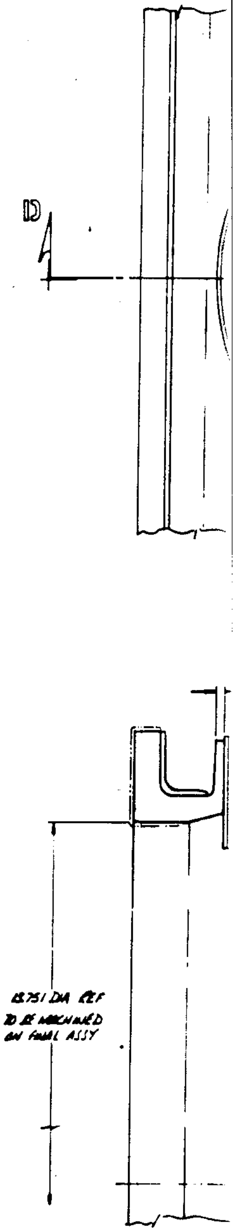
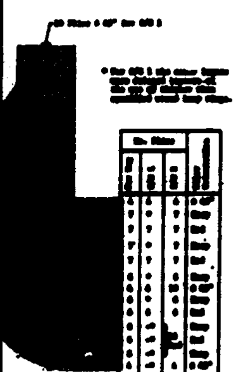


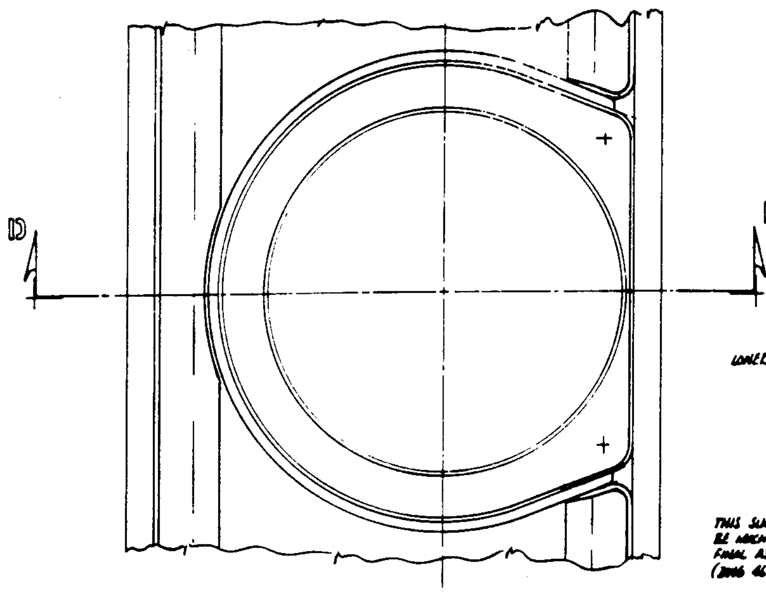
VIEW B-B



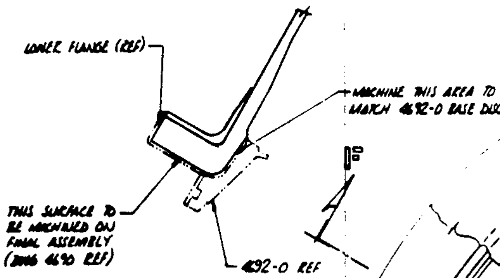


AL FIBER LAYUP FOR S/N 1 & 2
CE FLANGE)

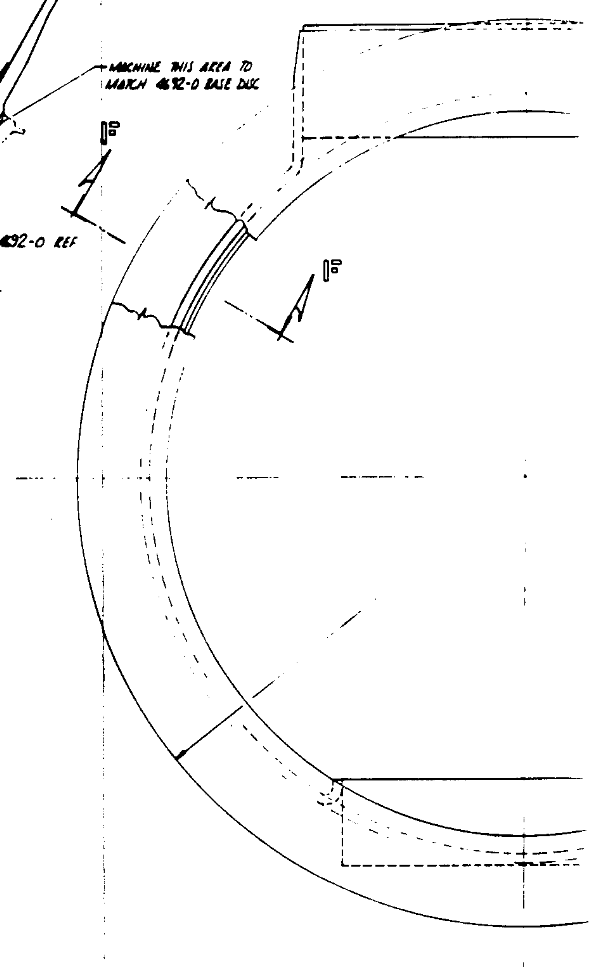
licopter
g
91).

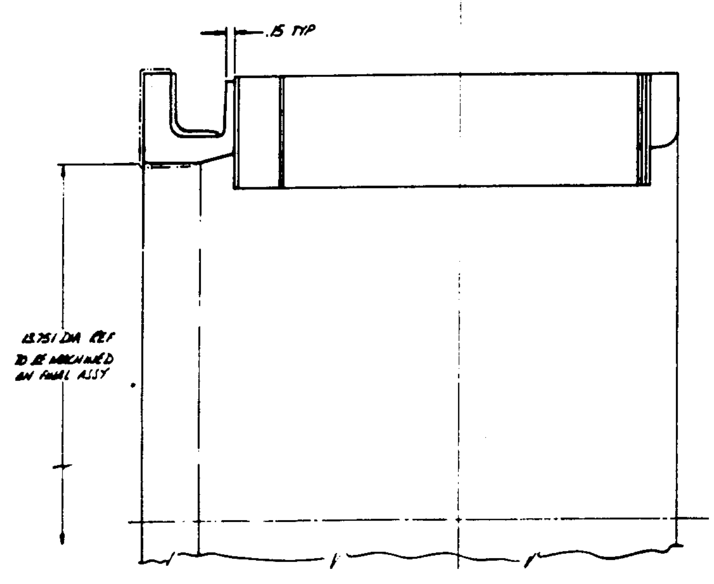


VIEW A-A



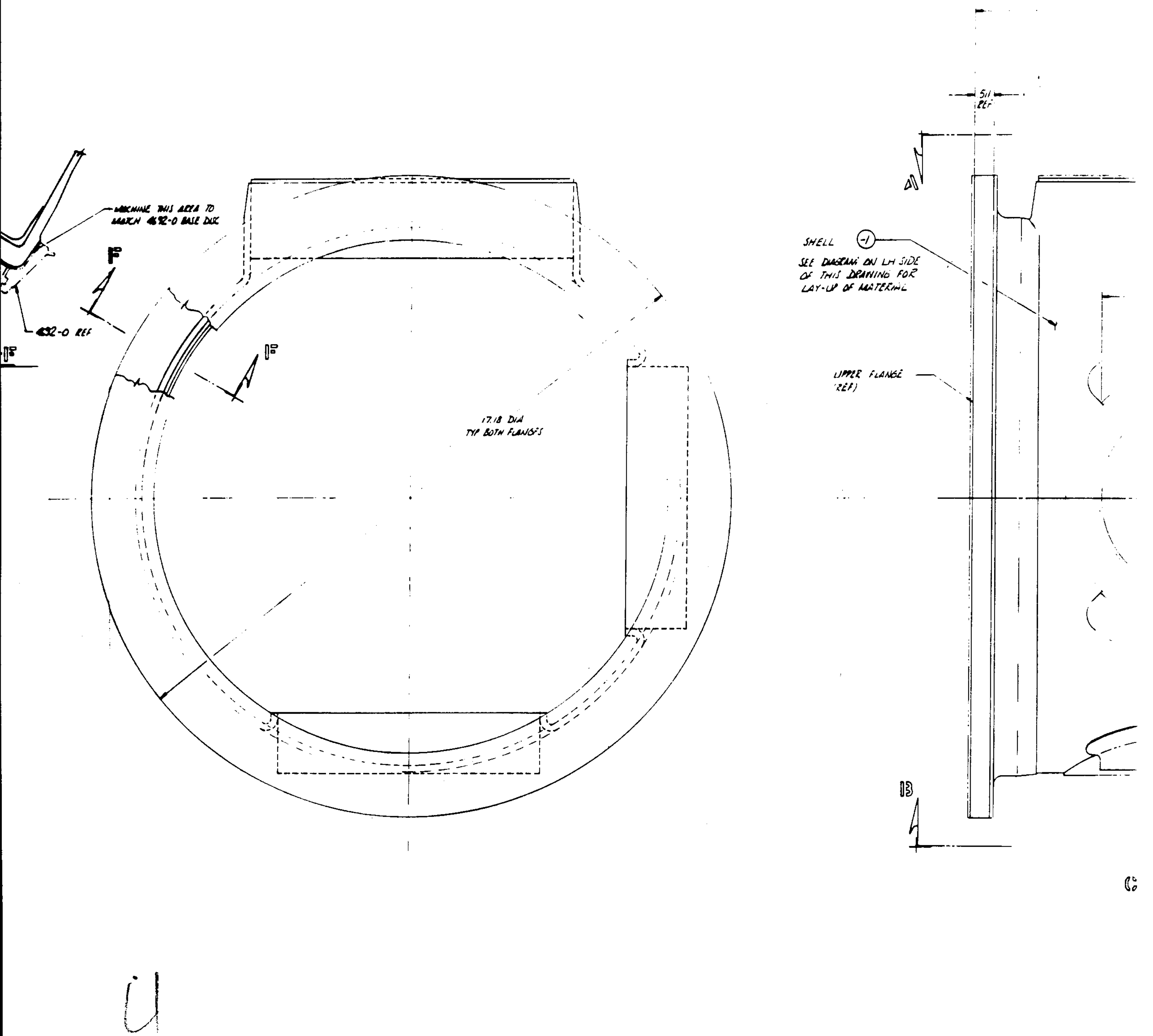
SECTION E-E





SECTION D-D

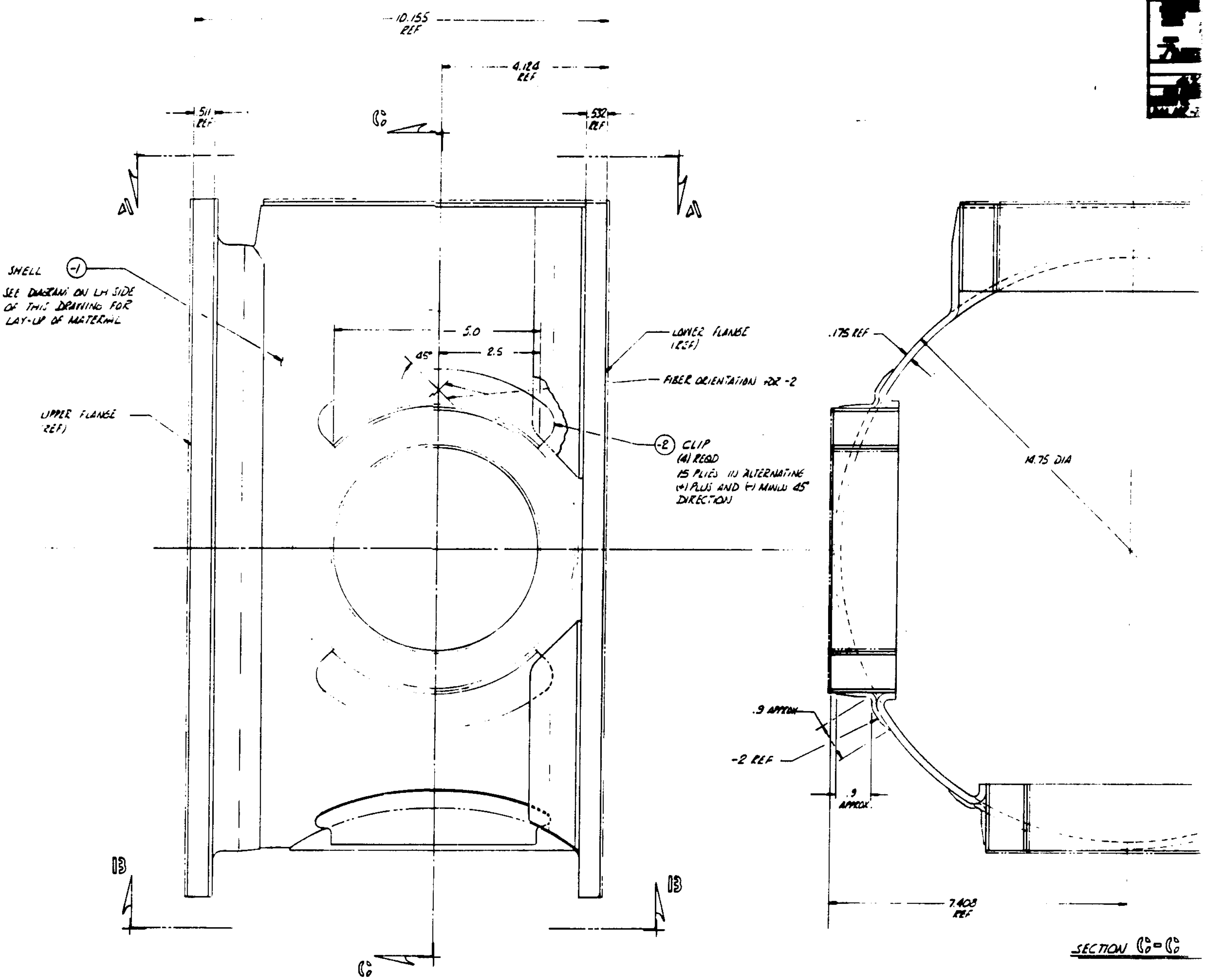
3



MACHINE THIS AREA TO MATCH 4692-0 BASE DISC
4692-0 REF
F
F
17.18 DIA
TYP BOTH FLANGES
.511
REF
B
SHELL
-1
SEE DIAGRAM ON LH SIDE OF THIS DRAWING FOR LAY-UP OF MATERIAL
UPPER FLANGE
(REF)
B

NOTES:

1. USE 4695-O MOLD ASSY TO MANUFACTURE -1 SHELL.
2. INSERT 4694-1 BEARING RINGS IN 4695-O MOLD PRIOR TO LAY-UP OF -1 MATERIAL



5

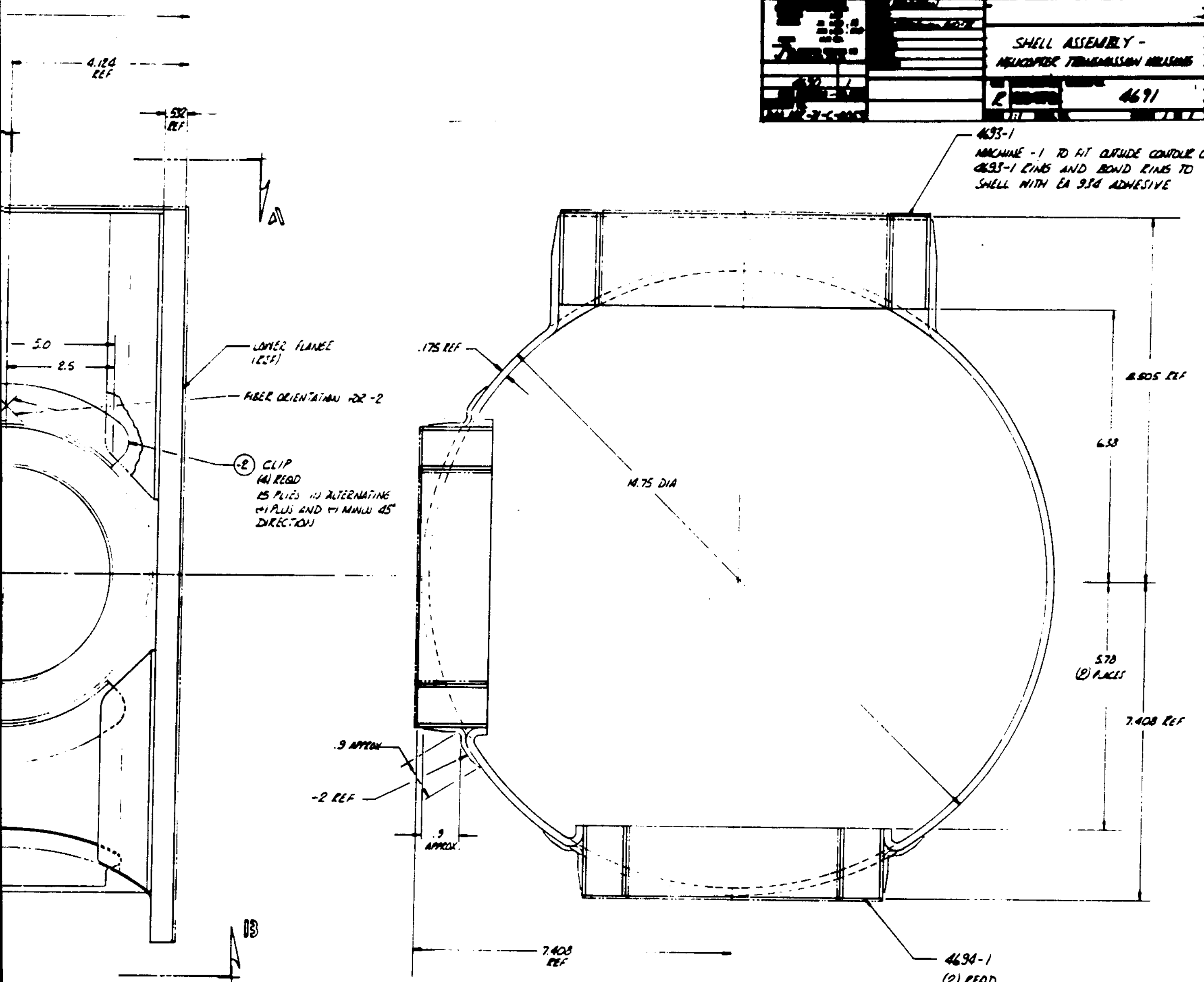
NOTES:

1. USE 4695-0 MOLD ASSY TO MANUFACTURE -1 SHELL.
2. INSERT 4694-1 BEARING RINGS IN 4695-0 MOLD PRIOR TO LAY-UP OF -1 MATERIAL

2	4694-1	BEARING RING AUX	
1	4693-1	BEARING RING MAIN	
4	-2	CLIP	MODMOR II / 5208
1	-1	SHELL	MODMOR II / 5208
	-3	SHELL ASSY	

SHELL ASSEMBLY - HELICOPTER TRANSMISSION HOUSING

4691



SECTION C-C

6

adhesive. The installation of the bearing support rings is shown in Figure 6.

The bearing support rings consist of a core made of glass/epoxy bulk molding compound, and two thin graphite filament-wound liners of the same width as the core ring. The graphite liners are bonded to the inside and outside diameters of the core ring after being cured. The thickness of the inner graphite liner has been selected so that a minimum of eight plies of continuous fibers remain after the final machining of the inside diameter. The final machining is performed after all components have been assembled into the transmission case. Detail drawings of the bearing support rings are:

4693 Bearing Ring, Main (Figure 7)

4694 Bearing Ring, Auxiliary (Figure 8)

4744 Bearing Ring, Main, Internal (Figure 9)

The base disc resembles a wheel with spokes (Figure 10). The center ring provides support for a bearing. The outer ring forms a part of the lower attachment flange in the transmission case. The disc is made entirely of graphite fiber material. The tape material is cut to appropriate length and size and laid up on a female tool and cured. The orientation of the fibers and the layup schedule are shown on drawing No. 4692 (Figure 11), which is the detail drawing of the base disc. Prior to bonding the disc to the case, the outer rim of the disc is machined to match a similarly machined surface at the lower flange of the case. The seat is made slightly conical to provide good contact pressure for bonding.

The requirement for an internal bearing structure attached to both the cylindrical case and the base disc presented a manufacturing problem. An early method under consideration was to build up a core of a soluble material after the base disc and cylinder had been jointed together, lay up the bearing structure material over the core and, after completing the curing cycle, wash out the core. This method was abandoned and instead the web structure was manufactured separately and bonded in place. The web is made up of 24 plies with fibers oriented at 0°, $\pm 45^\circ$ and 90°. The configuration is shown in section C-C of drawing No. 4690 (Figure 5). The bearing support ring, which is constructed in a manner similar to the other support rings described earlier, is also bonded in place. The web is located approximately in the center of the bearing, which made it possible to split the bearing support ring into two thinner rings and bond them on either side of the web. In order to maintain a smooth inner surface of the support ring, the inner thin graphite liner in the ring is continuous and penetrates through a hole in the web. The inner bearing structure and bearing insert ring are shown in Figures 12 and 13.

There are several protrusions or pads located on both outside and inside surfaces of the case. These protrusions serve to hold threaded inserts

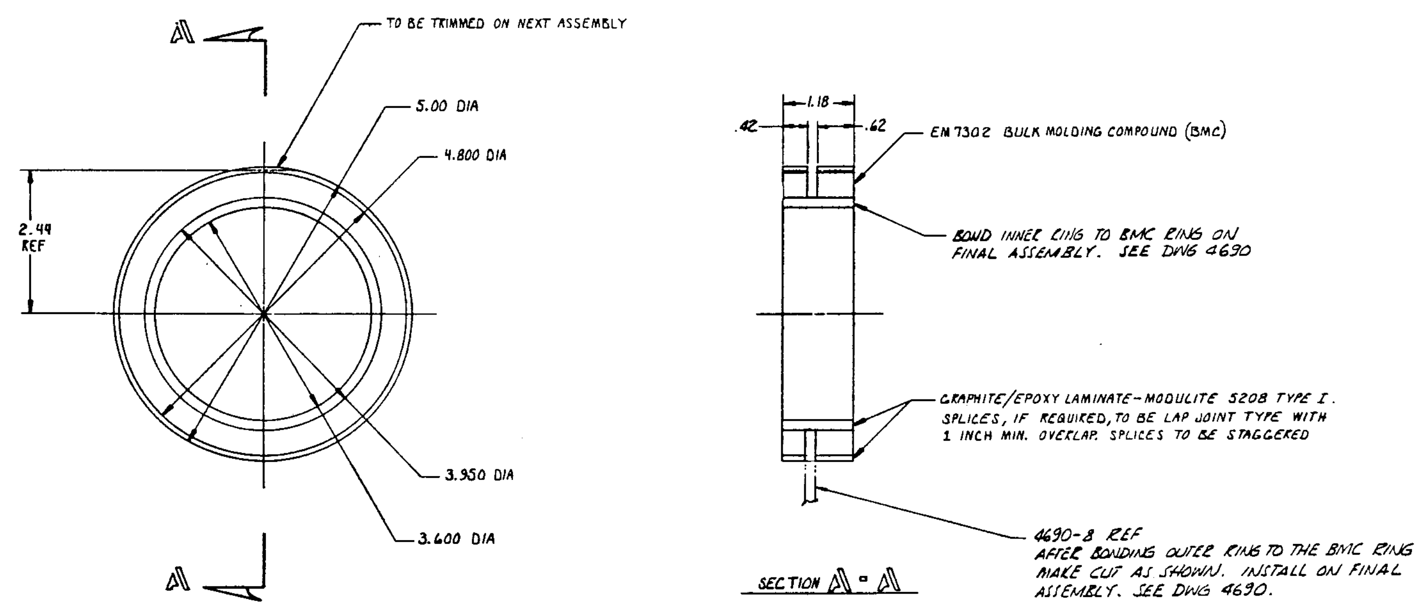


Figure 9. Bearing Ring, Main, Internal (WRD Drawing No. 4744).

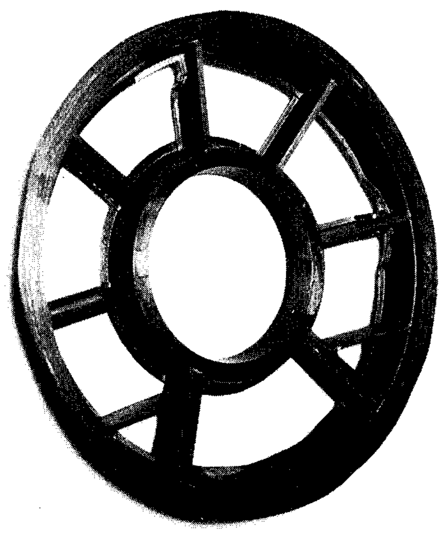


Figure 10. Carbon Composite Base Disc Bearing Support.

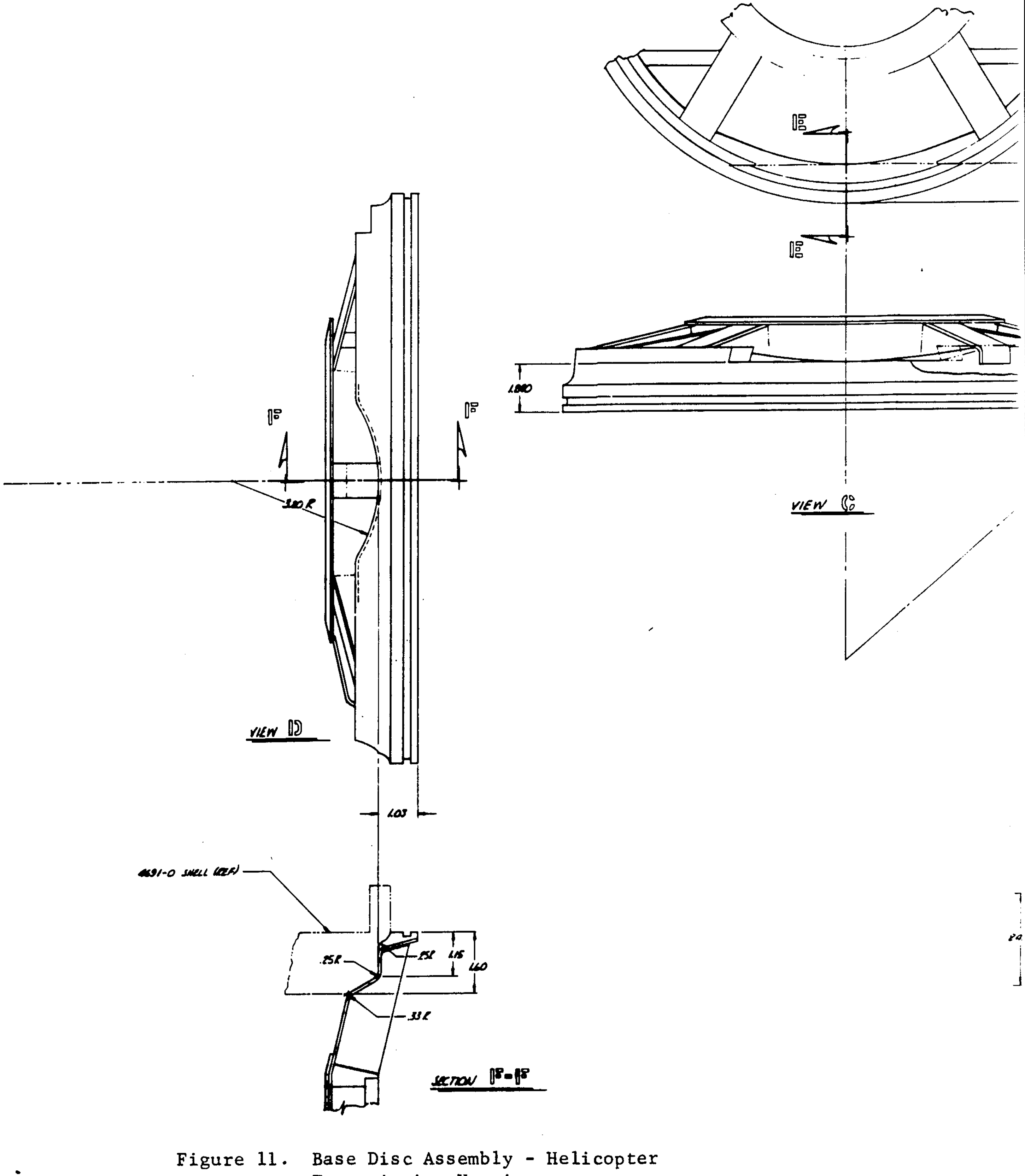
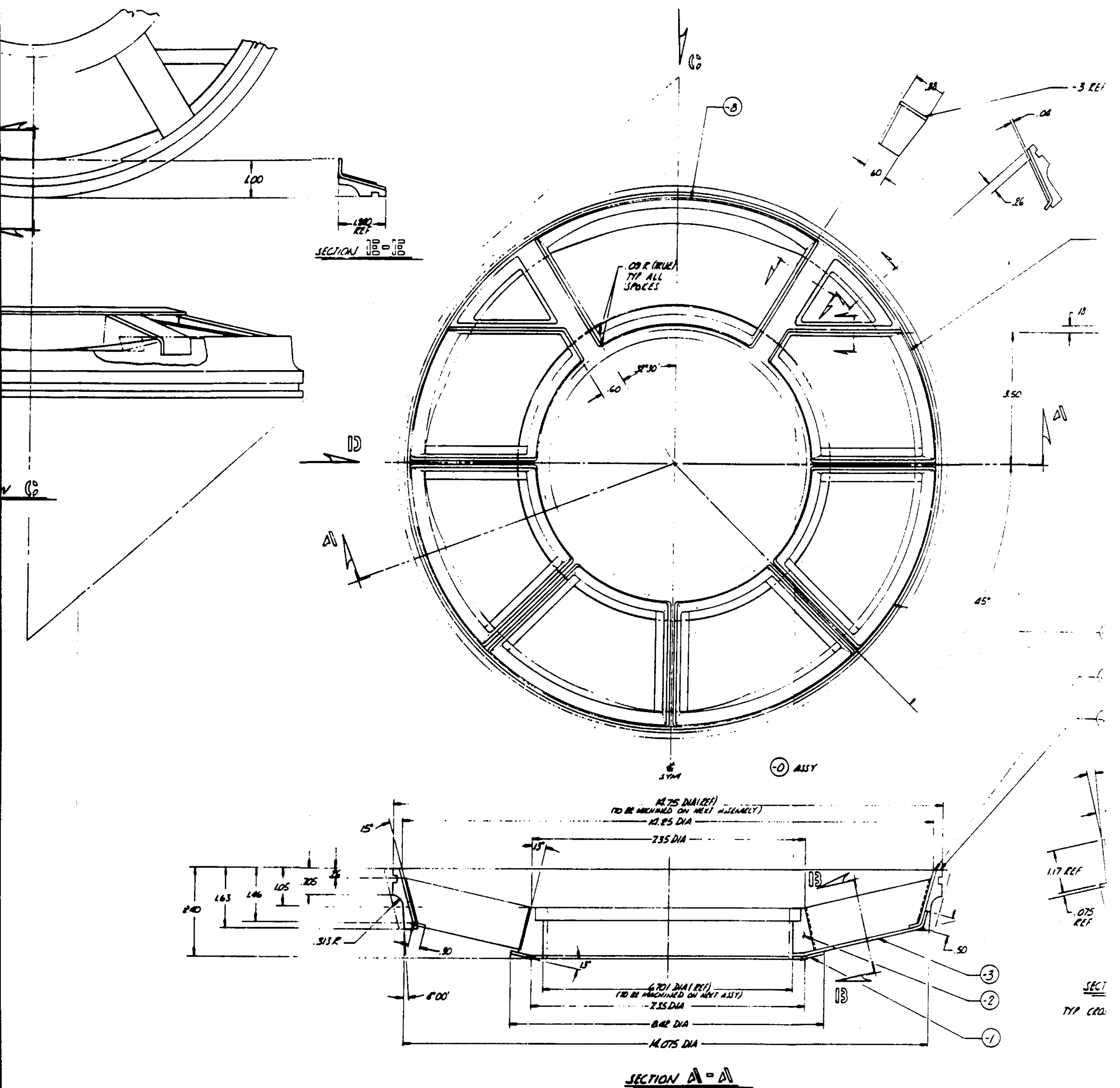
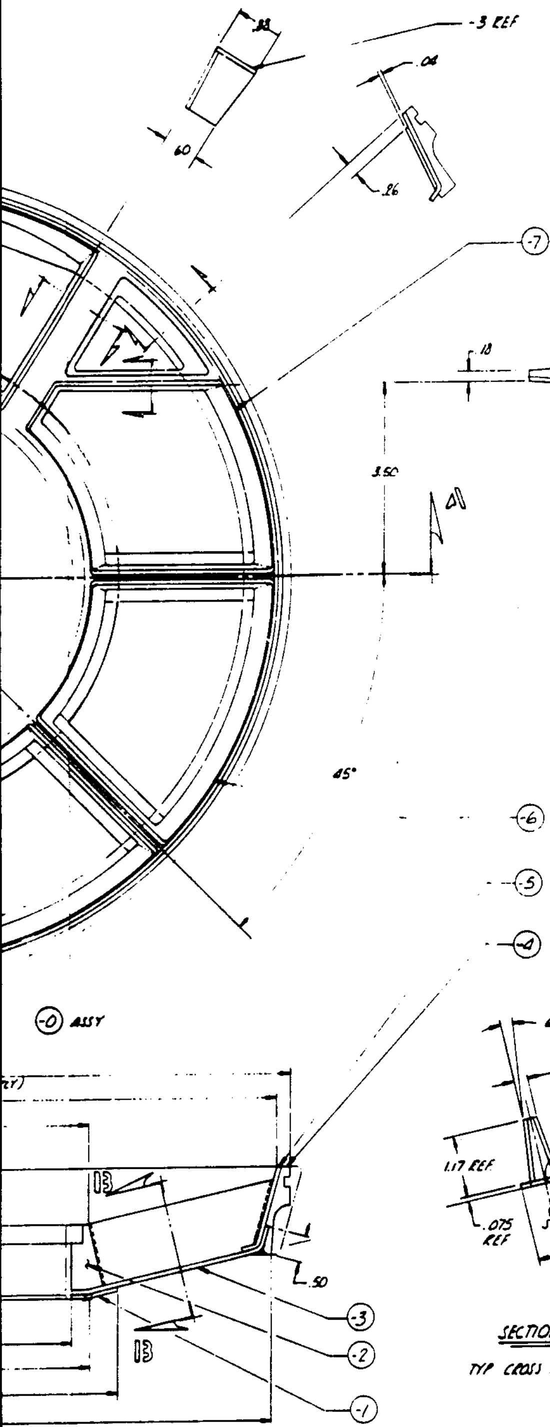
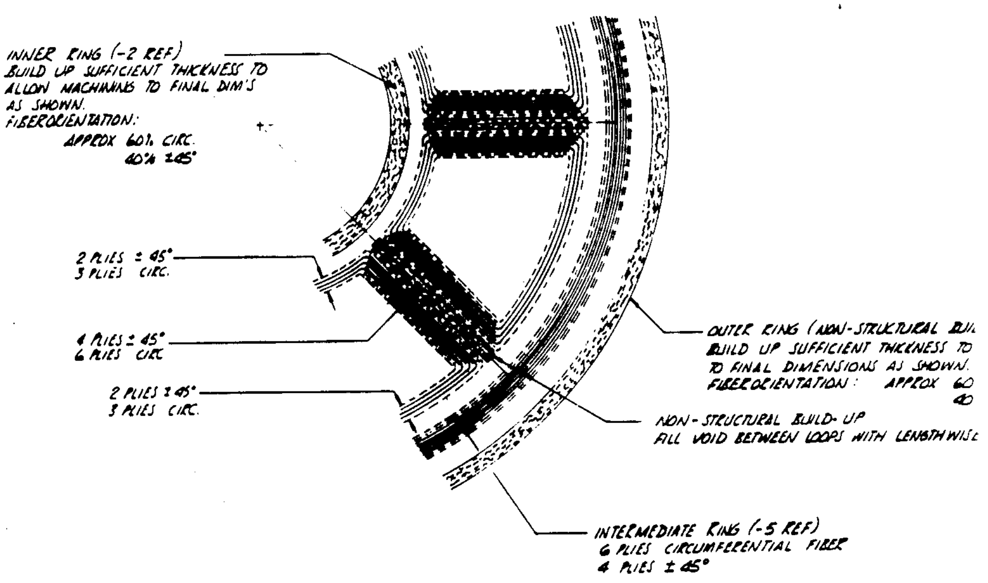


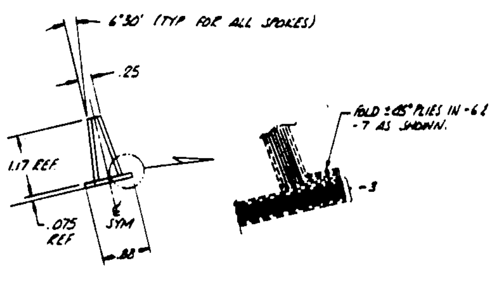
Figure 11. Base Disc Assembly - Helicopter Transmission Housing (WRD Drawing No. 4692).


-3 REF
.04
.26
.60
1.00
1.980 REF
SECTION B-B
.09 R (TRUE) TYP ALL SPOKES
.60
22°30'
3.50
45°
-0 ASSY
SYM
14.75 DIA (REF) (TO BE MACHINED ON NEXT ASSEMBLY)
14.25 DIA
7.35 DIA
15°
2.40
1.63
1.46
1.05
.705
.313 R
.90
6°00'
6.701 DIA (REF) (TO BE MACHINED ON NEXT ASSY)
7.35 DIA
8.42 DIA
14.075 DIA
1.17 REF
.075 REF
.50
SECTION A-A





SCHEMATIC OF FIBER LAY-UP



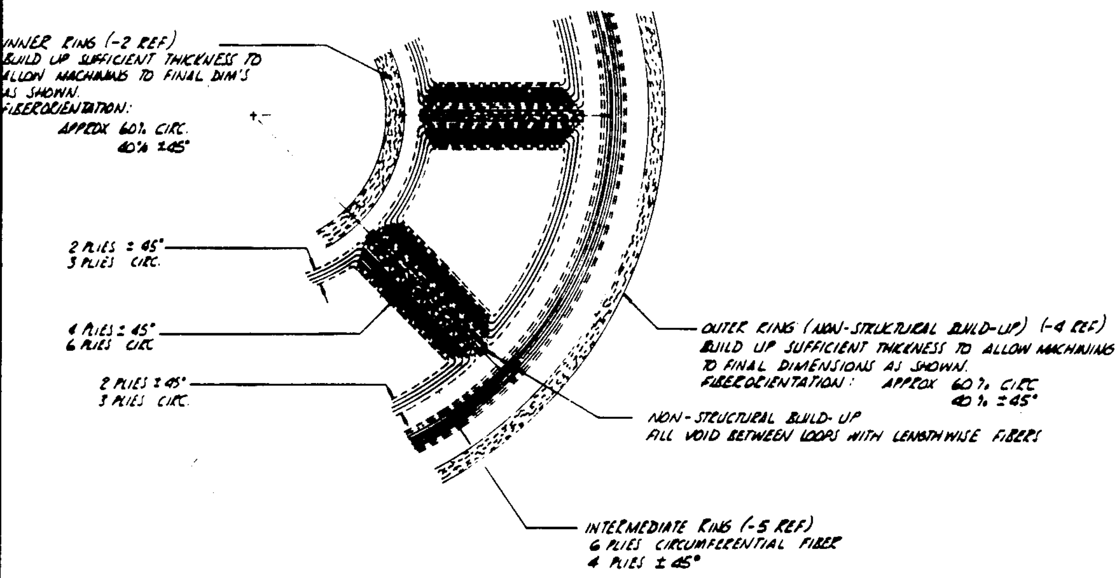
SECTION 13-13

TYP CROSS SECTION OF (5) SPOKES

NOTES:

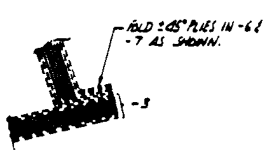
1. USE TOOL 4696 TO MANUFACTURE THIS PART.
2. UNLESS OTHERWISE SPECIFIED ± 45° FIBER ORIENTATION MEANS ± 45° TO AXIS OF ROTATION.
3. MATERIAL FOR -1 & -3:
   4 PLIES ± 45°
   6 PLIES CIRC. (RADIAL FOR -3)
   LAY-UP TO BE SIMILAR TO -5 WITH 6 PLIES OF CIRC. FIBERS SANDWICHED BETWEEN ±45° FIBERS - 2 PLIES ON EACH SIDE.

DAA J02-71-C-0059



SCHEMATIC OF FIBER LAY-UP

(... ALL SPOKES)



NOTES:

1. USE TOOL 4696 TO MANUFACTURE THIS PART.
2. UNLESS OTHERWISE SPECIFIED ±45° FIBER ORIENTATION MEANS ±45° TO AXIS OF ROTATION.
3. MATERIAL FOR -1 & -3:
   4 PLIES ± 45°
   6 PLIES CIRC. (RADIAL FOR -3)
   LAY-UP TO BE SIMILAR TO -5 WITH 6 PLIES OF CIRC. FIBERS SANDWICHED BETWEEN ±45° FIBERS - 2 PLIES ON EACH SIDE

...S) SPOKES

-8	LINER	MODMOR I / 5208
-7	LINER	
-6	LINER	
-5	RING, INNER	
-4	RING, OUTER	
-3	CAP	
-2	HUB	
-1	RING, HUB	MODMOR I / 5208
-0	HOUSING ASSY	

BASE DISC ASSEMBLY - HELICOPTER TRANSMISSION HOUSING

E 4692

DAA J02-71-C-0059

Figure 12. Inner Bearing Support.

Figure 13. Inner Bearing Support Ring Insert.

for mounting oil fittings and to provide adequate material thickness for drilling of oil passages. The protrusions are not heavily loaded. They are molded of glass/epoxy bulk molding compound, shaped to fit the mating surfaces, and bonded in place.

The correct relationship between features like flange surfaces, holes for bearings, mounting holes, etc., is achieved by a final machining operation which is performed after all composite material items have been assembled. The machining operation includes grinding of flat surfaces and large-diameter bearing cutouts, and drilling and threading holes. Finally, sleeve type inserts are installed and bonded in the mounting flanges, and threaded inserts and studs are installed in the same manner as on the magnesium transmission case. To prevent electrolytic activities, all inserts and studs that are in direct contact with graphite are made of stainless steel, whereas the ones mounted in the bulk molding compound are cadmium-plated steel.

DESIGN ANALYSIS

Loads

The basic loads for the composite material transmission housing were obtained from Bell Helicopter Company Report No. 212-099-098. Two loading conditions were considered as critical:

Condition I - Rolling pullout with maximum left tail rotor thrust.

Condition II - Forward crash (8g)

These loads result in the maximum head moments and axial and torsional loadings to the housing and are indicated in Figure 14.

Since these basic loading conditions are external loads applied to the main housing, an analysis was conducted in order to distribute these loads properly through the housing structure. Specific loading distributions were determined on the upper and lower flanges, radial and thrust loadings at each of the bearing locations, and the net resultant support reaction loads. This complete external and internal loads distribution analysis is presented in Appendix I.

Weight

A detailed weight analysis of the composite material transmission case was not performed during the design stage in the program. A rough estimate indicated that the weight would be nearly the same as for the magnesium case. This was a reasonable assumption since the configurations of the two cases and the material densities are very similar. The densities for the graphite composite and the bulk molding compound are 0.058 lb/cu in. and 0.071 lb/cu in., respectively; for the magnesium, 0.065 lb/cu in. Threaded inserts and studs were nearly identical for the two cases. The graphite case had steel inserts in the mounting holes in the flanges, which did not exist on the magnesium case. The weight of the 32 inserts was 0.51 lb. The measured weight for the magnesium case was 23.2 lb and for the graphite case 21.5 lb and 24.8 lb for S/N 1 and S/N 2 respectively. The weight increase for S/N 2 is due to added plies in the cylinder wall and in the flanges. This was required to increase the torsional and axial stiffness, which for S/N 1 measured lower than had been predicted.

Structural Analysis

Based on the internal and external loading distributions, a detailed stress analysis was conducted on the housing. This stress analysis is presented in Appendix II. Materials used in the composite material helicopter transmission gear housing are:

Graphite/Epoxy Laminate - Modulite 5208 Type I

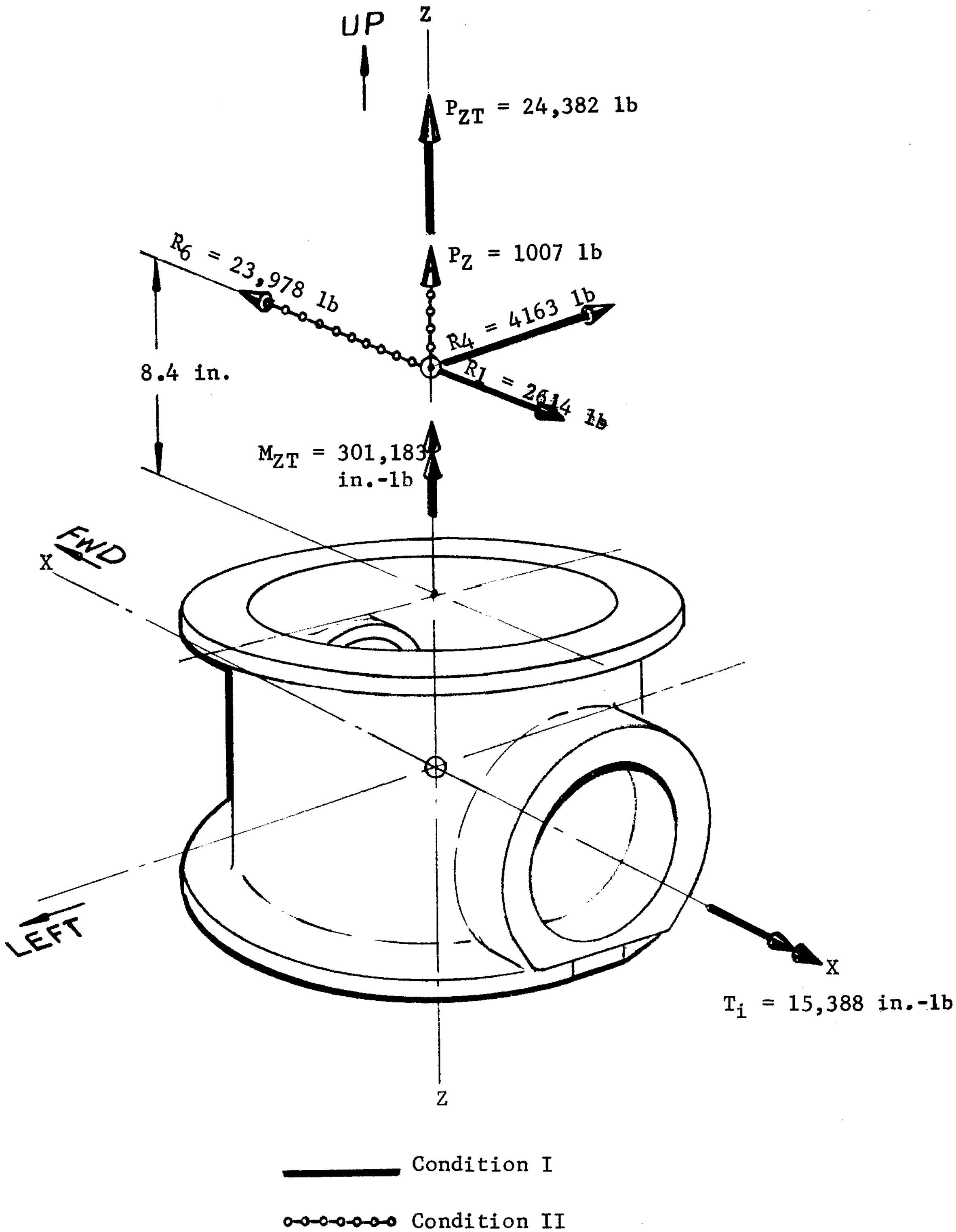


Figure 14. Critical Design Limit Loads.

Bulk Molding Compound - EM 7302-1/2

Adhesive - Hysol Adhesive EA 934

Allowable stress and modulus of elasticity of the respective graphite/epoxy laminates at RT and at 350°F were determined from available experimental data and by established analytical prediction methods. Allowable stresses for EM 7302 bulk molding compound and EA 934 adhesive were obtained from Whittaker Research and Development test data. The margins of safety were established based on 350°F conditions. They are summarized in Table I.

Although structural integrity is a necessary design consideration, the increase in stiffness under load was considered a primary design requirement. In each of the major areas, stiffness comparisons were made with the magnesium housing using room-temperature material properties. The predicted % increase in stiffness is calculated as follows:

$$\left(\frac{\text{COMPOSITE STIFFNESS}}{\text{MAGNESIUM STIFFNESS}}\right) - 1 \times 100 = \%\ \text{INCREASE}$$

The predicted results are summarized in Table II. They show that the established goal of a 50% increase in stiffness was in most cases theoretically achievable. In the bearing supports, the bending stiffness increases calculated were considerably greater than 50%. However, the calculated axial stiffness indicates only 42% increase. Since the loading on bearing supports results in a combination of bending and axial loading, it was expected that the combination would result in the desired increase in stiffness.

The analysis of the flange areas on the basis of EI (bending) shows a 52% predicted increase in stiffness for the composite housing design.

TABLE I. MINIMUM DESIGN MARGINS OF SAFETY				
Item	Load Condition	Type of Stress	Margin of Safety	Appendix II Page
Cylinder Wall	II	Compression	+0.96	98
Cylinder Wall	II	Tension	+1.30	99
Cylinder Wall	II	Shear	+0.69	101
Cylinder Wall at Lower Flange	II	Tension	+0.52	118
Main Drive Bearing Support	I	Tension	+1.18	130
Main Drive Bearing Support Adhesive	I	Shear	+1.08	132

TABLE II. PREDICTED PERCENT INCREASE IN DESIGN STIFFNESS

Item	Bending Stiffness (EI)	Axial Stiffness (AE)	Shear Stiffness (Gt)	Appendix II Page
Cylinder Wall	-	51	71	96
Lower Flange	54	-	-	108
Upper Flange	52	-	-	120
Main Drive Bearing Support	274	42	-	124
Main Drive Internal Bearing Support	189	42	-	135
Auxiliary Bearing Supports	1510	51	-	137
Base Disc Spoke	132	121	-	140

MATERIAL AND PROCESS SELECTION

The material selection task involved the selection of the following four materials:

Fiber Reinforcement
Resin Matrix
Short Random Fiber Bulk Molding Compound
Adhesive

Since the primary objective of the program was to obtain a transmission housing having increased stiffness, the selection of the fiber reinforcement was confined to those which exhibit high elastic modulus properties. Essentially, the selection was between boron or graphite fiber reinforcements. The boron fiber reinforcement was eliminated due to the complex configuration of the component which made fabrication from boron composite material impractical. This narrowed the selection to a graphite fiber, with the task being to select one from the many which are available. Modmor Type I fiber with an elastic modulus of 55-65 x 10^6 ksi and a tensile strength of 200-300 ksi was selected for utilization on the housing. The selection was based on the high modulus obtainable in a composite combined with a reasonable level of strength. Of secondary consideration was experience at WRD in the handling and use of the Type I fiber.

The selection of the matrix resin system had as primary considerations property retention at 350°F, room-temperature shelf life of the prepreg material, and resistance to transmission fluid at elevated temperature. The resin system selected was Narmco's 5208. Mechanical property data for laminates based on 5208/Modmor I are shown in Table III. The long-term elevated temperature test in air and transmission fluid was performed at 220°F, since this is a normal operating temperature. The 350°F temperature condition is experienced only for a short-term duration under adverse operating conditions.

A major consideration in the selection of the Modmor Type I/5208 was its long-term stability in prepreg form at room-temperature conditions. The layup time required for the prototype transmission housing was in excess of two weeks.

U.S. Polymeric's EC-7302 epoxy/glass bulk molding compound exhibited good strength retention to 350°F (Table IV) and good molding characteristics. In addition, it could readily be drilled and taped to accept threaded studs. These factors led to its selection for the molded bearing inserts.

TABLE III. PROPERTIES OF MODULITE 5208 TYPE I UNIDIRECTIONAL LAMINATES*

Property	Test Temperature	Prior Conditioning	Strength (psi x 10^3)	Modulus (psi x 10^6)
Tension	RT	None	143.7	26.4
	220°F	None	147.3	28.4
	350°F	None	139.0	27.3
Compression	RT	None	105.3	31.8
	220°F	None	86.3	29.0
	350°F	None	90.8	32.0
Flexure	RT	200 hr in transmission oil @ 220°F	148.7	22.8
Flexure	RT	None	157.1	24.5
	220°F	None	136.9	24.7
	350°F	None	136.6	25.6
Flexure	RT	100 hr @ 220°F	150.4	25.4
	220°F	"	133.3	26.0
	350°F	"	129.3	24.6

*Cure Schedule:

1. 275°F for 75 minutes in vacuum bag at 3 in. Hg pressure.
2. 350°F for 2 hours @ 50 psi autoclave pressure.
3. 375°F for 4 hours.

TABLE IV. PROPERTIES OF EM 7302 EPOXY/GLASS BULK MOLDING COMPOUND*

Property	Test Temperature	Strength (psi x 10^3)	Modulus (psi x 10^6)
Flexure	RT	39.0	2.4
	220°F	36.4	2.3
	350°F	23.6	1.5
Shear	RT	7.0	-
	220°F	5.3	-
	350°F	3.6	

* Panels pressed at 320°F x 1000 psi x 20 min. Postcure 3 hr at 325°F.

For the adhesive bonding of various components of the assembly, a paste adhesive which could be cured initially at room temperature was desirable. Hysol's EA 934 met these requirements and gave high-strength bonds at 350°F (Table V).

TABLE V. PROPERTIES OF EA 934 EPOXY ADHESIVE WITH CARBON COMPOSITE ADHERENDS*

Property	Test Temperature	Strength (psi x 10^3)
Tensile Shear	RT	1.5**
	350°F	8.4

*Modulite 5208 Type I cured at RT x 24 hr x 28 in. Hg. Postcure 3 hr x 350°F.

** Failures in adherends.

The fabrication process selected for the transmission housing was autoclave molding in a female mold. Autoclave molding was considered the most practical fabrication method in that the housings were experimental prototypes and therefore did not warrant expensive tooling which might have been considered otherwise.

HOUSING CONSTRUCTION

Tooling

The limited number of assemblies which were to be fabricated and the complex configuration of these details were pertinent factors in the selection of glass-reinforced plastic for tooling material rather than metal. Two basic tools were required: one to fabricate the cover plate and the second to fabricate the housing shell. A third tool was required to fabricate the internal bearing mount. This tool was machined from an aluminum billet because of its rather simple geometry. The tools are shown in Figures 15, 16, and 17.

The tool for the fabrication of the base cover was a one-piece female mold which formed the intricate shape of the cover plate. The tool for the fabrication of the transmission housing shell was a three-piece segmented design which formed the outside surface of the housing and located the three bearing inserts. The mold was made in three pieces to facilitate removal from the cured graphite/epoxy housing. The mating surfaces of the three mold sections were held together by locating dowel pins and bolts.

Fabrication

Two complete transmission case assemblies were fabricated. While the two cases contain some differences in the number of plies and ply orientations, the basic fabrication process was the same. The case assembly was made up of three subassembled details. These were the main case housing, the base disc cover, and the inner bearing mount. Other details, such as bearing inserts which were prefabricated and installed during layup of the case, were molded from an epoxy/chopped glass fiber compound. Details added to the case during the final assembly included the bearing races and the attachment lug inserts. The following discussion of the fabrication process includes fabrication of individual elements, assembly, and machining.

Bearing Inserts

The bearing inserts consisted of an epoxy/chopped glass fiber molding with sleeves of unidirectional graphite composite on the inside and outside diameters. With the exception of the bearing insert for the main drive shaft, which was horseshoe shaped, the other three bearing inserts were circular. They were prepared by machining molded billets of epoxy/chopped glass fiber to the proper dimensions. The inner and outer sleeves were prepared by wrapping unidirectional graphite fiber prepreg tape on aluminum mandrels to the desired thickness. The sleeves were machined as necessary to fit the molded insert. Mating surfaces of the sleeves and the molded insert were sandblasted and assembled together by bonding with EA 934 adhesive. The bonded detail was final machined on the outside surface prior to installation.

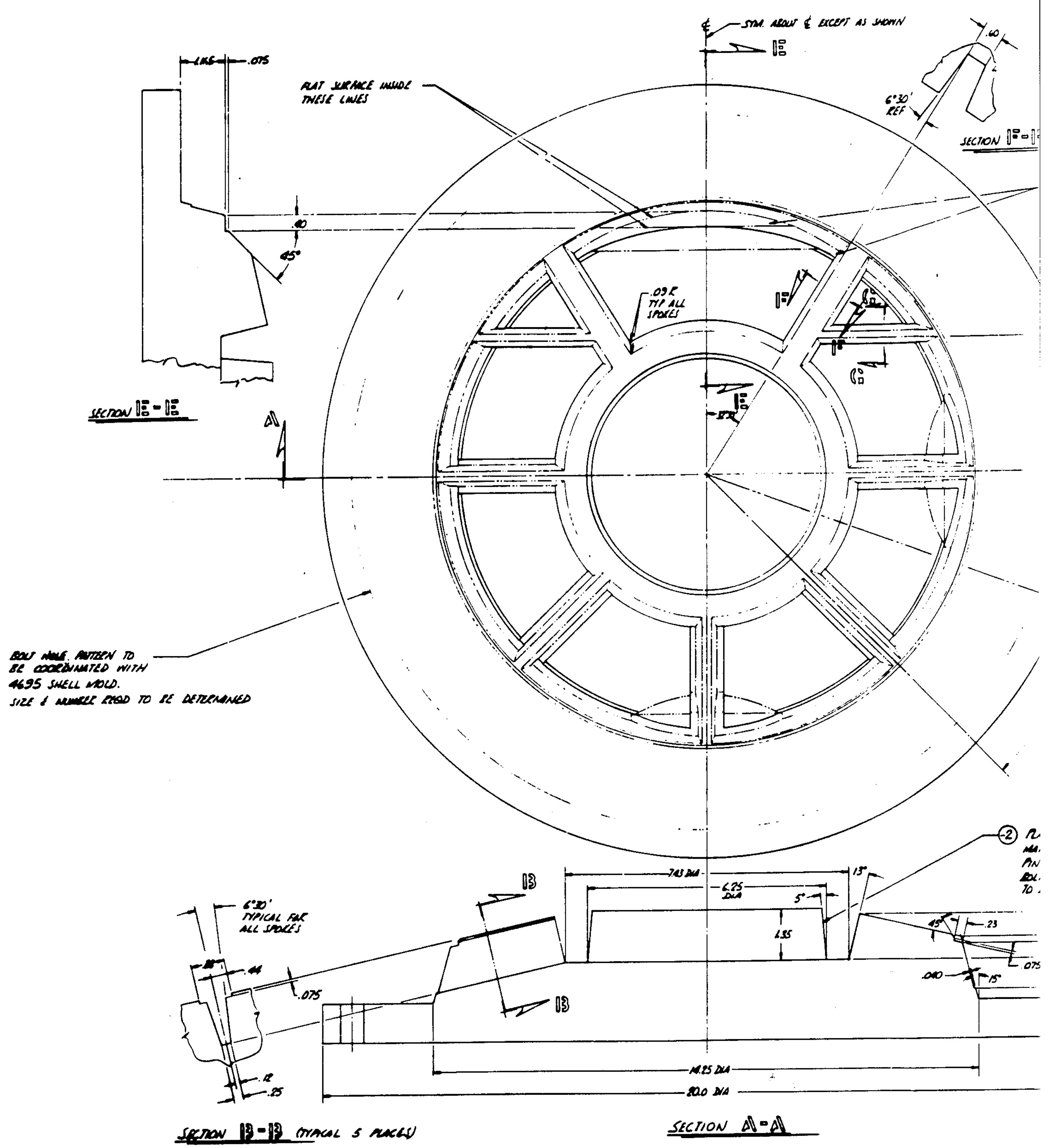
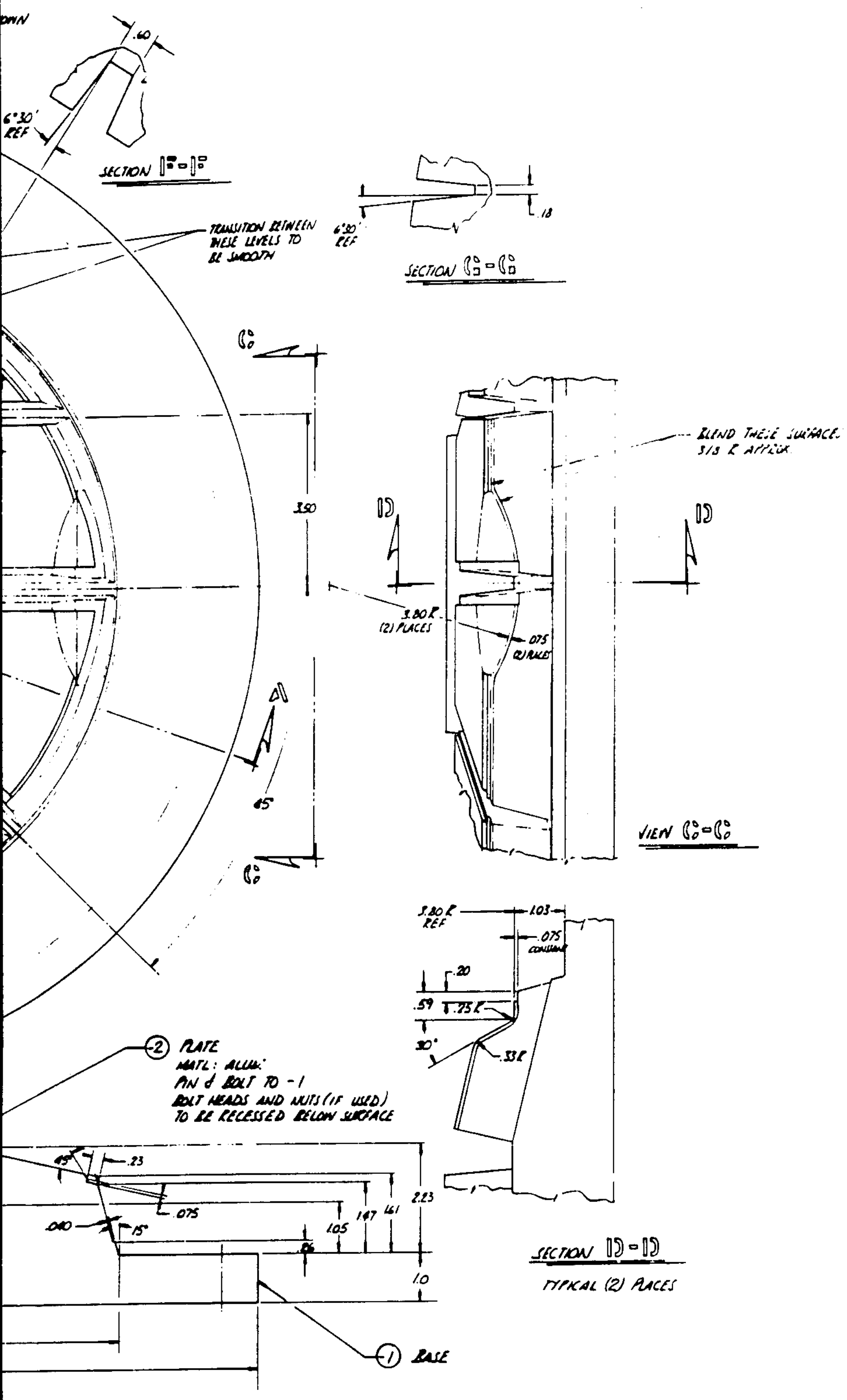


Figure 15. Base Disc Mold - Helicopter Transmission Housing (WRD Drawing No. 4696).



NOTES:

1. MATERIAL FOR -1 BASE:
   120, 181 OR 1000 STYLE FIBERGLASS WITH 52 B/ 954 TOOLING RESIN OR EQUIV.

   ALTERNATE MATL: ALUM.

2. EXCEPT AS NOTED CORNER AND FILLET RADII TO BE .03.

-1 MOLD ASSY	
	BASE DISC MOLD - HELMHOLTZ TRANSMISSION HOUSINGS
NONR-71-C-0053	4696

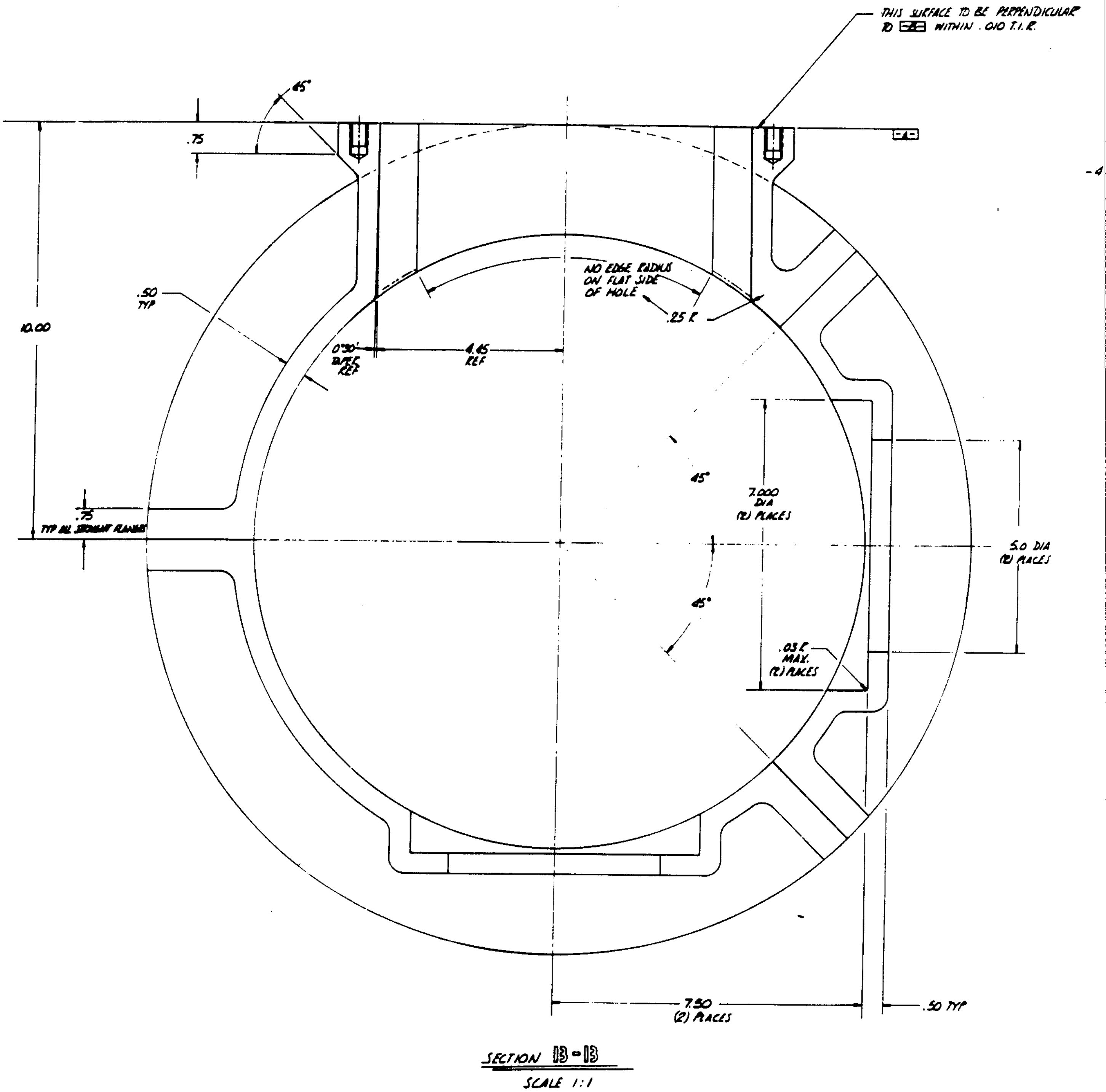
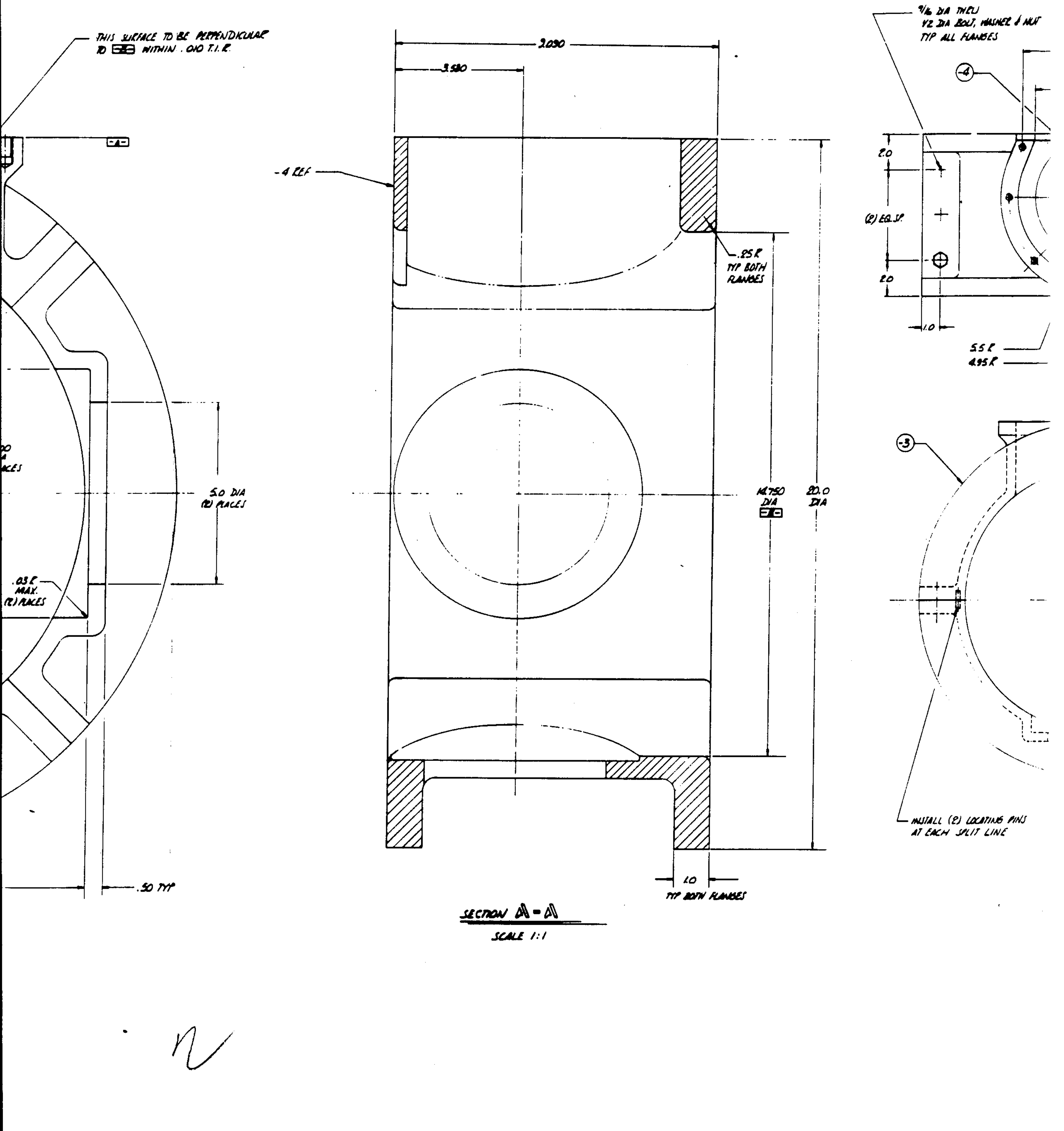
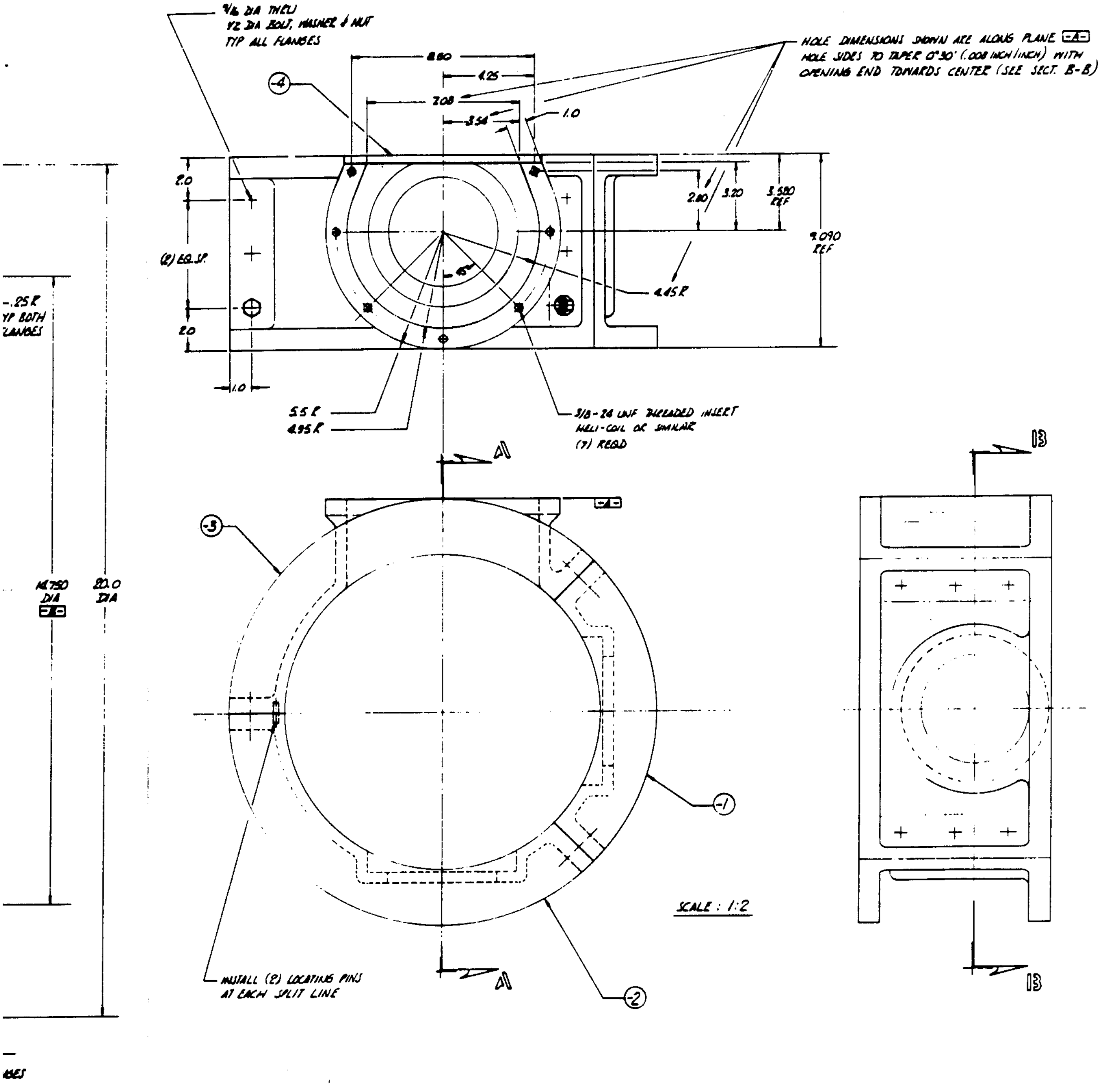


Figure 16. Shell Mold Assembly - Helicopter Transmission Housing (WRD Drawing No. 4695).


THIS SURFACE TO BE PERPENDICULAR TO -A- WITHIN .010 T.I.R.
5.0 DIA (2) PLACES
.03 R MAX. (2) PLACES
.50 TYP
2090
3.580
-4 REF
.25 R TYP BOTH FLANGES
14.750 DIA
20.0 DIA
1.0 TYP BOTH FLANGES
SECTION A-A
SCALE 1:1
9/16 DIA THRU
1/2 DIA BOLT, WASHER & NUT
TYP ALL FLANGES
-4
2.0
(2) EQ. SP.
2.0
1.0
5.5 R
4.95 R
-3
INSTALL (2) LOCATING PINS AT EACH SPLIT LINE

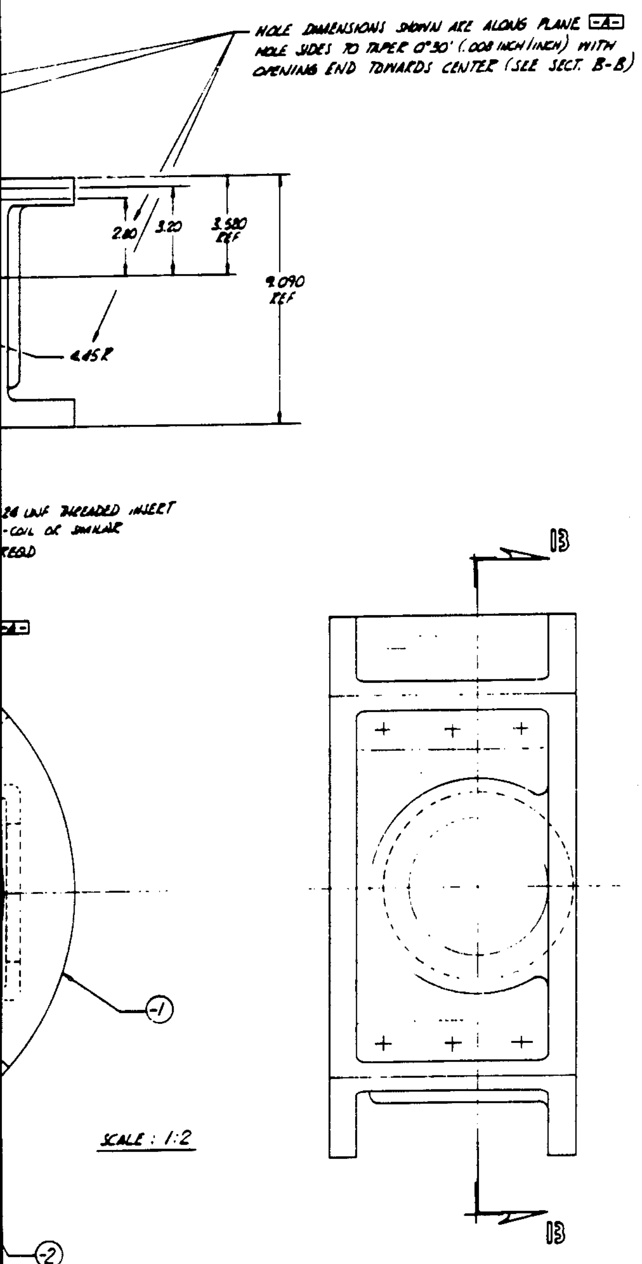


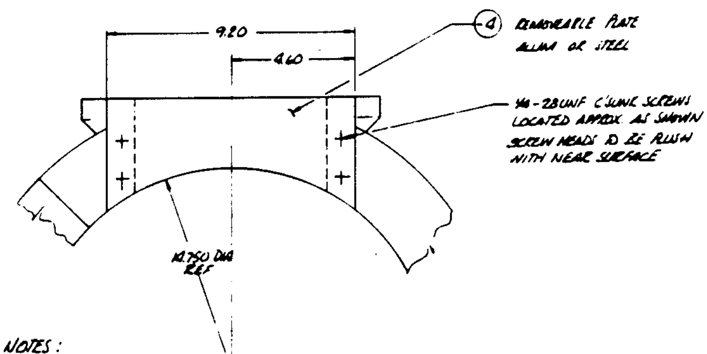
NOTES :

1. M

2. E

3. U





NOTES:

1. MATERIAL FOR -1, -2 & -3 :
   120, 181 OR 1000 STYLE FIBERGLASS WITH 52 B / 954 TOOLING RESIN OR EQUIV.
2. EXCEPT AS NOTED, FILLET RADII TO BE .38
3. USE THIS TOOL TO MAKE 4691 SHELL ASSY

-0 MOLD ASSY

SHELL MOLD ASSY-
HELICOPTER TRANSMISSION HOUSINGS

R

4695

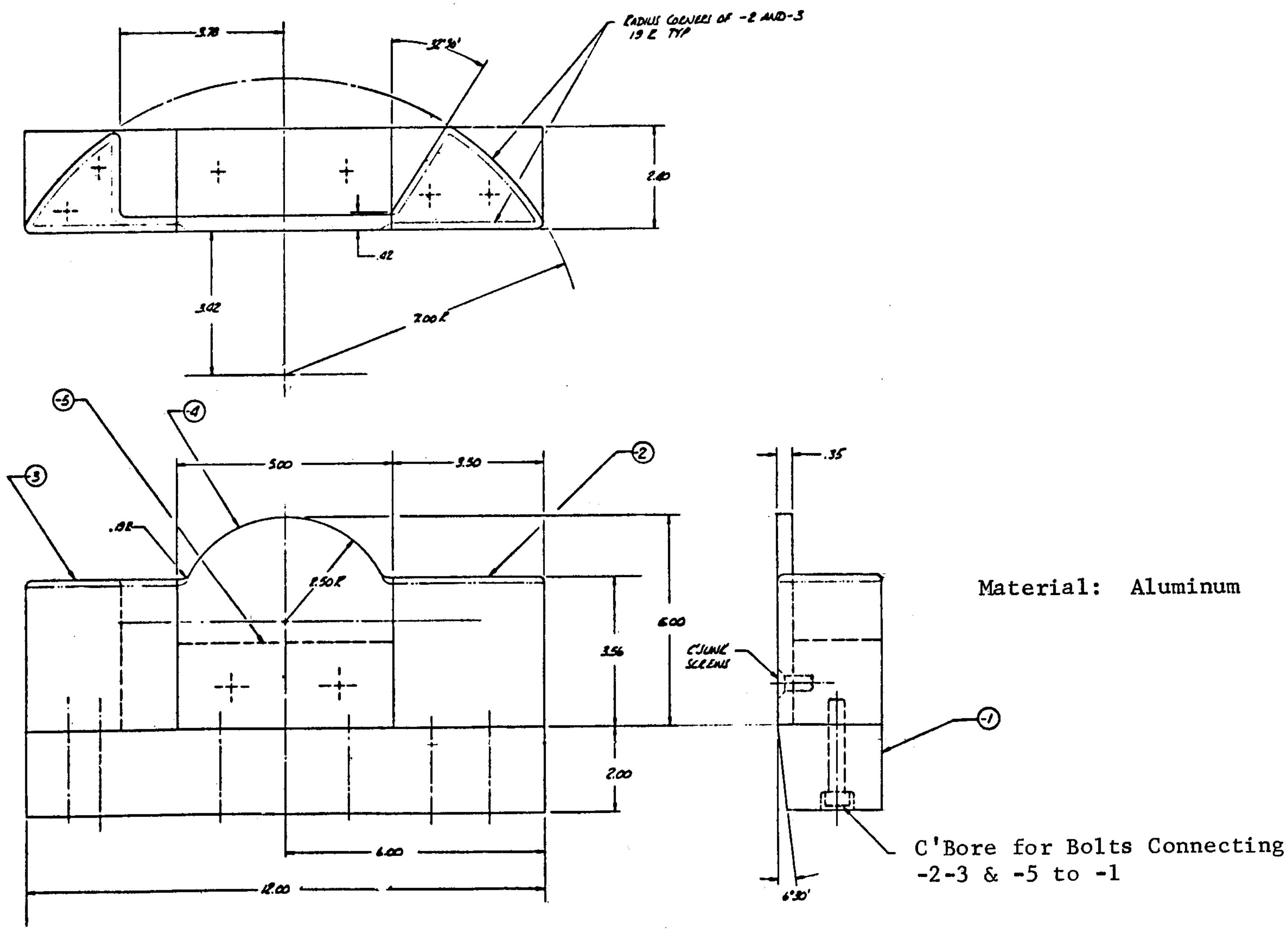


Figure 17. Layup Tool, Internal Bearing Support - Helicopter Transmission Housing (WRD Drawing No. 4713).

Transmission Case Housing

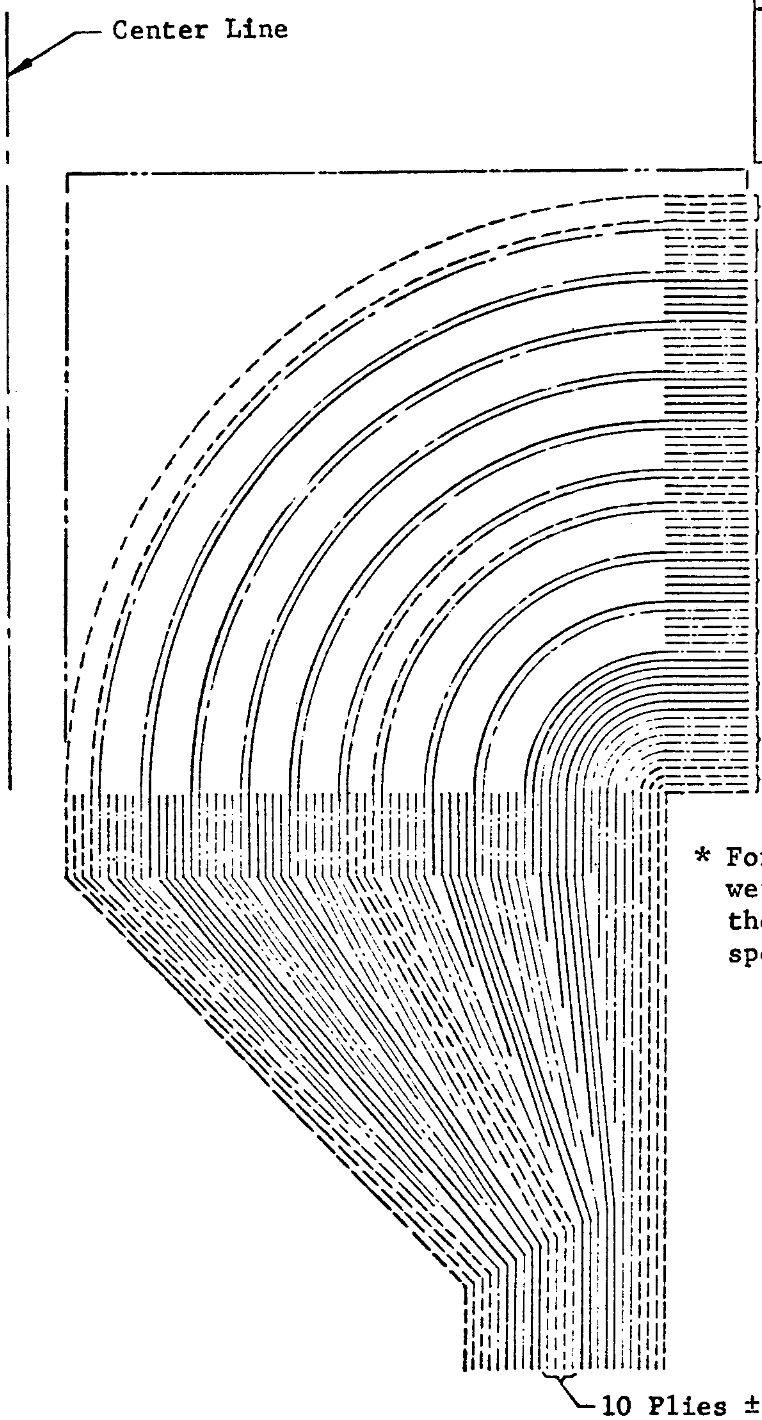
On S/N 1 housing, the prefabricated bearing inserts were positioned into the mold recesses prior to layup. With the bearing inserts in place, the graphite fiber prepreg was applied manually per the layup sequence and orientations specified (Figures 18 and 19). As illustrated, there are wall thickness variations from the midwall to the flange. The staggered wall thickness presented a problem of maintaining a smooth, unwrinkled layup due to the bulk factor of the thick sections. To prevent the fiber distortion in the thicker areas, several debulking cycles under vacuum bag pressure and at a temperature of approximately 150°F were performed during the layup.

The radial and 45° oriented plies were carried continuously from the flange through the wall out to the opposite flange. The hoop plies were laid up on the tool in two different configurations. The inner housing wall was laid up from the 3-inch-wide tape prepreg (Figures 20 and 21). However, the wide prepreg tape could not be used for the hoop plies in the flange. Instead, ring-shaped prepreg preforms were prepared by filament winding continuous graphite fibers. The bulkiness of these preforms, however, contributed to some distortion at the wall/flange transition area.

After the housing layup was completed, a final precompaction cycle was performed and measurements were made to assure that sufficient material was available in the flange and wall buildup areas. At that time it was noted that the total flange thickness was 0.200 inch greater than expected. This was later determined to be due to excessive thickness of the six circumferential plies which were prepared from filament-wound preforms.

The housing layup was cured using vacuum bag autoclave techniques. Due to the very complex contour of the layup, a double bag was used to decrease chances of leaks through the vacuum bag plastic. The part was cured at 95 psi and 350°F for a period of 2 hours. After cure, the housing was allowed to cool to room temperature under pressure prior to bag removal. The bag and bleeder material were removed from the part and the mold tool was disassembled. No difficulties were encountered during the removal of the tool from the cured housing.

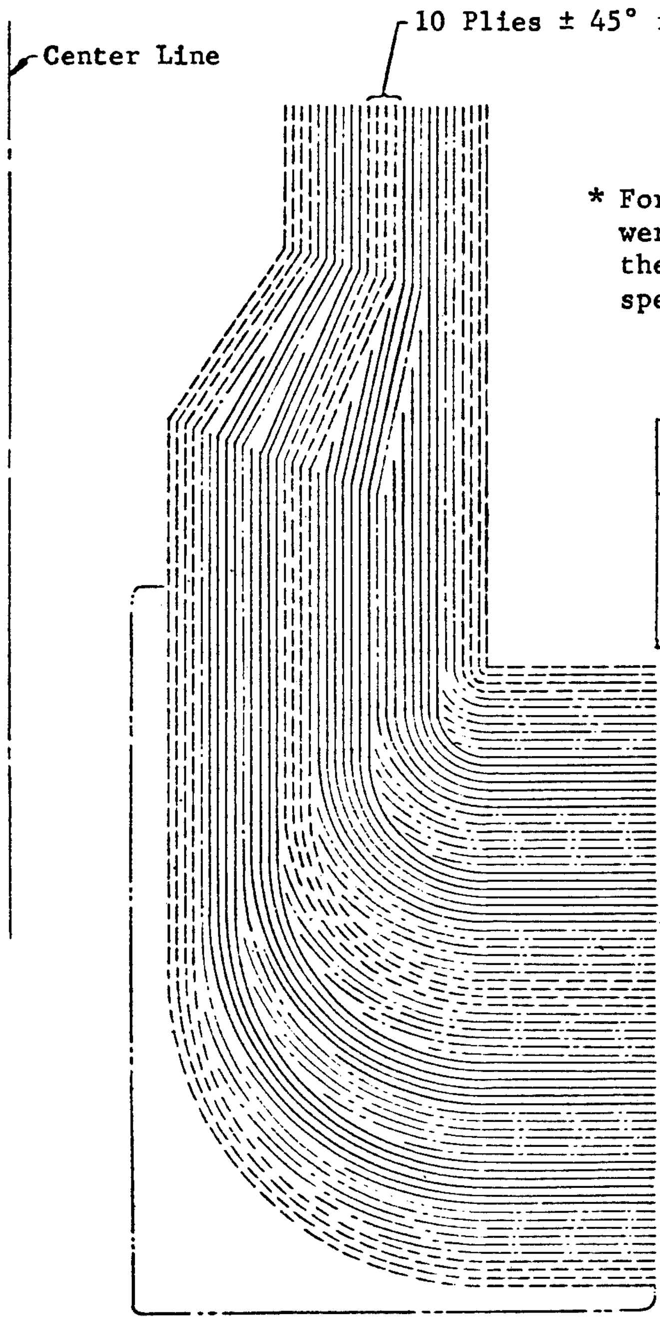
After the excess resin flash was removed from the cured housing, measurements were made to determine wall and flange thicknesses. The inner wall thicknesses were found to be slightly less than design requirements. The thicker buildup areas at the upper and lower portions of the housing wall were thinner than specified on the drawing, while the flange thicknesses were approximately 0.150 inch greater than the drawing dimensions. To compensate for the thinner portion of the housing wall at the flange/wall intersection, a secondary layup was made in this local area. This increased the thickness sufficient to accept the base disc cover plate.



No. Plies			
Per Dwg	S/N 1	S/N 2	Fiber Orientation
4	-*	4	± 45°
6	-*		Hoop
6	-*	16 Rad	Rad
6	-*		Hoop
6	6	6	Rad
6	*	6	Hoop
4	4	10	± 45°
6	*	6	Hoop
6	6	6	Rad
6	*	6	Hoop
7	7	7	Rad
6	*	6	Hoop
4	4	4	± 45°

* For S/N 1 the outer layers were deleted because of the use of thicker than specified wound hoop rings.

Figure 18. Fiber Layup Schedule for Upper Flange, Showing Difference Between S/N 1 and S/N 2.



* For S/N 1 the outer layers were deleted because of the use of thicker than specified wound hoop rings.

No. Plies			Fiber Orientation
Per Dwg	S/N 1	S/N 2	
4	4	4	± 45°
7	*	7	Hoop
7	7	7	Rad
7	*	7	Hoop
7	7	7	Rad
6	*	6	Hoop
4	4	10	± 45°
6	*	6	Hoop
6	6	6	Rad
6	-*		Hoop
6	-*	16 Rad	Rad
6	-*		Hoop
4	-*	4	± 45°

Figure 19. Fiber Layup Schedule for Lower Flange, Showing Difference Between S/N 1 and S/N 2.

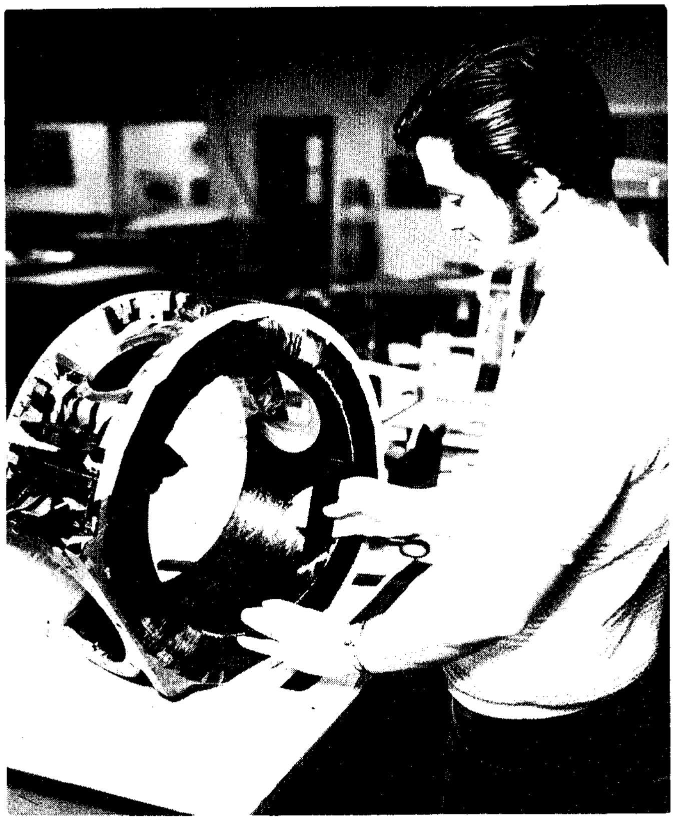


Figure 20. Layup of Circumferential Tape in the Barrel Section of the Transmission Housing.

Figure 21. Tailoring of the Tape To Fit Around the Molded Bearing Inserts.

At the same time the extra buildup was added to the flange/wall area, prepreg plies were applied to the wall/bearing insert area and are in accordance with the design. These two layups were cured simultaneously in a vacuum bag under 95 psi pressure.

The next step in the fabrication of the housing was the machining of the flange and mating surfaces for the base disc ring and the inner bearing mount. However, this was not accomplished until the two pre-assembled details were fabricated and their actual dimensions used to assure that the mating surfaces would align properly.

As a result of tests conducted on S/N 1 housing, design modifications were made and incorporated into the fabrication process of the S/N 2 housing. Also, unlike S/N 1 procedures, the bearing inserts were not installed into S/N 2 housing until one-half of the layup had been completed. This change was made to simplify the layup of the case wall. Figures 18 and 19 show the modifications made in the number of plies and orientations used in the S/N 2 housing. Figure 22 shows the additional buildup that was applied to the outside of the housing at the flange/wall area in a secondary layup and cure operation.

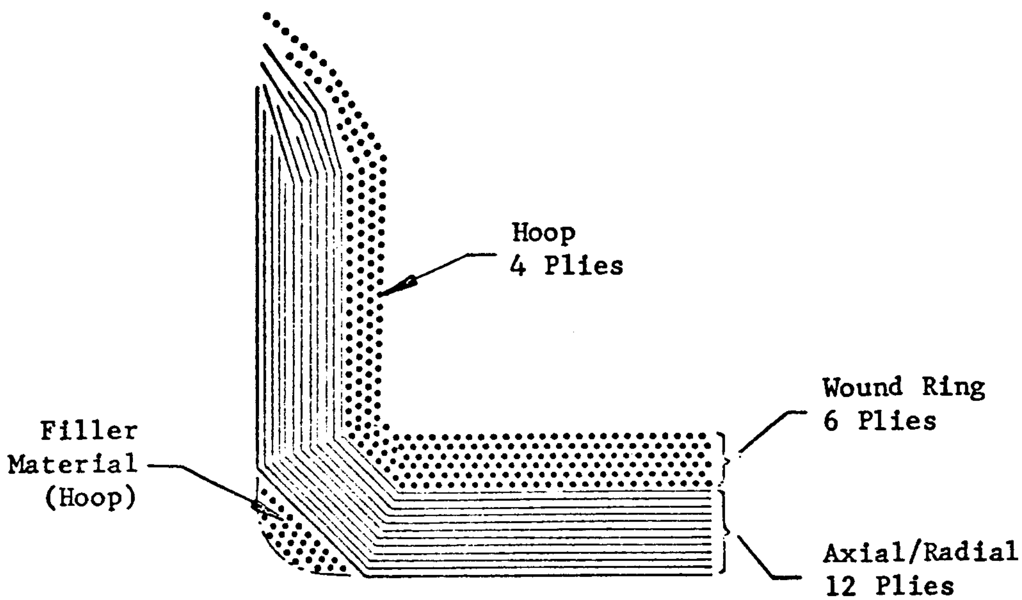
Inner Bearing Mount

During the conceptual design phase it was planned to lay up the inner bearing mount from graphite prepreg directly onto the inner surface of the cured housing wall. To accomplish this,it was planned to prepare wash-out mandrels to form the contour of the inner bearing mount. Due to the close-tolerance dimensional requirements and the overall complexity of the inner bearing mount design, it was later determined that a better approach was to fabricate a cured subassembly and secondarily bond it to the inner housing wall.

The layup of the graphite/epoxy prepreg was done manually and was completed in one step (Figure 23). Vacuum bag autoclave cure techniques were used to cure the bearing mount element. After cure, the part was removed from the aluminum tooling and trimmed to final size prior to installation in the housing. Some removal of localized material was required to achieve an acceptable fit of the inner bearing mount between the cover plate and the housing wall.

Bearing Support Base Plate

The bearing support base plate was laid up manually in a female tool from prepreg tape. Continuous plies were laid against the mold surface and the surface which is exposed. The interior of these sections consisted of short chopped fiber material obtained from the prepreg salvage. After completion of the layup, the part was autoclave cured at 95 psi and 350°F. Figure 24 shows the bagged layup after removal from the autoclave, and Figure 25 shows the part after removal from the mold.



Layup Schedule

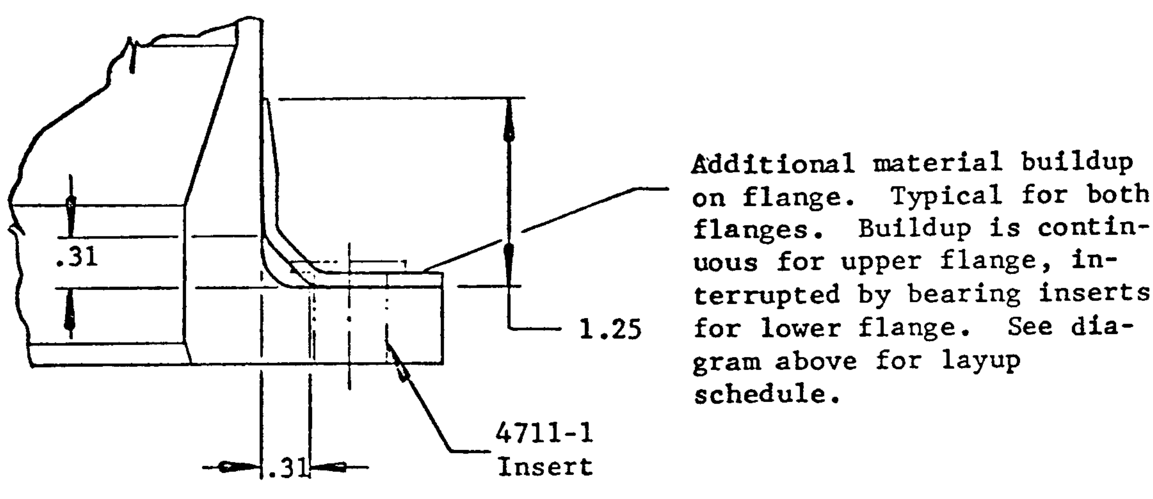


Figure 22. Modification of Exterior of Flange on S/N 2.

Figure 23. Layup of the Internal Bearing Support Component.

Figure 24. Bagged Wheel-Shaped Bearing Support After Removal From Autoclave Cure.

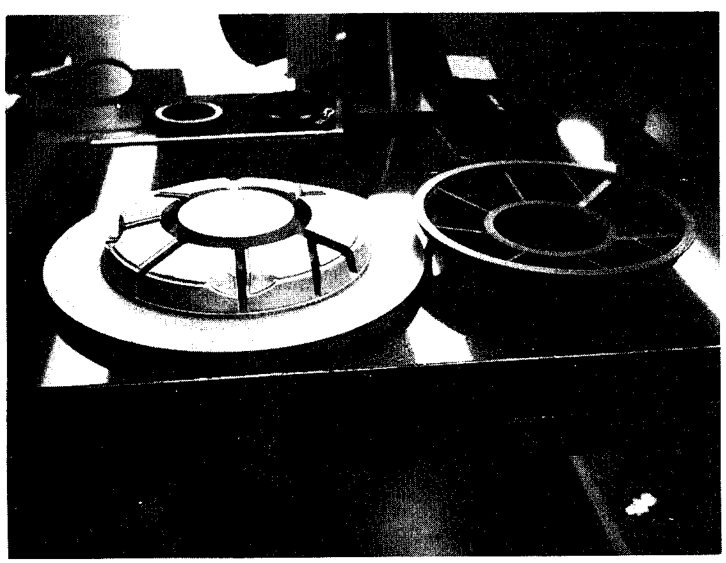


Figure 25. Cured Bearing Support Base Plate and Glass/Epoxy Tool.

Machining

All machining operations were accomplished by grinding with an aluminum oxide grinding wheel mounted in a horizontal milling machine. The first machining step involved grinding the flange surfaces. This was required to accurately position and locate the base disc cover.

The second machining step involved the grinding of the outside diameters of the top and bottom flanges on the gear case housing. These diameters were made true to the outer diameter of the housing case which was formed by the layup tool. Having established this diameter and the flange thickness, the 4° tapered surfaces were machined on the inside of the gear housing and on the outside of the base disc cover for the eventual mating and assembly of these two parts (Figures 26 and 27).

The third machining operation involved the rough machining of the remainder of the assembled gear housing and was performed on S/N 1 case only. In this step, the bearing support faces were ground to dimension, as well as the bearing insert hole and the base disc cover. Case S/N 2 was left oversize in all areas to be final machined prior to installation into a transmission case test rig.

Assembly

The assembly of the housing shell, base disc cover, and inner bearing mount was accomplished by secondary adhesive bonding. Each of the three details was prefit and measured for dimensional accuracy prior to bonding.

The first step in the assembly was the bonding of the base disc cover to the housing shell. Mating surfaces were lightly sandblasted prior to the application of EA 934 epoxy adhesive. An ample quantity of the adhesive was applied to both surfaces to assure that all interfaces were completely coated and that no voids existed in the glue line. After the assembly of the two details, the excess adhesive was removed from the edges of the mating interface. The part was then clamped and allowed to cure for 16 hours at room temperature. An additional post-cure in an air-circulating oven for 2 hours at 200°F completed the cure of the adhesive.

The second bonding step involved the installation of an inner bearing mount between the base disc ring and the housing wall. After a proper fit was obtained, the bonding of the inner bearing mount was accomplished in the same manner as the base disc cover.

The third bonding operation involved the installation of the oil reservoir cups over the two bearing inserts in the housing wall. After proper fit was obtained, the two reservoir cups were bonded in place.

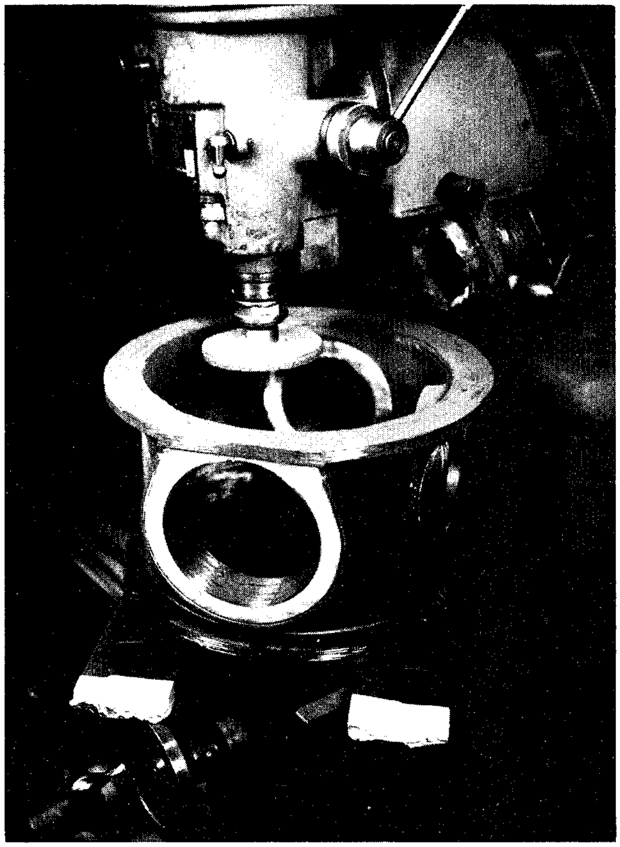
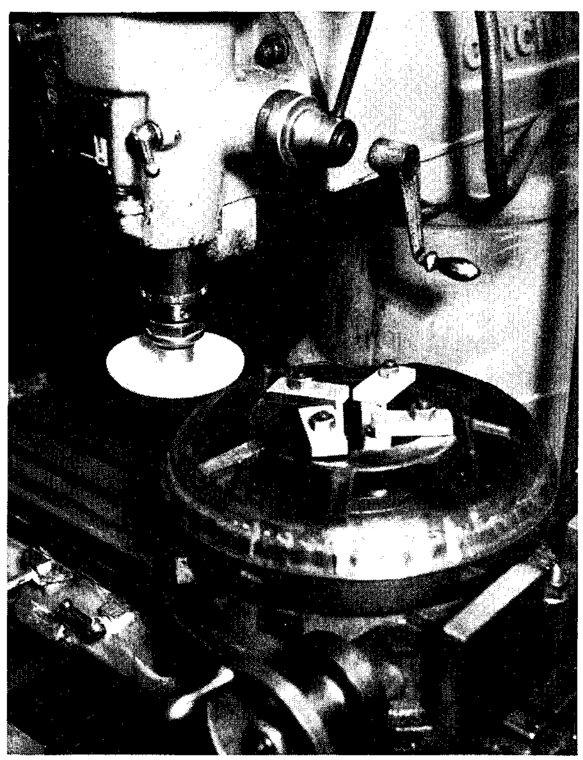
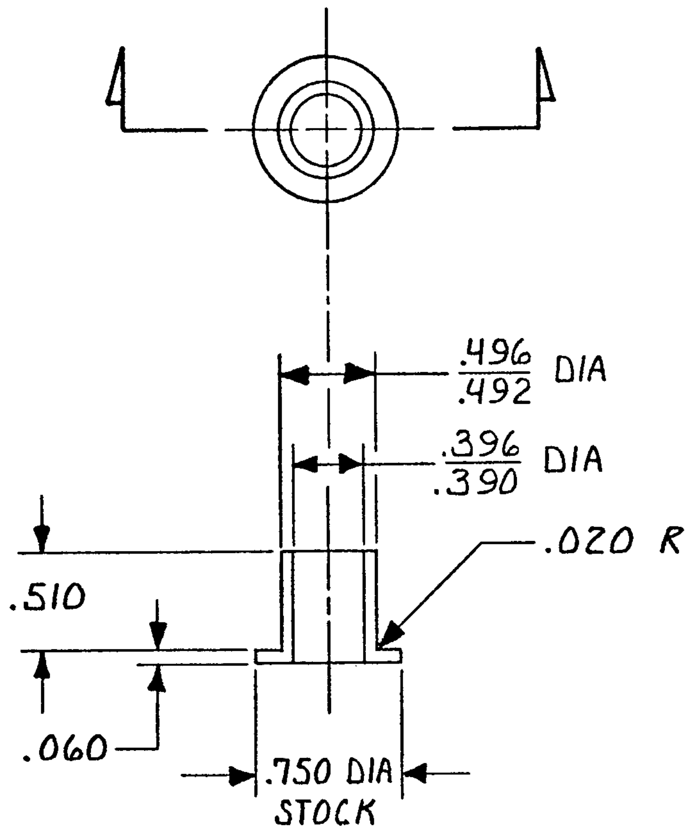


Figure 26. Machining of the Flanged Barrel Section of the Transmission Housing.

Figure 27. Machining of the Wheel-Shaped Bearing Support Base Plate.



The final task in the assembly operation was the installation of the bushings (Figure 28, D/N 4711) in the flange mounting holes and the installation of the bearing inserts in the base disc cover and the inner bearing mount. Also during this final task the glass-reinforced epoxy bulk molding compound bosses located on the external surface of the housing shell were fit and bonded at their proper location. The finished housing is shown in Figure 29.



Finish: Passivate

Material: 303 CRES

Figure 28. Insert, Helicopter Transmission Housing (WRD Drawing No. 4711).

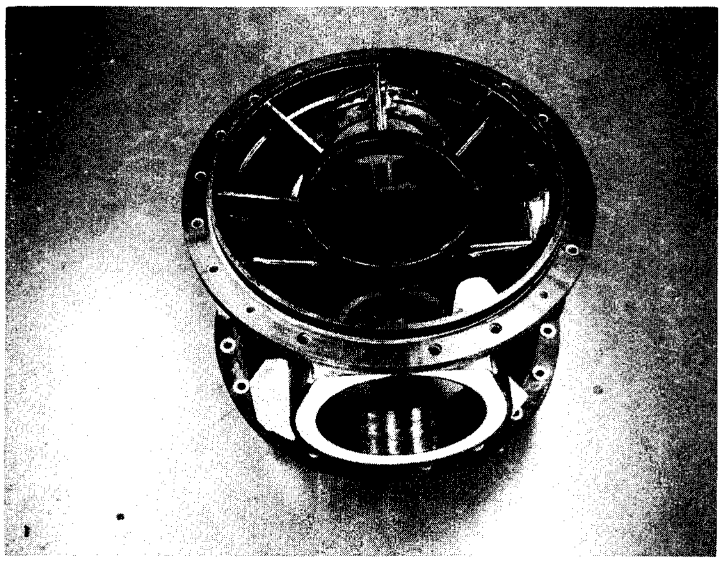


Figure 29. Completed Carbon Composite Transmission Housing.

HOUSING STIFFNESS EVALUATION

Stiffness Tests

Stiffness tests were conducted on the magnesium and on the graphite/epoxy transmission housings. Both the torsional stiffness and the axial tension stiffness were measured at room temperature and at 250°F. In order to compare directly the relative stiffness of the housings, identical fixtures, instrumentation, and test loadings were used. For the axial condition, both flange-to-flange stiffness and the cylindrical body stiffness were measured. Dual strain gage extensometers were calibrated and used for measuring axial extension and torsional rotation. For the body section, two strain gages were bonded to the body of the transmission housing, 5 inches apart. The arrangements for the tests are shown in Figures 30 and 31, respectively. Figures 32 and 33 show the case being tested for torsional and axial tension loading conditions. The cases were loaded to 25% of limit load conditions. Load deflection curves are shown in Figure 34 for room temperature and in Figure 35 for elevated temperature of 250°F.

Comparison Between the Plastic Composite and Metal Housing

For the purpose of stiffness comparison, parameters in the form of spring constants were selected and determined analytically and experimentally. These spring constants are specified by lb/in. of axial elongation, and by in.-lb/rad of torsional rotation. They were determined for the magnesium housing and for the two fabricated graphite composite housings. The values are summarized in Table VI.

After the first composite housing (S/N 1) had been tested, it was found that the stiffness was less than predicted. The axial tension stiffness was especially low. In order to identify reasons, the axial stiffness of the cylindrical section was compared with the total stiffness from flange to flange. It was found that the axial stiffness of the composite cylinder was double that of the magnesium case.

Thus, the main deformation in the composite case was caused by the deflection of the flanges. This deformation was not considered in the analytical predictions, as it was considered negligible. The problem was compounded by the fact that fiber orientation in the flange of S/N 1 deviated from the design requirements. This occurred as a result of excessive thickness per ply for the hoop reinforcement, which made it necessary to remove a number of plies by machining the flange to the required thickness. This in turn changed the overall fiber orientation in the flange.

Case S/N 1 was tested at elevated (250°F) and ambient temperature for torsional stiffness. At the elevated temperature condition, a 23% increase in stiffness over the metal case was measured. It was determined that the ply thickness of the layup in the barrel section of the case was somewhat less than specified in the design. The actual wall thickness of

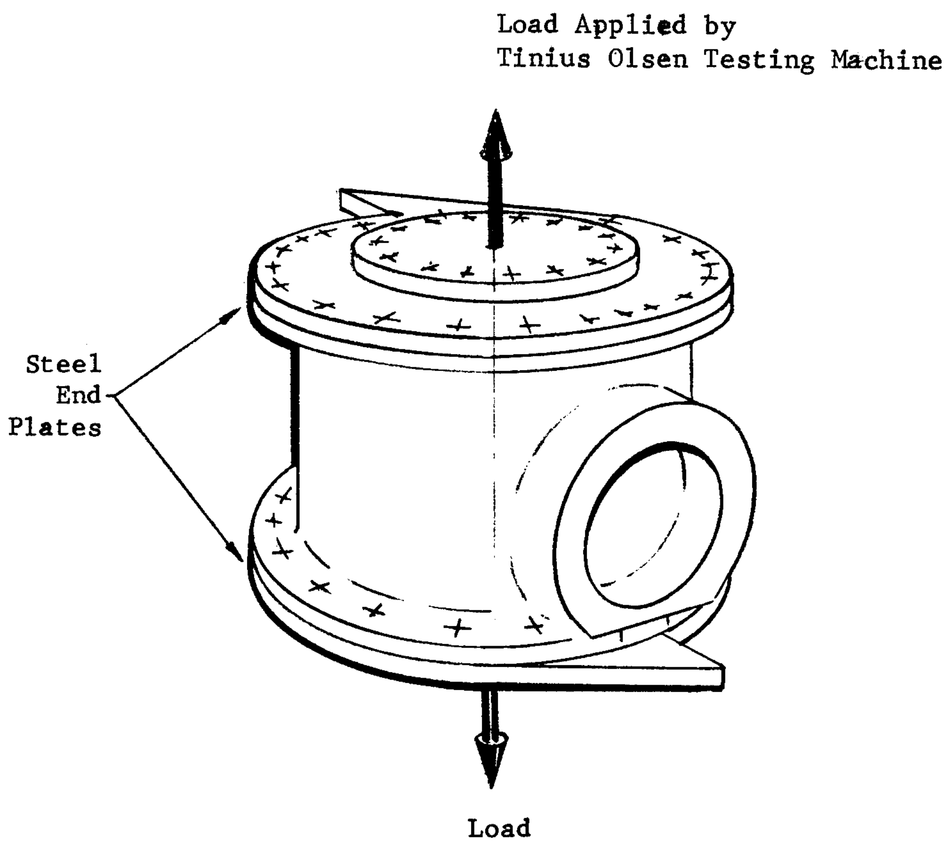


Figure 30. Tension Test.

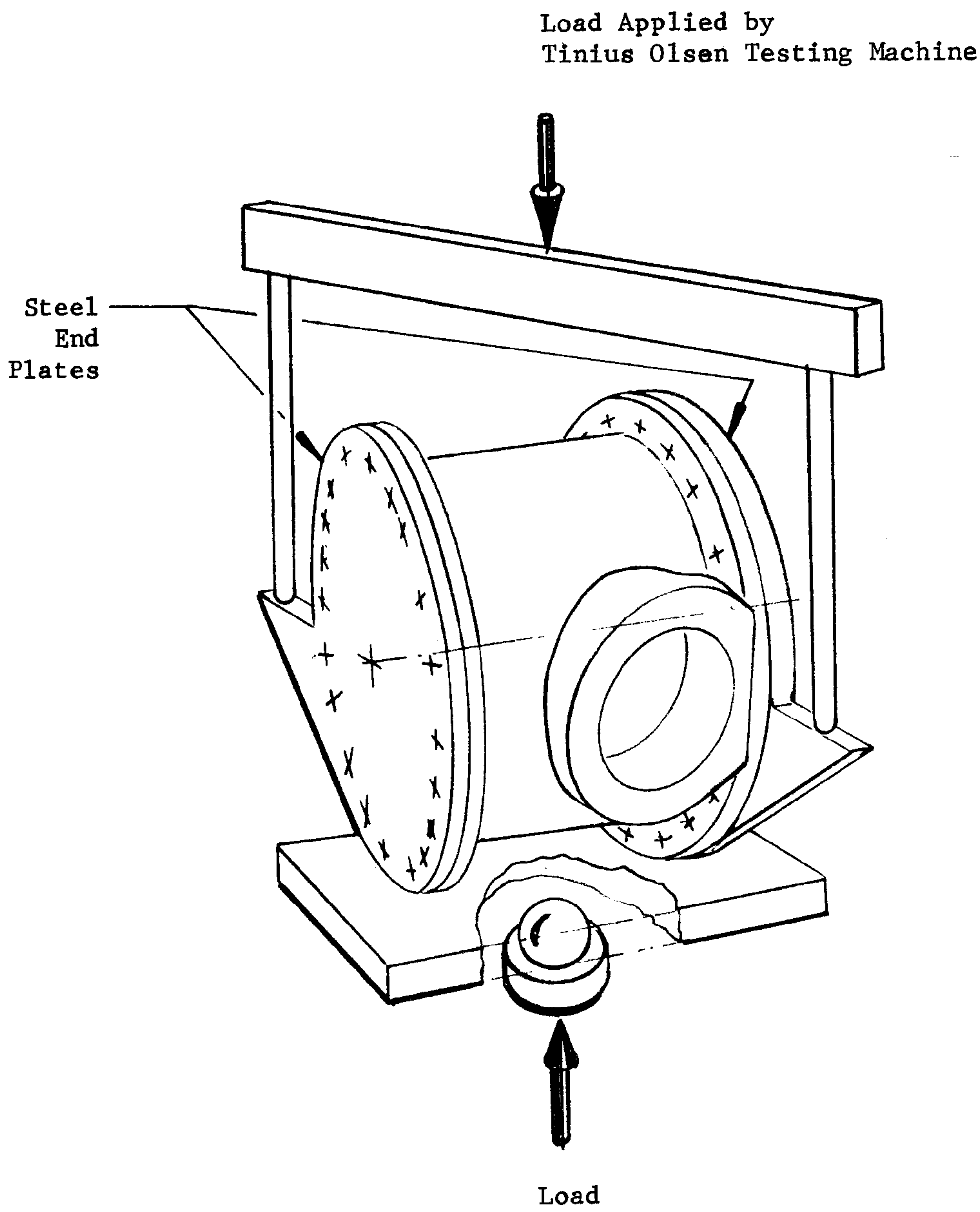


Figure 31. Torsion Test.

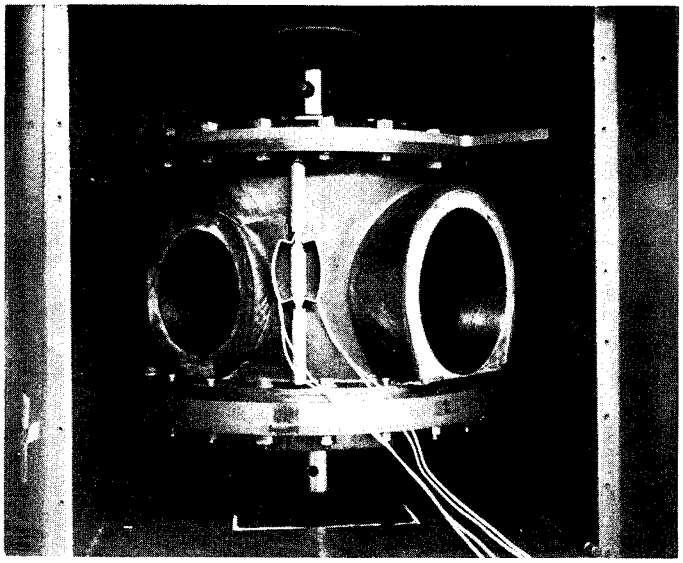


Figure 32. Tension Stiffness Test.

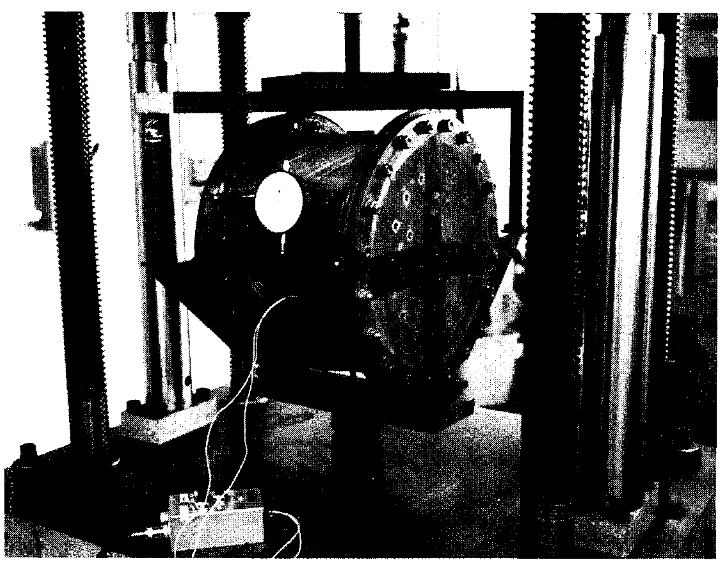


Figure 33. Torsion Stiffness Test.

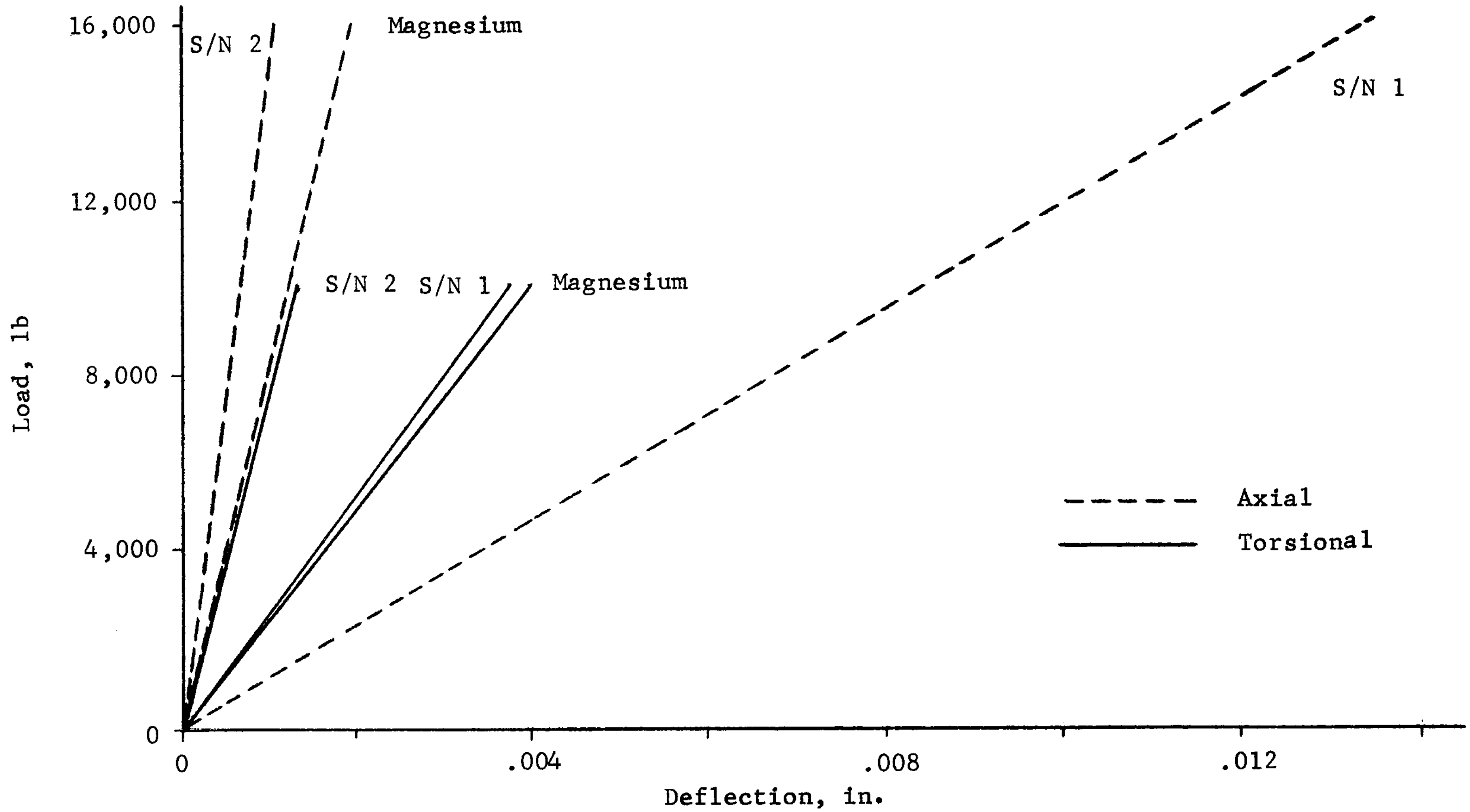


Figure 34. Axial and Torsional Load/Deflection Curves for Transmission Cases at Room Temperature.

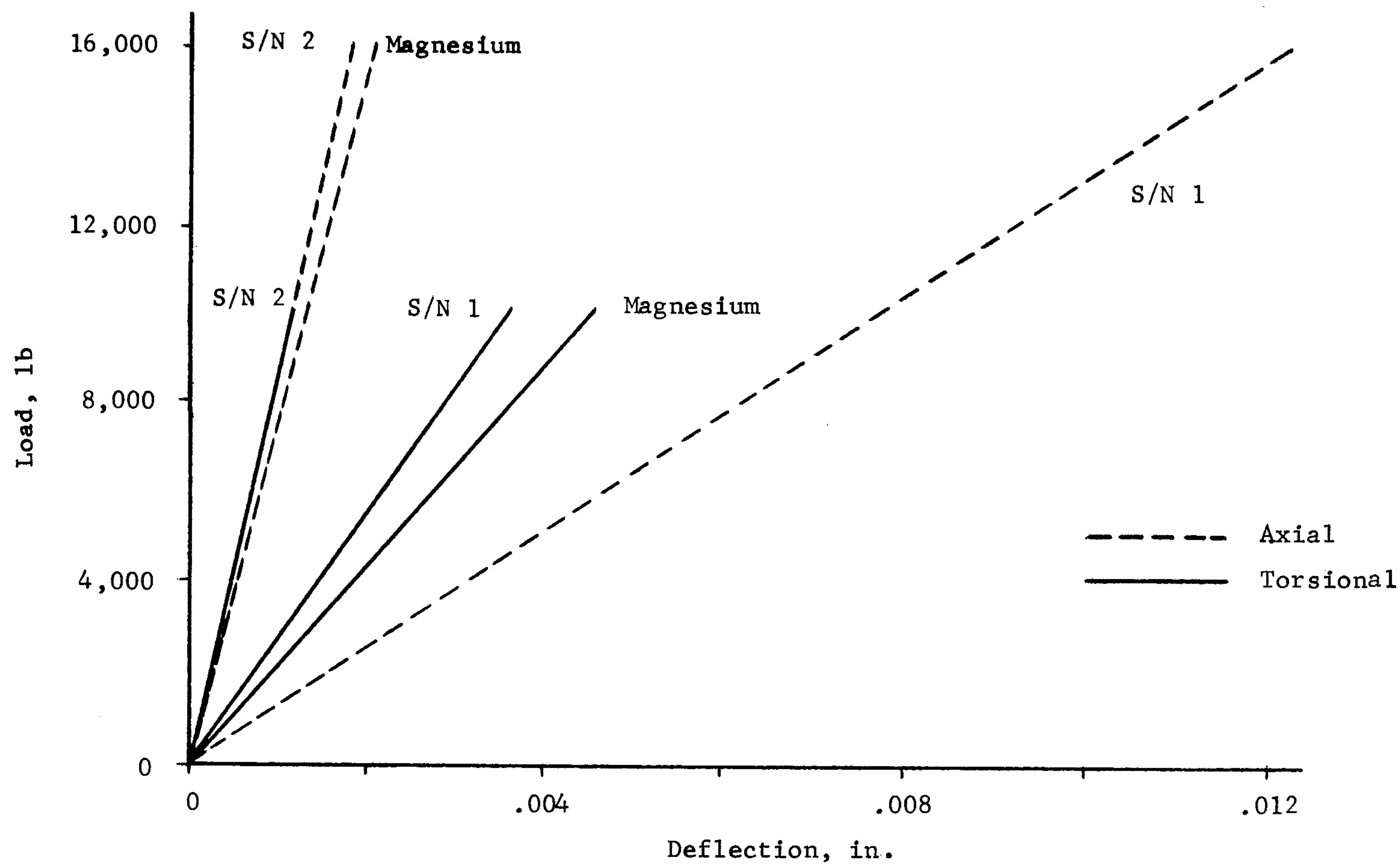


Figure 35. Axial and Torsional Load/Deflection Curves for Transmission Cases at 250°F.

TABLE VI. SPRING CONSTANTS OF TRANSMISSION GEAR HOUSING

Method of Loading	Determined	Spring Constants, 10^6 lb/in. or 10^6 in.-lb/rad			% Change in Stiffness [1]	
		Magnesium Housing	Composite Housing S/N 1	Composite Housing S/N 2	S/N 1	S/N 2
Axial, RT, lb/in. from Flange to Flange [2]	Analyt.	7.2	10.7	-	-	-
	Exper.	7.6	1.2	13.7	-85	+80
Axial, RT, lb/in. Cylindrical Section Only	Analyt.	-	-	-	-	-
	Exper.	9.0	18.2	-	+100	-
Axial, 250°F, lb/in. from Flange to Flange [2]	Analyt.	6.7	10.0	-	-	-
	Exper.	7.6	1.3	8.2	-84	+8
Torsional, RT, in.-lb/rad	Analyt.	140.0	235.1	-	-	-
	Exper.	123.0	130.0	440.0	+6	+256
Torsional, 250°F, in.-lb/rad	Analyt.	126.0	222.0	-	-	-
	Exper.	109.0	137.0	440.0	+25	+300

[1] % Change in stiffness of graphite/epoxy case over magnesium case, experimental average.

[2] The analysis did not include flange bending.

the composite case was 0.165 inch as opposed to 0.190 inch required. Calculations showed that additional material needed to give the required thickness would have resulted in approximately a 33% increase in stiffness over the metal case.

As a result of these tests and their analysis, the second composite housing (S/N 2) was substantially stiffened through the addition of graphite/epoxy material in the flanges and in the cylindrical body.

Tests were then conducted to determine the stiffness of S/N 2. Due to the requirement that the bearing mounting holes not be final machined and the steel ring not be installed in these holes, the deflection at and near these holes was expected to be larger. To prepare a more realistic estimate of the stiffness, three deflection measurements were taken for both axial and torsional stiffness. The gages were placed at three positions, 120° apart, around the circumference of the case.

The results of these tests indicated that the axial stiffness varied around the circumference of the case. If the average stiffness is considered, the composite at room temperature was much stiffer than the magnesium case. If the large deflection due to unreinforced bearing cutout is disregarded and average deflection is used as a basis for stiffness calculation, the composite case was 80% stiffer than the magnesium case.

In the torsion test, another factor complicated the stiffness definition. Since the torque load was introduced to the flange by 17 bolts, the flange load would be uniform only if all 17 bolts were loaded equally. Since some bolts had a closer fit than others, a nonuniform loading resulted. Again the shaft hole, without the steel reinforcing, produced relatively large deflections at one location. Thus, the average of the other two deflections was utilized for calculating stiffness. For torsion, the room-temperature stiffness based on average deflection (neglecting contribution by hole deformation) was 256% greater than the magnesium case. At 250°F the stiffness was approximately identical to the room-temperature values, but was 300% greater than the magnesium case.

Table VI includes the summary of values for the spring constants for the three gear housings investigated and the percentage of actual improvement achieved on the composite housings as compared with the magnesium housing. Since one of the design goals of the program was to achieve a 50% increase in stiffness, comparison of the tabulated data shows that in most cases this design goal has been met. The analysis of the spring constants is presented in Appendix III.

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of fabricating helicopter transmission housings made from graphite materials has been demonstrated by the successful fabrication and testing of two prototype housings. The required improvement in stiffness parameters was achieved and exceeded.

The axial tension loading condition proved the most difficult for obtaining increased housing stiffness through the use of fibrous composite materials. Specifically, the flange area and shaft openings presented problems for keeping deflection down. For case S/N 1, bending of the flange was encountered. For the redesigned case S/N 2, flange bending was eliminated, and the deflections measured were primarily attributed to shear deformation in the flange area. This conclusion is supported by the decrease in stiffness at elevated temperature, indicating resin matrix dependency for this loading condition. Future efforts should examine flange configurations for improved efficiency. It was easier to achieve the improved torsional stiffness.

The simplified stiffness test employed for the composite transmission housing did not consider the combined loading conditions or the reinforcing effects of steel bearing inserts and shafts which will be experienced in actual use. In order to obtain a more accurate picture of the housing's stiffness characteristics in future development efforts, testing should be performed on composite and metal transmission housings in greater detail and depth. This testing should include combined loading conditions, a larger number of strain gages, and fitting the housing with steel bearing inserts, simulated shafting, etc.

The manual layup method employed for fabrication of these prototype transmission cases is time consuming and costly. The development of mechanized fabrication methods and design adjustments to improve the producibility of the housing are recommended.

The prototype transmission case developed under this program is essentially a duplication of the metal configuration. Typically, this approach does not fully utilize the properties of the composite material. Future efforts should be devoted to investigation of design configurations which allow more design freedom and efficient utilization of the composite material.

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2. Walker, R., BASIC TRANSMISSION DIMENSIONAL DATA, Bell Helicopter Company, Fort Worth, Texas, Report 209-099-250, April 30, 1969.

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5. Timoshenko, S., STRENGTH OF MATERIALS, Second Edition, New York, D. Van Nostrand Company, Inc., 1941, pp. 178, 181.

6. Roark, Raymond J., FORMULAS FOR STRESS AND STRAIN, Fourth Edition, New York, McGraw-Hill Book Company, 1965, pp. 302, 178.

7. HYSOL BULLETIN A9-234, Hysol Division of the Dexter Corporation.

APPENDIX I
LOAD ANALYSIS

This appendix includes the following items:

Discussion

Loading Condition I, Sheet No. 1

Distributed Bending Loads, Case Upper Surface, Sheet No. 3

Distributed Axial Loads, Case Upper Surface, Sheet No. 4

Shear Flow, Case Upper Surface, Sheet No. 18

Shear Flow, Case Lower Surface, Sheet No. 5

Distributed Bending Loads, Case Lower Surface, Sheet No. 6

Distributed Axial Loads, Case Lower Surface, Sheet No. 6

Forward Pinion Bearing Loads, Sheet No. 12

Aft Pinion Bearing Loads, Sheet No. 13

Vertical Shaft Lower Bearing Loads, Sheet No. 16

Loading Condition II, Sheet No. 19

Shear Flow, Case Upper Surface, Sheet No. 19

Distributed Bending Loads, Case Upper Surface, Sheet No. 20

Distributed Axial Loads, Case Upper Surface, Sheet No. 20

Shear Flow, Case Lower Surface, Sheet No. 21

Distributed Bending Case Lower Surface, Sheet No. 21

Distributed Axial Case Lower Surface, Sheet No. 21

DISCUSSION

Loads for the composite material helicopter transmission gear housing are obtained from Bell Helicopter Company Report [1]. Two loading conditions are considered:

CONDITION I

Rolling pullout with maximum left tail rotor thrust

CONDITION II

Forward (8g) crash

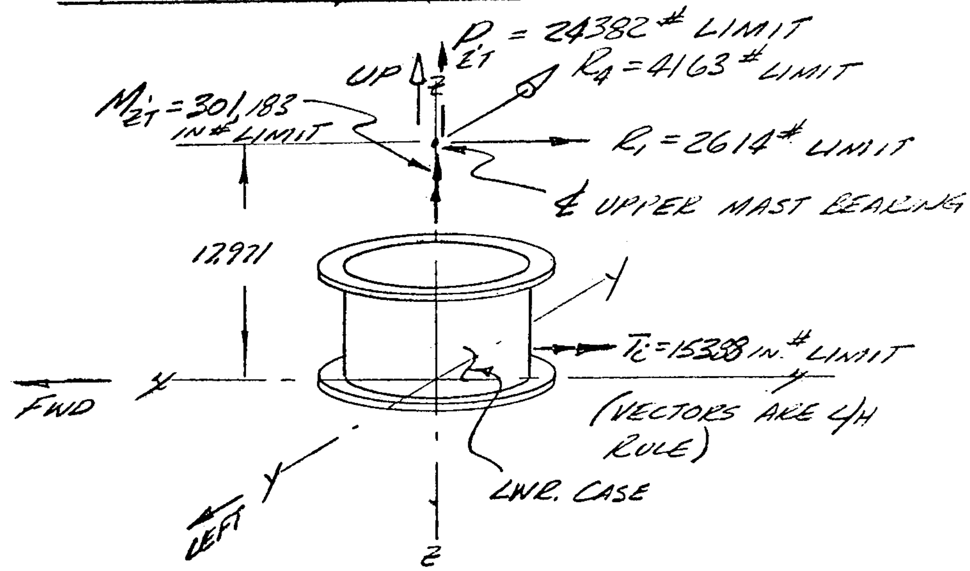
Internal gear loads and bearing loads acting on the case are calculated using data obtained from Bell Helicopter Company Report [2], IBM 360 Program A-101.

NOTE: On the following hand-written pages of this appendix, the stress analyst made numerous references to other page numbers of the appendix. These page numbers refer to the sheet numbers in the lower right-hand box of each page.

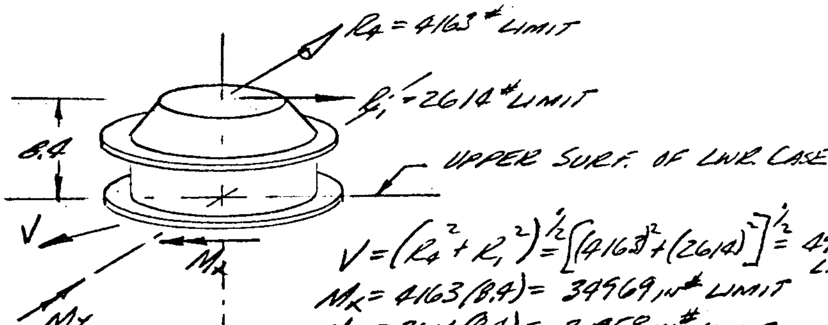
ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE ~

LOAD CONDITION I
SYM. DIVE & PULL-OUT



SIDE LOAD R_4 & DRAG R_1 ~



$V = (R_4^2 + R_1^2)^{1/2} = [(4163)^2 + (2614)^2]^{1/2} = 4916$ # LIMIT

$M_X = 4163(8.4) = 34969$ IN# LIMIT

$M_Y = 2614(8.4) = 21958$ IN# LIMIT

$M_{TOT} = [M_X^2 + M_Y^2]^{1/2} = 41291$ IN# LIMIT

MJO NO. 4316-001	SUBJECT	DATE 7/16/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 1

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE ~

LOADING CONDITION I
DISTRIBUTED LOADS @ TOP OF TRANSMISSION CASE DUE TO DRAG (R_1) & SIDE (R_4) LOADS

$$q_{MAX} = f_{S_{MAX}} t = \frac{V Q_{N.A.}}{I(2t)}(t) \quad , \quad f_{S_{MAX}} = \frac{4}{3}\frac{V}{A}\left(1 + \frac{Dd}{D^2+d^2}\right)$$

ASSUMING $D = d$

$$= \frac{4}{3}\frac{V}{A}\left(1 + \frac{1}{2}\right)$$

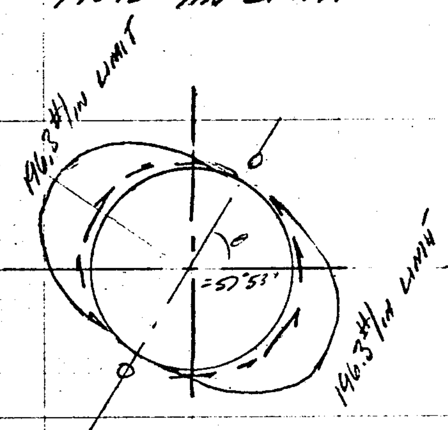
$$= 2\frac{V}{A}$$

@ BOLT CIRCLE
$R = 7.97$ IN

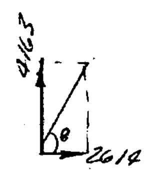
$$= 2\frac{V}{2\pi R t}(t)$$

$$= \frac{2(4916)}{2\pi(7.97)}$$

$= 196.3$ #/IN LIMIT



VIEW LKG DN.



$TAN\theta = \frac{4163}{2614} = 1.59257$
$\theta = 57°53'$

AFT

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-601		7/16/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	2

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I

DISTRIBUTED AXIAL LOADS AT TOP OF TRANSMISSION CASE DUE TO BENDING:

$$w_{b_{MAX}} = f_b t = \frac{MR(t)}{\pi R^3 t},$$

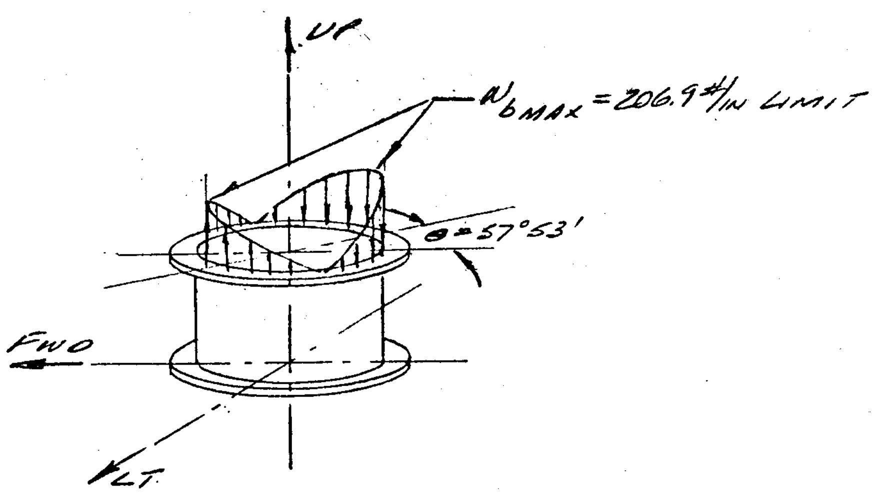
@ BOLT CIRCLE
$R = 7.97$ IN

$$= \frac{M}{\pi R^2}$$

$M = 41291$ IN# LIMIT
(REF. PG 1)

$$= \frac{41291}{\pi(7.97)^2}$$

$$w_{b_{MAX}} = 206.9 \text{ \#/IN LIMIT}$$



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		7/16/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	3

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

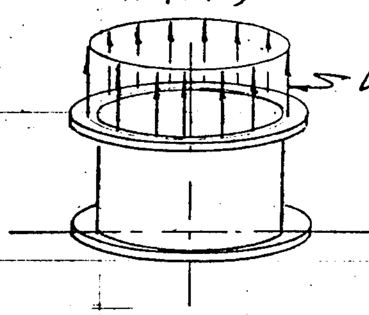
LOADING CONDITION I

DISTRIBUTED LOAD @ TOP OF TRANSMISSION CASE DUE TO VERT LOAD ($P_{Z'T}$)

$P_{Z'T}' = 24382$ # LIMIT

$$W_T = \frac{P}{A}(t) = \frac{P}{2\pi R t}(t)$$

$$= \frac{24382}{2\pi(7.97)} = 486.9 \text{ \#/IN LIMIT}$$



$W_T = 486.9$ #/IN LIMIT

COMBINED AXIAL + BENDING LOADS:

$W_T + W_b = 486.9 + 206.9 = 693.8$ #/IN LIMIT

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TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	(4)

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING COND. I

LOADS @ LWR SURF. OF TRANSMISSION CASE ~

$$M = \left\{ \left[T_i + R_4(17.971) \right]^2 + \left[R_1(17.971) \right]^2 \right\}^{1/2}$$

$= 101,701$ IN# LIMIT (REF. BELL CALCS)

$P = P_{Z'T} = 24382$ # LIMIT

$T = M_{Z'T} = 301,183$ IN# LIMIT

$V = (R_1^2 + R_4^2)^{1/2} = 4916$ # LIMIT.

$$q_{MAX} = \frac{VQ}{Ib}(t) + \frac{T}{2A}$$

@ BOLT CIRC. $R = 7.97$ IN

$$= 196.3 + \frac{\overset{754.6}{301,182}}{2[\pi(7.97)^2]}$$

$= 950.9$ #/IN LIMIT

$950.9\,(1.5) = 1426$ #/IN ULT.

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4316-001		7/16/71	
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		A.M.T.	5

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I

LOADS @ LWR. SURF. OF TRANSMISSION CASE (CONT.)

DIST. VERT LOAD DUE TO BENDING

$$W_{b_{MAX}} = \frac{Mc}{I} t$$

$$= \frac{101,701}{41291}(206.9) \quad ; \text{ (BY RATIO FROM LOADS @ TOP OF CASE)}$$

$$= 509.6 \text{ \#/IN LIMIT}$$

$$W_T = \frac{P}{A} t = 486.9 \text{ \#/IN LIMIT (REF. PG. 4)}$$

$$W_{TOT_{MAX}} = W_{b_{MAX}} + W_T$$

$$W_{TOT_{MAX}} = 509.6 + 486.9 = 996.5 \text{ \#/IN LIMIT}$$

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		A.M.T.	6

ENGINEERING CALCULATIONS

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I, PINION & GEAR LOADS DUE TO INPUT TORQUE

$T_i = 15388$ IN# LIMIT @ 6400 RPM

NO. OF PINION TEETH = 29
NO. OF GEAR TEETH = 62

GEAR RPM $= \frac{29}{62}(6400) = 2994$ RPM

TORQUE IN VERT. SHAFT:

$$T_{GEAR} = \frac{T_i \times RPM_i}{RPM_{GEAR}}$$

$$= \frac{15388(6400)}{2994}$$

$$= 32894 \text{ IN\# LIMIT}$$

PITCH DIAMETERS:

PINION, $d = 5.380$ IN

GEAR, $D = 11.501$ IN

MJO NO. 4316-001	SUBJECT	DATE 8/10/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 7

ENGINEERING CALCULATIONS

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING COND. I

TANGENTIAL LOAD ON PINION

$$W_t = \frac{126050\,P}{n\,d_m}$$

(REF. MACHINERY HANDBOOK PG. 753)

$$= \frac{126050\,(1562.5)}{6400\,(4.7445)}$$

$= 6486$ LBS LIMIT

$P = 1.25\,(1250)$
$= 1562.5$ H.P.

$n = 6400$ RPM

$d_m = d - F\sin\gamma_d$
$= 5.38 - 1.5\sin 25°4'$
$= 4.7445$

$F = 1.5$ IN
$\gamma_d = 25°4'$

PINION AXIAL FORCE,
PINION HAS L/H SPIRAL
& CLOCKWISE ROTATION

$$W_x = \frac{W_t}{\cos\psi}\left(\tan\phi\sin\gamma_d + \sin\psi\cos\gamma_d\right)$$

(REF. MACHINERY HDBK, PG. 753)

$\psi = 35°$
$\phi = 20°$

$$= \frac{6486}{\cos 35°}\left[\tan 20°\sin 25°4' + \sin 35°(\cos 25°4')\right]$$

$= 5335$ LBS LIMIT

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TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 6

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I

GEAR SEPARATING FORCE

$$W_S = \frac{W_t}{\cos\psi}\left[\tan\phi \cos\gamma_O - \sin\psi \sin\gamma_O\right]$$

$\gamma_O = 64°56'$

$$= \frac{6486}{\cos 35°}\left[\tan 20° \cos 64°56' - \sin 35° \sin 64°56'\right]$$

$= 5335$ LBS LIMIT ✓

PINION SEPARATING FORCE:

$$W_S = \frac{W_t}{\cos\psi}\left[\tan\phi \cos\gamma_d - \sin\psi \sin\gamma_d\right]$$

$$= \frac{6486}{\cos 35°}\left[\tan 20° \cos 25°4' - \sin 35° \sin 25°4'\right]$$

$= 686$ LBS LIMIT

GEAR AXIAL FORCE:

$$W_x = \frac{W_t}{\cos\psi}\left[\tan\phi \sin\gamma_O - \sin\psi \cos\gamma_O\right]$$

$$= \frac{6486}{\cos 35°}\left[\tan 20° \sin 64°56' - \sin 35° \cos 64°56'\right]$$

$= 686$ LBS LIMIT ✓

MJO NO. 4316-001	SUBJECT	DATE 8/10/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 9

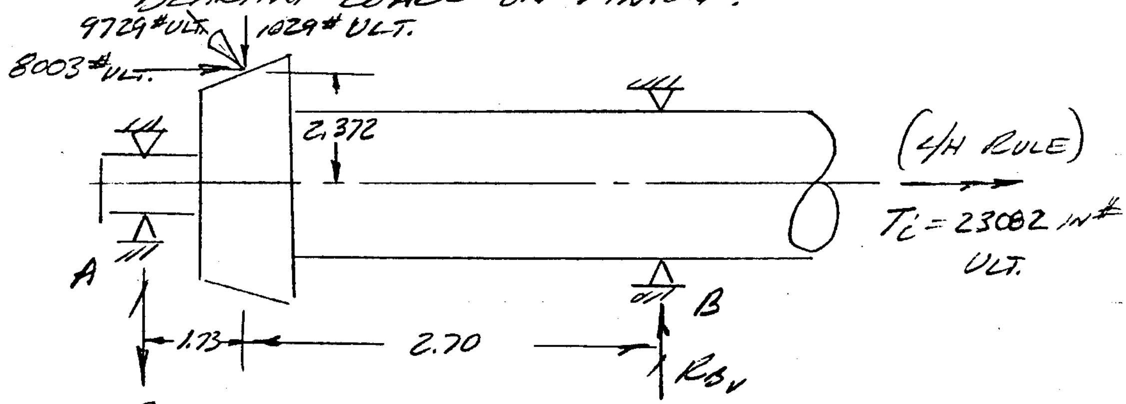
LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I

SUMMARY, PINION & GEAR LOADS

	PINION	GEAR
TORQUE	15388 IN# LIMIT	32894 IN# LIMIT
TANGENTIAL FORCE	6486 # "	6486 # "
SEPARATING "	686 # "	5335 # "
AXIAL FORCE	5335 # "	686 # "

BEARING LOADS ON PINION:



ΣM_B: R_{A_V}

$$R_{A_V} = \frac{-1029(2.70) + 8003(2.372)}{2.70 + 1.73} = 3658\ \#\ \text{ULT. (DN)}$$

ΣM_A:

$$R_{B_V} = \frac{8003(2.372) + 1029(1.73)}{2.70 + 1.73} = 4687\ \#\ \text{ULT. (UP)}$$

$\Sigma F_V \quad = 1029$ # ULT. ✓

MJO NO. 4316-001	SUBJECT	DATE 8/10/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 10

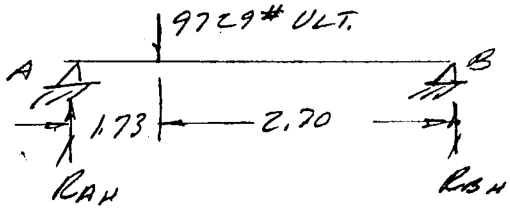
ENGINEERING CALCULATIONS

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I (CONT.)

BEARING LOADS ON PINION (CONT.)

FROM SIDE LOAD:



$$R_{AH} = \frac{9729(2.70)}{4.43} = 5930\,\#\ ULT.$$

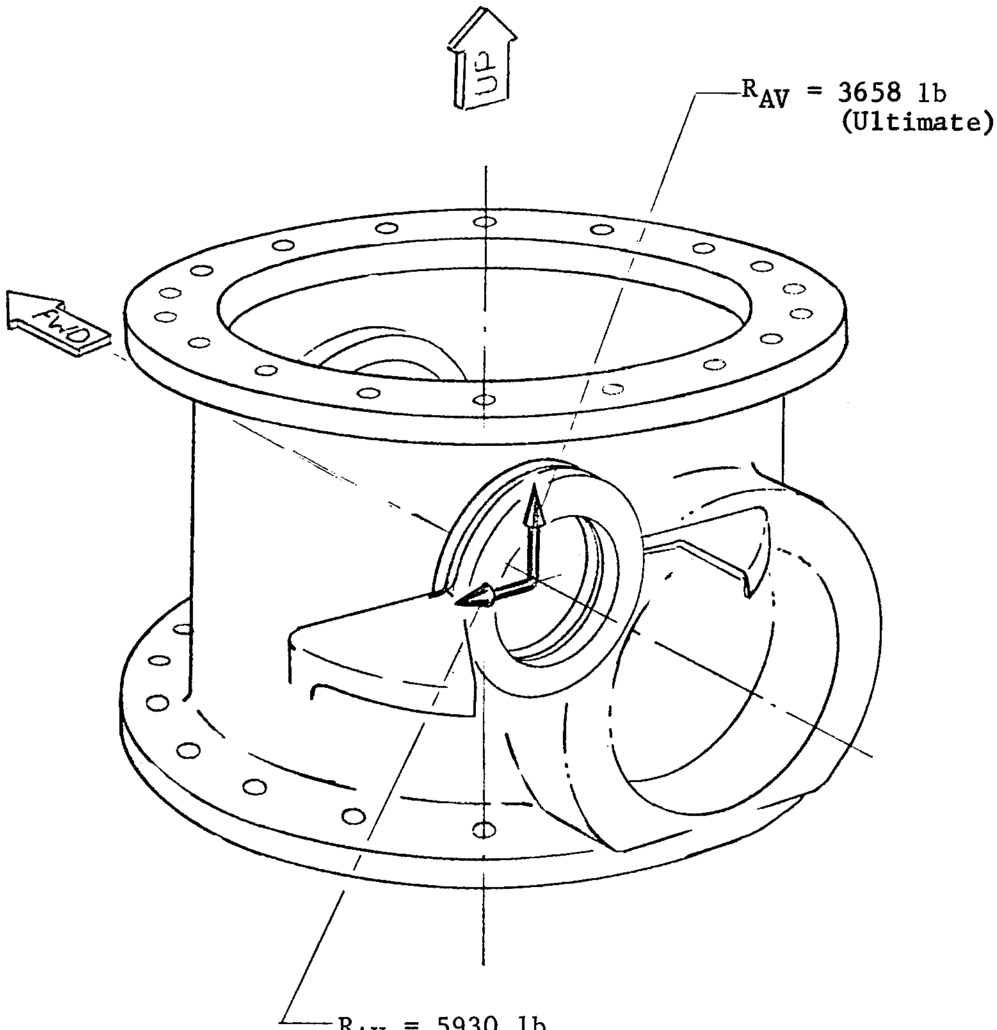
$$R_{BH} = \frac{9729(1.73)}{4.43} = 3799\,\#\ ULT.$$

$$\Sigma F_H = 9729\,\#\ ULT. \checkmark$$

MJO NO. 4316-001	SUBJECT	DATE 8/10/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 11

LOADS AT FORWARD PINION BEARING (POINT "A")

LOADING CONDITION I

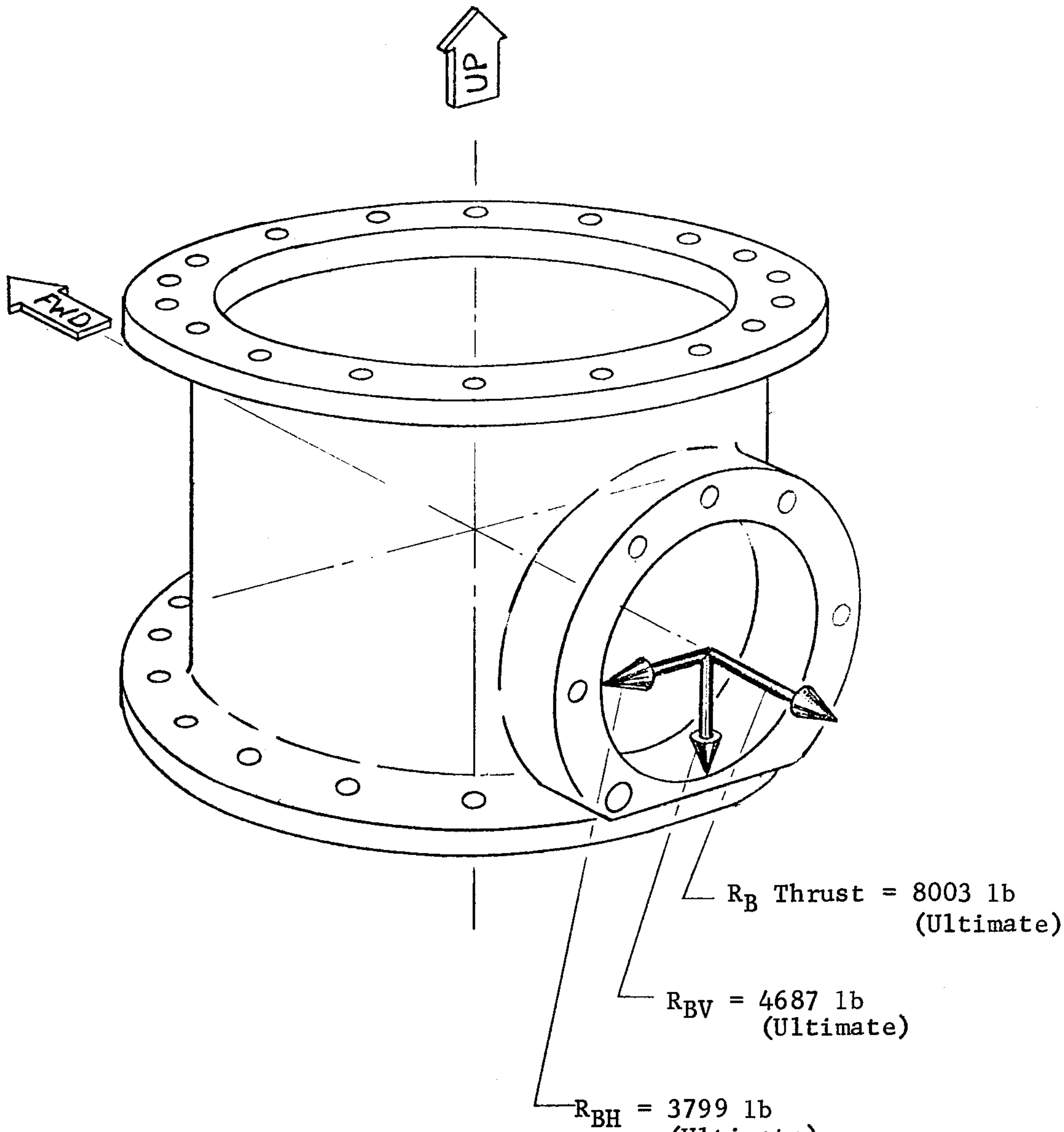


$(R_{AV}^2 + R_{AH}^2)^{\frac{1}{2}}$ = 6967 lb (Ultimate)

Sheet No.
12

LOADS AT TRIPLEX BEARING AT INPUT TORQUE SHAFT (POINT "B")

LOADING CONDITION I



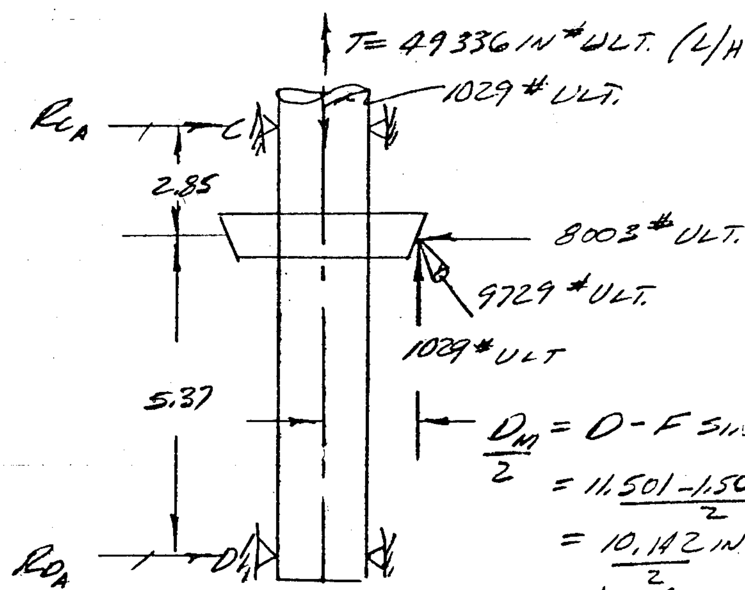
$$(R_{BH}^2 + R_{BV}^2)^{\frac{1}{2}} = 6033 \text{ lb (Ultimate)}$$

Sheet No.
13

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I

BEARING LOADS ON VERTICAL SHAFT



$$\frac{D_M}{2} = D - F \sin \gamma_D$$
$$= \frac{11.501 - 1.50 \sin 64°56'}{2}$$
$$= \frac{10.142 \text{ IN.}}{2} = 5.071$$

$$T = W_t \left(\frac{D_M}{2}\right)$$
$$= 9729(5.071)$$
$$= 49336 \text{ IN\# ULT.}$$

ΣM_D:

$$R_{C_A} = \frac{8003(5.37)}{5.37+2.85} + \frac{1029(5.071)}{5.37+2.85}$$
$$= 5863 \text{ \# ULT.}$$

ΣM_C:

$$R_{D_A} = \frac{8003(2.85)}{5.37+2.85} - \frac{1029(5.071)}{5.37+2.85} = 2140 \text{ \# ULT.}$$

ΣF_A: $5863 + 2140 = 8003$ # ULT. ✓

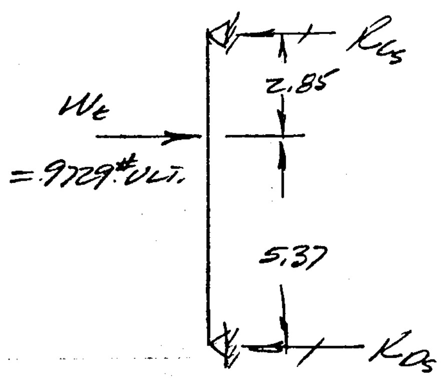
MJO NO. 4316-001	SUBJECT	DATE 8/10/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 14

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I (CONT.)

BEARING LOADS ON VERT. SHAFT (CONT.)

FROM TANGENTIAL LOAD ON GEAR:



VIEW LKG FWD

$$R_{Cs} = \frac{9729(5.37)}{8.22} = 6356 \text{ \# ULT.}$$

$$R_{Ds} = \frac{9729(2.85)}{8.22} = \underline{3373} \text{ \# ULT.}$$

$$\Sigma F_S = 9729 \text{ \# ULT.} \checkmark$$

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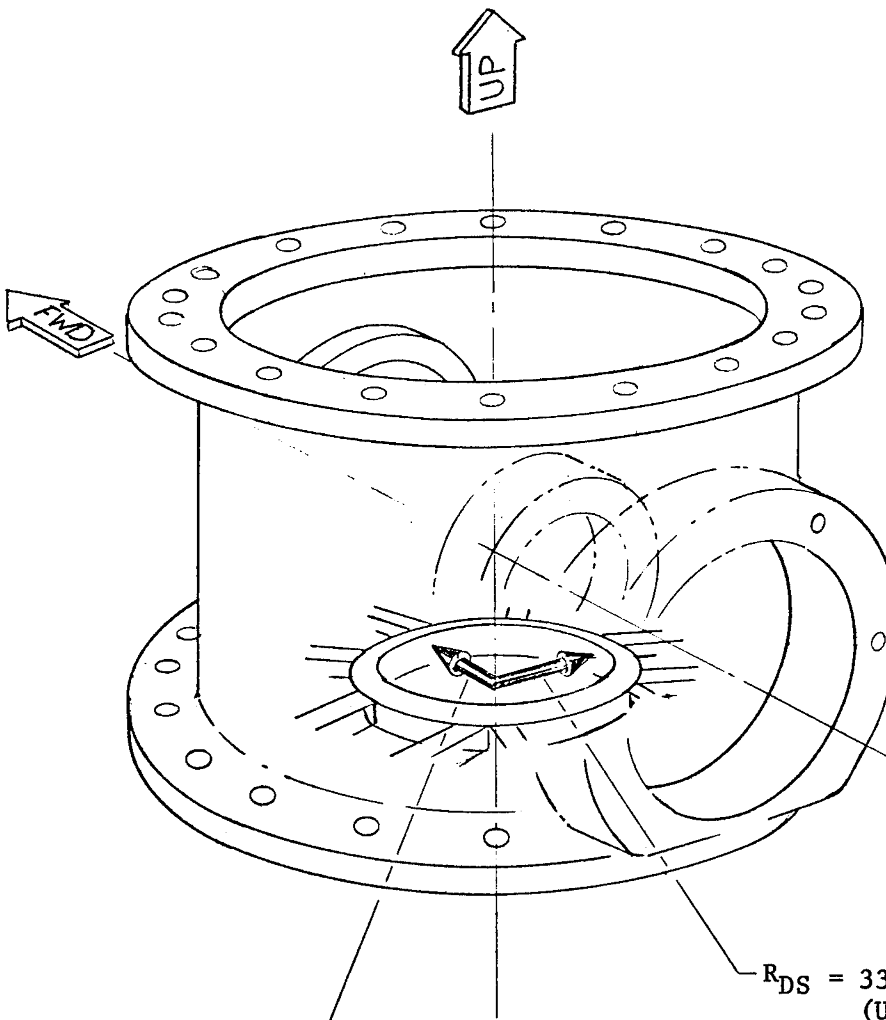
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 15

LOADS AT LOWER BEARING OF VERTICAL SHAFT (POINT "D")

LOADING CONDITION I



R_{DS} = 3373 lb (Ultimate)

R_{DFWD} = 2140 lb (Ultimate)

$(R_{DFWD}^2 + R_{DS}^2)^{\frac{1}{2}}$ = 3995 lb (Ultimate)

Sheet No. 16

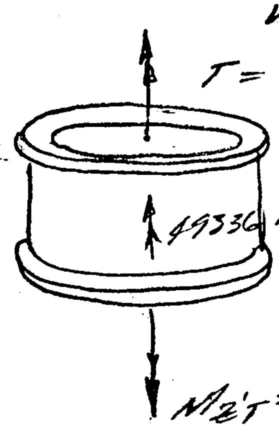
LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT'D)

LOADING CONDITION I:

TORQUE ABOUT VERTICAL AXIS DUE TO BEVEL GEAR LOADS = 49336 IN # ULT.
(REF. PG. 14)

VECTORS ARE L/H RULE

$T = 451775 - 49336 = 402439$ IN # ULT.



$M_{Z'T} = 301183(1.5)$
$= 451775$ IN # ULT.

AT TOP OF TRANSMISSION CASE:

$q_T = \frac{T}{2A}$

@ BOLT CIRCLE
$R = 7.97$ IN

$= \frac{402439}{2(199.6)}$

$A = \pi R^2$
$= \pi(7.97)^2 = 199.6$ IN^2

$= 1008$ #/IN ULT.

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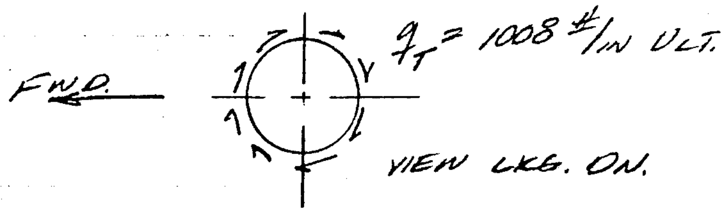
4316-001		8/10/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	17

ENGINEERING CALCULATIONS

LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION I.

AT UPPER SURFACE OF CASE



FROM SHEAR LOADS,

$q_{V_{MAX}} = 196.3(1.5) = 294$ #/IN ULT. (REF. PG. 2)

$q_{TOT_{MAX}} = 1008 + 294 = 1302$ #/IN ULT. (C. CLOCKWISE LKG ON.)

$q_{TOT_{MAX}}$ IS LOCATED 32° 07' CLOCKWISE FROM FORE & AFT ℄ OF CASE (SEE SKETCH PG. 2)

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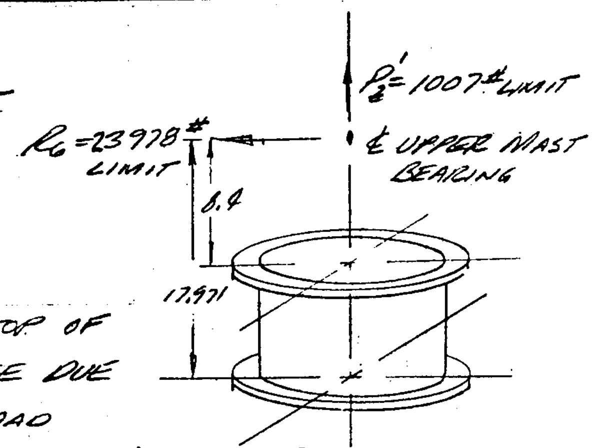
4316-001		5/10/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	18

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION II



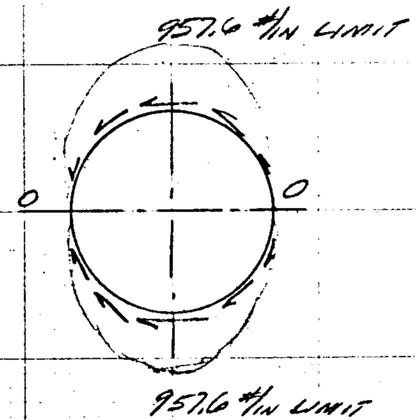
DIST. LOAD @ TOP OF TRANSMISSION CASE DUE TO DRAG (R_6) LOAD

$q_{max} = \dfrac{V}{\pi R}$ (REF. PG. 2), $V = R_6 = 23978$ LB LIMIT

$R_{@\,BOLT\ CIRCLE} = 7.97$ IN

$= \dfrac{23978}{\pi(7.97)}$

$= 957.6$ #/IN LIMIT



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		7/19/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	19

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

-LOADING COND. II

AXIAL LOADS DUE TO BENDING:

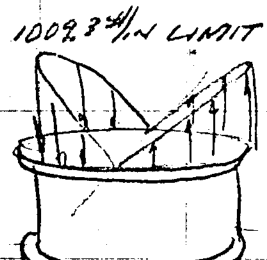
$$w_b = \frac{M}{\pi R^2} \text{ (REF. PG. 3)}, \quad M = R_L(8.4)$$

$$= 23978(8.4)$$

$$= 201{,}415 \text{ IN}^{\#} \text{ LIMIT}$$

$$= \frac{201{,}415}{\pi(7.97)^2}$$

$$= 1009.3 \ \#/\text{IN LIMIT}$$



AXIAL LOADS @ TOP OF CASE DUE TO P_2',

$$w_T = \frac{P_2'}{2\pi R} = \frac{1007}{2\pi(7.97)} = 20.1 \ \#/\text{IN LIMIT}$$

COMBINED AXIAL & BENDING LOADS:

$$w_T + w_b = 20.1 + 1009.3 = 1029.4 \ \#/\text{IN LIMIT}$$

MJO NO. 0316-001	SUBJECT	DATE 7/19/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 20

ENGINEERING CALCULATIONS

PRELIMINARY LOADS ANALYSIS ~ BELL TRANSMISSION CASE (CONT.)

LOADING CONDITION II

LOADS @ LWR. SURF. OF TRANSMISSION CASE ~

$$M = R_6 (17.971)$$
$$= 23978 (17.971)$$
$$= 430{,}909 \text{ IN}^{\#} \text{ LIMIT}$$

$$P = P_2 = 1007^{\#} \text{ LIMIT}$$

$$V = R_6 = 23978^{\#} \text{ LIMIT}$$

$$q_{MAX} = 9526 \ ^{\#}/\text{IN LIMIT (REF. PG. } \underline{19}\text{)}$$

$$w_b = \frac{M}{\pi R^2} = \frac{430{,}909}{\pi (7.97)^2} = 2159.3 \ ^{\#}/\text{IN LIMIT}$$

$$w_T = \frac{P_2}{2\pi R} = 20.1 \ ^{\#}/\text{IN LIMIT}$$

$$w_{TOT} = w_b + w_T = 2159.3 + 20.1 = 2179.4 \ ^{\#}/\text{IN LIMIT}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		7/19/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	21

APPENDIX II
STRESS ANALYSIS

This appendix includes the following items:

Discussion

Figures 36 through 43

Basic Cylinder Wall - Loads, Sheet No. 1

Basic Cylinder Wall - Layup, Sheet No. 2

Basic Cylinder Wall - Stiffness, Sheet No. 3

Basic Cylinder Wall - Compression Stress, Sheet No. 4

Basic Cylinder Wall - Tension Stress, Sheet No. 6

Basic Cylinder Wall - Shear Stress, Sheet No. 7

Discontinuity Stress at Lower Flange/Cylinder Intersection, Sheet No.11

Lower Flange Layup, Sheet No. 14

Upper Flange Layup, Sheet No. 26

Main Drive Bearing Support - Loads, Sheet No. 29

Main Drive Bearing Support - Ring Analysis, Sheet No. 32

Main Drive Internal Bearing Support, Sheet No. 40

Auxiliary Bearing Supports, Sheet No. 43

Base Disc, Sheet No. 45

DISCUSSION

The composite material helicopter transmission gear housing is analyzed for the loads shown in Appendix I.

The stiffness of various structural elements of the composite material transmission gear housing is calculated and compared to the stiffness of the present cast magnesium gear housing. Stiffness comparisons are made using room temperature properties of the materials.

The strength of the composite material gear housing is checked to determine the ability of the housing to support the imposed loads. Material properties at 350°F are used for the stress analysis.

Materials used in the composite material helicopter transmission gear housing are:

Graphite/Epoxy Laminate - Modulite 5208 Type I
Bulk Molding Compound - EM 7302-1/2
Adhesive - Hysol Adhesive EA 934

Allowable stress and modulus of elasticity of the graphite/epoxy laminates at RT and at 350°F are shown in Figures 36 through 43.

Allowable stresses for EM 7302 bulk molding compound and EA 934 adhesive are obtained from Whittaker Research and Development test data.

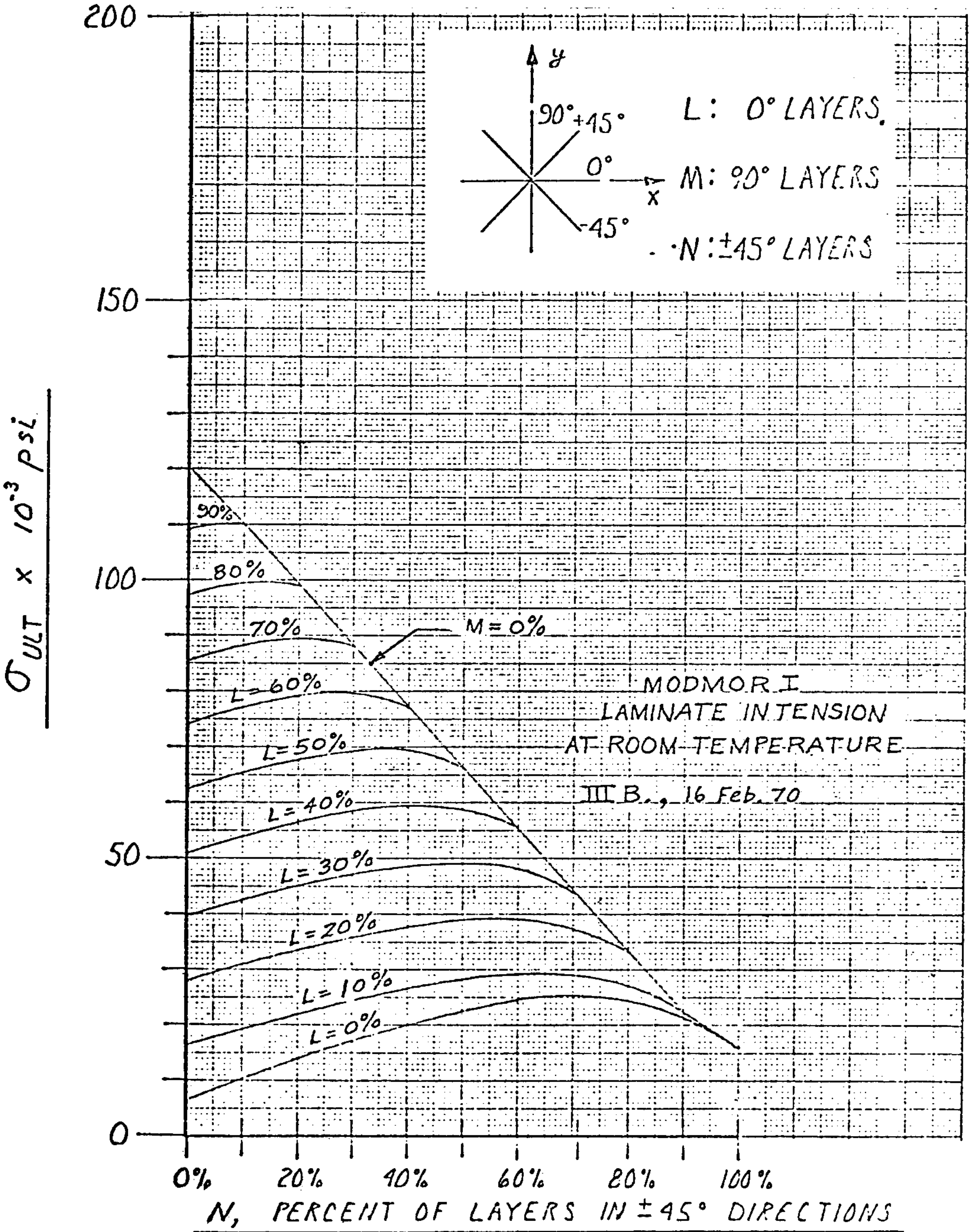


Figure 36. Ultimate Tensile Strength of Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate.

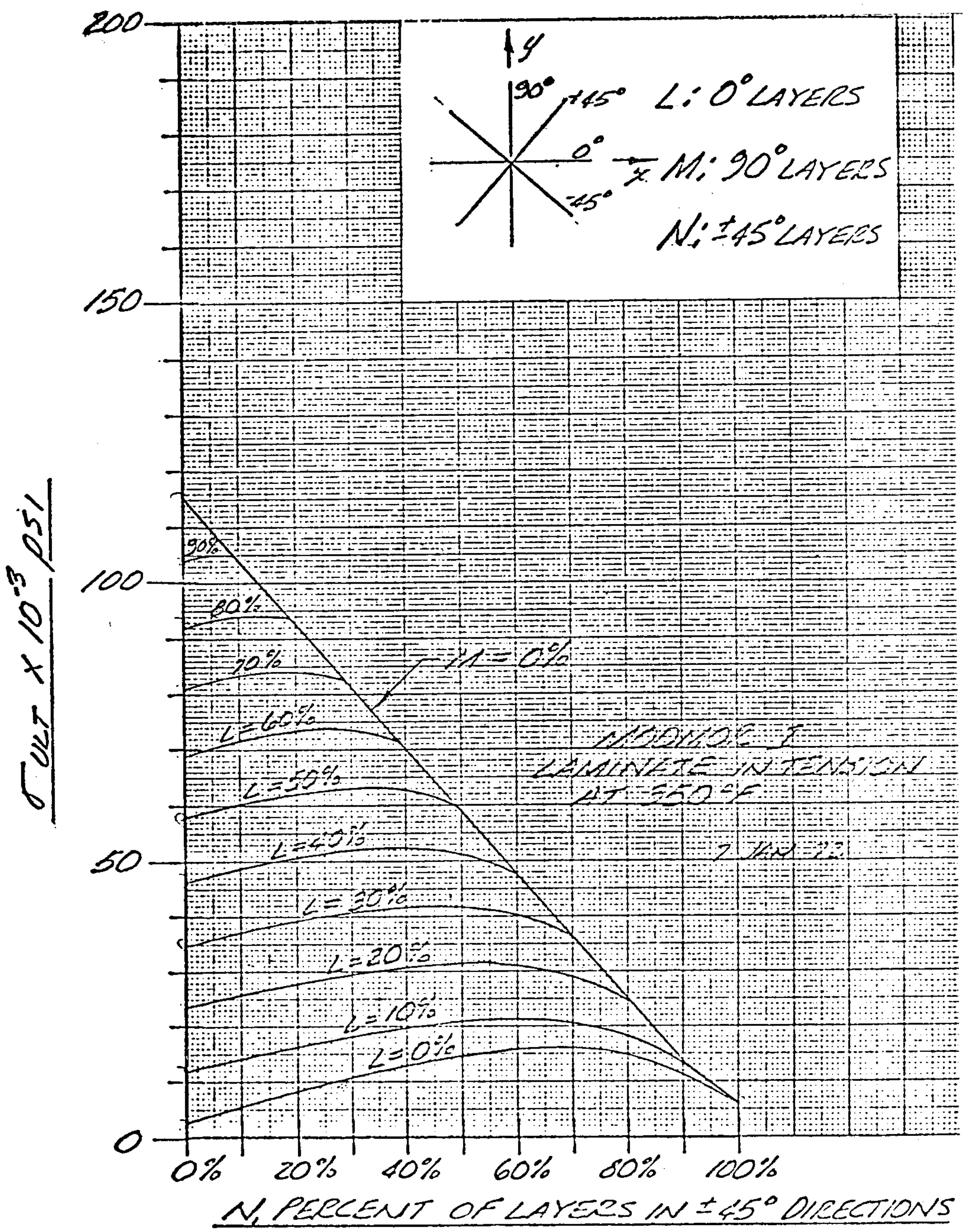


Figure 37. Ultimate Tensile Strength of Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate at 350°F.

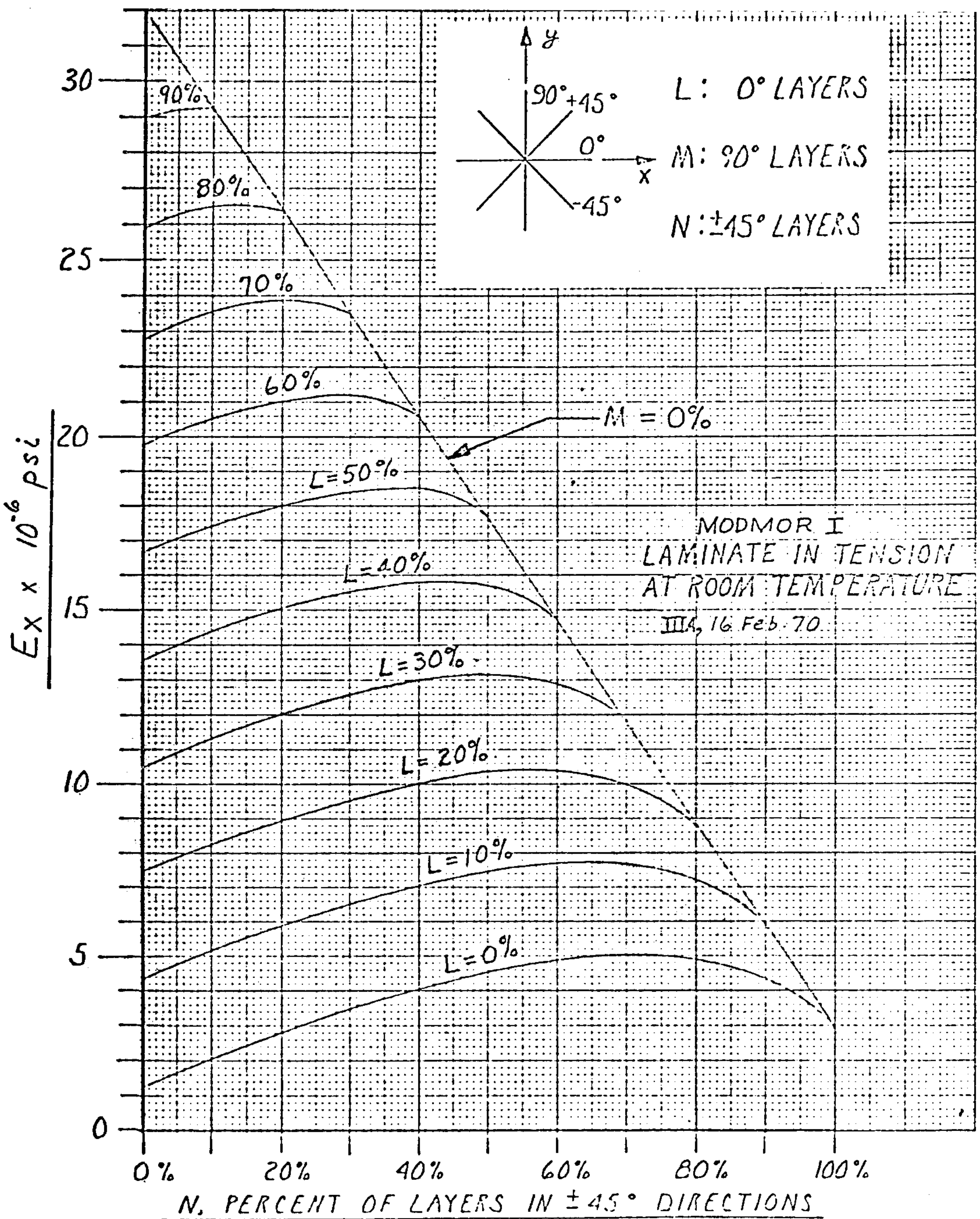


Figure 38. Tensile Modulus of Elasticity for Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate.

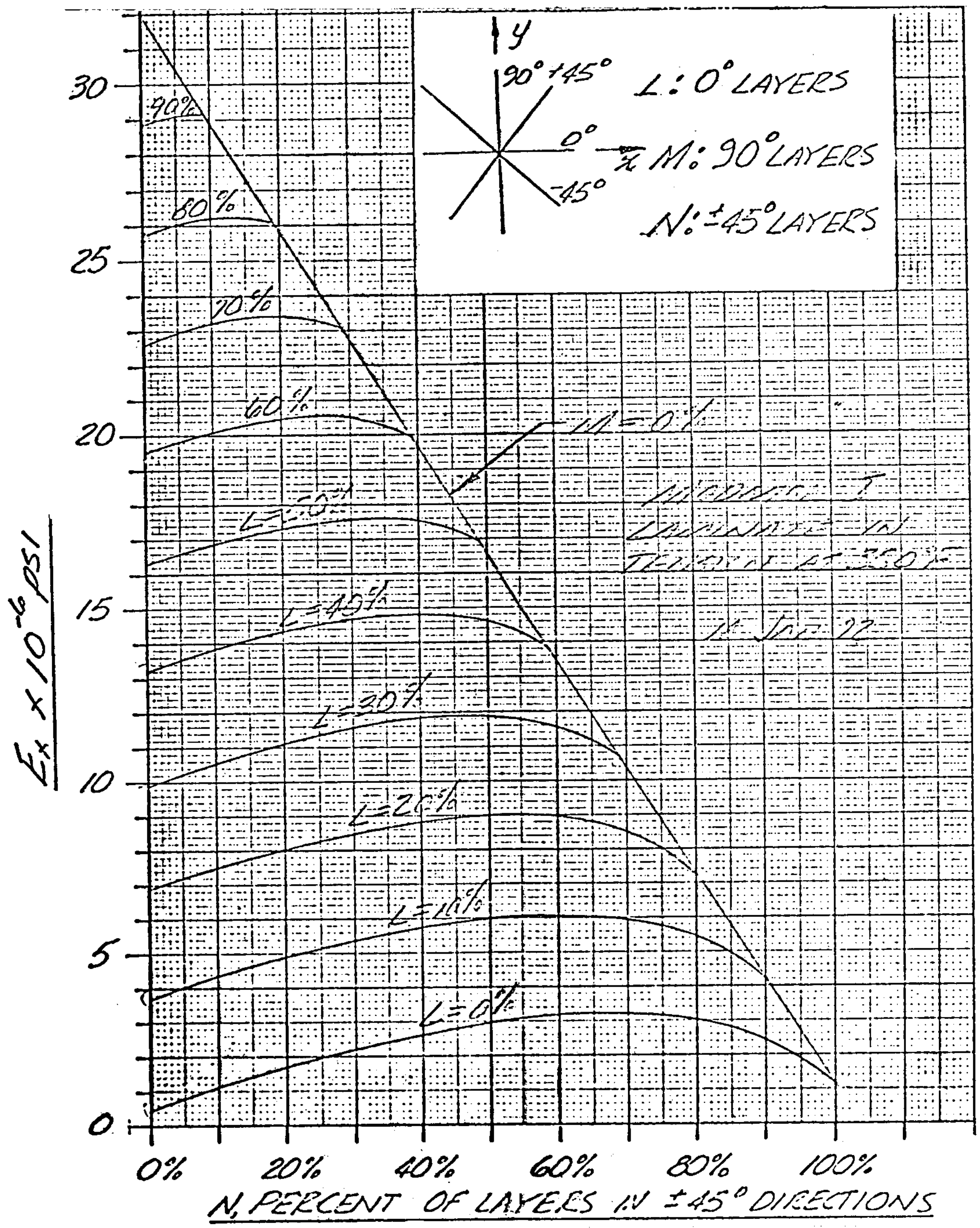


Figure 39. Tensile Modulus of Elasticity for Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate at 350°F.

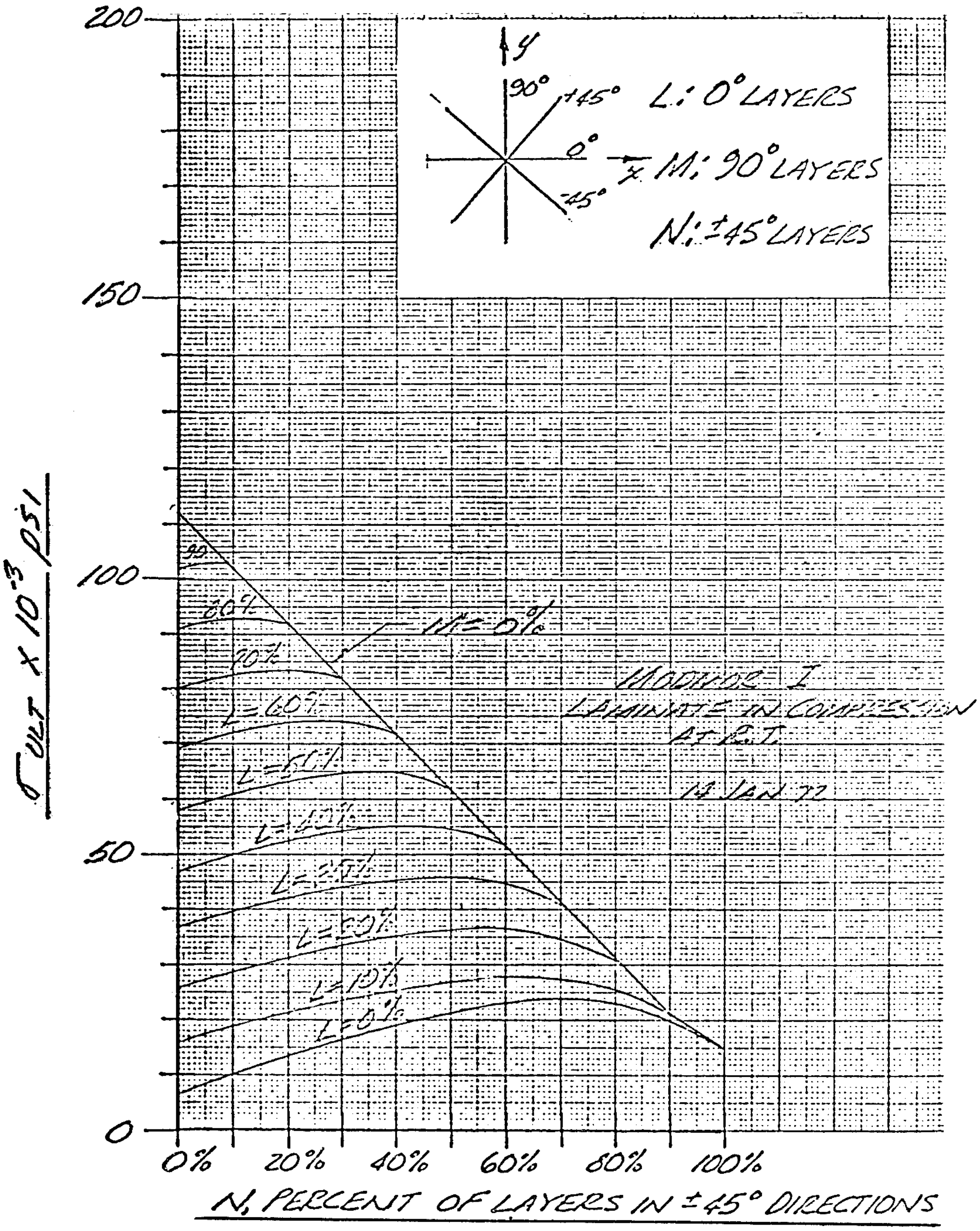


Figure 40. Ultimate Compression Strength of Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate at RT.

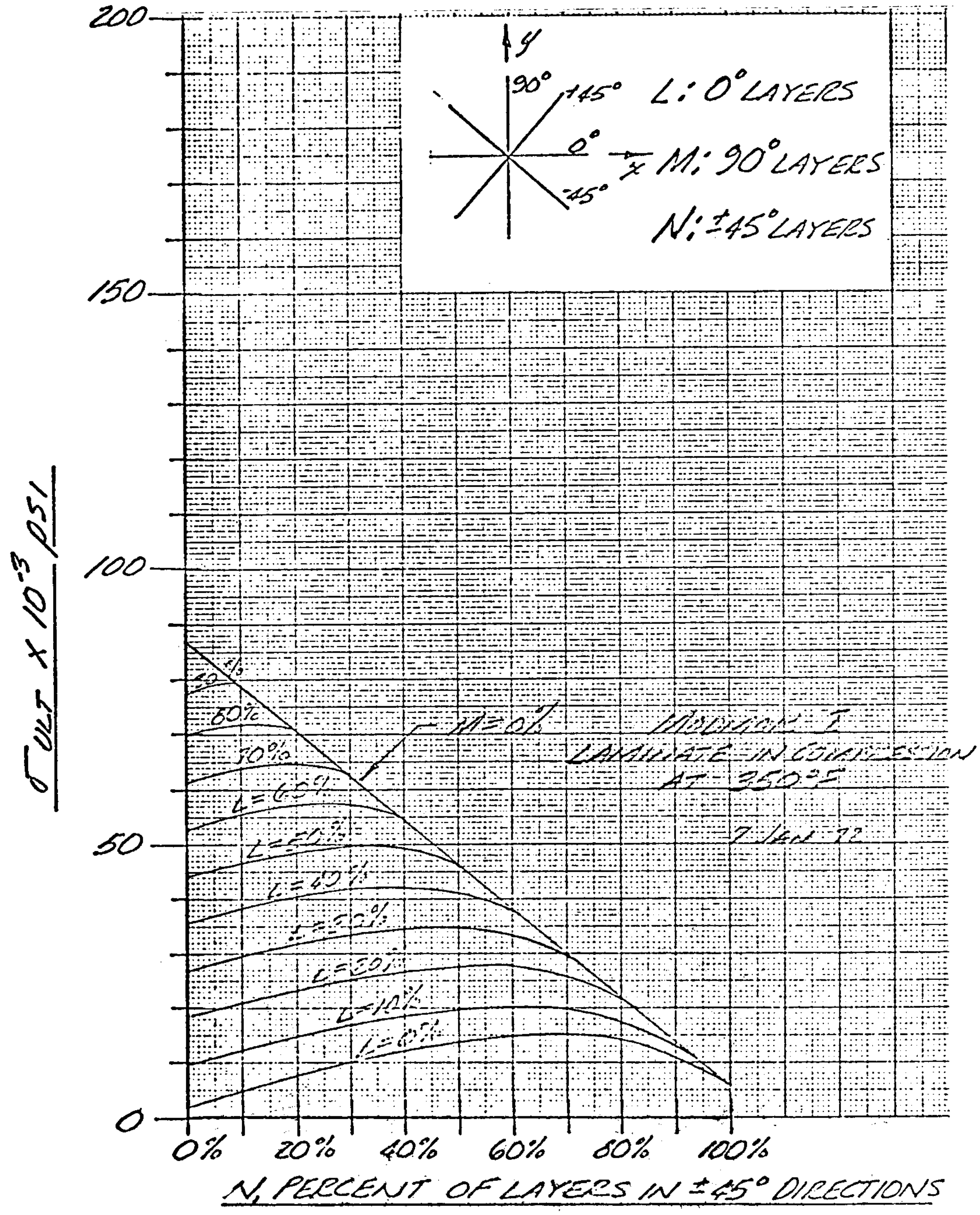


Figure 41. Ultimate Compression Strength of Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate at 350°F.

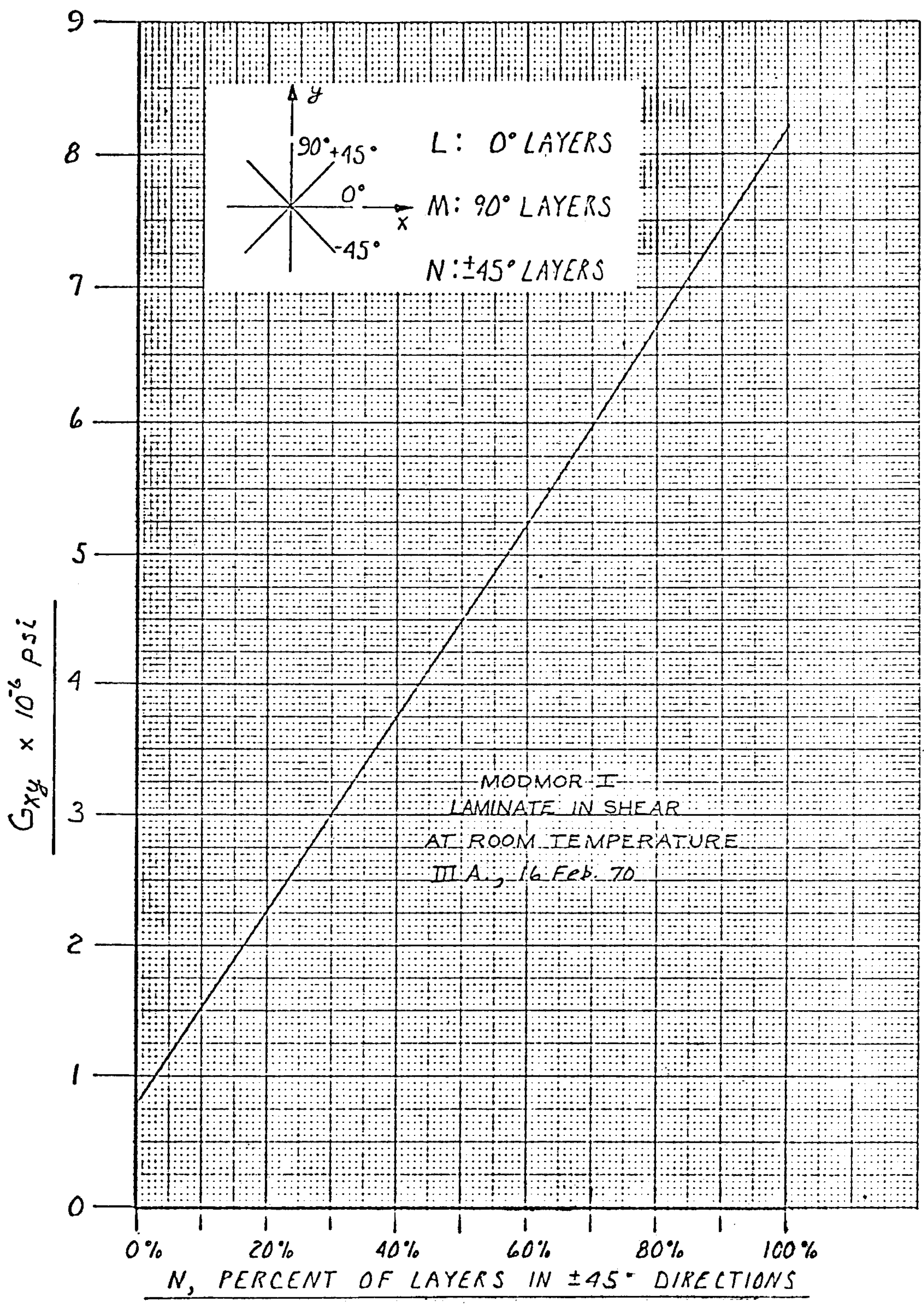


Figure 42. Shear Modulus for Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate.

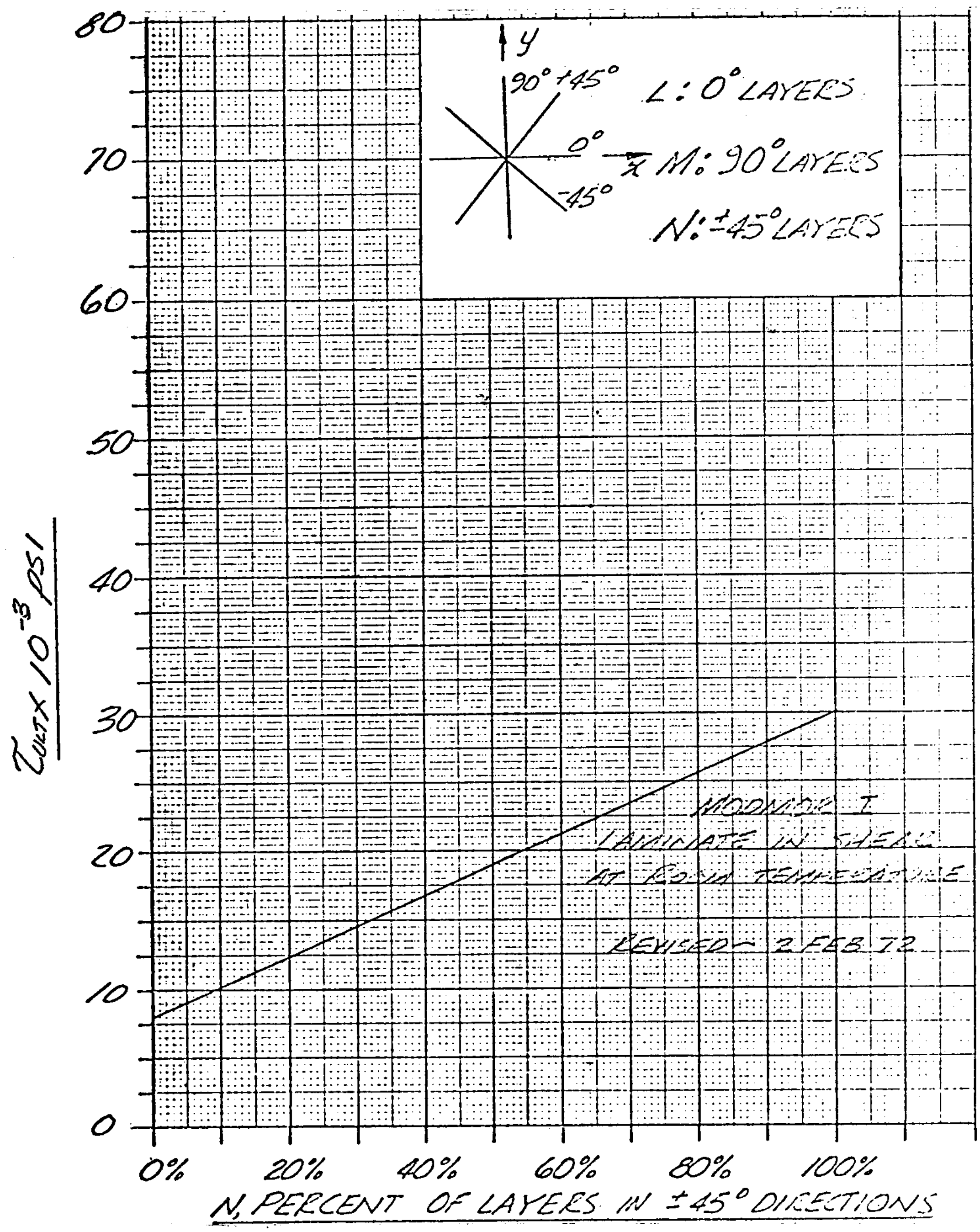
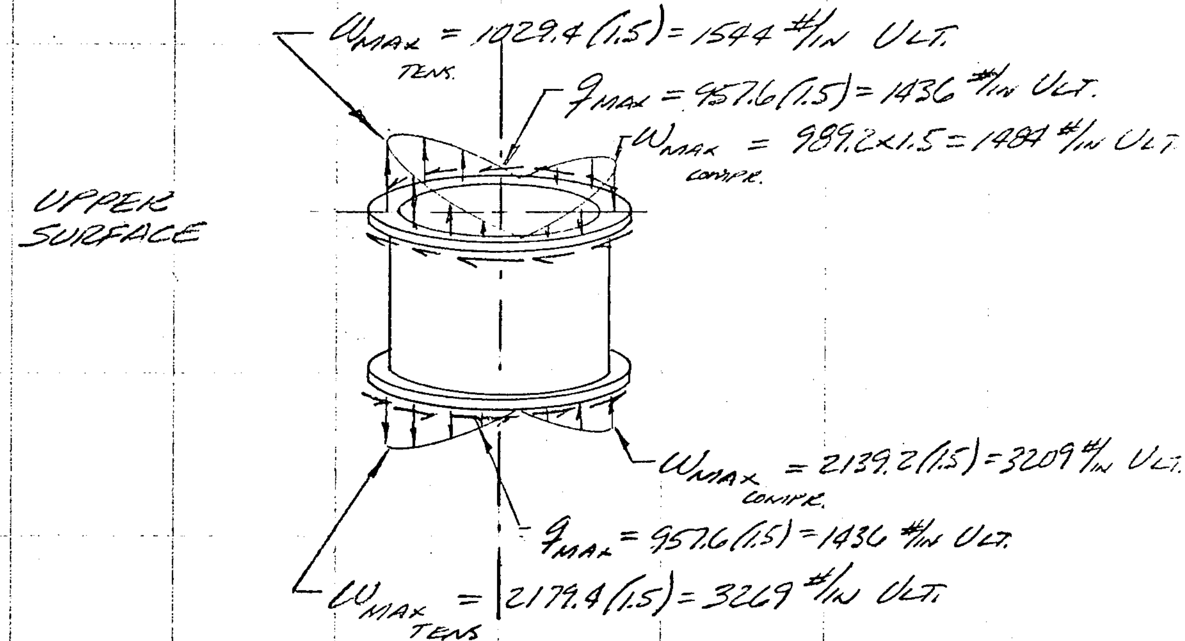
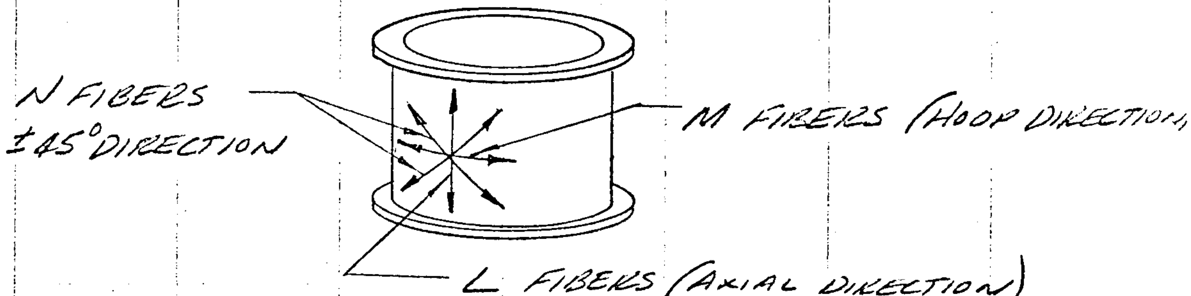


Figure 43. Ultimate Shear Strength for Modmor I/Epoxy [0°, 90°, ± 45°] Composite Laminate.

BASIC CYLINDER WALL ~

LOADS FROM CONDITION II, FWD. CRASH (8-g's) ARE MAXIMUM ~ (SEE APPENDIX I)





CYLINDER LAYUP NOMENCLATURE

MJO NO. 4316-001	SUBJECT COMPOSITE MATERIAL	DATE 1/5/72	CHECKED BY
TASK NO.	TRANSMISSION CASE	CALCULATIONS BY A.M.T.	SHEET NO. 1

BASIC CYLINDER WALL (CONT.)

LAYUP OF BASIC WALL ~ MATERIAL IS
MODULITE 5206 TYPE I

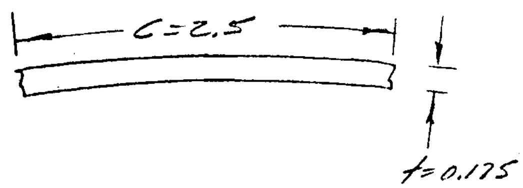
	%		
L (AXIAL)	32.0	8 PLIES	$t = 8(.007) = .056$
M (HOOP)	20.0	5 PLIES	$t = 5(.007) = .035$
N ($\pm 45°$)	48.0	12 PLIES	$t = 12(.007) = .084$
		$t_{TOT} = 25(.007)$	$= 0.175$ IN

IN AXIAL DIRECTION (L),

$E_x = 13.7 \times 10^6$ psi @ R.T., REF. WKR R&D DESIGN DATA

FOR TYPICAL WALL SEGMENT 2.5 IN WIDE

$A = tc$



$A = 0.175(2.5)$

$A = 0.438 \text{ IN}^2$

$EA_{COMPOSITE} = 13.7 \times 10^6 (0.438) = 6.00 \times 10^6$

FOR N = 45 %,

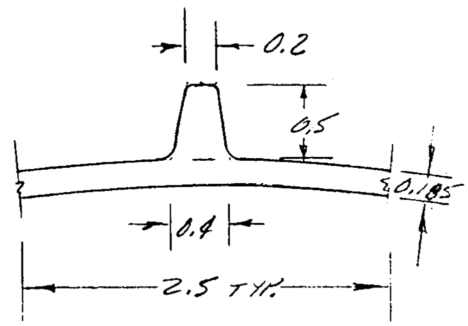
$G_{xy} = 4.33 \times 10^6$ psi @ R.T., REF. WKR R&D DESIGN DATA.

$Gt_{COMPOSITE} = 4.33 \times 10^6 (.175) = 0.758 \times 10^6$

MJO NO. 4316-001	SUBJECT COMPOSITE MATERIAL TRANSMISSION CASE	DATE 1/5/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 2

BASIC CYLINDER WALL (CONT.)

TYPICAL SEGMENT OF MAGNESIUM CASTING CYLINDER WALL ~



$A = 2.5(.185) + \frac{0.2+0.4}{2}(0.5)$

$= 0.613 \text{ IN}^2$

$E_{MAG} = 6.5 \times 10^6$ PSI (AZ91C-T6 CASTING, REF. MIL HDBK 5, [3] TABLE 4.2.6.0(b))

$EA_{MAG} = 6.5\times10^6(0.613) = 3.985\times10^6$

$G_{MAG} = 2.4\times10^6$ (REF. MIL HDBK 5, [3] TABLE 4.2.6.0(b))

$Gt_{MAG} = 2.4\times10^6(0.185) = 0.444\times10^6$

STIFFNESS COMPARISON:

AXIAL STIFFNESS ~

$\frac{EA_{COMPOSITE}}{EA_{MAG}} = \frac{6.00\times10^6}{3.985\times10^6} = \text{— —}\ \underline{\underline{1.51}}$

SHEAR STIFFNESS ~

$\frac{Gt_{COMPOSITE}}{Gt_{MAG}} = \frac{0.758\times10^6}{0.444\times10^6} = \text{— —}\ \underline{\underline{1.71}}$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE MAT'L TRANSMISSION CASE	1/5/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	3

BASIC CYLINDER WALL ~ (CONT.)

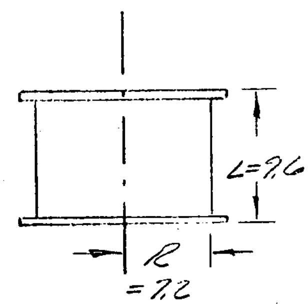
COMPRESSION STRESS IN CYL. WALL IN AXIAL (L) DIRECTION:

$f_{b_c} = \dfrac{W}{t}$, $W_{MAX\ COMPR.} = 3209$ #/IN ULT. (REF. PG. 1 COND. II)

$= \dfrac{3209}{0.175}$ $t = 0.175$ IN (REF. PG. 2)

$f_{b_c} = 18337$ PSI ULT. (COND. II @ 350°F)

$\dfrac{L}{R} = \dfrac{9.6}{7.2} = 1.33$



$\dfrac{R}{t} = \dfrac{7.2}{0.175} = 41.1$

$\dfrac{F_{b_{CR}}}{E} = 0.014$ (REF BRUHN, FIG C8.13) [4]

$F_{b_{CR}} = 0.014(E_{COMPOSITE})$.

$E_{COMPOSITE} = 12.5 \times 10^6$ IN L DIRECTION AT 350°F

$F_{b_{CR}} = 0.014(12.5 \times 10^6) = 175,000$ PSI (NOT CRITICAL)

MJO NO. 4316-001	SUBJECT	DATE 1/5/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 4

ENGINEERING CALCULATIONS

BASIC CYLINDER WALL ~ (CONT.)

@ 350°F, FOR L = 32%, M = 20%, N = 48%
IN AXIAL DIRECTION (L),
F_{cu} = 36000 psi (REF. WKR R & D DESIGN DATA)

$$M.S. = \frac{F_{cu}}{f_{bc}} - 1$$

$$= \frac{36,000}{18337} - 1 = \text{———} \quad \text{———} \quad \underline{\underline{+0.96}}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/18/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	5

BASIC CYLINDER WALL ~ (CONT.)

TENSION STRESS IN CYL. WALL IN AXIAL (L) DIRECTION:

$f_t = \frac{w}{t}$, $w_{MAX\ TENSION} = 3269$ #/IN ULT. (REF PG 1, COND II)

$t = 0.175$ IN (REF P. 2)

$f_t = \frac{3269}{0.175}$

$f_t = 18,680$ psi ULT. @ 350°F

WHEN L = 32%, M = 20%, N = 48%, IN L DIRECTION:

$F_{tu} = 43,000$ psi @ 350°F, (REF. WKR RG IV DESIGN DATA)

$M.S. = \frac{F_{tu}}{f_t} - 1$

$= \frac{43,000}{18,680} - 1 =$ ——— ——— $\underline{\underline{+1.30}}$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/18/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	6

ENGINEERING CALCULATIONS

BASIC CYLINDER WALL ~ (CONT.)

SHEAR STRESS IN CYL WALL:

$q_{MAX} = 1436$ #/in ULT., COND. II @ 350°F
(REF. PG. 1)

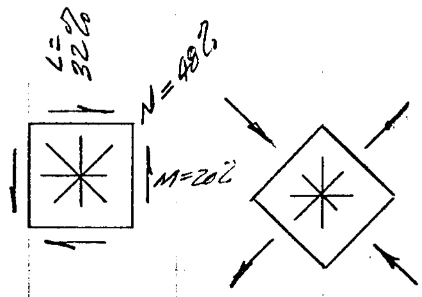
$f_s = \dfrac{q}{t}$, $t = 0.175$ (REF. PG. 2)

$= \dfrac{1436}{0.175}$

$f_s = 8206$ psi ULT. @ 350°F

FOR L = 32%, M = 20% & N = 48%,

$F_{SU} = 18{,}500$ psi @ R.T. (REF. WKR. R&D DESIGN DATA)



FOR ELEMENT ROTATED 45°,
L' = 24%, M' ≐ 24%, N' ≐ 52%

MJO NO. 4316-001	SUBJECT	DATE 1/18/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 7

BASIC CYLINDER WALL - (CONT.)

SHEAR STRESS IN CYL. WALL (CONT.)

FOR ROTATED ELEMENT;

	F_{TU}	F_c
R.T.	43,000	40,000
350°F	36,000	30,000

$$\frac{F_{TU_{350}}}{F_{TU_{R.T.}}} = \frac{36}{43} = 0.84$$

$$\frac{F_{c_{350°}}}{F_{c_{R.T.}}} = \frac{30}{40} = 0.75$$

ASSUME F_{SU} @ 350°F = 0.75 F_{SU} @ R.T.

$$F_{SU_{350°F}} = 0.75(18{,}500)$$
$$= 13{,}880 \text{ psi}$$

$$M.S. = \frac{F_{SU}}{f_s} - 1$$

$$= \frac{13{,}880}{8206} - 1 = \text{———— ————} \underline{\underline{+0.69}}$$

MJO NO. 4316 - 001	SUBJECT	DATE 1/18/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 8

BASIC CYLINDER WALL ~ (CONT.)

SHEAR STRESS IN CYL. WALL (CONT.)

SHEAR FLOW IS PRICIPALLY DUE TO TORSION IN CASE. THEREFORE, CHECK THE CASE WALL FOR SHEAR BUCKLING DUE TO TORSION.

USE E AT 45° (N DIRECTION) @ 350°F FOR SHEAR BUCKLING CALCULATIONS.

$L' = 29\%$, $N' = 52\%$

$E = 10.2 \times 10^6$ psi @ 350°F

SHEAR BUCKLING ALLOWABLE STRESS ~.
(REF. BRUHN[4] PG. C8.11)

$$Z_L = \frac{L^2}{Rt}\left(1-\mu^2\right)^{1/2}, \qquad \begin{matrix} L = 9.6 \text{ IN} \\ R = 7.2 \text{ IN} \end{matrix} \Big\} \text{ (REF. PG. 4)}$$

$$= \frac{(9.6)^2}{(7.2)(.175)}\left(1-0.3^2\right)^{1/2}$$

$t = 0.175$ IN (REF. PG. 2),

$\mu = 0.3$ (ASSUME FOR MAT'L WITH LAYUP APPROX. ISOTROPIC)

$= 69.8$

$K_t = 17$ (REF. BRUHN,[4] FIG. C8.18)

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/18/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	9

ENGINEERING CALCULATIONS

BASIC CYLINDER WALL ~ (CONT.)

SHEAR STRESS IN CYL. WALL (CONT.)

$$F_{SCR} = \frac{K_t \pi^2 E}{12(1-\mu^2)} \left(\frac{t}{L}\right)^2$$

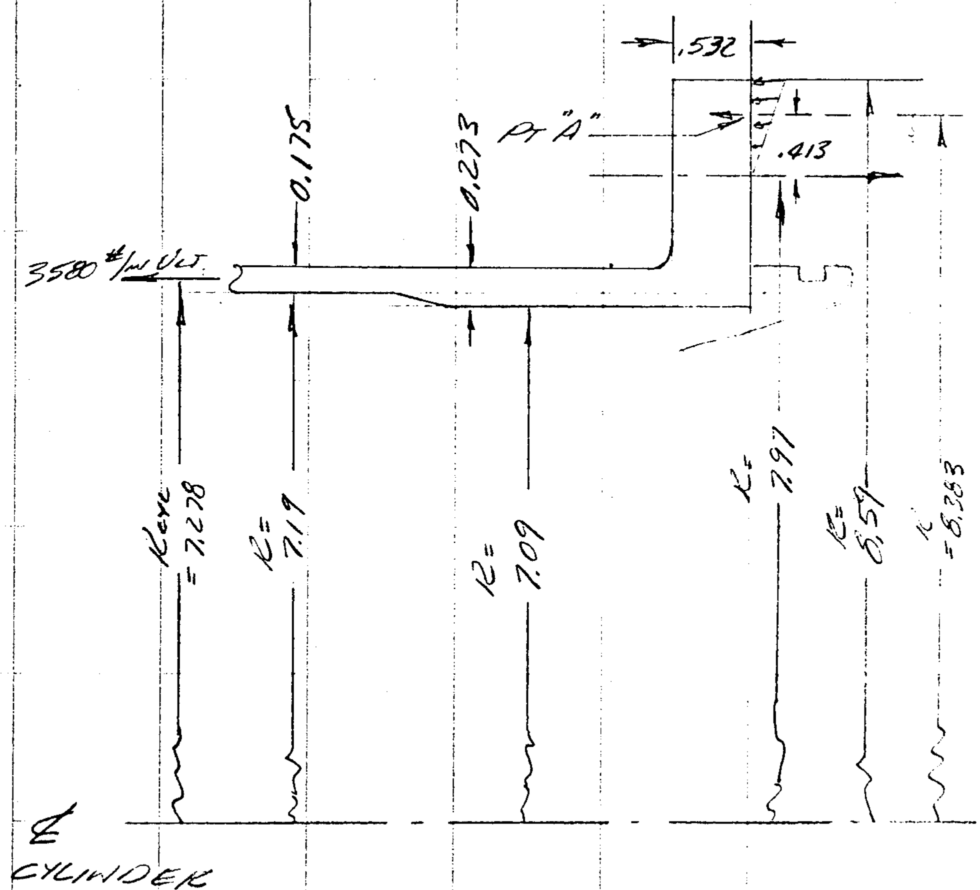
$$= \frac{17 \pi^2 (10.2 \times 10^6)}{12(1-0.3^2)} \left(\frac{.175}{9.6}\right)^2$$

$F_{SCR} = 52{,}000$ psi @ 350°F

ULT. SHEAR STRENGTH (F_{SU}) IS MORE CRITICAL, (SEE CALC. PG. 8)

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/13/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	10

DISCONTINUITY STRESS @ LOWER FLANGE/CYL INTERSECTION ~



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	11

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LOWER FLANGE/CYL INTERSECTION (CONT.)

FLIGHT COND. II HAS MAX. DIST. LOAD

$\omega_{MAX} = 2179.4$ #/IN LIMIT (SEE APPENDIX I PAGE 21)

$= 3269$ #/IN ULT. @ BOLT CIRC. (R=7.97)

AXIAL LOAD IN CYL. WALL:

FROM $\Sigma F_V = 0$

$\omega_{CYL} 2\pi R_{CYL} = \omega_{MAX} 2\pi R_{B.C.}$, $R_{CYL} = 7.278$, $R_{B.C.} = 7.97$

$$\omega_{CYL} = \frac{3269(7.97)}{7.278}$$

$= 3580$ #/IN ULT.

FROM $\Sigma M_{PT.\text{"}A\text{"}}$

FOR A WEDGE SEGMENT OF $\Delta\theta$, $\Delta S = R\Delta\theta$

$$W_{CYL} R_{CYL} \Delta\theta (8.383 - 7.278) = \omega_{BOLT\ CIRC.} R_{BC} \Delta\theta (.413)$$

$$\omega_{BOLT\ CIRC.} = \frac{3580(7.278)(1.105)}{7.97(.413)}$$

$= 8747$ #/IN ULT.

$\Sigma M_{BOLT\ CIRC.}$:

$$\omega_{PRYING} R_{PRY.} \Delta\theta(.413) = W_{CYL} R_{CYL} \Delta\theta(7.97 - 7.278)$$

$$W_{PRY.} = \frac{3580(7.278)(.692)}{8.383(.413)} = 5208 \text{ #/IN ULT.}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	12

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)

CHECK ΣF_Y:

$$W_{CYL}\, 2\pi R_{CYL} + W_{PRY}\, 2\pi R_{PRY} = W_{B.C.}\, 2\pi R_{BC}$$

$$3580(7.278) + 5208(8.383) = 8747(7.97)$$

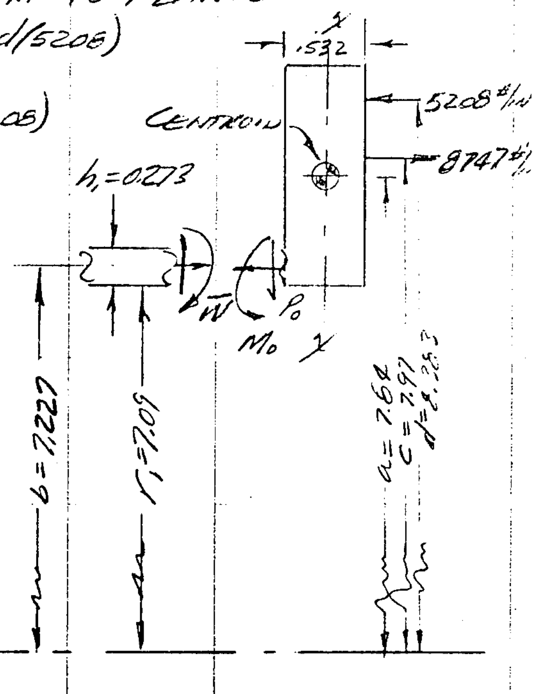
$$69714 = 69714 \quad (O.K.)$$

THEN: FOR LOAD IN CYL. WALL AT INCREASED WALL THICKNESS NEXT TO FLANGE—

$$2\pi b \overline{W} = 2\pi c(8747) - 2\pi d(5208)$$

$$\overline{W} = \frac{7.97(8747) - 8.383(5208)}{7.227}$$

$$= 3605 \ \#/IN \ ULT.$$



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		**CALCULATIONS BY**	**SHEET NO.**
		A.M.T.	13

DISCONTINUITY STRESS AT LWR. FLANGE/CYL INTERSECTION (CONT.)

LAYUP OF LOWER FLANGE ~

MATERIAL IS MODULITE 5206 TYPE I

	%		
L (RADIAL)	34.2	26 PLIES	$t = 26(.007) = 0.182$
M (HOOP)	50.0	38 PLIES	$t = 38(.007) = 0.266$
N ($\pm 45°$)	15.8	12 PLIES	$t = 12(.007) = \underline{0.084}$

$t_{TOT} = 76(.007) = 0.532$ IN

IN HOOP (M) DIRECTION

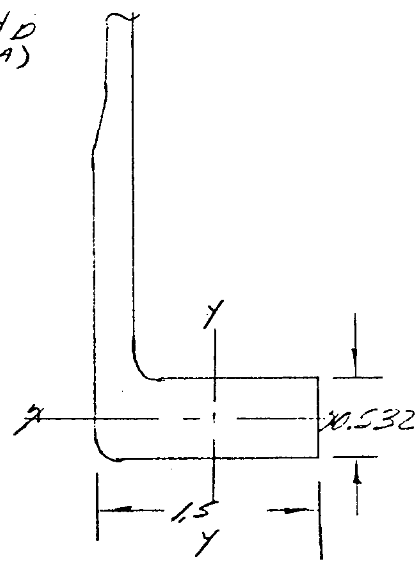
$E = 17.8 \times 10^6$ psi (REF. WKR. R&D DESIGN DATA)

$$EI_{YY} = (17.8\times10^6)\,\frac{0.532(1.5)^3}{12}$$

$$= 2.663 \times 10^6$$

$$EI_{xx} = 17.8\times10^6\,\frac{(1.5)(0.532)^3}{12}$$

$$= 0.335 \times 10^6$$

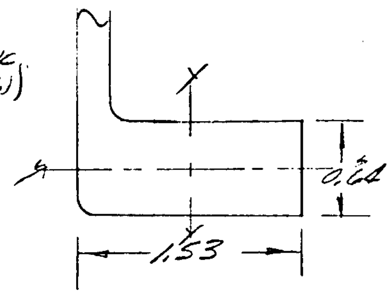


MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/19/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	14

DISCONTINUITY STRESS AT LOWER FLANGE/CYL INTERSECTION (CONT.)

LOWER FLANGE OF MAG. CASTING

$E = 6.5 \times 10^6$ (REF. MIL HDBK. 5, TABLE 4.2.6.0(b))



$$EI_{YY} = \frac{6.5 \times 10^6 (0.64)(1.53)^3}{12}$$

$$= 1.242 \times 10^6$$

$$EI_{XX} = \frac{6.5 \times 10^6 (1.53)(0.64)^3}{12}$$

$$= 0.217 \times 10^6$$

STIFFNESS COMPARISON

LOWER FLANGE BENDING STIFFNESS

$$\frac{EI_{YY\,COMPOSITE}}{EI_{YY\,MAG.}} = \frac{2.663 \times 10^6}{1.242 \times 10^6} = \underline{\underline{2.14}}$$

$$\frac{EI_{XX\,COMPOSITE}}{EI_{XX\,MAG}} = \frac{0.335 \times 10^6}{0.217 \times 10^6} = \underline{\underline{1.54}}$$

MJO NO. 4316-001	SUBJECT	DATE 1/19/22	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 15

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)

FOR DISTRIBUTED TORQUE APPLIED TO A RING

(1) $\theta = \dfrac{M_t a^2}{EI_{zz}}$ (REF. TIMOSHENKO, STRENGTH OF MAT'LS PART II, PG. 176) [5]

$EI_{xx} = 0.335 \times 10^6$ (REF. PG. 14)

TORQUE ABOUT FLANGE CENTROID (SEE SKETCH, P. 13)

(2) $M_t = 8747(7.97-7.84) - 5208(8.383-7.84)$
$- P_0\left(\frac{.532}{2}\right) - M_0 + \overline{W}(7.84-7.228)$, $\overline{W} = 3605$ #/in (REF PG. 13)

$= 1137 - 2828 - .266P_0 - M_0 + 2206$

$= 515 - .226P_0 - M_0$

$M_0 = 2\beta D\theta$
$P_0 = \beta M_0$ } REF. TIMOSHENKO, STRENGTH OF MAT'LS PART II, PG 181) [5]

SUBSTITUTING (2) IN (1):

$\theta = \dfrac{(515 - .226P_0 - M_0)(7.84)^2}{0.335 \times 10^6}$

$= [94492 - 41.47P_0 - 183.48M_0] \times 10^{-6}$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANS. CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	16

DISCONTINUITY STRESS AT LWR. FLANGE/CYL INTERSECTION (CONT.)

CYLINDER WALL LAYUP AT LOWER FLANGE ~

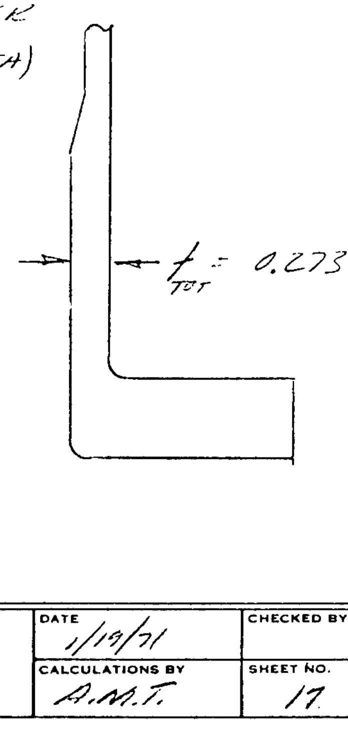
MATERIAL IS MODULITE 5206 TYPE I

	%		
L (AXIAL)	56.4	22 PLIES	$t = 22(.007) = 0.154$
M (HOOP)	12.8	5 PLIES	$t = 5(.007) = 0.035$
N ($\pm 45°$)	30.8	12 PLIES	$t = 12(.007) = \underline{0.084}$

$t_{TOT} = 39(.007) = 0.273$ IN

IN AXIAL (L) DIRECTION:

$E = 20.1 \times 10^6$ psi (REF WKR R&D DESIGN DATA)



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/19/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	17

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LWR FLANGE/CYL INTERSECTION (CONT.)

$P_o = \beta M_o$

$= 0.9239 M_o$

$M_o = 2\beta D \theta$

$= 2(0.9239)(0.03742 \times 10^6)\theta$

$= 0.06914 \times 10^6 \theta$

$\beta = \left[\dfrac{3(1-\mu^2)}{r_1^2 h_1^2}\right]^{1/4}$, $r_1 = 7.09$, $h_1 = .273$

$= \left[\dfrac{3(.91)}{(7.09)^2(.273)^2}\right]^{1/4}$

$= 0.9239$

$D = \dfrac{E h_1^3}{12(1-\mu^2)}$, $E = 20.1 \times 10^6$ (REF. PG. 17)

$= \dfrac{20.1 \times 10^6 (.273)^3}{12(.91)}$

$= .03742$

$\theta = \left[94492 - 41.47 P_o - 183.48 M_o\right] \times 10^{-6}$ (REF. PG. 16)

$\theta = \left[94492 - 41.47(0.9239)M_o - 183.48(0.06914 \times 10^6)\theta\right] \times 10^{-6}$

$\theta = .094492 - 2.649\,\theta - 12.686\,\theta$

$\theta(1 + 2.649 + 12.686) = .094492$

$\theta = \dfrac{.094492}{16.335} = 0.00578$

$M_o = 0.06914 \times 10^6 (0.00578) = 399.6$ in#/in ULT.

$P_o = 0.9239(399.6) = 369.2$ #/in ULT.

MJO NO. 4316-001	SUBJECT	DATE 9/30/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 18

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)

CHECK.

$$\theta = [94492 - 41.47 P_o - 183.48 M_o] \times 10^{-6}$$

$$0.00578 = \left[.094492 - \frac{41.47(369.2)}{10^6} - \frac{183.45(399.6)}{10^6}\right]$$

$$.00578 = .00587 \quad \leftarrow OK$$

BENDING MOMENT IN FLANGE X-SECT ABOUT X-X AXIS DUE TO DISTRIBUTED TORQUE: (SEE SKETCH PG. 13)

$$M = M_f\, a \quad , \quad M_f = 515 - 0.226 P_o - M_o \quad (\text{REF PG. } 16)$$

$$= [515 - .226 P_o - M_o]\, a$$

$$= [515 - .226(369.2) - 399.6]\, 7.84$$

$$= (31.96)(7.84)$$

$$= 250.6 \text{ IN}^\# \text{ ULT.}$$

HOOP LOAD DUE TO RADIAL LOAD P_o IN FLANGE:

$$P_{Hoop} = P_o\, b = 369.2(7.227) = 2668^\# \text{ ULT.}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	19

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS AT LWR. FLANGE/CYL INTERSECTION (CONT.)

FLANGE STRESS ~ CONDITION II

$$f_c = \frac{M y E}{E I_{xx}} + \frac{P}{A} \quad , \quad E = 17.8 \times 10^6$$

IN FLANGE HOOP DIRECT.~

(REF. PG. 14)

$EI_{xx} = 0.335 \times 10^6$ (REF. PG. 14)

$$= \frac{250.6\left(\frac{.532}{2}\right)(17.8 \times 10^6)}{0.335 \times 10^6} + \frac{2668}{0.532(1.5)}$$

= 6885 psi ULT. @ 350°F (COND. II)

IN M DIRECTION FOR M = 50.0%, N = 15.8% AT 350°F, (REF. PG. 14)

F_c = 48,000 psi (REF. WKR R&D DESIGN DATA)

$$M.S. = \frac{F_c}{f_c} - 1 = \frac{48,000}{6885} - 1 = \text{— —} \underline{\underline{+6.0}}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/19/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	20

DISCONTINUITY STRESS AT LOWER FLANGE/CYL INTERSECTION (CONT.)

LOADS ON CYL AT LWR. FLANGE/CYL INTERSECTION:

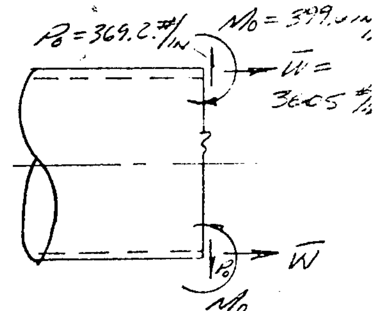
COND. II

$\overline{W} = 3605$ #/IN ULT. (REF. PG. 13)

$M_0 = 399.6$ IN#/IN ULT. (REF. PG. 18)

$P_0 = 369.2$ #/IN ULT. (REF. PG. 18)

CHECK FOR SHORT CYLINDER CORRECTION REQUIREMENT



$L = 9.6$

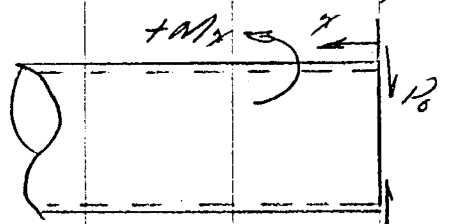
$$\frac{6}{\beta} = \frac{6}{0.9239} = 6.5$$

$L > \frac{6}{\beta}$, THEREFORE LONG CYLINDER EQUATIONS WILL BE USED WITHOUT SHORT CYLINDER CORRECTION FACTORS.

MJO NO.	SUBJECT	DATE 1/19/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 21

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)

BENDING MOMENTS, SHEARS & HOOP STRESS IN CYL. DUE TO P_o & M_o:



REF. ROARK,[6] PG. 302, CASE 14

P_o (POSITIVE AS SHOWN)

$\beta = 0.9239$ (REF. PG. 18)

$P_o = -369.2$ #/IN ULT. (REF. PG. 18), ROARK'S[6] SIGN CONVENTION

FOR P_o LOADS,

$$M_x = -\frac{1}{\beta} P_o e^{-\beta x} \sin\beta x$$

$$V_x = P_o e^{-\beta x}(\cos\beta x - \sin\beta x)$$

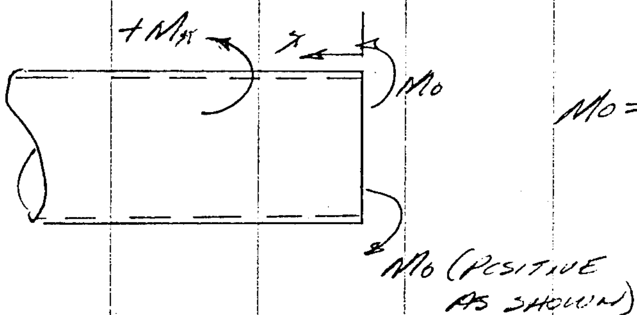
REF. ROARK,[6] PG. 302, CASE 14

x IN	βx	$e^{-\beta x}$	$\sin\beta x$	$\cos\beta x$	M_{xP_o} IN#/IN	V_{xP_o} #/IN
0	0	1.0	0	1.0	0	-369.2
0.2	.18478	.832	.18372	.98298	61.1	-245.5
0.4	.36956	.691	.36120	.93249	99.7	-145.7
0.6	.55434	.575	.52637	.85025	120.9	-68.8
0.8	.73912	.478	.67363	.73906	128.7	-11.5
1.0	0.9239	.397	.79795	.60272	126.6	26.6

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	22

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)



$M_0 = -399.6$ IN#/IN. CIRC.
(NEG. VALUE FOR CONSISTENT SIGN FOR M_x), (REF. PG. 18)

$$M_x = M_0 e^{-\beta x}(\cos\beta x + \sin\beta x)$$
$$V_x = 2\beta M_0 e^{-\beta x}\sin\beta x$$

REF. ROARK, PG. 302 [6] CASE 15

x IN	βx	$e^{-\beta x}$	$\sin\beta x$	$\cos\beta x$	M_x MO IN#/IN	V_x MO #/IN
0	0	1.0	0	1.0	-399.6	0
.2	.18478	.832	.18372	.98298	-387.9	-112.9
.4	.36956	.691	.36120	.93249	-357.2	-184.3
.6	.55434	.575	.52637	.85025	-316.3	-223.5
.8	.73912	.478	.67363	.73906	-269.8	-237.8
1.0	.92390	.397	.79795	.60272	-222.2	-233.9

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	23

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS @ LWR. FLANGE/CYL INTERSECTION (CONT.)

SUMMARY ~ DISCONTINUITY SHEARS & MOMENTS IN CYL AT LWR FLG. ~ COND II

x IN.	$V_{x_{P_0}}$	$V_{x_{M_0}}$	$V_{x_{TOT}}$ #/IN ULT.	$M_{x_{P_0}}$	$M_{x_{M_0}}$	$M_{x_{TOT}}$ IN-#/IN
0	-369.2	0	-369.2	0	-399.6	-399.6
.2	-245.5	-112.9	-358.4	61.1	-387.9	-326.8
.4	-145.7	-184.3	-330.0	99.7	-357.2	-257.5
.6	-68.8	-223.5	-292.3	120.9	-316.3	-195.4
.8	-11.5	-237.8	-249.3	128.7	-269.8	-141.1
1.0	28.6	-233.9	-205.3	126.6	-222.2	-95.6

MAXIMUM MOMENT IN CYL WALL OCCURS AT $x = 0$.

@ $x = 0$

$$f_t = \frac{6M}{bt^2} + \frac{P}{A}, \quad P = \overline{W} = 3605 \text{ \#/in ULT.}$$

(REF. PG 13)

$$f_t = \frac{6(399.6)}{(1)(.273)^2} + \frac{3605}{(1.0)(.273)}$$

$= 45,380$ psi ULT. @ 350°F (CASE II)

FOR $L = 56.4\%$, $N = 30.8\%$ (REF. PG. 17) IN L DIRECTION,

$F_{tu} = 69,000$ psi @ 350°F (REF. WKR R&D DESIGN DATA)

MJO NO.	SUBJECT	DATE	CHECKED BY
9316-001	COMPOSITE TRANSMISSION CASE	9/30/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	24

ENGINEERING CALCULATIONS

DISCONTINUITY STRESS AT LOWER FLANGE/CYL INTERSECTION (CONT.)

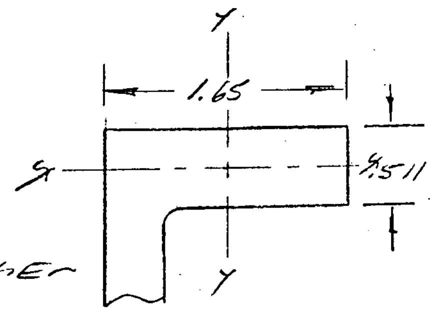
STRESS IN CYL. WALL

$$M.S. = \frac{F_{tu}}{f_t} - 1$$

$$= \frac{69{,}000}{45{,}380} - 1 = \text{——— ——— ———} +\underline{\underline{0.52}}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		1/19/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	25

UPPER FLANGE STIFFNESS ~



LAYUP OF UPPER FLANGE ~

MATERIAL IS MODULITE

5206 TYPE I

	%		
L (RADIAL)	34.2	25 PLIES	$t = 25(.007) = .175$
M (HOOP)	49.3	36 PLIES	$t = 36(.007) = .252$
N ($\pm 45°$)	16.5	12 PLIES	$t = 12(.007) = .084$
			$t_{TOT} = 73(.007) = 0.511$

IN HOOP (M) DIRECTION:

$E = 17.6 \times 10^6$ psi (REF. WKR R&D DESIGN DATA)

$$EI_{xx} = 17.6 \times 10^6 \frac{(1.65)(0.511)^3}{12} = 0.323 \times 10^6$$

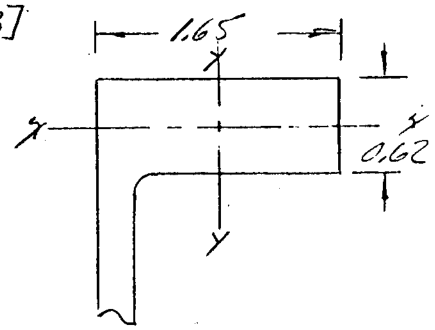
$$EI_{YY} = 17.6 \times 10^6 \frac{(0.511)(1.65)^3}{12} = 3.367 \times 10^6$$

MJO NO. 4316-001	SUBJECT	DATE 1/20/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 26

UPPER FLANGE STIFFNESS (CONT.)

UPPER FLANGE OF MAG CASTING ~

$E = 6.5 \times 10^6$ (REF. MIL HDBK 5, [3] TABLE 4.2.6.0(b1))



$$E\bar{I}_{YY} = 6.5 \times 10^6 \frac{(0.62)(1.65)^3}{12}$$

$$= 1.509 \times 10^6$$

$$E\bar{I}_{xx} = 6.5 \times 10^6 \frac{(1.65)(.62)^3}{12}$$

$$= 0.213 \times 10^6$$

STIFFNESS COMPARISON.
UPPER FLANGE BENDING STIFFNESS ~

$$\frac{EI_{YY\,COMPOSITE}}{EI_{YY\,MAG}} = \frac{3.367 \times 10^6}{1.509 \times 10^6} = \underline{\underline{2.23}}$$

$$\frac{EI_{xx\,COMPOSITE}}{EI_{xx\,MAG}} = \frac{0.323 \times 10^6}{0.213 \times 10^6} = \underline{\underline{1.52}}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316 - 001		1/20/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	27

DISCONTINUITY STRESS AT UPPER FLANGE/CYL INTERSECTION ~

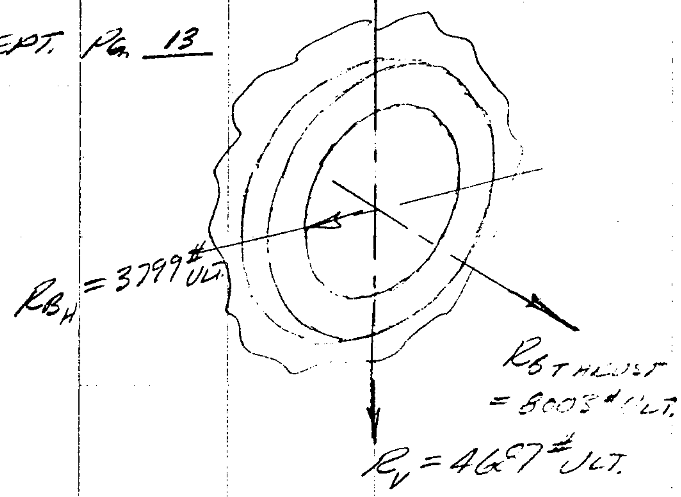
DISCONTINUITY STRESSES AT THE UPPER FLANGE ARE NOT CRITICAL BY INSPECTION. LOADS AT THE UPPER FLANGE ARE SMALLER THAN LOADS AT THE LOWER FLANGE. THE LOCAL THICKNESS OF THE CYLINDER WALL AT THE UPPER FLANGE IS LARGER THAN THE CYLINDER WALL THICKNESS AT THE LOWER FLANGE. THE MARGIN OF SAFETY FOR BENDING & HOOP COMPRESSION IN THE LOWER FLANGE IS VERY HIGH.

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT

LOADING COND I IS CRITICAL

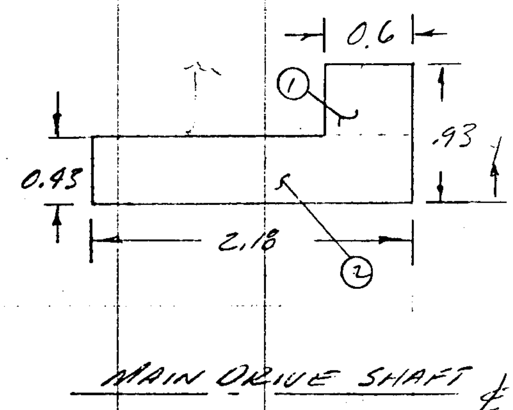
REF. LOADS REPT. PG. 13



$$\left[R_{B_H}^2 + R_{B_V}^2\right]^{1/2}$$

$= 6033^{\#}$ ULT.

BENDING OF RING X-SECTION & HOOP LOADING OF RING X-SECTION ARE ASSUMED TO BE MOST IMPORTANT FOR STIFFNESS.



MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001	COMPOSITE TRANSMISSION CASE	10/1/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	29

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

STIFFNESS OF MAG. X-SECTION

ITEM	A	y	Ay	Ay^2	I_o
1	$.6 \times .5 = 0.300$	.68	.20400	.13972	.00625
2	$.95 \times .2 \cdot .18 = .937$	.215	.20145	.04331	.01444
	1.237		.40545	.18203	.02069

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{.40545}{1.237} = 0.328$$

$$I = \Sigma Ay^2 + \Sigma I_o - \bar{y}\Sigma Ay$$

$$= .18203 + .02069 - .328(.40545)$$

$$= .06974 \text{ IN}^4$$

$$EI = 6.5 \times 10^6 (.06974)$$

$$= 0.453 \times 10^6$$

$E_{MAG} = 6.5 \times 10^6$ (REF. MIL HDBK 5,[3] TABLE 4.2.6.0(b))

$$EA = 6.5 \times 10^6 (1.237)$$

$$= 8.041 \times 10^6$$

MJO NO.	SUBJECT	DATE	CHECKED BY
2316-001	COMPOSITE TRANSMISSION CASE	10/1/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	30

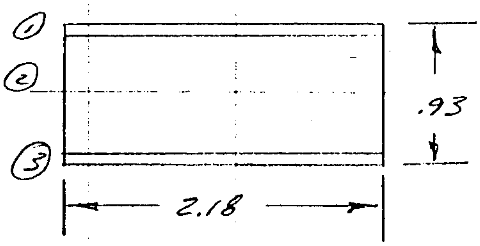
ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

FACINGS ~

8 PLIES CIRC. WOUND

MODMOR I/EPOXY



$t = 8(.007) = .056$

$E = 32 \times 10^6$

CORE ~

GLASS EPOXY BMC

$t = 0.93 - 2(.056) = 0.818 \text{ IN}$

$E \approx 2.0 \times 10^6$

$$\Sigma EI = 2\left[2.18(.056)(.437)^2 + \frac{2.18(.056)^3}{12}\right]32\times10^6$$

$$+ \frac{(.93-.112)^3(2.18)}{12}(2\times10^6)$$

$$= (1.493 + 0.199)\times10^6$$

$$= 1.692\times10^6$$

STIFFNESS COMPARISON:

$EI_{\text{COMPOSITE}}/EI_{\text{MAG}}$

$$= \frac{1.692\times10^6}{.453\times10^6} = 3.74$$

$$\Sigma EA = 2(2.18)(.056)(32\times10^6) + (.93-.112)(2.18)(2\times10^6)$$

$$= 11.38\times10^6$$

$EA_{\text{COMP}}/EA_{\text{MAG}} = \frac{11.38}{8.04} = 1.42$ (O.K. SINCE BENDING STIFFNESS OF X-SECT. IS HIGH)

MJO NO.	SUBJECT	DATE 10/11/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 31

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

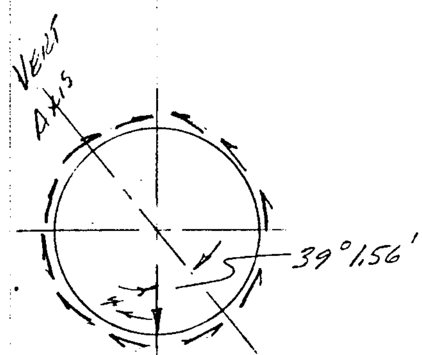
RING ANALYSIS ~

REF. ROARK [6] PG. 178

CASE 25

$q = \frac{P \sin x}{\pi R}$, $R = \frac{6.75}{2} + \frac{.93}{2}$

$= 3.84$ IN.



$z = \sin x$

$u = \cos x$

$\theta = 0$

$c = \cos\theta = 1$

$P = -6033$ # ULT. (REF. PG. 29)

$M = PR\left[0.23868u - \frac{z}{2} + 0.15915(xz + \theta s + c - uc^2)\right]$

$= -6033(3.84)\left[0.23868\cos x - \frac{\sin x}{2} + .15915(x\sin x + 0 + 1 - \cos x)\right]$

$= -5529\cos x + 11583\sin x - 3687x\sin x - 3687 + 3687\cos x$

$= -1842\cos x - (3687x - 11583)\sin x - 3687$

$T = -P\left[0.15915(xz - uc^2) - 0.07958u - \frac{z}{2}\right]$

$= -6033\left[0.15915(x\sin x - \cos x) - .07958\cos x - \frac{\sin x}{2}\right]$

$= -960.2x\sin x + 960.2\cos x + 480.1\cos x + 3016.5\sin x$

$= +1440.3\cos x - (960.2x - 3016.5)\sin x$

$V = -P\left[0.15915(xu - \frac{z}{2} + zc^2) - \frac{u}{2}\right]$

$= -6033\left[.15915(x\cos x - \frac{\sin x}{2} + \sin x) - \frac{\cos x}{2}\right]$

$= -960.2x\cos x - 480.1\sin x + 3016.5\cos x$

$= (3016.5 - 960.2x)\cos x - 480.1\sin x$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		10/11/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	32

ENGINEERING CALCULATIONS

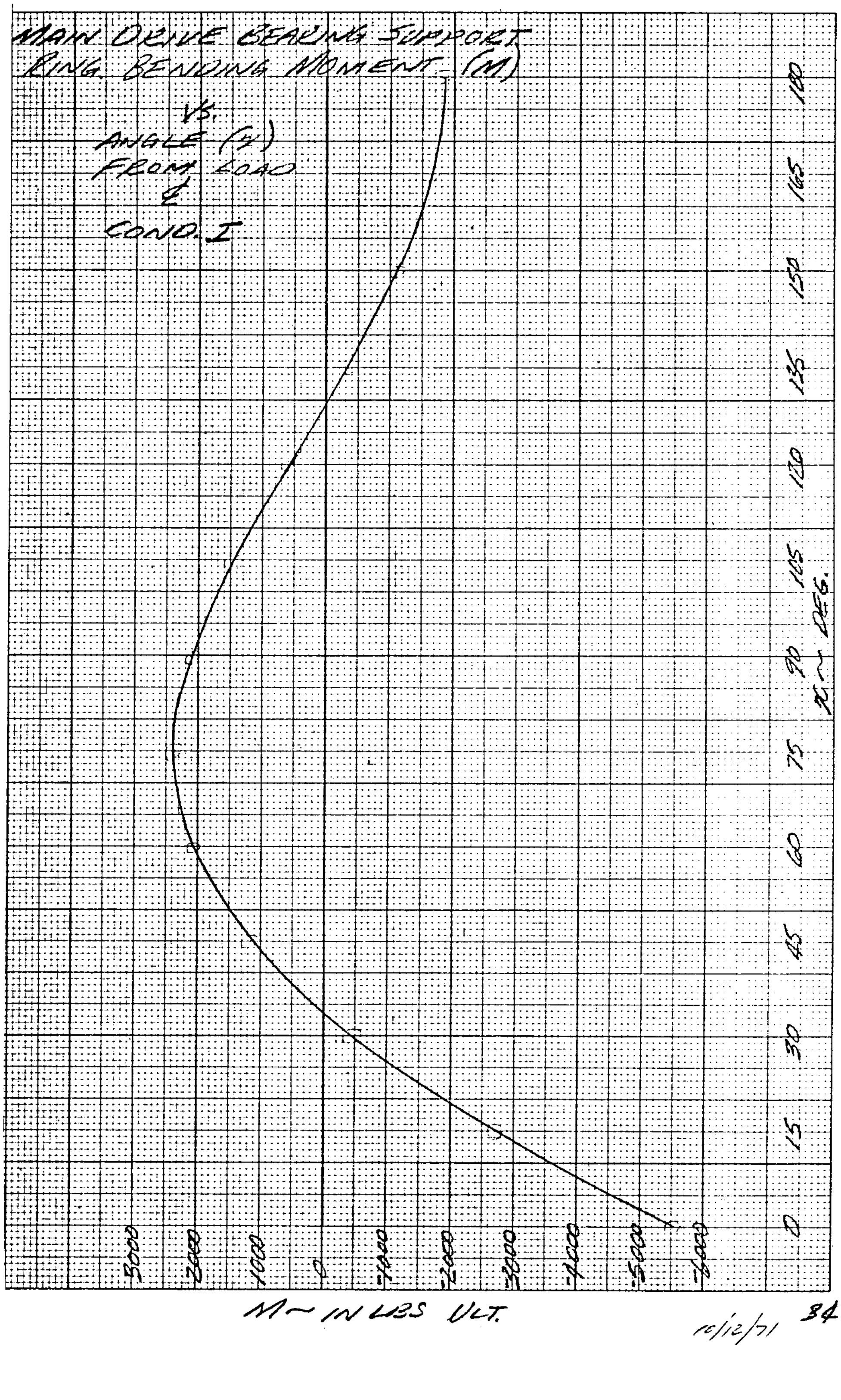
MAIN DRIVE BEARING SUPPORT (CONT.)

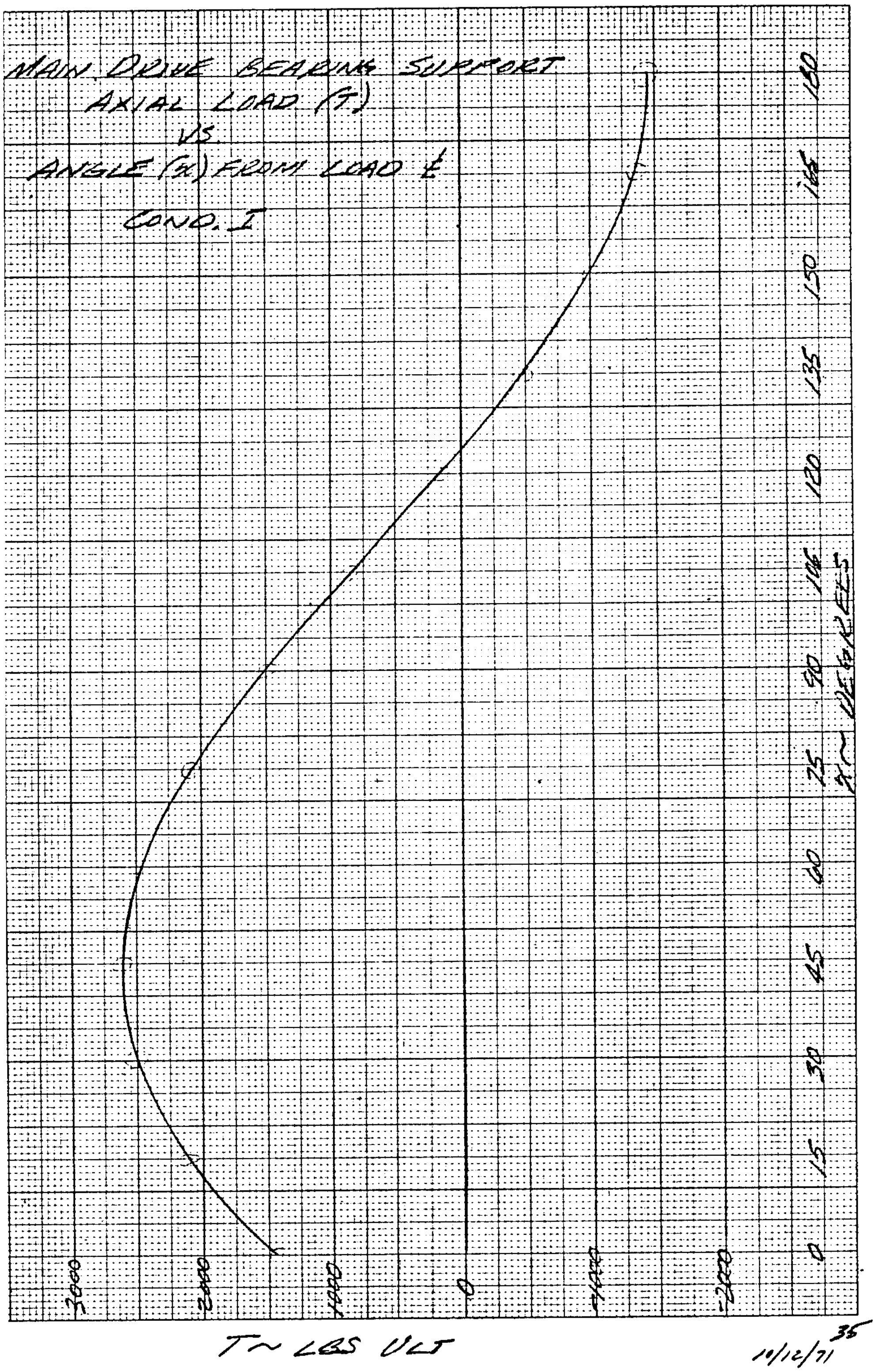
RING ANALYSIS (CONT.)

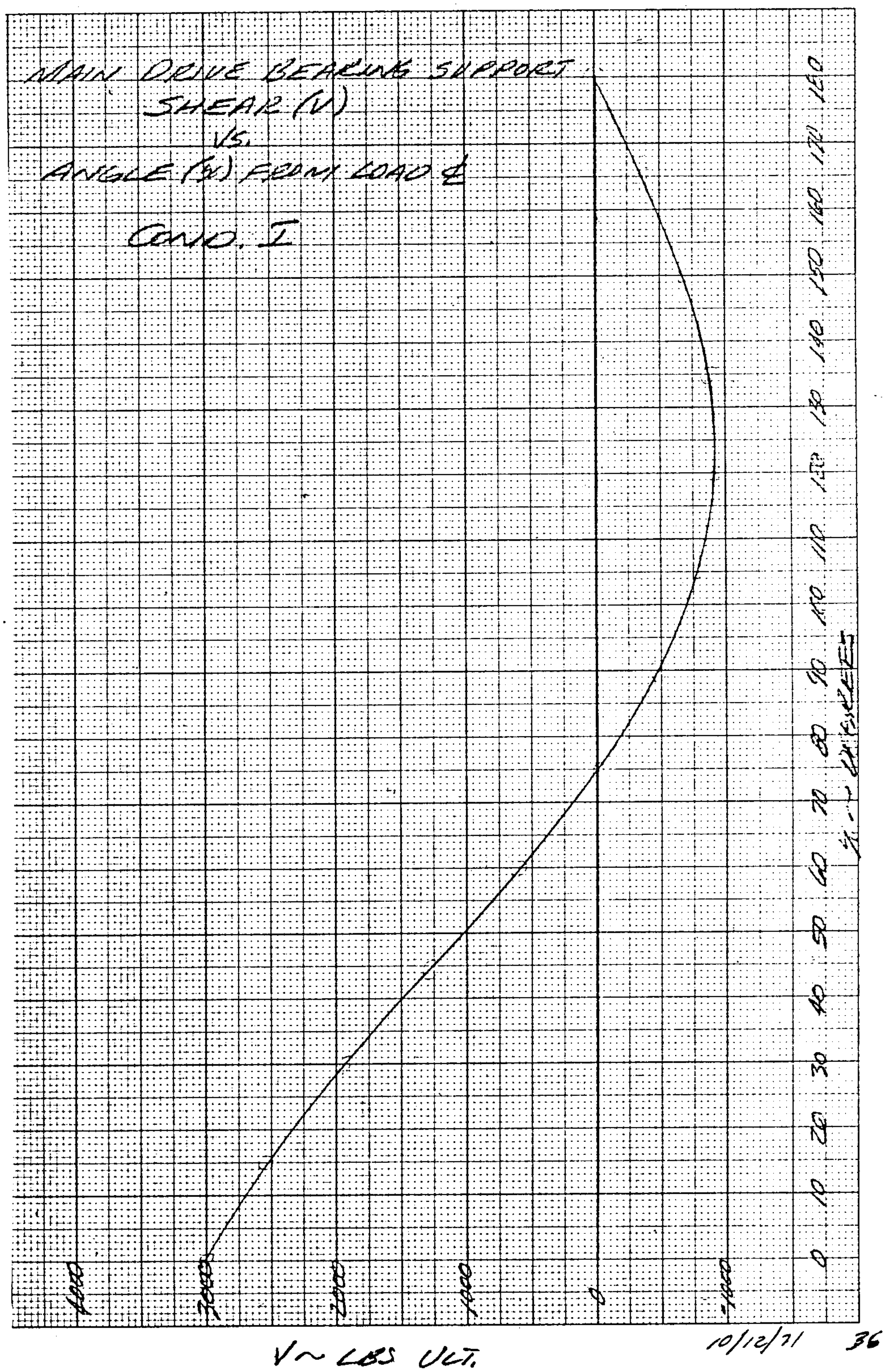
ϕ DEG.	ϕ RAD	SIN ϕ	COS ϕ	M IN# ULT.	T # ULT.	V # ULT.
0	0	0	1	-5529	1440	3016.5
15	.2618	.25882	.96593	-2716	2107	2547
30	.5236	.50000	.86603	-456	2504	1937
45	.7854	.70711	.70711	+1153	2618	1260
60	1.0472	.86603	.50000	+2079	2462	590
75	1.3090	.96593	.25882	+2363	2072	-8
90	1.5708	1.0000	0	+2104	1508	-480
105	1.8326	.96593	-.25882	+1452	841	-789
120	2.0944	.86603	-.50000	+576	151	-919
135	2.3562	.70711	-.70711	-337	-465	-873
150	2.6180	.50000	-.86603	-1127	-996	-675
165	2.8798	.25882	-.96593	-1658	-1326	-367
180	3.1416	0	-1.0	-1845	-1440	0

DATA FROM THIS TABULAR SOLUTION ARE PLOTTED ON PAGES 34, 35 & 36.

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		10/12/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	33


MAIN DRIVE BEARING SUPPORT
RING BENDING MOMENT (M)
VS.
ANGLE (ψ)
FROM LOAD ℄
COND. I
0
15
30
45
60
75
90
105
120
135
150
165
180
ψ ~ DEG.
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
M ~ IN LBS ULT.
10/12/71
34


MAIN DRIVE BEARING SUPPORT
AXIAL LOAD (T)
VS
ANGLE (x) FROM LOAD ℄
COND. I
x ~ DEGREES
0
15
30
45
60
75
90
105
120
135
150
165
180
3000
2000
1000
0
-1000
-2000
T ~ LBS ULT
10/12/71
35


MAIN DRIVE BEARING SUPPORT
SHEAR (V)
VS.
ANGLE (ψ) FROM LOAD ℄
COND. I
V ~ LBS ULT.
10/12/71
36

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

MAX. BENDING MOMENT OCCURS AT LOAD APPLICATION PT. ($x=0$), (REF. PG. 34)

@ $x=0$

$M = -5529$ IN# ULT. (COMPRESSION INSIDE SURFACE)

$T = 1440$ # ULT. (REF. PG. 35) (TENSION)

$$f_t = \frac{MyE}{\Sigma EI} + \frac{TE}{\Sigma AE}$$, $y = \frac{0.93}{2} = 0.465$

$\Sigma EI = 1.692 \times 10^6$ (REF. PG. 31)

$$= \frac{5529(.465)(32\times10^6)}{1.692\times10^6} + \frac{1440(32\times10^6)}{11.38\times10^6}$$

$\Sigma EA = 11.38 \times 10^6$ (REF. PG. 31)

$= 52673$ psi ULT.

FOR UNIDIRECTIONAL MODMOR I/EPOXY, $E = 32\times10^6$

$F_{tu} = 115{,}000$ psi @ 350°F (REF. WKK R&D DESIGN DATA)

$$M.S. = \frac{F_{tu}}{f_t} - 1 = \frac{115{,}000}{52673} - 1 = \underline{\underline{+1.18}}$$

IN B.M.C. CORE

$$f_t = \frac{MyE}{\Sigma EI} + \frac{TE}{\Sigma AE}$$, $y = 0.465 - .056 = 0.409$

$E = 2.0 \times 10^6$

$$= \frac{5529(.409)(2.0\times10^6)}{1.692\times10^6} + \frac{1440(2\times10^6)}{11.38\times10^6}$$

$= 2926$ psi ULT.

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4316-001		10/13/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	37

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

TENSION STRESS IN B.M.C. (CONT.)

@ 350°F ASSUME $F_{tu} = F_b$

$F_{tu} = 12800$ PSI (REF. WKR R&D TEST DATA, 2σ VALUE)

$$M.S. = \frac{F_{tu}}{f_t} - 1 = \frac{12800}{2926} - 1 = \text{———} \quad \underline{\underline{+3.37}}$$

MAX. SHEAR OCCURS @ LOAD APPLICATION PT. ($f_y=0$), (REF. PG. 36).

$V = 3016.5$ LBS ULT.

IN B.M.C. @ N.A.

$$f_s = \frac{V \Sigma EQ}{\Sigma EI\, b}, \quad \Sigma EQ = 2.18(.056)(.437)(32\times10^6) + 2.18(.409)\left(\frac{.409}{2}\right)(2\times10^6)$$

$$= \frac{3016.5(2.07\times10^6)}{1.692\times10^6(2.18)} \qquad = 2.07\times10^6$$

$= 1693$ PSI ULT.

@ 350°F IN BMC

$F_{su} = 2500$ PSI (REF. WKR R&D TEST DATA, 2σ VALUE)

$$M.S. = \frac{F_{su}}{f_s} - 1 = \frac{2500}{1693} - 1 = \text{———} \quad \underline{\underline{+0.48}}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		10/13/71	
TASK NO.		CALCULATIONS BY: A.M.T.	SHEET NO. 38

ENGINEERING CALCULATIONS

MAIN DRIVE BEARING SUPPORT (CONT.)

BEARING SUPPORT ATTACHMENT TO CASE WALL

MAX. SHEAR FLOW OCCURS 90° FROM LOAD APPLICATION PT.

$$q = \frac{P \sin \alpha}{\pi R}, \qquad \alpha = 90^\circ$$

$$P = 6033\ \#\ \text{ULT.}$$

$$= \frac{6330(1)}{\pi(4.305)} \qquad R = \frac{6.75}{2} + 0.93 = 4.305$$

$$= 468\ \#/\text{IN ULT.}$$

BEARING SUPPORT TO WALL BOND ATTACHMENT

BOND WIDTH = w = 1.30 IN (MINIMUM WIDTH)

$$f_s = \frac{q}{w} = \frac{468}{1.30} = 360\ \text{PSI ULT.}$$

@ 350°F

$F_{su_{BOND}}$ = 750 PSI (HYSOL[7] EA 934 REF HYSOL BULLETIN A9-234 & WKR TEST DATA)

$$M.S. = \frac{F_{su}}{f_s} - 1 = \frac{750}{360} - 1 = \text{———} \quad \underline{\underline{+1.08}}$$

IN CASE WALL,

$$f_s = \frac{q}{t} = \frac{468}{.175} = 2674\ \text{PSI ULT.}, \quad t = 0.175\ \text{IN}$$

$N(\pm 45)$ = 48% (REF. R. 2)

F_{su} = 18,500 PSI @ R.T.

$$M.S. = \frac{F_{su}}{f_s} - 1 = \frac{12700}{2674} - 1 = \underline{\underline{+3.7}} \qquad F_{su} = .69(18,500) = 12700 @ 350°F$$

MJO NO. 4316-001	SUBJECT	DATE 10/13/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 39

ENGINEERING CALCULATIONS

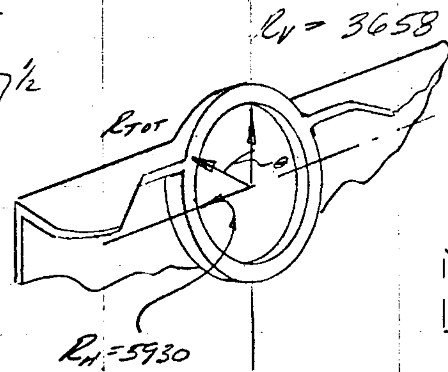
MAIN DRIVE INTERNAL BEARING SUPPORT

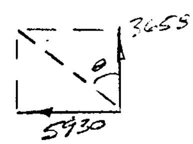
LOADING CONDITION I IS CRITICAL:

$$R_{TOT} = \left(R_V^2 + R_H^2\right)^{1/2}$$

$$= \left[(3658)^2 + (5930)^2\right]^{1/2}$$

$$= 6967 \text{ \# ULT.}$$





$$\tan\theta = \frac{5930}{3655} = 1.6211$$

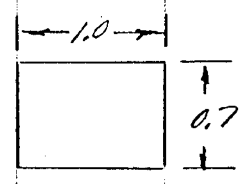
$$\theta = 58^\circ\ 20$$

MJO NO. 4316-001	SUBJECT	DATE 10/13/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 40

ENGINEERING CALCULATIONS

MAIN DRIVE INTERNAL BEARING SUPPORT (CONT.)

MAG CASTING RING STIFFNESS.



$$EI = (6.5\times10^6)\frac{(1.0)(0.7)^3}{12}$$

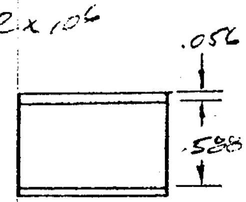
$$= 0.186\times10^6$$

$$EA = 0.7(6.5\times10^6)$$

$$= 4.55\times10^6$$

TRY SAME X-SECT WITH BMIL CORE & 8 PLIES MOD. I/EPOXY FACINGS

$t = 8(.007) = .056$ (FACING)



$$\Sigma EI = 2\left[1.0(.056)(.322)^2 + \frac{1.0(.056)^3}{12}\right]32\times10^6$$

$$+ \frac{1.0(.588)^3}{12}(2.0\times10^6)$$

$$= 0.373\times10^6 + .034\times10^6$$

$$= 0.406\times10^6$$

$$\Sigma EA = 2(.056)(1.0)(32\times10^6) + .588(1.0)(2.0\times10^6)$$

$$= 4.76\times10^6$$

$$\frac{\Sigma EI_{COMPOS.}}{\Sigma EI_{MAG}} = \frac{0.406}{0.186} = 2.18$$

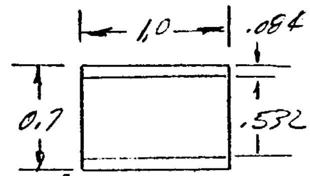
$$\frac{\Sigma EA_{COMPOS.}}{EA_{MAG}} = \frac{4.76}{4.55} = 1.05$$ (TOO LOW, TRY 12 PLIES)

MJO NO.	SUBJECT	DATE 10/13/71	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 41

MAIN DRIVE INTERNAL BEARING SUPPORT (CONT.)

12 PLIES MOD I/EPOXY FACINGS

CORE ~ GLASS/EPOXY BMC



$$\Sigma EI = 2\left[.084\left(\frac{.532+.084}{2}\right)^2 + \frac{(.084)^3}{12}\right]32\times10^6 + \frac{(.532)^3}{12}(2.0\times10^6)$$

$$= 0.538\times10^6$$

$$\Sigma EA = 2(.084)(32\times10^6) + .532(2.0\times10^6)$$

$$= 6.44\times10^6$$

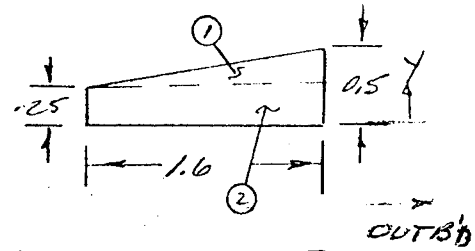
STIFFNESS COMPARISON

$$\frac{\Sigma EI_{COMPOS}}{EI_{MAG}} = \frac{0.538}{0.186} = 2.89$$

$$\frac{\Sigma EA_{COMPOS.}}{EA_{MAG}} = \frac{6.44}{4.55} = 1.42 \quad \text{ok.}$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		10/13/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	42

AUXILIARY BEARING SUPPORTS.



ITEM	A	Y	Ay	Ay^2	I_o
1	.200	.333	.06660	.02218	.00069
2	.400	.125	.05000	.00625	.00208
	0.600		.11660	.02843	.00277

$$\bar{y} = \frac{.1166}{.600} = 0.194$$

$$EI = \left[\Sigma Ay^2 + \Sigma I_o - \bar{y}\Sigma Ay\right]E$$

$$= \left[.02843 + .00277 - .194(.1166)\right](6.5 \times 10^6)$$

$$= .0558 \times 10^6$$

$$EA = 6.5 \times 10^6 (0.6) = 3.9 \times 10^6$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		2/1/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	43

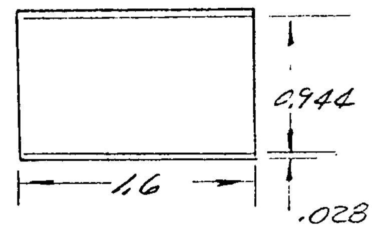
AUXILIARY BEARING SUPPORTS (CONT.)

FACINGS ~

4 PLIES MODMOR I/EPOXY

$t = 4(.007) = .028 \text{ IN}$

$E = 32 \times 10^6 \text{ PSI}$



CORE ~

GLASS/EPOXY BIAX

$E \simeq 2.0 \times 10^6$

FOR COMPOSITE X-SECTION:

$$EI = 2\left[(1.6 \times .028)\left(\frac{.944 + .028}{2}\right)^2 + \frac{1.6(.028)^3}{12}\right]32 \times 10^6$$

$$+ \frac{1.6(0.944)^3}{12}(2.0 \times 10^6)$$

$$= 0.900 \times 10^6$$

$$EA = 2\left[1.6(.028)(32 \times 10^6)\right] + 0.944(1.6)(2.0 \times 10^6)$$

$$= 5.89 \times 10^6$$

STIFFNESS RATIO:

$$\frac{EI_{COMPOSITE}}{EI_{MAG}} = \frac{0.900 \times 10^6}{.0558 \times 10^6} = 16.1$$

$$\frac{EA_{COMPOSITE}}{EA_{MAG}} = \frac{5.89 \times 10^6}{3.9 \times 10^6} = 1.51$$

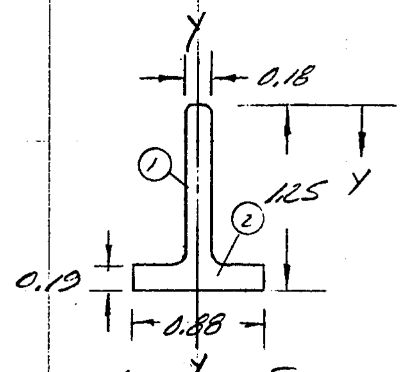
MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		2/2/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	44

ENGINEERING CALCULATIONS

BASE DISC ~

TYPICAL SPOKE IN MAGNESIUM CASTING CASE:

VERTICAL BENDING STIFFNESS



ITEM	A	y	Ay	Ay^2	$\bar{I}_0$
1	.196	.545	.10682	.05821	.01942
2	.167	1.155	.19288	.22277	.00050
	0.363		.29970	.28098	.01992

$$\bar{y} = \frac{\Sigma Ay}{\Sigma A} = \frac{.29970}{0.363} = 0.826$$

$$\Sigma EI_{x\cdot x} = \left[\Sigma Ay^2 + \Sigma \bar{I}_0 - \bar{y}\,\Sigma Ay\right]E$$

$$= \left[0.28098 + .01992 - 0.826(.29970)\right] 6.5\times 10^6$$

$$= 0.347 \times 10^6$$

$$\Sigma EA = 0.363(6.5\times 10^6)$$

$$= 2.360 \times 10^6$$

MJO NO.	SUBJECT	DATE	CHECKED BY
9316-001		11/8/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	45

BASE DISC ~ (CONT.)

TYPICAL SPOKE IN MAGNESIUM CASTING CASE (CONT.)

SIDE BENDING STIFFNESS

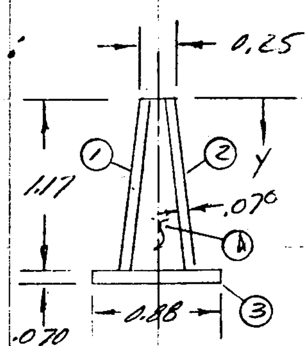
ITEM	A	x	Ax	Ax²	I_o
1	.196	0	0	0	.00052
2	.167	0	0	0	.01078
					.01130

$EI_{y-y} = .01130\,(6.5\times10^6) = 0.07345\times10^6$

COMPOSITE SPOKE STIFFNESS:

LAYUP ~ ITEMS ① & ②:

	%		
L (RADIAL)	60	6 PLIES	$t=6(.007)=.042$
M (VERT.)	0	0	
N (±45°)	40	4 PLIES	$t=4(.007)=.028$
			$t_{TOT}=0.070$



IN RADIAL DIRECTION,

$E = 20.6\times10^6$ (REF. WKR RC & D DESIGN DATA)

LAYUP ~ ITEM ③ ~ SAME AS ITEM ① & ②

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		11/8/71	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	46

BASE DISC (CONT.)

COMPOSITE SPOKE

VERTICAL BENDING STIFFNESS

ITEM	A	E $\times 10^6$	AE $\times 10^6$	Y	AEY $\times 10^6$	AEY^2 $\times 10^6$	EI_0
1	.082	20.6	1.689	.585	.98805	.57801	.19240
2	.082	20.6	1.689	.585	.98805	.57801	.19240
3	.062	20.6	1.277	1.205	1.53878	1.85422	.00049
4	.276	2.0	0.552	.80	.44160	.35328	.06082
Σ			5.207		3.95648	3.36352	.44611

$$\bar{Y} = \frac{\Sigma AEY}{\Sigma AE} = \frac{3.95648}{5.207} = 0.75983$$

$$\Sigma EI_{x-x} = \Sigma AEY^2 + \Sigma EI_0 - \bar{Y}\Sigma AEY$$

$$= 3.36352 + 0.44611 - 0.75983(3.95648)$$

$$= 0.803 \times 10^6$$

$$\Sigma EA = 5.207 \times 10^6$$

STIFFNESS COMPARISON

$$\frac{EI_{x-x\ \text{COMPOSITE}}}{EI_{MAG}} = \frac{0.803 \times 10^6}{0.347 \times 10^6} = 2.32$$

$$\frac{EA_{\text{COMPOSITE}}}{EA_{MAG}} = \frac{5.207 \times 10^6}{2.360 \times 10^6} = 2.21$$

MJO NO.	SUBJECT	DATE	CHECKED BY
4316-001		2/2/72	
TASK NO.		CALCULATIONS BY	SHEET NO.
		A.M.T.	47

BASE DISC (CONT.)

SIDE BENDING STIFFNESS, COMPOSITE SPOKE

ITEM	A	E $\times 10^6$	AE $\times 10^6$	Y	AEY $\times 10^6$	AEY^2 $\times 10^6$	EI_0 $\times 10^6$
1	.082	20.6	1.689	0.16		.04323	.00066
2	.082	20.6	1.689	-0.16		.04323	.00066
3	.062	20.6	1.277	0		0	.08188
4	.276	2.0	0.552	0		0	.00264
					Σ	.08646	.08584

$$EI_{Y-Y} = \Sigma AEY^2 + \Sigma EI_0$$
$$= 0.08646 + 0.08584$$
$$= 0.172 \times 10^6$$

STIFFNESS COMPARISON, SIDE BENDING STIFFNESS ~

$$\frac{EI_{Y-Y\,COMPOSITE}}{EI_{MAG}} = \frac{0.172 \times 10^6}{0.07345 \times 10^6} = \underline{\underline{2.35}}$$

MJO NO. 4316-001	SUBJECT	DATE 2/2/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 48

APPENDIX III

STIFFNESS ANALYSIS

This appendix includes the following items:

Summary

Magnesium Housing, Sheet Numbers 1 through 10

Composite Housing S/N 1, Sheet Numbers 13, 14, 19, 20

Composite Housing S/N 2, Sheet Numbers 15, 16, 23, 24

SUMMARY

Table I contains the analytically predicted and experimentally determined axial and torsional stiffness of the cast magnesium transmission gear housing and of the graphite-epoxy composite housing S/N 1 and S/N 2. Data is presented for both room-temperature and 250°F.

Based on the analysis enclosed, the correlation between the experimental spring constants and the analytical predictions is better for the axial loading than for torsion. Due to the complexity of the transmission case, simplified analysis considering the case as a cylindrical shell was used as the model for both analytical predictions. A more sophisticated analysis including either finite-element techniques or subsectional analysis could be conducted but is not considered warranted. For example, it is assumed in the analysis that the axial ribs contribute very little to the torsional stiffness. However, if the axial rib areas were "smoothed out", the effective increase in cylindrical wall thickness would be approximately 36%, resulting in an increase of the same magnitude in the prediction of the spring torsional constant. In addition, due to the large reinforcing rings around the cutouts, some effect on torsional stiffness might be predicted if a more detailed analysis were conducted.

Experimental load deflection curves are presented on Figure 36 for room-temperature torsional and axial stiffness and on Figure 37 for 250°F torsional and axial stiffness.

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING

DEFLECTION FOR AXIAL TENSION LOAD ~

TYPICAL X-SECTION AREA OF HOUSING ~

$A_{TOT} = A_{CYLINDER} + A_{RIBS}$

$$A = \frac{\pi(D^2-d^2)}{4} + 20\left(\frac{0.2+0.4}{2}\right)(0.5), \quad D = 14.75, \quad d = 14.38$$

$$= 11.47 \text{ IN}^2$$

ANALYTICAL DEFLECTION ~

$$\Delta L = \frac{PL}{AE}$$

$$\Delta L = \frac{16{,}000\,(10.15)}{11.47\,(6.5\times10^6)}$$

$$\Delta L = .0022 \text{ IN @ R.T.}$$

$E = 6.5\times10^6$ psi (AZ 91C CASTING, REF. MIL HDBK 5 [3], TABLE 4.2.6.0(b)) @ R.T.

$L = 10.15$ IN (FLG. TO FLG.)

ANALYTICAL AXIAL SPRING CONSTANT AT R.T.

$P = 16{,}000$ # (MAX. TEST LOAD)

$$K_A = \frac{P}{\Delta L}$$

$$K_A = \frac{16000}{.0022}$$

$$K_A = 7.273\times10^6 \text{ \#/IN (@ R.T.)}$$

MJO NO.	SUBJECT	DATE 3/23/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 1

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM
TRANSMISSION GEAR HOUSING

DEFLECTION FOR AXIAL TENSION LOAD (CONT.)

EXPERIMENTAL DEFLECTION

$\Delta L = .0021$ IN, (AT $P = 16,000^{\#}$)

EXPERIMENTAL AXIAL SPRING CONSTANT AT R.T.

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16,000}{.0021}$$

$$K_A = 7.619 \times 10^6$$

MJO NO.	SUBJECT	DATE 3/27/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 2

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING

DEFLECTION FOR AXIAL TENSION LOAD (CONT.)

@ 250°F

$E = 0.90\,E_{R.T.}$, (REF. MIL HDBK 5, [3] FIG. 4.2.6.4.4)

ANALYTICAL DEFLECTION:

$$\Delta L = \frac{PL}{AE}$$

$$= \frac{16{,}000\,(10.15)}{11.47\,(0.9 \times 6.5 \times 10^6)}$$

ΔL = .0024 IN @ 250°F

ANALYTICAL AXIAL SPRING CONSTANT AT 250°F

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16{,}000}{.0024}$$

$K_A = 6.667 \times 10^6$ #/IN

MJO NO.	SUBJECT	DATE 3/23/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 3

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING ~

DEFLECTION FOR AXIAL TENSION LOAD AT 250°F ~

EXPERIMENTAL DEFLECTION.

$\Delta L = .0021 \text{ IN}$ (AT $P = 16,000$ #)

EXPERIMENTAL AXIAL SPRING CONSTANT AT 250°F

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16,000}{.0021}$$

$$K_A = 7.619 \times 10^6$$

MJO NO.	SUBJECT	DATE 3/27/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 4

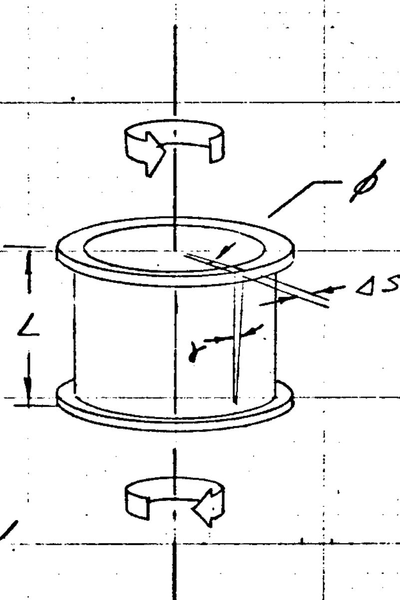
ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING ~

DEFLECTION FOR TORSION LOAD ~

$$\frac{\Delta S}{L} = \gamma = \frac{f_s}{G} = \frac{TR}{JG}$$

$$\Delta S = \frac{TRL}{JG}$$



NEGLECTING RIBS WHICH WILL HAVE VERY LITTLE EFFECT ON TORSIONAL STIFFNESS,

$$R_{AVG} = \frac{14.38}{2} + \frac{.185}{2} = 7.28 \text{ IN}$$

$$J = 2(\pi R_{AVG}^3 t), \quad t = 0.185 \text{ IN}$$

$$J = 2\pi(7.28)^3(.185)$$

$$J = 448.5 \text{ IN}^4$$

$G = 2.4 \times 10^6$ PSI (REF. MIL HDBK 5, [3] TABLE 4.2.6.0(b))

$L = 10.15$ IN (SURF. TO SURF.)

$L' = 8.90$ IN (BETWEEN FLANGES)

MJO NO.	SUBJECT	DATE 3/23/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 5

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING ~

DEFLECTION FOR TORSIONAL LOAD (CONT.)

ANALYTICAL DEFLECTION ~

FROM TEST, $T_{MAX} = 57,500 \text{ IN}^{\#}$

$$\Delta S = \frac{TRL'}{JG}$$

$$\Delta S = \frac{57,500\,(7.28)(8.90)}{448.5\,(2.4 \times 10^{6})}$$

$\Delta S = .0035$ IN (@ R.T.)

EXPERIMENTAL DEFLECTION ~

$\Delta s = .004$ IN @ R.T.

FOR 250°F

ANALYTICAL DEFLECTION ~

$G_{250°F} = 0.9\, G_{R.T.}$

$\Delta S = \frac{0.0035}{0.9} \doteq 0.0039$ IN @ 250°F

MJO NO.	SUBJECT	DATE 3/23/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 6

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING (CONT.)

TORSIONAL DEFLECTION AT 250°F

EXPERIMENTAL DEFLECTION ~

$\Delta S = .0045$ IN AT 250°F

ANALYTICAL TORSIONAL SPRING CONSTANT AT R.T.

$$\phi = \frac{\Delta S}{R_{OF}}$$

R_{OF} = OUTSIDE RADIUS OF FLANGE

$$= \frac{.0035}{8.56}$$

$R_{OF} = 8.56$ IN

$$= .00041 \text{ RAD}$$

ϕ = ANGLE OF TWIST OF CYLINDER (SEE SKETCH, PG. 5)

$$K_T = \frac{T}{\phi}$$

$$= \frac{57{,}500}{.00041}$$

$K_T = 140 \times 10^6$ IN#/RAD (@ R.T.)

MJO NO.	SUBJECT	DATE 3/23/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 7

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM
TRANSMISSION GEAR HOUSING (CONT.)

EXPERIMENTAL TORSIONAL SPRING
CONSTANT AT R.T.

$$\phi = \frac{\Delta S}{R_{OF}}$$

$$= \frac{.004}{8.56}$$

$$= .000468 \text{ RAD.}$$

$$K_T = \frac{T}{\phi}$$

$$= \frac{57,500}{.000468}$$

$$K_T = 123 \times 10^6 \text{ IN}^{\#}/\text{RAD}$$

MJO NO.	SUBJECT	DATE 3/27/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 8

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING (CONT.)

ANALYTICAL TORSIONAL SPRING CONSTANT AT 250°F

$$\phi = \frac{\Delta S}{R_{OF}}$$

$$= \frac{.0039}{8.56}$$

$$= .000456 \text{ RAD.}$$

$$K_T = \frac{T}{\phi}$$

$$= \frac{57,500}{.000456}$$

K_T = 126 x 10^6 IN# /RAD. (@ 250°F)

MJO NO.	SUBJECT	DATE 3/27/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 9

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ MAGNESIUM TRANSMISSION GEAR HOUSING (CONT.)

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT 250°F

$$\phi = \frac{\Delta S}{R_{OF}}$$

$$= \frac{.0045}{8.56}$$

$$\phi = .000527 \text{ RAD}$$

$$K_T = \frac{T}{\phi}$$

$$= \frac{57,500}{.000527}$$

$$\underline{\underline{K_T = 109 \times 10^6}} \text{ IN \#/RAD } (@ 250°F)$$

MJO NO.	SUBJECT	DATE 3/27/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 10

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

DEFLECTION FOR AXIAL TENSION LOAD AT R.T. ~

ANALYTICAL DEFLECTION ~

$$\Delta L = \frac{PL}{AE} \,, \qquad P = 16{,}000\,\#$$

$$L = 10.15 \text{ IN}$$

$$= \frac{16{,}000\,(10.15)}{8.00\,(13.7\times10^6)} \qquad A = 2\pi R_{AVG}\, t$$

$$= 2\pi(1.278)(.175)$$

$$\underline{\Delta L = .0015 \text{ IN}} \text{ @ R.T.} \qquad = 8.00$$

$E = 13.7\times10^6$ @ R.T. (SEE APPENDIX II,

ANALYTICAL AXIAL SPRING CONSTANT AT R.T.

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16{,}000}{.0015}$$

$$\underline{K_A = 10.67\times10^6\ \#/\text{IN}} \text{ (@ R.T.)}$$

SUBJECT	DATE 3/23/72	CHECKED BY
	CALCULATIONS BY A.M.T.	SHEET NO. 11

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

DEFLECTION FOR AXIAL TENSION LOAD AT 250°F ~

$$\Delta L_{250°F} = \Delta L_{R.T.} \left(\frac{E_{R.T.}}{E_{250°F}} \right) , \quad E = 12.93 \times 10^6 \text{ @ } 250°F$$

$$\Delta L_{250°F} = .0015 \left(\frac{13.7 \times 10^6}{12.93 \times 10^6} \right)$$

$$\Delta L_{250°F} = 0.00159 \text{ IN @ } 250°F$$

ANALYTICAL AXIAL SPRING CONSTANT AT 250°F ~

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16{,}000}{.00159}$$

$$K_A = 10.0 \times 10^6 \text{ \#/IN} \text{ (@ } 250°F)$$

MJO NO.	SUBJECT	DATE 11/1/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 12

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

EXPERIMENTAL DEFLECTION FOR AXIAL TENSION LOAD AT R.T. ~ S/N 1

$P = 16\,000$ LBS

$\Delta L = 13.5 \times 10^{-3}$ IN

EXPERIMENTAL AXIAL SPRING CONSTANT AT R.T. ~ S/N 1

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16{,}000}{13.5 \times 10^{-3}}$$

$K_A = 1.18 \times 10^6$ #/IN AT R.T.

MJO NO.	SUBJECT	DATE 11/1/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 13

STIFFNESS TEST ~ COMPOSITE MATERIAL
TRANSMISSION GEAR HOUSING

EXPERIMENTAL DEFLECTION FOR
AXIAL TENSION LOAD AT 250°F ~ S/N 1

$P = 16{,}000$ LBS

$\Delta L = 12.5 \times 10^{-3}$ IN.

EXPERIMENTAL AXIAL SPRING
CONSTANT AT 250°F ~ S/N 1

$$K_A = \frac{P}{\Delta L}$$

$$= \frac{16{,}000}{12.5 \times 10^{-3}}$$

$$K_A = 1.26 \times 10^{6}\ \#/_{IN}\ @\ 250°F$$

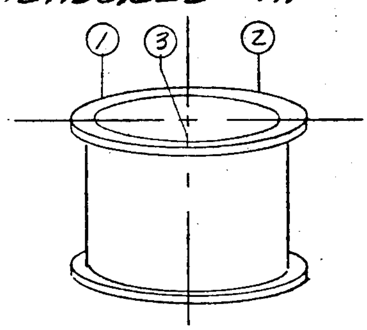
MJO NO.	SUBJECT	DATE 11/1/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 14

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

EXPERIMENTAL AXIAL SPRING CONSTANT- AT R.T. ~ S/N 2

DEFLECTION (ΔL) WAS MEASURED AT THREE LOCATIONS:

DEFLECTION FLANGE TO FLANGE = ΔL (IN.)



RUN	DEFLECTION ~ $\Delta L \times 10^{-3}$ IN.			STIFFNESS		
	LOCATION					
	1 EXTENSOM	2 DIAL IND.	3 DIAL IND.	K_1	K_2	K_3
1	2.0	3.3	0.1	—	—	—
2	2.0	3.2	0.4	—	—	—
3	2.0	3.2	0.5	—	—	—
AVG	2.0	3.23	0.33	8×10^6	5×10^6	48.5×10^6

$K = \frac{P}{\Delta L} = \frac{16000}{\Delta L}$, $K_{AVG} = \frac{61.5}{3} = 21 \times 10^6$ #/IN

AVG. OF LOCATION 1 & 3,

$\Delta L = \frac{2.33}{2} = 1.17$, $K_{AVG} = \frac{16000}{1.17\times10^{-3}} = 13.7\times10^6$ #/IN

MJO NO.	SUBJECT	DATE 11/1/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 15

ENGINEERING CALCULATIONS

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

EXPERIMENTAL AXIAL SPRING CONSTANT AT 250°F ~ S/N 2

$$\Delta L = 5.4 \times 10^{-3} \text{ IN}$$

$$K_{A_{250}} = K_{A_{R.T.}} \left(\frac{\Delta L_{R.T.}}{\Delta L_{250°F}} \right)$$

$$= 13.7 \times 10^{6} \left(\frac{3.25 \times 10^{-3}}{5.4 \times 10^{-3}} \right)$$

$$K_{A_{250°F}} = 8.2 \times 10^{6} \text{ \#/IN}$$

MJO NO.	SUBJECT	DATE 11/1/72	CHECKED BY
TASK NO.		CALCULATIONS BY A.M.T.	SHEET NO. 16

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

DEFLECTION FOR TORSION LOAD ~

$\Delta S = \dfrac{TRL}{JG}$

$= \dfrac{57{,}500(7.278)(9.11)}{423.8(4.33 \times 10^6)}$

$\Delta S = .0021$ IN

$R_{AVG} = 7.19 + \dfrac{.175}{2}$

$= 7.278$ IN

$L = 9.11$ IN (BETWEEN FLANGES)

$J = 2\pi R_{AVG.}^3 t$

$= 2\pi(7.278)^3(.175)$

$= 423.8$ IN^4

$G = 4.33 \times 10^6$ PSI @ R.T.

(SEE APPENDIX II)

$T = 57{,}500$ IN#

ANALYTICAL TORSIONAL SPRING CONSTANT AT R.T.

$\phi = \dfrac{\Delta S}{R_{OF}}$

$= \dfrac{.0021}{8.56}$

$\phi = .000245$ RAD

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STIFFNESS TEST ~ COMPOSITE MATERIAL
TRANSMISSION GEAR HOUSING

ANALYTICAL TORSIONAL SPRING CONSTANT
AT R.T. (CONT.)

$$K_T = \frac{T}{\varphi}$$

$$= \frac{57{,}500}{.000245}$$

$$\underline{\underline{K_T = 235 \times 10^6}} \text{ IN}^{\#}/\text{RAD @ R.T.}$$

ANALYTICAL TORSIONAL SPRING CONSTANT
AT 250°F ~

$$G_{250°F} = 4.09 \times 10^6 \text{ PSI @ } 250°F$$

$$K_{T_{250}} = K_{T_{R.T.}} \left(\frac{G_{250°F}}{G_{R.T.}} \right)$$

$$= 235 \times 10^6 \left(\frac{4.09 \times 10^6}{4.33 \times 10^6} \right)$$

$$\underline{\underline{K_T = 222 \times 10^6 \text{ IN}^{\#}/\text{RAD @ } 250°F}}$$

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STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING ~

EXPERIMENTAL DEFLECTION FOR TORSION AT R.T. ~ S/N 1

$T = 57,500$ IN LBS

$\Delta S = .0038$ IN @ R.T.

$$\phi = \frac{\Delta S}{R_{OF}}$$

$$= \frac{.0038}{8.56}$$

$\phi = .000443$ RAD

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT R.T. ~ S/N 1

$$K_T = \frac{T}{\phi}$$

$$= \frac{57,500}{.000443}$$

$K_T = 130 \times 10^6$ IN #/RAD @ R.T.

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STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING ~

EXPERIMENTAL DEFLECTION FOR TORSION AT 250°F

$T = 57{,}500 \text{ IN}^{\#}$

$\Delta S = .0036 \text{ IN}$

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT 250°F ~ S/N 1

$$K_T = \frac{T\, R_{OF}}{\Delta S}$$

$$= \frac{57{,}500\,(8.56)}{.0036}$$

$$K_T = 137 \times 10^6 \text{ IN}^{\#}/\text{RAD AT } 250°\text{F}$$

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ENGINEERING CALCULATIONS

STIFFNESS TEST ~ COMPOSITE MATERIAL
TRANSMISSION GEAR HOUSING

EXPERIMENTAL DEFLECTION FOR AXIAL TENSION LOAD AT R.T., MEASURED BY STRAIN GAGE ~ S/N 1

$P = 12000$ LBS

$\epsilon = 72\ \mu$ IN/IN

GAGE LENGTH = 9.13 IN (FLANGE TO FLANGE)

TOTAL DEFLECTION,

$\Delta L = \epsilon \times$ GAGE LENGTH

$= 72\ (9.13)$

$\Delta L = 660\ \mu$ IN

EXPERIMENTAL AXIAL SPRING CONSTANT AT R.T. ~ S/N 1 (STRAIN GAGE)

$$K_b = \frac{P}{\Delta L}$$

$$= \frac{12000}{660 \times 10^{-6}}$$

$$\underline{\underline{K_b = 18.2 \times 10^6\ \#/\text{IN}}}$$

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STIFFNESS TEST ~ COMPOSITE MATERIAL
TRANSMISSION GEAR HOUSING

EXPERIMENTAL AXIAL SPRING CONSTANT AT R.T. FOR MAGNESIUM CASE, MEASURED BY STRAIN GAGE

$$\epsilon = 140 \mu \text{ in/in}$$

$$P = 12{,}000 \text{ LBS.}$$

$$K_b = \frac{P}{\epsilon \times (\text{GAGE LENGTH})}$$

$$= \frac{12{,}000}{140(9.13) \times 10^{-6}}$$

$$K_b = 9.0 \times 10^6 \text{ \#/in} \quad @ \text{ R.T.}$$

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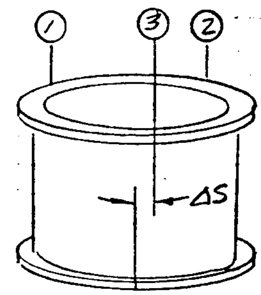
STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT R.T. ~ S/N 2

ROTATION (ΔS) FLANGE TO FLANGE MEASURED AT THREE LOCATIONS:



RUN	DEFLECTION ~ $\Delta S \times 10^{-3}$ IN			STIFFNESS		
	LOCATION			K_1	K_2	K_3
	1 EXTENSOM	2 DIAL IND.	3 DIAL IND.			
1	1.9	8.4	0.05	—	—	—
2	1.8	8.6	0.6	—	—	—
3	1.9	7.7	0.5	—	—	—
AVG.	1.87	8.3	0.38	262×10^6	59×10^6	1290×10^6

TORSIONAL STIFFNESS (K_T)

$$K_T = \frac{T\,R_{OF}}{\Delta S} = \frac{57{,}500(8.56)}{\Delta S} = \frac{490 \times 10^3}{\Delta S}$$

$$K_{T_{AVG}} = \frac{262 + 59 + 1290}{3} \times 10^6 = \underline{537 \times 10^6} \text{ IN \#/RAD}$$

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ENGINEERING CALCULATIONS

STIFFNESS TEST ~ COMPOSITE MATERIAL TRANSMISSION GEAR HOUSING

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT R.T. ~ S/N 2 (CONT.)

$\Delta S_{AVG.}$ FOR LOCATIONS 1 & 3

$$\Delta S_{AVG} = \frac{(1.87+0.38)\times 10^{-3}}{2}$$

$$\Delta S_{AVG} = 1.125 \times 10^{-3} \text{ IN}$$

$$K_{AVG\ 1\&3} = \frac{490 \times 10^{3}}{1.125 \times 10^{-3}}$$

$$K_{AVG\ 1\&3} = 4.40 \times 10^{6} \text{ IN}^{\#}/\text{RAD}$$

EXPERIMENTAL TORSIONAL SPRING CONSTANT AT 250°F ~ S/N 2

THE DEFLECTION (ΔS) AND TORSIONAL SPRING CONSTANT (K_T) AT 250°F IS FOR ALL PRACTICAL PURPOSES EQUAL TO THOSE AT R.T.

THUS,

$$K_{T_{250°}} = 440 \times 10^{6} \text{ IN}^{\#}/\text{RAD}$$

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13. ABSTRACT

This program investigated the feasibility of applying advanced fiber-reinforced plastic composite materials to the UH-1 helicopter main transmission gear housing in order to increase stiffness of the structure and to reduce gear and bearing wear. A design analysis was performed for the composite transmission housing based on carbon fiber (Modmor I) reinforced epoxy composite material. Two prototypes were fabricated and tested for stiffness in torsion and tension at ambient and elevated temperatures, and were compared to the present magnesium housing. Prototype S/N 1 showed a substantial increase in torsional stiffness but a reduction in tension stiffness over the metal case. Prototype case S/N 2 incorporated a modification of the fiber orientation. It was tested extensively, with deflection measurements being made at a number of intervals around the housing's circumference for both tension and torsion loading. Depending on the gage location, the measurements were either only a small fraction of or slightly greater than those of the metal case. The design of the prototypes demonstrated that stiffness of the housing can be increased by correct application of high-modulus fiber composites.

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Fiber orientation						
High-modulus fiber						
Design and analysis						
Composite structure						

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