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FINAL REPORT
ON
THE DEVELOPMENT OF CONTOURED INTERLOCKING TAPE WOUND TITANIUM ROCKET MOTOR CASES

PART I
DESIGN, METALLURGY AND EXPERIMENTAL FABRICATION

February 15, 1961

CURTISS-WRIGHT CORPORATION
WOOD-RIDGE, NEW JERSEY

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Submitted in Partial Fulfillment of U. S. Army
Ordnance Materials Research Office Contract DA-30-069-ORD-3101

Director of Engineering

Wright Aeronautical Serial Report No. MP.00-224

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DESIGN, METALLURGY AND EXPERIMENTAL FABRICATION

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Curtiss-Wright Corporation
Wright Aeronautical Division
Wood-Ridge, New Jersey

Wright Aeronautical Serial Report No. MP.00-224

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1.0 INTRODUCTION

The development of pressure vessels for use in solid fuel rocket motor cases has reached a state wherein further progress may be restricted by lack of suitable high strength metals and limitations in methods of fabrication. Though the potentially high strength to weight ratio of fiber reinforced cases is recognized, the use of metallic cases offers certain advantages peculiar to metals alone.

~~The application of metal wire or tape as reinforcement in pressure vessels dates back at least a century. High-tensile steel wire has been used as the banding material on certain rifles and guns as well as in other hollow bodies (1). With the possible exception of one recent investigation (2, 3) no attempt has been made to utilize the transverse strengths of wire or tape to support the axial stress in pressurized vessels. Valenta (2) describes vessels reinforced with wound profile strip which is shrunk on to a vessel (while simultaneously quenched to high strength), putting the monolithic portion of the vessel into compression. Though the tape is contoured and interlocked, it does not appear to support any of the axial load. The present report describes a means whereby the transverse strength of severely cold reduced tape is fully utilized. The method simultaneously facilitates application of ultra high strength materials which might otherwise be difficult or impossible to use.~~

~~The interlocking titanium tape concept is an outgrowth of relatively recent work carried out by this contractor (4) in the development of the high strength titanium alloy B120VCA. In sheet form, this alloy is heat-treatable to a yield strength of 180,000 psi, a strength level which on a strength-to-weight basis is higher than that of the best ferrous materials used in rocket motor casings today. Unfortunately, this alloy is difficult to weld and even a successful weld cannot be heat treated to maximum strength because the aging response of base material and weldment differ considerably. It was observed that this alloy, similarly to most precipitation hardenable alloys, benefits considerably as a result of cold work prior to aging. Thus, the useful strength level of B120VCA can be increased to 300,000 psi, a strength which if fully utilized in a pressure vessel would result in a strength-to-weight ratio of about 1.7 x 10^6 in.~~

1.0 INTRODUCTION (Continued)

The objectives of the present contract consisted primarily of the development of fabrication and metallurgical procedures for the manufacture of two basic structural shapes, the development of a wrapping machine and finally the experimental manufacture of two sub-scale vessels. These objectives have been met.

The Curtiss-Wright Corporation wishes to acknowledge financial support from the U. S. Army through the Ordnance Materials Research Office. The assistance of Dr. J. L. Martin, Messrs. G. A. Darcy, Jr. and I. Kahn of that Office as well as of Messrs. R. L. Weatherington and C. H. Martens of the U. S. Army Rocket and Guided Missile Agency is gratefully acknowledged.

2.0 SUMMARY

During the contract period, June 15, 1960 to January 14, 1961, the Wright Aeronautical Division of the Curtiss-Wright Corporation has pursued the work program as originally detailed in the Proposal (5) and has demonstrated the feasibility of interlocked tape wound pressure vessels from both the metallurgical and experimental manufacturing standpoint. Demonstration of the design concept as based on hydrostatic pressure and other environmental tests will be carried out as part of a proposed follow-on to the present contract (6).

"I" beam and channel shapes were designed, fabricated and tested. Turks heading was selected in preference to die drawing, though the latter process might be utilized at a future date for final sizing.

A structural rig for experimental verfication of stress analysis data has been fabricated. Several techniques for precise determination of tape dimensions have been evaluated resulting in the selection of a metallographic method. A specification for B120VCA titanium starting wire has been written and coordinated with two potential sources. The static coefficients of friction of drawn and heat treated tape have been measured and separate interference fit measurements of the interlock have been carried out. The aging response of both shapes in terms of metallographic structure and mechanical properties have been determined and a final heat treatment selected. The low temperature properties of the B120VCA sheet, including notch sensitivity tests have been determined. Several vessel liner materials and bonding methods have been evaluated.

Vessel wrapping apparatus including dummy arbors, collapsible mandrels and other auxiliary apparatus have been designed, manufactured and utilized in the fabrication of two prototype vessels. Design modifications in tape as well as manufacturing techniques based on experience gained in the present program have been carried out and will be incorporated in the proposed follow-on effort.

3.0 RECOMMENDATIONS FOR FUTURE WORK

Limitations inherent in the "Turks Heading" process of wire manufacture, together with observations made both during interference fit testing and wrapping require that the currently used tape shapes be redesigned to incorporate deeper grooves in both shapes. This will assure greater contact area and permit loosening of tolerances on internal corner radii.

Several changes in the wrapping apparatus, collapsible arbor and mandrel removal will be carried out. Presently used 300M steel used in end adapters will be replaced by 25% nickel iron resulting in a higher available yield strength.

The proposed second phase of the present contract will include experimental manufacture of six pressure vessels which will be subjected to hydrostatic tests. The program will further include such studies and analyses relating to adapter attachment, wrapping technique, tape design, metallurgy and other areas found critical during the course of investigation leading to the development of a practical application of the concept.

4.0 DESIGN AND STRESS

4.0 DESIGN

4.1 Mechanical Design

The feasibility of using a high-strength interlocking tape wrapped vessel for a light-weight rocket motor was investigated from a design and stress point of view. Figure 1 shows the selected interlocking tape configuration of three layers. The configurations analyzed were based on a motor I.D. of 6.2 inches and an operating pressure of 4700 psi. This diameter sub-scale vessel was selected because of the availability of a piston rig adaptable to hydrotesting this vessel. In the stress analysis of this vessel, the effects of the small diameter on bending stresses and elastic instability were neglected. This was done to permit direct up scaling to a larger diameter motor.

The design of the interlocking titanium tape is based on a minimum allowable longitudinal and transverse yield strength of 250,000 psi and total (elastic plus plastic) strain of 4% in the transverse direction.

Based on these mechanical properties, two interlocking configurations were studied with emphasis placed on manufacturing feasibility and minimum weight. Figure 2 (b) shows one arrangement with "full-line" contact between adjacent butted channels; and Figure 2 (a) shows another arrangement resulting in "point" contact (under load) between butted channels. Stress analysis has indicated that the full-line butted contact between adjacent channels produces the more efficient arrangement. The final tape dimensions for both the channel and "I" beam are shown in Figure 3.

Additional stress analysis was performed on the inner channel layer in order to determine the local bending stress in each channel caused by the internal pressure (Figure 4). This bending stress is a result of the longitudinal bending of the channel between "I" beam flanges, and adds directly to the longitudinal stress. However, this condition would not arise in a full-scale rocket motor case since the internal pressure for the same tape stress level would be greatly reduced. The present six inch diameter sub-scale test vessel is designed to yield at 4700 psi pressure, whereas a larger diameter vessel would operate at approximately 1000 psi. To alleviate this local bending stress in the sub-scale vessel, the width of the "I" beam flanges was increased from .025 to .040 inches (Figure 5). This reduces the free beam length of the channel and thus reduces the local bending stress.

4.1 Mechanical Design (Continued)

As seen in Figure 3, the legs of the "I" beam and channels are tapered. This is to permit assembly of the wires under the worst tolerance condition. To insure interlocking of the wire assembly, the "I" beams are pre-stressed in the transverse direction. The theoretical load required to force an "I" beam or channel into position is approximately equal to 2500 pounds. This load should be exerted by a roller of 5 inches minimum diameter. The theoretical axial tension required when wrapping either an "I" beam or channel should not exceed 200 pounds. The 2500 pound applied load required to force the wire into position was calculated on the basis of an assumed coefficient of friction between titanium of 0.2 and a roller contact length of .1 inch. A survey of the literature, later confirmed by direct tests, indicated that this value is low and a value of 0.3 is more realistic. The maximum axial load of 200 pounds results in a residual pre-stress of 50,000 psi for the tape in position on the vessel. This assumes that the entire axial winding load remains in the wrapped tape due to friction along the interlocking surface.

4.2 Stress Analysis

Stress analyses of the butted and spaced channel configurations have been completed. When the channel ends are spaced, it is possible to design channels and "I" beams so that only two different tape shapes are required and any number of layers can be added. This situation will occur when

$t_{1A} = t_{1B}$ and $L_D = L_C$. (See Figure 6 for nomenclature). The spacing between the channels will then equal the spacing between the "I" beams. This arrangement is not ideal from a stress standpoint. The loading on the channels produces bending stresses in addition to the axial stresses. This arrangement also results in a varying load distribution across the wall of the vessel which tends to overstress the inside and outside layers while understressing the middle layers. Thus, the efficiency is reduced.

When the adjacent channel ends are butted, two different shapes of tape are sufficient only when n (the number of "I" beams) is equal to 1 (3 layers) or the spacing between the "I" beams is 0. For all other configurations, more than one shape of "I"

4.2 Stress Analysis (Continued)

beam is required. For optimum hoop stress design, it is desirable to have spacing between the "I" beams; therefore, the case where n = 1 is recommended. This case also affords the minimum overall wall thickness. From a stress standpoint, the butted channel arrangement is preferable to the spaced channel arrangement because the channel bending stresses and the varying load distribution across the wall are reduced.

Having established the interlock configuration which yields minimum stresses, an analysis was performed to determine the actual tape dimensions. The butted channel tape configurations were analyzed in detail and the results are shown in Figure 7.

An outline of the stress analysis is given below:

(a) Consideration of the load in the longitudinal direction determines the shank thicknesses of the "I" beam and the channel. Since there are two channel layers sandwiching an "I" beam layer in a three layer vessel, the shank must be twice as thick as the channel shank. This assumes no pre-stressing of the "I" beam at the interlock. However, an initial compressive prestress imposed on the butted channel ends will tend to maintain line-to-line contact and minimize channel bending.

(b) The thickness of the interlocking legs is obtained next. For short interlocking leg heights ($\triangle = 0.010$), the allowable shear stress determines the thickness of the leg. In general, this thickness is more than two and one-half times the channel leg height. Since the interlocking legs are relatively short in height and broad in thickness, the interlocking load was assumed to be transmitted in shear without accounting for bending effects.

(c) The length of the "I" beam must be equal to the sum of twice the channel leg thickness plus twice the "I" beam leg thickness.

(d) The height of the channel leg ($\triangle$) is determined by the allowable bearing stress on the interlocking joints.

4.2 Stress Analysis (Continued)

(e) The length of the channel (Lc) is determined last. The metal-filled area of the wall is varied by varying the channel lengths. For an optimum design, the metal-filled area is sized for the allowable vessel hoop stress.

The detailed stress calculations made in determining the final shapes of the "I" beam and channel are shown in Appendix I.

4.3 Weight Estimates

A weight estimate was made to determine the percent weight saving of the titanium tape over a solid wall steel shell of 300M material having a uniaxial yield strength of 200,000 psi minimum. The weight of the tape wrap includes the interlocking tape and the plastic liner. The weight of the interlocking tape shell is 50% less than the weight of the 300M shell (Figure 8).

4.4 End Attachments

The design for attaching the ends of the interlocking tape to the domes is shown schematically in Figure 9. All three layers of tape, after being wrapped around the threaded dome adapter, are held in place by groove pins. (An investigation of other bonding methods was carried out and is reported in Section 5.) Because of the helical winding of the interlocking tape, the natural tendency of the tape under pressure would be to unwind (See Figure 10). The necessary restraint can be attained in three ways: (1) by bonding the interlocking tapes with an epoxy resin to withstand the shearing tendency to unwind; (2) by using a counter-winding combination of layers in which the unwinding tendencies can be mechanically neutralized; (3) by relying on the interference fit between interlocking tapes to withstand the unwinding tendency through friction. Stress analyses have indicated that the torsional shear stresses are low (422 psi) and the friction between tapes will restrain the vessel from unwinding.

Figure 9 shows the adapter to be tapered where the unsupported cylindrical section of the interlocking tape starts. This taper minimizes the discontinuity stresses at the intersection. Under internal pressure the tapered adapter section in contact with the tape will yield radially outward and reduce the discontinuity effects.

4.4 End Attachments (Continued)

Sealing of the vessel against internal pressure can be accomplished by coating the inside of the motor with a layer of vinyl. Vinyl, which has a relatively low modulus of elasticity, is capable of adhering to the tape wrapped vessel without cracking when subjected to the radial and longitudinal strains of the pressurized vessel.

The final design of the sub-scale vessel is shown in Figure 11. This drawing shows details of the tape, adapters, and the assembly. The piston rig, which is used for hydrotesting, is shown in Figure 12.

4.5 Piston Rig - Jacking Fixture

In order to test the operation of the Piston Rig Apparatus, a burst test of a solid 300M steel vessel was carried out. The vessel was pressurized to a burst pressure of 5000 psi without damage to the piston rig. However, in assembling the piston covers containing the hard rubber "O" rings and leather back-up ring, a larger than expected force was required to compress the "O" ring. This force was transmitted through the vessel to ground. Consequently, a jacking fixture was designed and fabricated which will prevent this high compressive force from being transmitted into the vessel. The design of the jacking fixture is shown in Figure 13.

4.6 Structural Rig

A structural rig which will be used to evaluate the interference fit has been designed and fabricated. The purpose of this rig is to determine the parameters which affect the stresses in the tapes. Schematically shown in Figure 14 is a freebody diagram of the channel subjected to the loads resulting from the interference fit. It may be observed that the interference fit tends to clamp the channel flange and prevent rotation during pressurization. Figure 15 shows the apparatus which will be used to evaluate these stresses. The channel sections are fabricated from B120VCA titanium strip and will be ten times the actual cross-sectional dimensions. The clamping plates will also be fabricated from B120VCA titanium. These plates when bolted together will produce an interference fit with the channel sections. Hoop restraint is induced by transverse clamping which simulates the internal pressure effects. The test procedure to be used for this rig is detailed in Appendix II, and the instrumentation layout is shown in Figure 16.

4.7 Roll Redesigns

The following procedure was used to determine the dimensions of the proper finish "I" beam rolls that would yield the correct tape cross-section. The form rolls were not reworked and are shown in Figure 17. Figure 18 shows the finished rolls assembled, the dimensions of the rolls, and the resulting rolled tape dimensions. Since the angle of 17° is more than the desired 12°, a new roll was made (Figure 19) having an angle of 1 to 3°. This roll produced a tape angle of 7.5°. A plot was then constructed (Figure 20) which relates roll angle to tape angle. Based on this data a new roll was made having angles of 4.5 to 5.5°. The resulting tape dimensions are shown in Figure 21. The "I" beam roll width was also changed to produce a greater interference fit.

A similar procedure was carried out for the redesign of finish channel rolls. The form rolls shown in Figure 22 were also not reworked. The first shape rolled is shown in Figure 23, the second in Figure 24, and the third in Figure 25. A plot of channel roll angle versus tape angle is shown in Figure 26.

TYPICAL WIRE CONFIGURATION

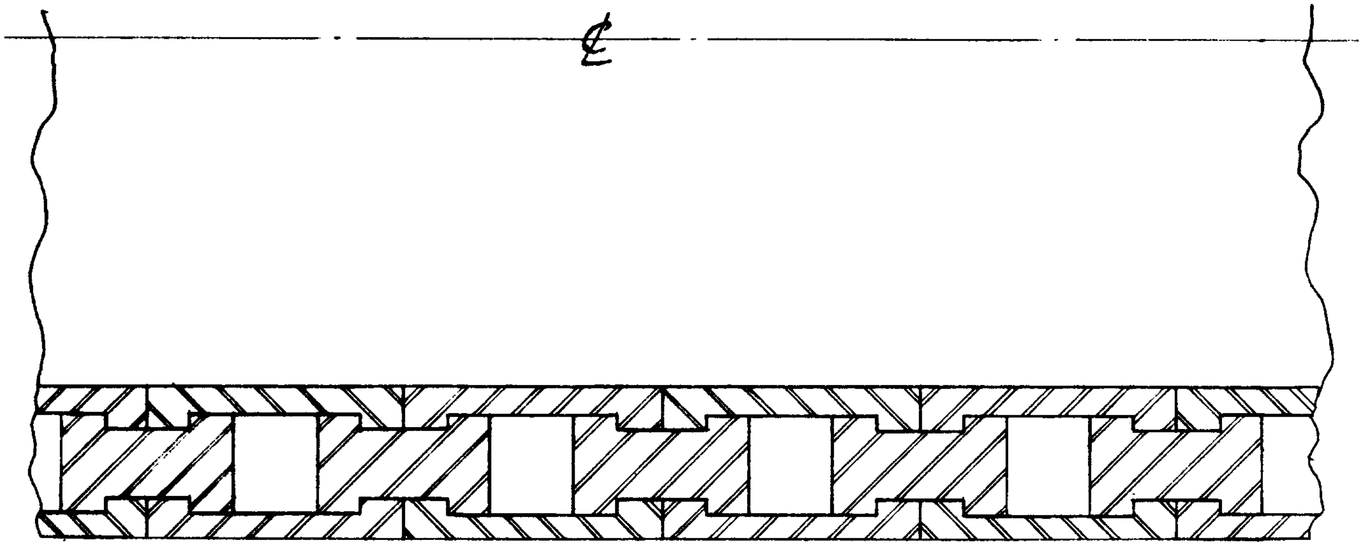
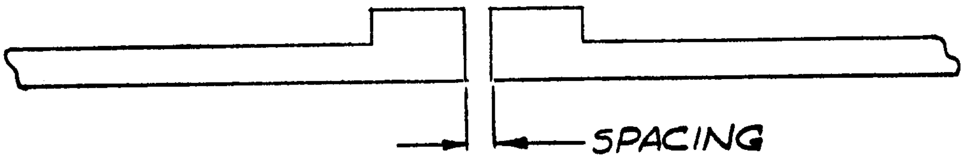


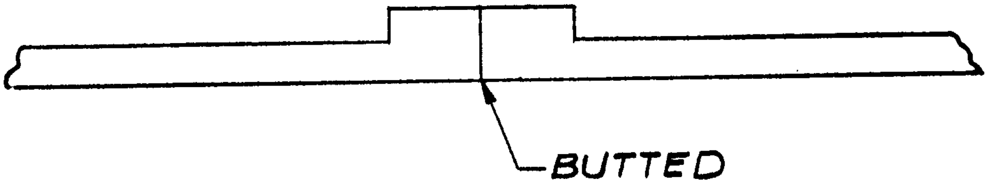
Figure 1

CHANNEL END ARRANGEMENT



CHANNEL ENDS SPACED

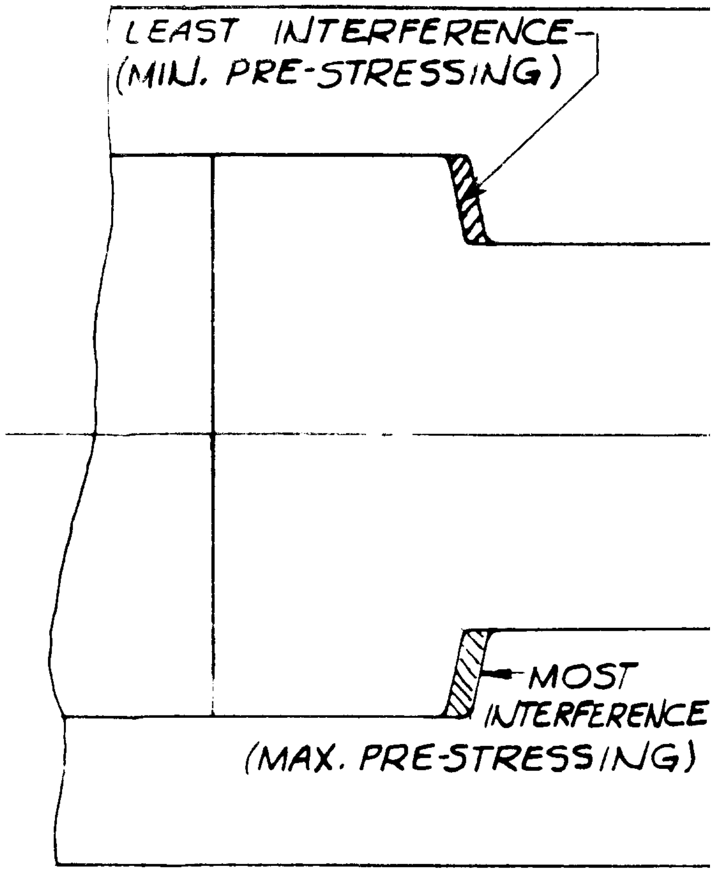
(a)



CHANNEL ENDS BUTTED

(b)

Figure 2



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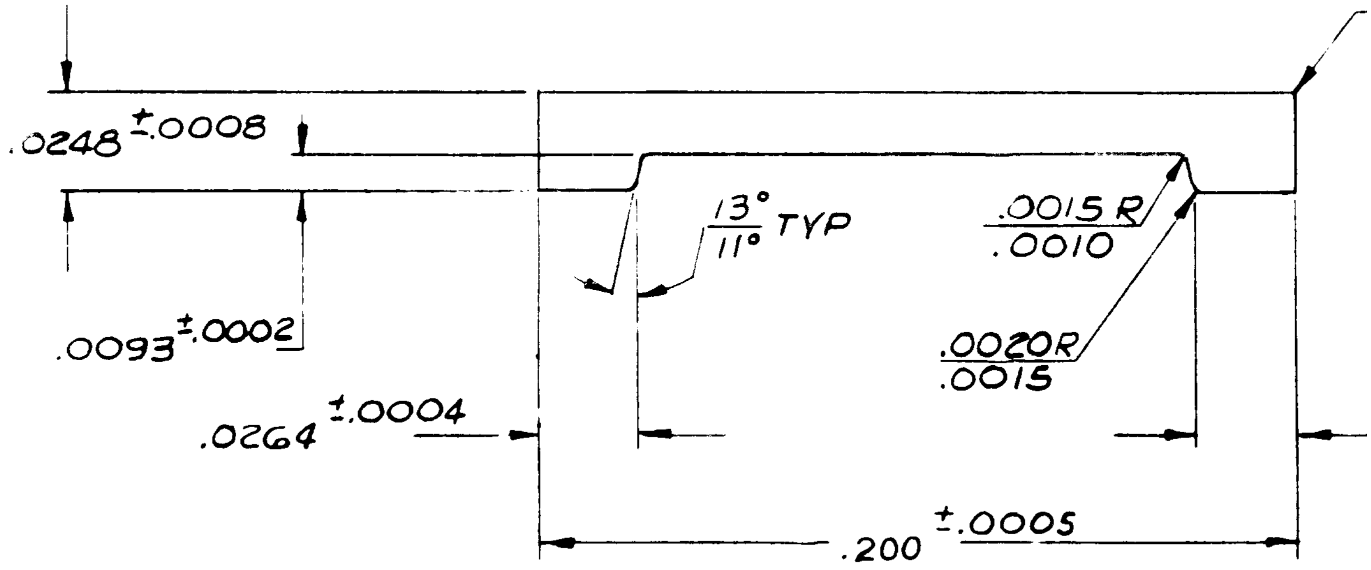

OUTER LOCKING WIRE DETAIL
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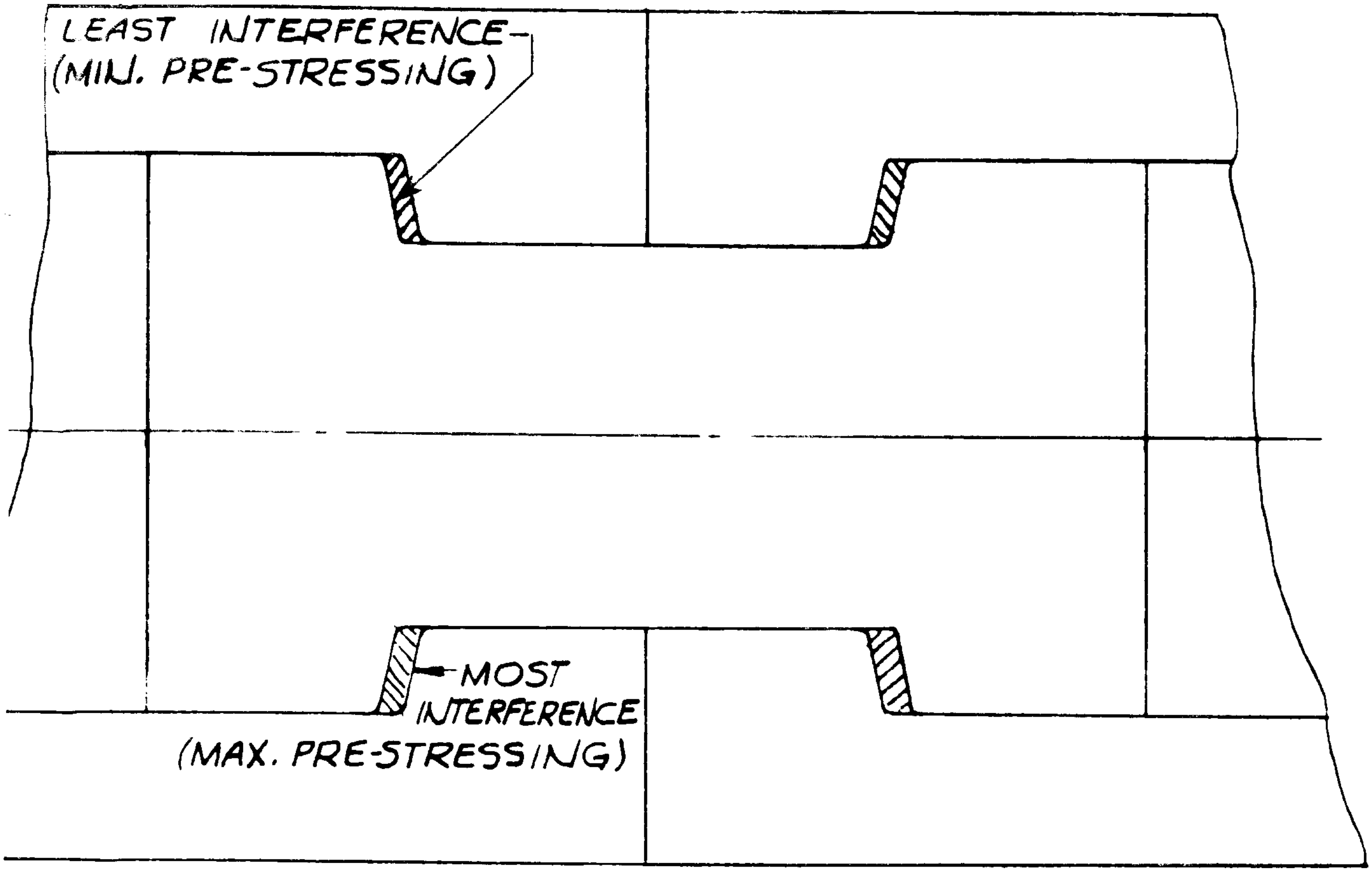

LOCKING WIRE ASSEMBLY
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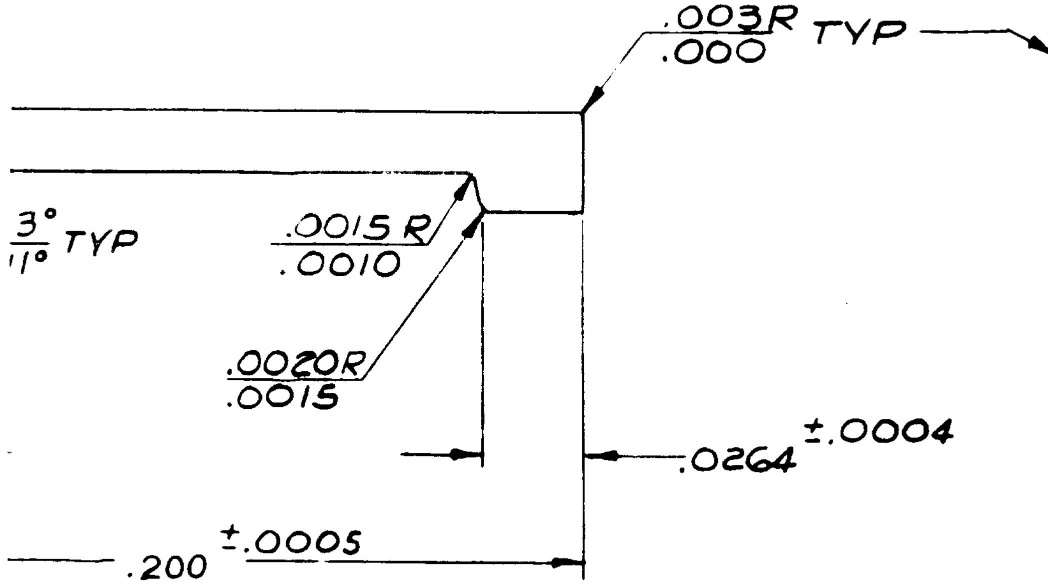

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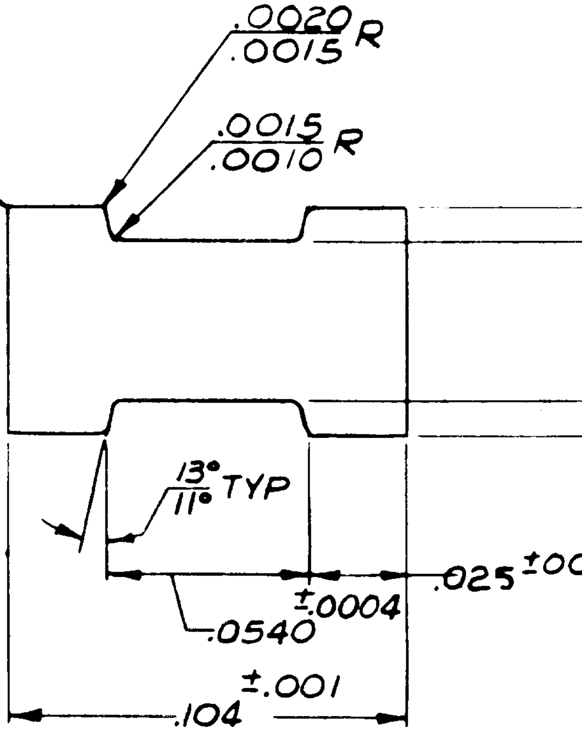

INNER LOCKING WIRE DETA
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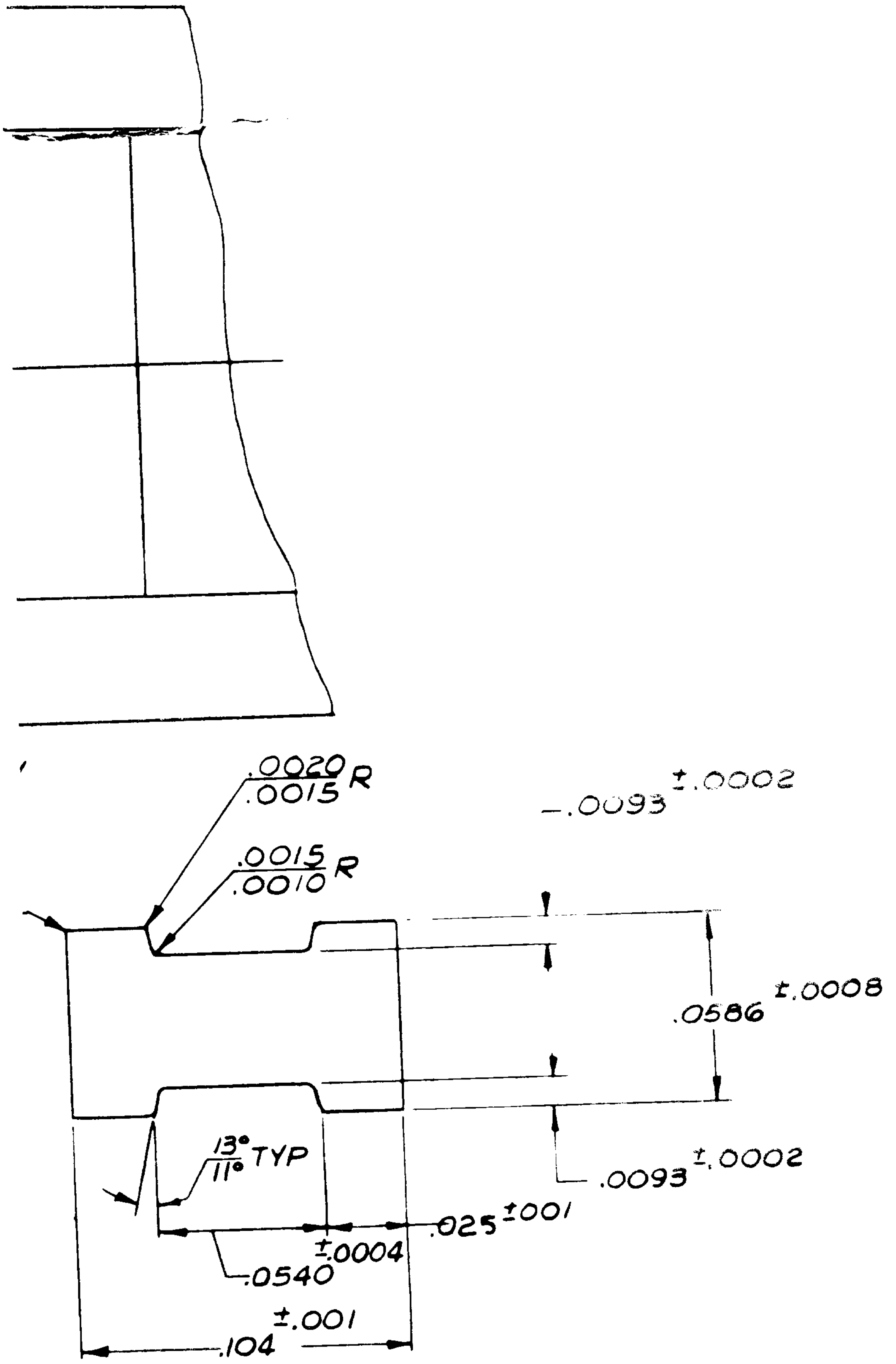

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Figure 3

BENDING STRESS - CHANNEL

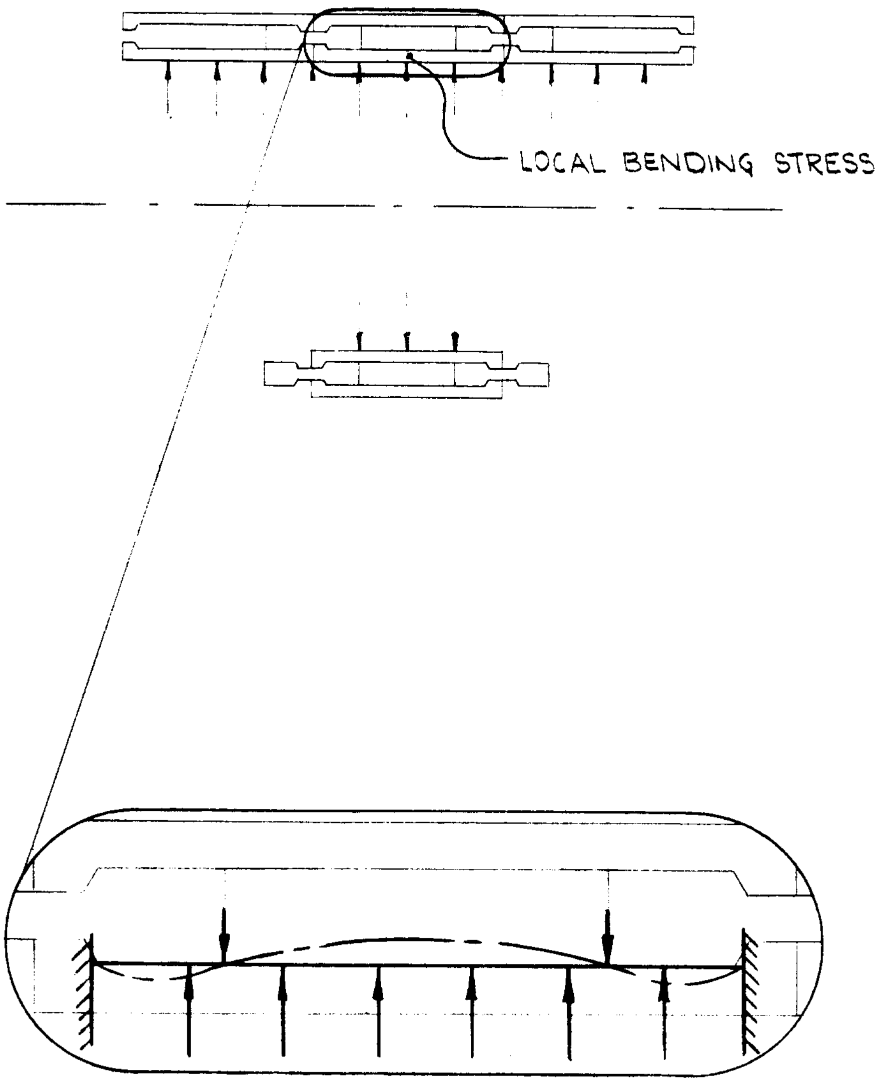
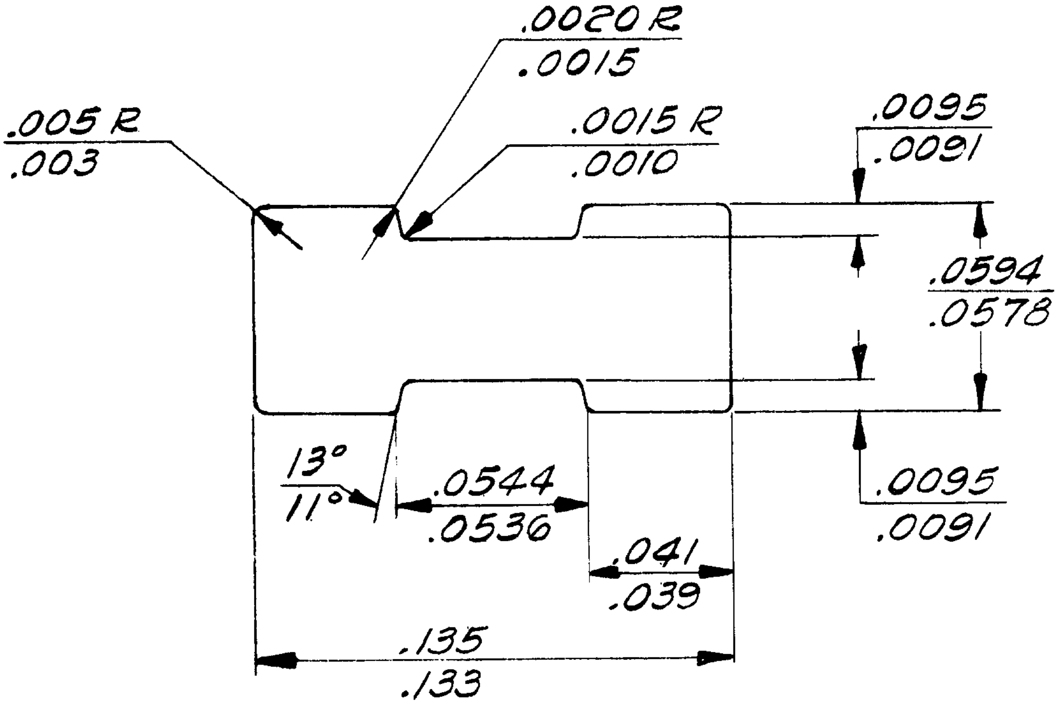


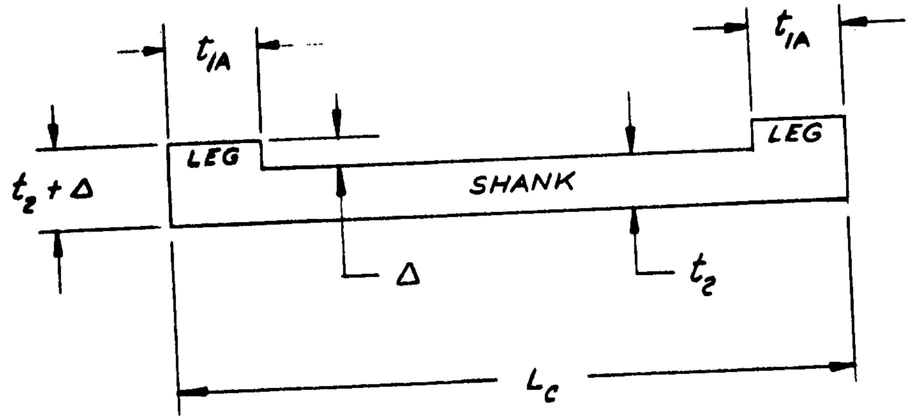
Figure 4



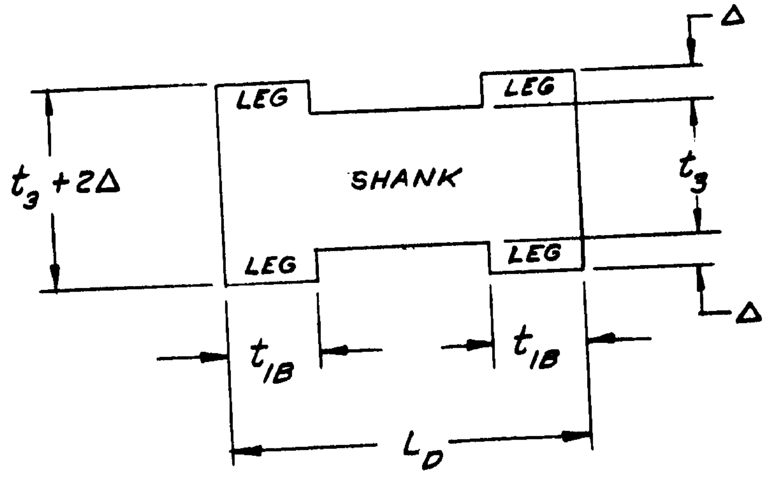
WIRE - I-BEAM

Figure 5

WIRE NOMENCLATURE



CHANNEL



DUMBBELL

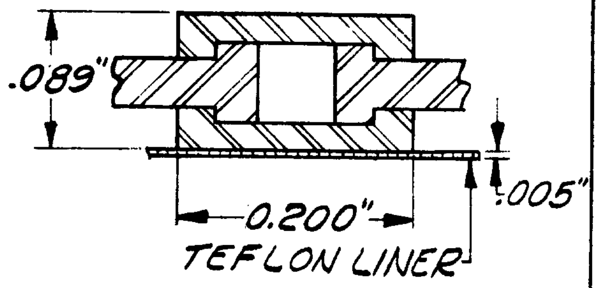
Figure 6

STRESS ANALYSIS SUMMARY

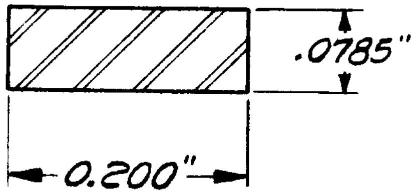
Configuration	3 Layers Butted Channels
Wire Material	Titanium Alloy, B120VCA
Mechanical Properties (psi)	
Longitudinal	250,000
Transverse	250,000
Bearing	417,000
Shear	150,000
Dumbell Dimensions (in.)	
Length - L_D	0.104
Shank Thick. - t_3	0.040
Leg Thick. - t_{1B}	0.026
Spacing - S	0.093
Interlock - Δ	0.0093
Channel Dimensions (in.)	
Length - L_C	0.197
Shank Thick. - t_2	0.0155
Leg Thick. - t_{1A}	0.026
Spacing - S	0
Interlock - Δ	0.0093
Overall Vessel Thickness (in.)	0.089
Helix Angle	0°-46.2'
Dumbell Stresses (psi)	
Hoop	250,000
Axial	250,000
Interlock Bearing	416,000
Channel Stresses (psi)	
Hoop	250,000
Axial	250,000
Leg Bending	0
Leg Shear	150,000
Shank Bending	0
Torsional Shear Stress (psi)	422

Fig. 7

WEIGHT COMPARISON



SEE FIGURE 3 FOR WIRE DIMENSIONS



TITANIUM AT 250,000 PSI Y.S.	TRICENT AT 200,000 PSI Y.S.
CHANNEL (2) = .001269# DUMBELL (1) = .000897 LINER = .000069 .002235#	SHELL = .00453#

WEIGHT SAVING OVER CYLINDRICAL SECTION OF TRICENT MOTOR $= \frac{.00453-.002235}{.00453} = 50\%$

Figure 8

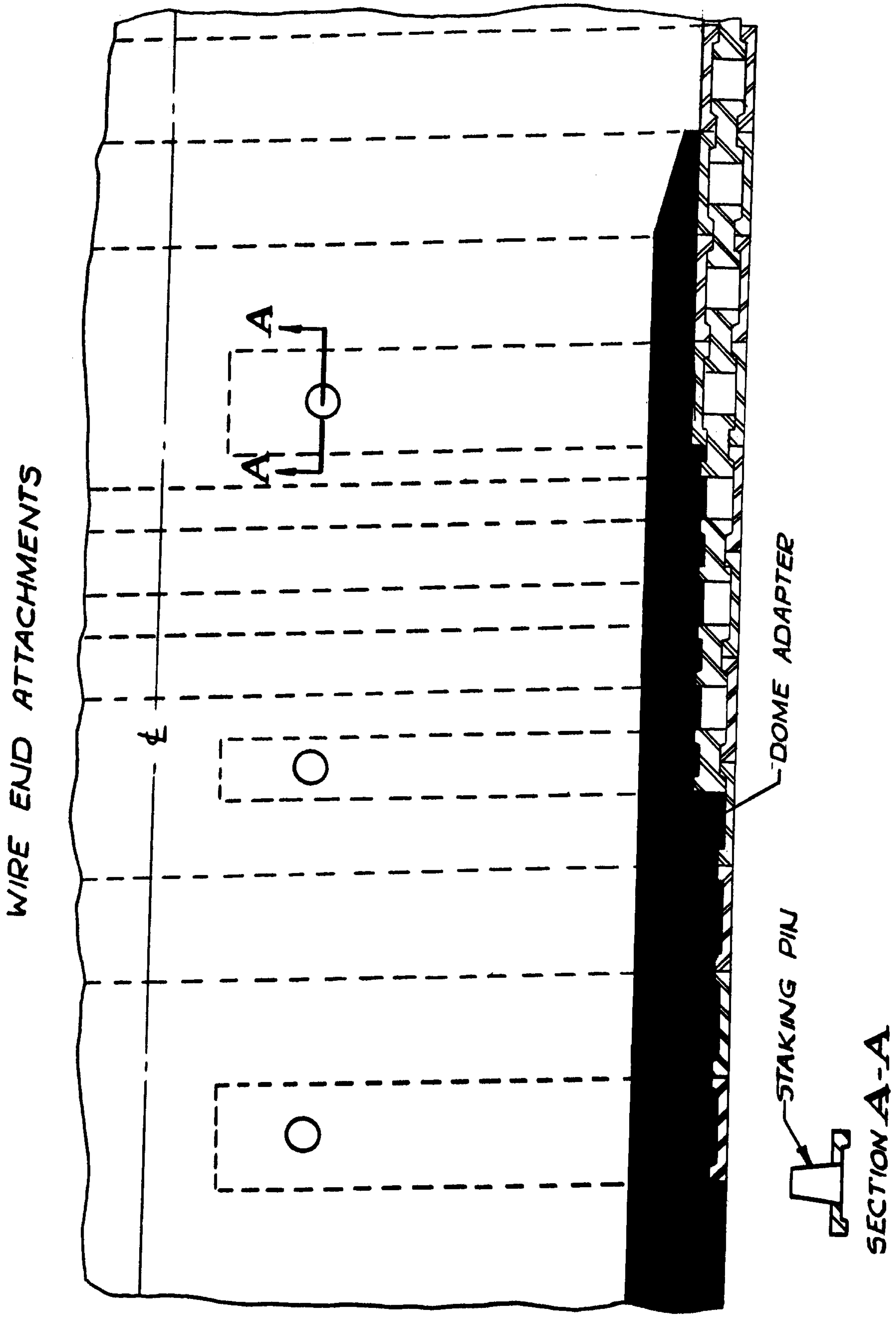
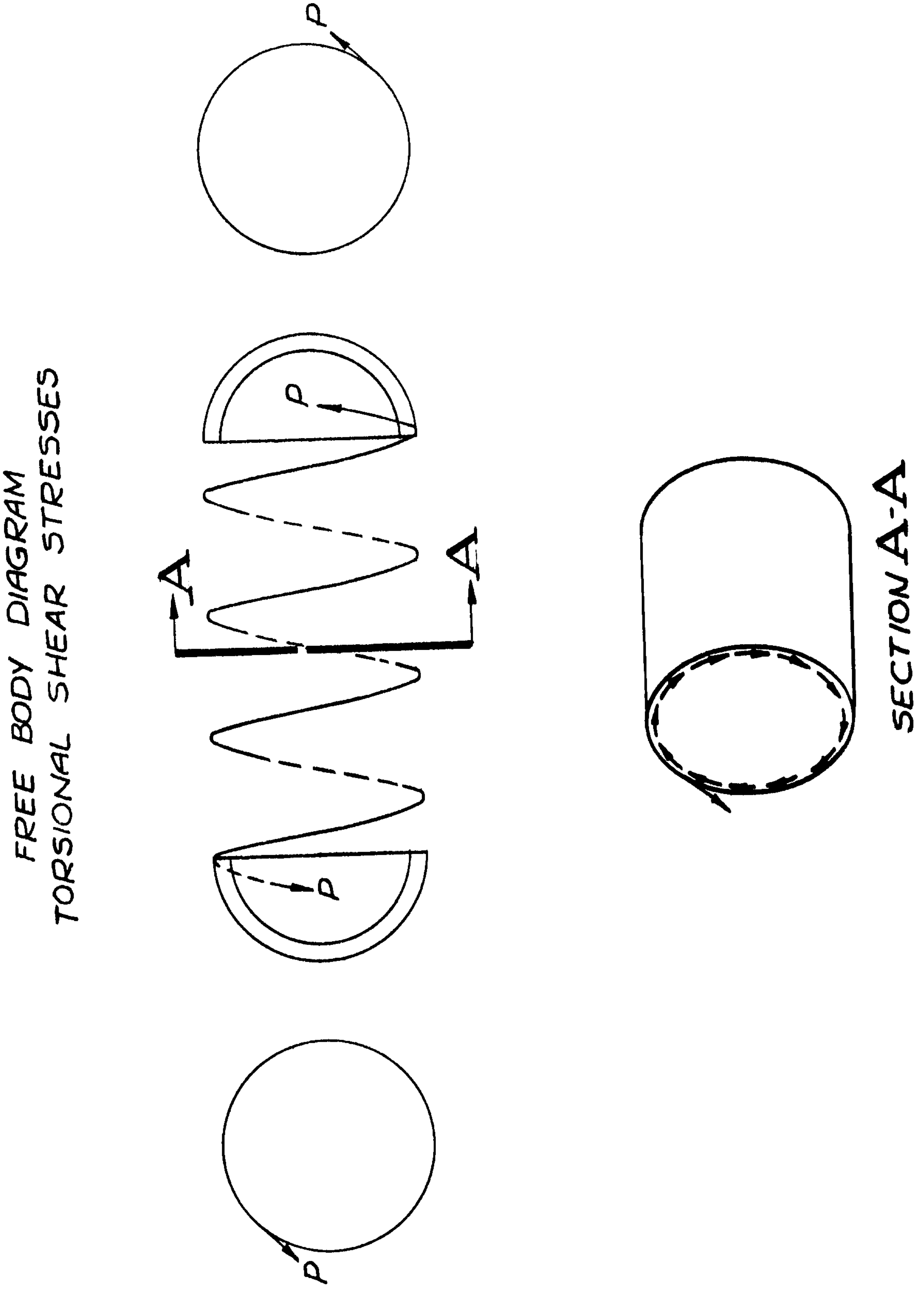
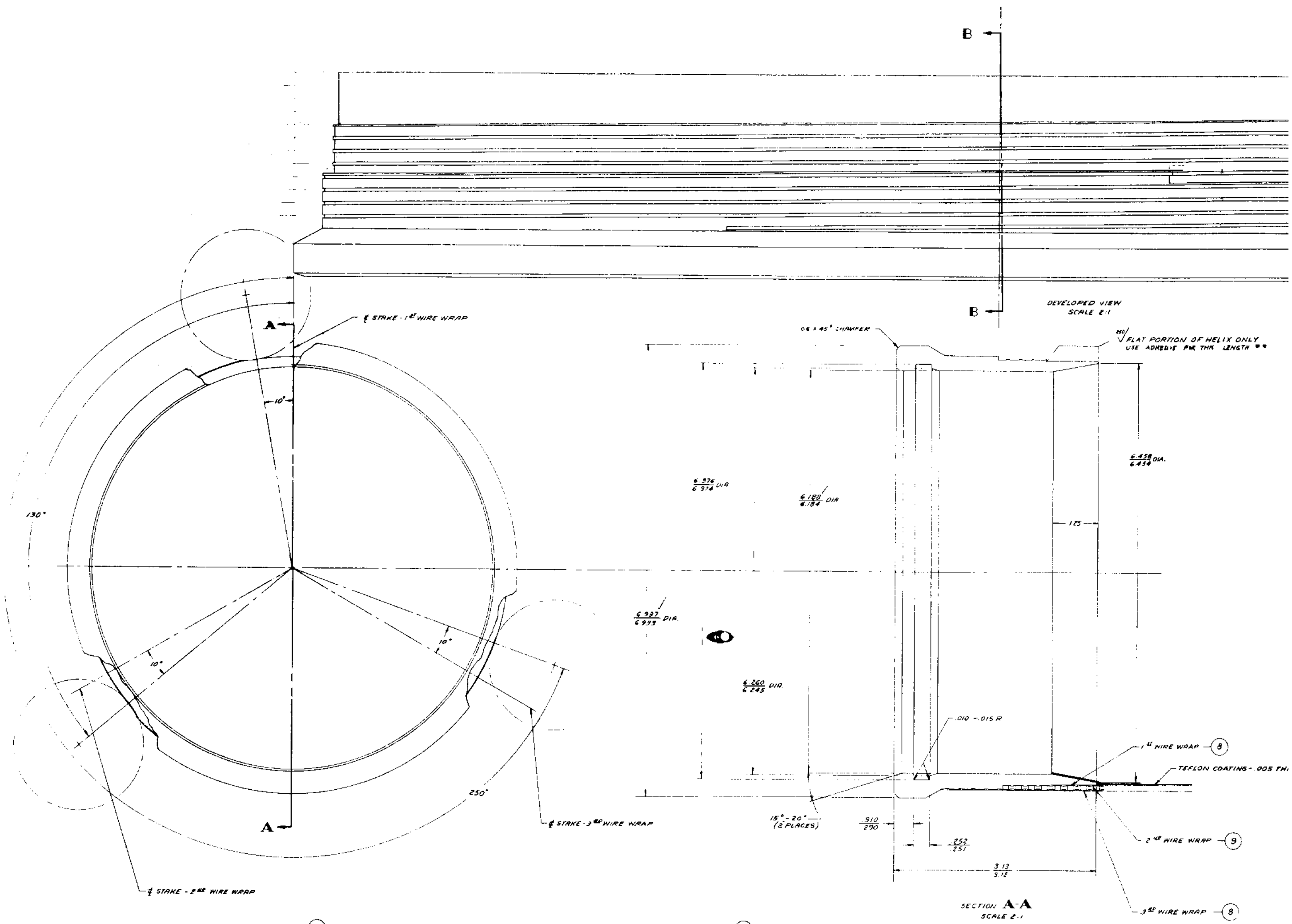

WIRE END ATTACHMENTS
℄
A
A
DOME ADAPTER
STAKING PIN
SECTION A-A

Figure 9



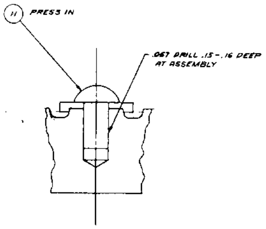
FREE BODY DIAGRAM
TORSIONAL SHEAR STRESSES
P
P
P
P
A
A
SECTION A-A

Figure 10

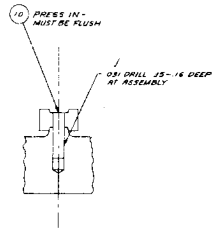


DEVELOPED VIEW
SCALE 2:1

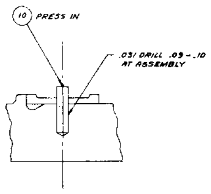
SECTION **A-A**
SCALE 2:1



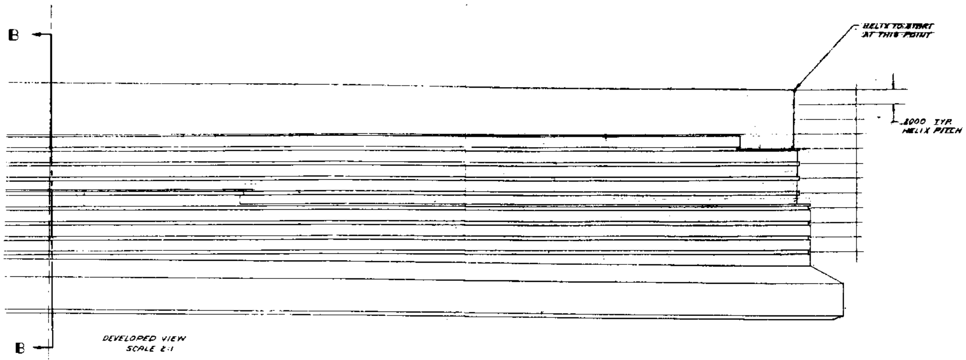
DETAIL OF STAKING - 3rd WIRE WRAP
SCALE 10:1



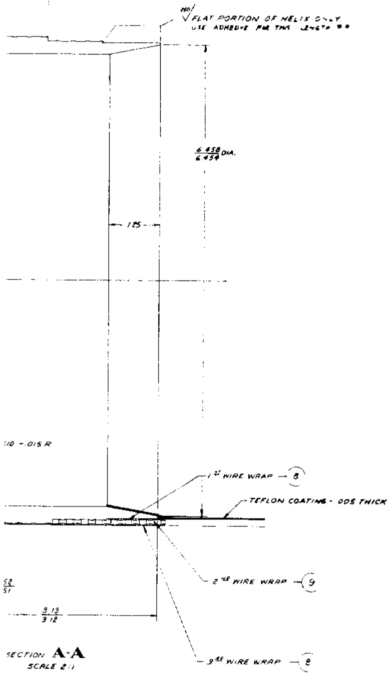
DETAIL OF STAKING - 2nd WIRE WRAP
SCALE 10:1



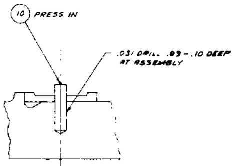
DETAIL OF STAKING - 1st WIRE WRAP
SCALE 10:1



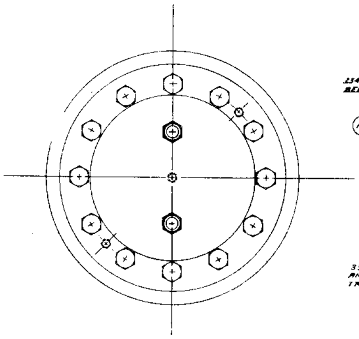
DEVELOPED VIEW
SCALE 2:1

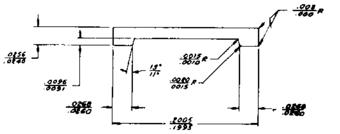


SECTION **A-A**
SCALE 2:1

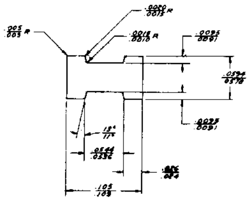


DETAIL OF STAKING - 1ST WIRE WRAP
SCALE 10:1

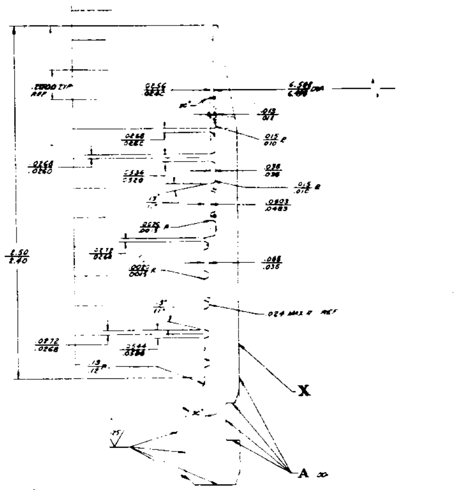




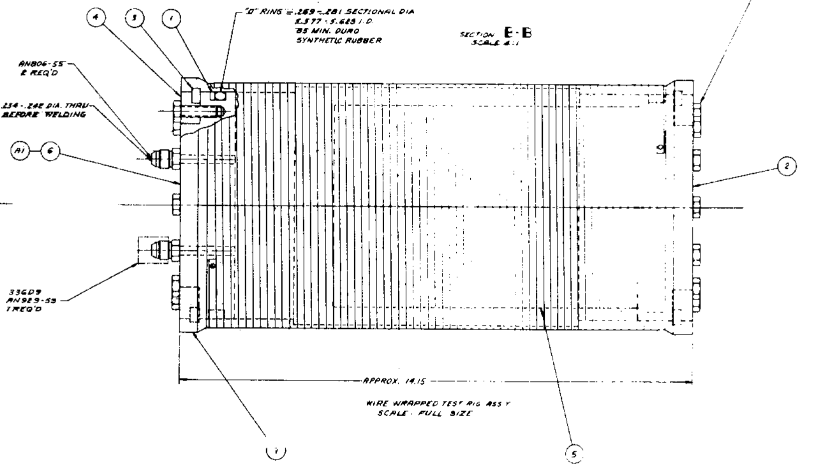
DETAIL OF PART NO ⑧
(1ST & 3RD WRAP)
SCALE 20:1



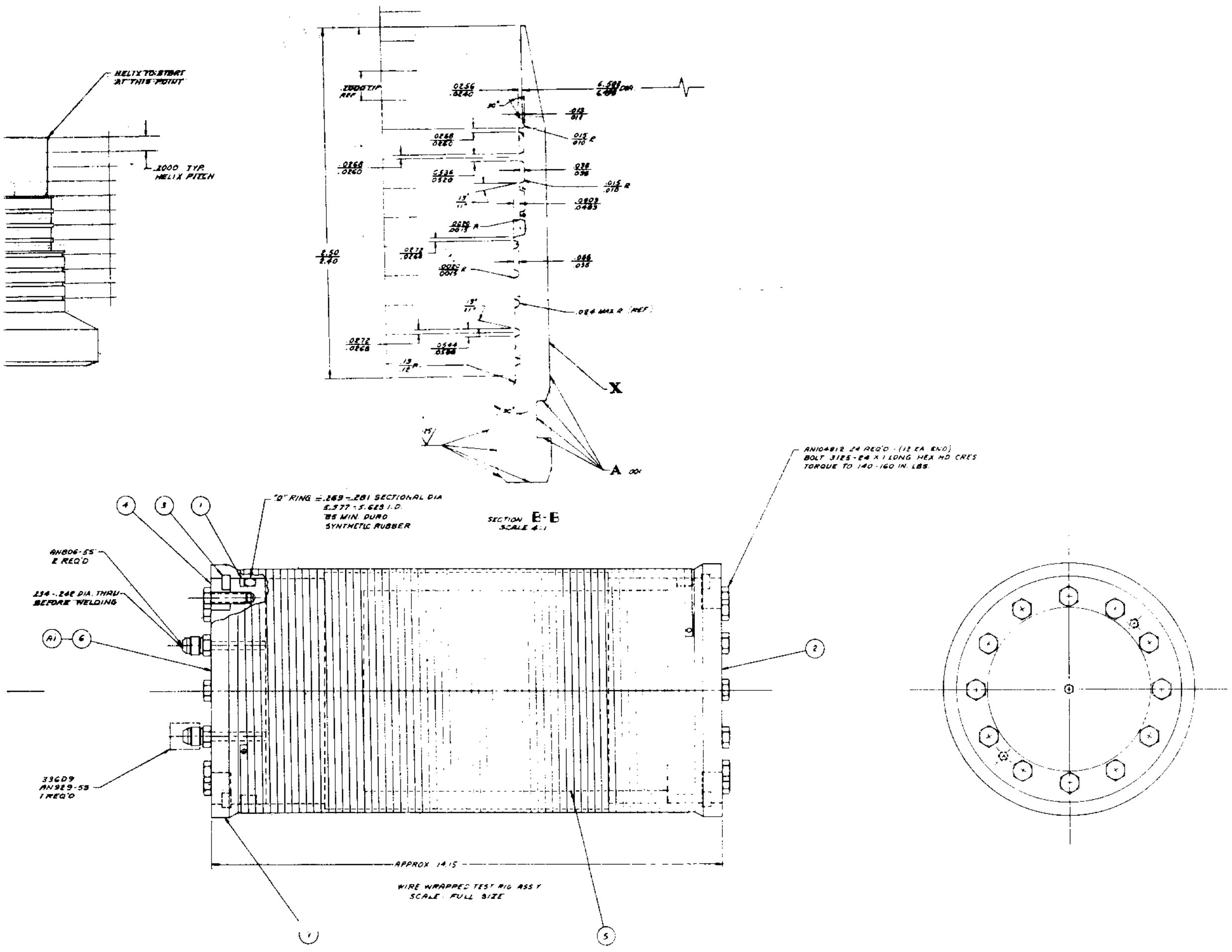
DETAIL OF PART NO. ⑨
(2ND WRAP)
SCALE 20:1

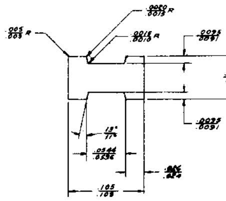


SECTION **E-E**
SCALE 4:1



WIRE WRAPPED TEST RIG ASS'Y
SCALE - FULL SIZE





DETAIL OF PART NO. ⑨
(.2 IN WRAP)
SCALE 20:1

FINISH $\sqrt{}$ UNLESS OTHERWISE SPECIFIED.

BREAK SHARP EDGES .01-.03 & BLEND UNLESS OTHERWISE SPECIFIED.

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED.

* PURCHASE FROM:
GROOV-PIN CORP.
1125 HENDRICKS CAUSEWAY
RIDGEFIELD, N.J.

** MARBLETTE INC.
RESIN NO. 532
HARDNER NO. 37
$S_{s(max)}$ = 4500 PSI

LS25439

ITEM NO.	PART NO (ADD)	ASS'Y (ADD)	PART NO. (REFERENCE)	PART NO (CANCEL)	QUAN.	DESCRIPTION	PATTERN	MAT'L.	OTHER SPECS	FORG. CAST W.B.
A1	LS23890-A1				1	PLUG & FITTING ASS'Y				
11					2	ROUND HD DRIVE STUD NO. 6		SAE 6150	1/4 LONG	
10					4	GROOV-PIN TYPE 3 - 1/32 DIA*		SAE 6150	1/4 LONG	
9					44 [illegible]	WIRE - I-BEAM		8120 VCA		
8					44 [illegible]	WIRE - CHANNEL		8120 VCA		
7					2	ADAPTER - WIRE R 46-50		TANGENT OR EQUIVALENT [illegible]		
	A929-55				1	CAP ASS'Y - PRESS SEAL		CORR RESIST. STEEL	TYPE 304 OR 347	
	AN806-55	A1			2	PLUG - FLARED TUBE		CORR RESIST. STEEL	TYPE 304 OR 347	
6	LS23890-7	A1			1	PLUG - INLET		SAE 4340 SAE 8740	RC 19-26	
5	LS23890-6				1	CYLINDER		OPTIONAL		
	AN104812				24	BOLT-HEX. HD. .3125 24 X 1" LG		C'RES		
					2	"O" RING - 5.600 I.D. .275 SECT. DIA		SYNTHETIC RUBBER	85 MIN DURO	
4	LS23890-5				2	PLATE - RESTRAINING		SAE 4340 SAE 8740	RC 19-26	
3	LS23890-4				6	RING - SEGMENT		SAE 4340 SAE 8740 SAE [illegible]	RC 47-51	
2	LS23890-3				1	PLUG - PLAIN		SAE 4340 SAE 8740	RC 19-26	
1	LS23890-2				2	RING - BACK-UP		LEATHER		

PARTS LIST

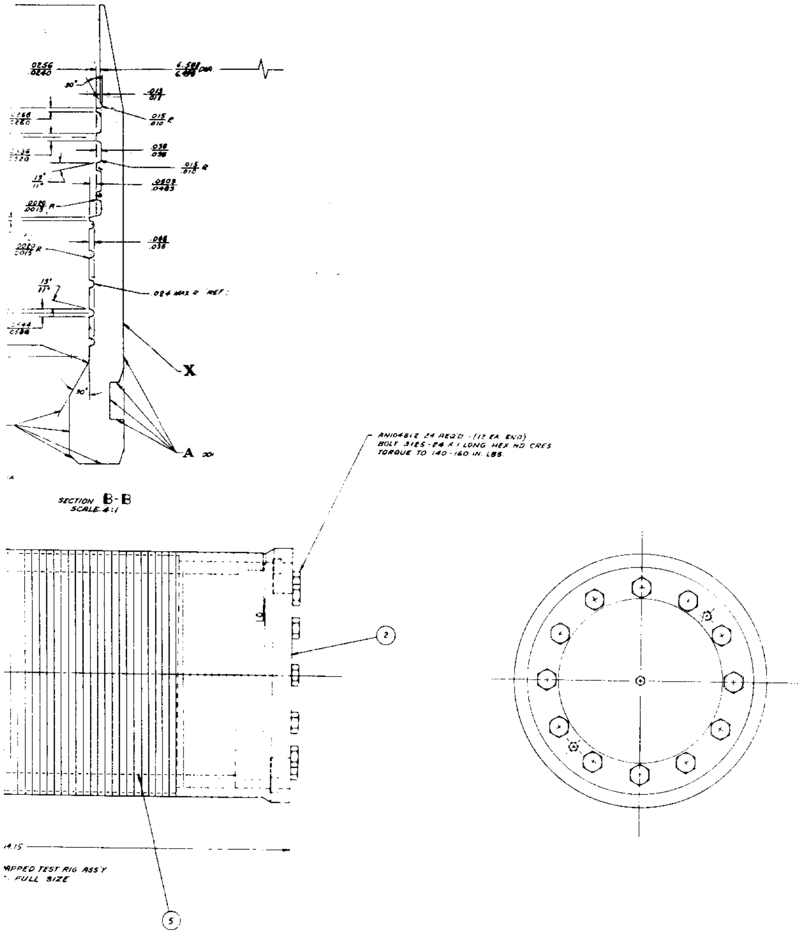
SCALE AS INDICATED
JOB NUMBER
H.H.
J.L.
2-1-60
3-1-60

CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY U.S.A.

TEST RIG -
WIRE WRAPPED

LS25439

Figure 11



LS25439

FINISH 63 UNLESS OTHERWISE SPECIFIED.

BREAK SHARP EDGES .01-.03 & BLEND UNLESS OTHERWISE SPECIFIED.

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED.

* PURCHASE FROM:
GROOV-PIN CORP.
1125 HENDRICKS CAUSEWAY
RIDGEFIELD, N.J.

** MARBLETTE INC.
RESIN NO. 532
HARDNER NO 37
$\sigma_{z(max)}$ = 4500 PSI

ITEM NO.	PART NO (ADD)	ASS'Y	PART NO (REFERENCE)	PART NO (CANCEL)	QUAN	DESCRIPTION		MAT'L	OTHER SPECS	FORG. CAST W.B.
A1	LS238904				1	PLUG & FITTING ASS'Y				
11					2	ROUND HD DRIVE STUD NO. 6		SAE 6150	1/8 LONG	
10					4	GROOV PIN TYPE 3 - 1/32 DIA *		SAE 6150	1/8 LONG	
9					[illegible]	WIRE - I-BEAM		8120 VCA		
8					[illegible]	WIRE - CHANNEL		8120 VCA		
7					2	ADAPTER - WIRE R. 46-50		[illegible]		
	A529-55				1	CAP ASS'Y - PRESS SEAL		CORR RESIST STEEL	[illegible]	
	AN806-55	A1			2	PLUG - FLARED TUBE		CORR RESIST STEEL	[illegible]	
6	LS23890-7	A1			1	PLUG - INLET		SAE 4340 SAE 8740	RC 19-26	
5	LS23890-6				1	CYLINDER		OPTIONAL		
	AN104812				24	BOLT-HEX. HD. .3125-24 X 1" LG		CRES		
					2	"O" RING - 5.600 I.D. .275 SECT. DIA		SYNTHETIC RUBBER	[illegible]	
4	LS23890-5				2	PLATE - RESTRAINING		SAE 4340 SAE 8740	RC 19-26	
3	LS23890-4				6	RING - SEGMENT		SAE 4340 SAE 8740 [illegible]	RC 47-51	
2	LS23890-3				1	PLUG - PLAIN		SAE 4340 SAE 8740	RC 19-26	
1	LS23890-2				2	RING - BACK-UP		LEATHER		

PARTS LIST

SCALE AS INDICATED

JOB NUMBER

2-1-60

3-1-60

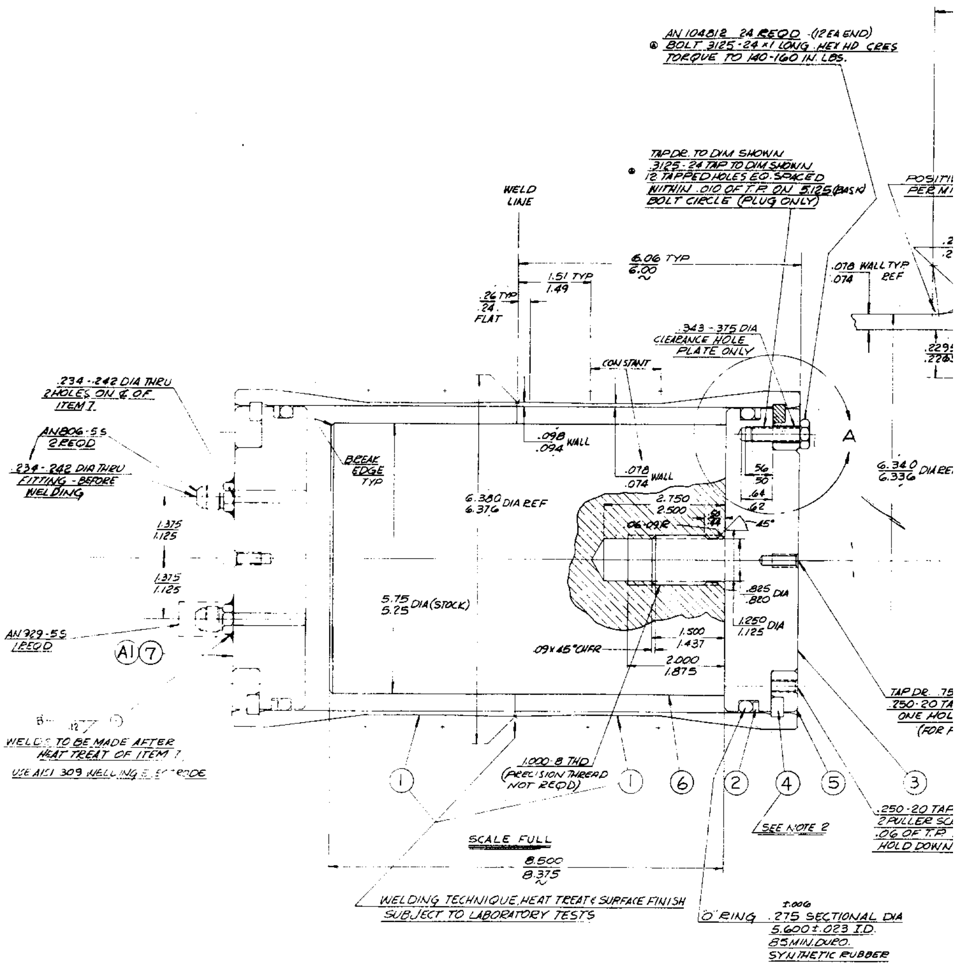
3-9-60

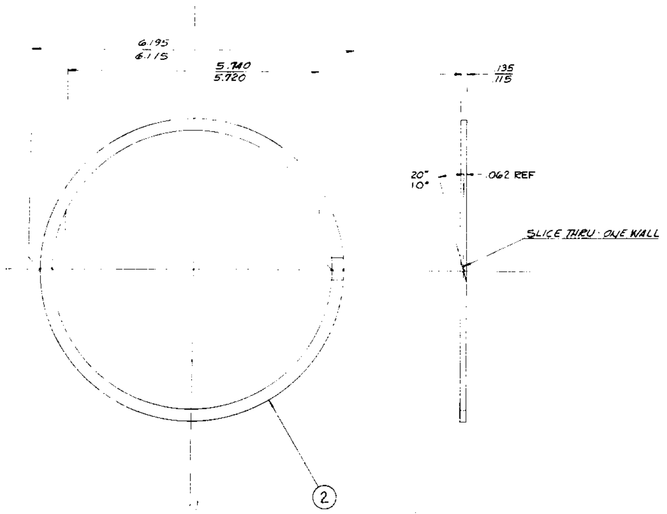
CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

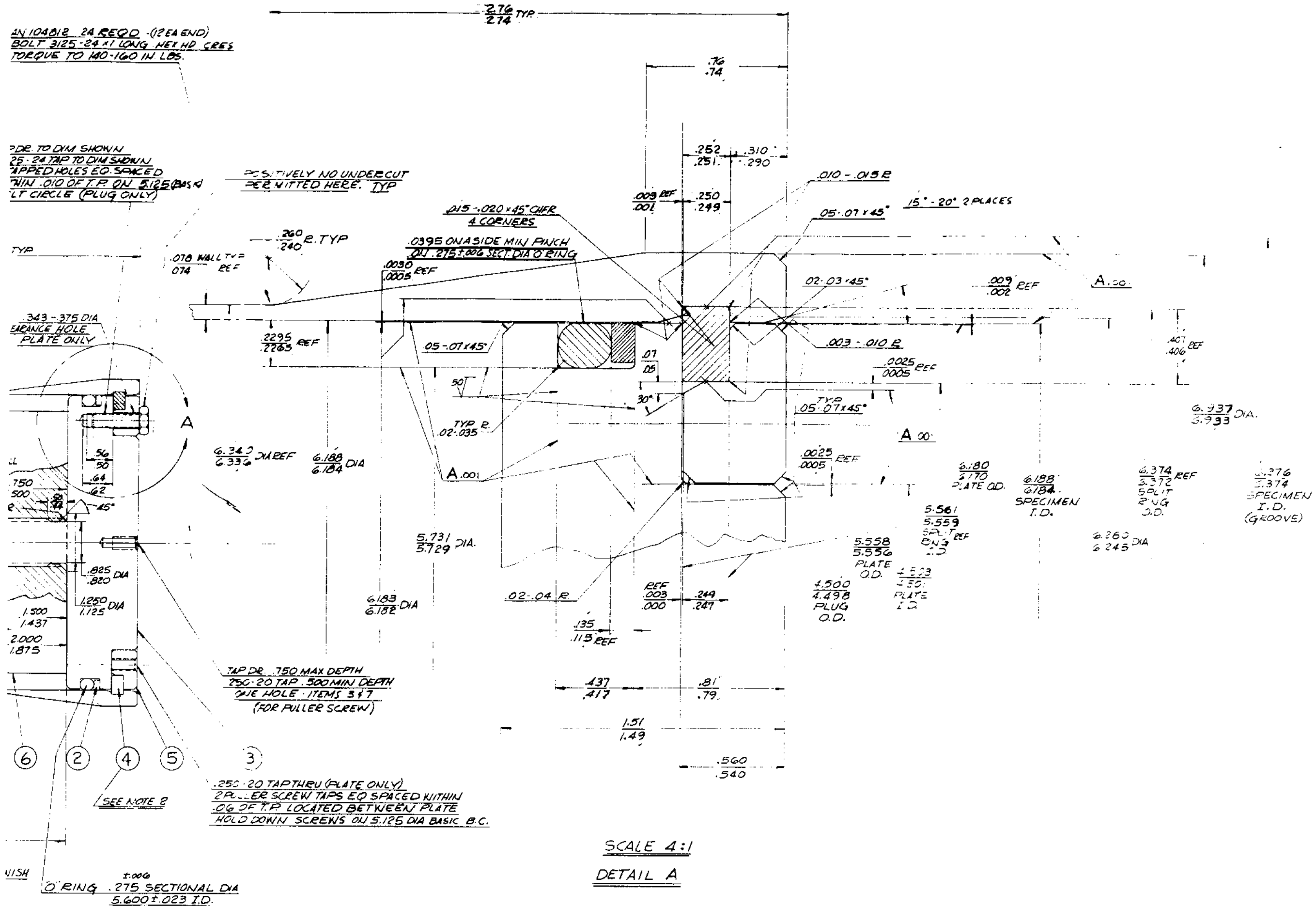
TEST RIG -
WIRE WRAPPED

LS25439

Figure 11

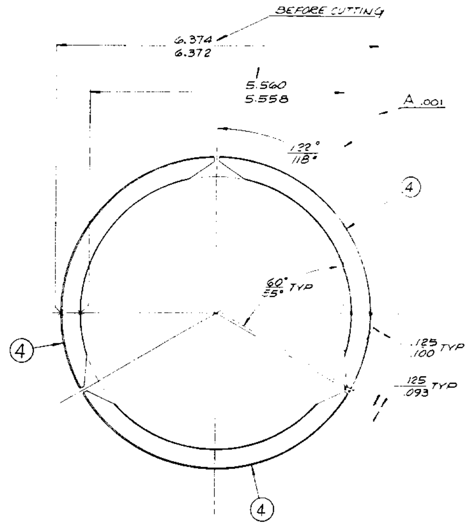

AN 104812 24 REQD (12 EA END)
BOLT 3125-24 × 1 LONG HEX HD CRES
TORQUE TO 140-160 IN. LBS.
TAP DR. TO DIM SHOWN
.3125-24 TAP TO DIM SHOWN
12 TAPPED HOLES EQ. SPACED
WITHIN .010 OF T.P. ON 5.125 (BASIC)
BOLT CIRCLE (PLUG ONLY)
POSITI
PER MI
WELD LINE
6.06 TYP
6.00
1.51 TYP
1.49
.26 TYP
.24
FLAT
.078 WALL TYP
.074 REF
.2
.2
.2295
.2265
.343 - .375 DIA
CLEARANCE HOLE
PLATE ONLY
CONSTANT
.234 - .242 DIA THRU
2 HOLES ON ℄ OF ITEM 7.
AN806-5S
2 REQD
.234 - .242 DIA THRU
FITTING - BEFORE WELDING
BREAK EDGE TYP
.098
.094 WALL
.078
.074 WALL
A
6.340
6.336 DIA REF
6.380
6.376 DIA REF
2.750
2.500
.06-.09R
.50
.44
45°
.56
.50
.64
.62
1.375
1.125
1.375
1.125
5.75
5.25 DIA (STOCK)
.825
.820 DIA
1.250
1.125 DIA
AN929-5S
1 REQD
A1 7
.09 × 45° CHFR
1.500
1.437
2.000
1.875
TAP DR. .75
.250-20 TA
ONE HOL
(FOR F
WELDS TO BE MADE AFTER
HEAT TREAT OF ITEM 7.
USE AISI 309 WELDING ELECTRODE
1.000-8 THD
(PRECISION THREAD NOT REQD)
1
1
6
2
4
5
3
SEE NOTE 2
.250-20 TAP
2 PULLER SC
.06 OF T.P.
HOLD DOWN
SCALE FULL
8.500
8.375
WELDING TECHNIQUE, HEAT TREAT & SURFACE FINISH
SUBJECT TO LABORATORY TESTS
"O" RING .275 ±.006 SECTIONAL DIA
5.600 ± .023 I.D.
85 MIN. DURO.
SYNTHETIC RUBBER


6.195
6.115
5.740
5.720
.135
.115
20°
10°
.062 REF
SLICE THRU ONE WALL
2



SCALE 4:1

DETAIL A



A1					1	PLUG & FITTING ASSEMBLY			WELD AFTER HEAT TREAT	
	A929-5S				1	CAP ASSEMBLY, PRESS SEAL		CRES STL	TYPE 304L OR 347	
	AN806-5S	A1			2	PLUG - FLARED TUBE		CORR RES STL	TYPE 304L OR 347	
7		A1			1	PLUG - INLET		SAE 4340 SAE 8740	RC 19-26	
6					1	CYLINDER		OPTIONAL		
Ⓐ	AN104812				24	BOLT HEX HD. .3125-24 x 1 LG. CRES				
					2	O RING - 5.600 I.D., .275 SECTIONAL DIA		SYNTHETIC RUBBER	85 MIN DURO	
5					2	PLATE - RESTRAINING		SAE 4340 SAE 8740	RC 19-26	
4					6	RING - SEGMENT		[illegible]	RC 47-51	
3					1	PLUG - PLAIN		SAE 4340 SAE 8740	RC 19-26	
2					2	RING - BACK-UP - LEATHER				
1					2	SPECIMEN				
	PART NO. REQ'D	AND	PART NO. REFERENCE	PART NO. CANCEL	QUAN	DESCRIPTION	INTERC.	MATL	OTHER SPECS	FORG CAST WR

FINISH 125√ UNLESS OTHE

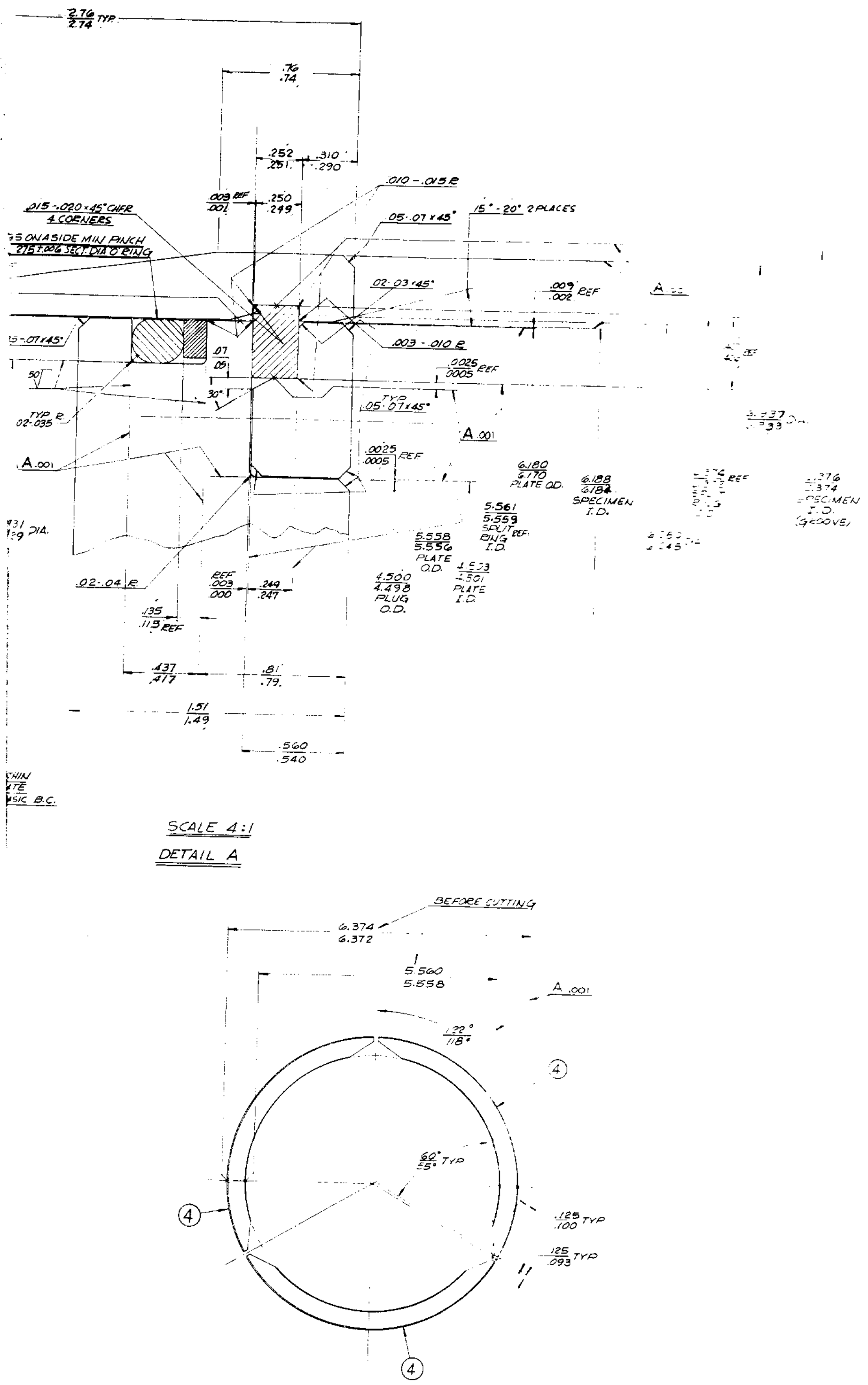
BREAK SHARP EDGES
INDICATED.

A SURFACES CONST
RIGHT ANGLES TO A
WITHIN FULL INDICAT

5-20
5-22

CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

GIRTH WELD
—RE DESIG



LS23898
A

	PART NO	ASSY	PART NO	PART NO	QUAN	DESCRIPTION	INTERCH.	MATL	OTHER SPECS	FORG CAST NR
A1						PLUG & FITTING ASSEMBLY			WELD AFTER HEAT TREAT	
	A929-55					CAP ASSEMBLY PRESS SEAL		[illegible] STL	TYPE 304L OR 347	
	AN806-5S	A1			2	PLUG - FLARED TUBE		CORR. RESIST. STL	TYPE 304L OR 347	
7		A1				PLUG - INLET		SAE 8740 SAE 8740	RC 19-26	
6						CYLINDER		OPTIONAL		
Ⓐ	AN104812				24	BOLT HEX HD. .3125-24 x 1 LG. CRES				
					2	O RING 5.600 I.D., .275 SECTIONAL DIA		SYNTHETIC RUBBER	85 MIN DURO	
5					2	PLATE - RESTRAINING		SAE 4340 SAE 8740	RC 19-26	
4					6	RING - SEGMENT		[illegible]	RC 47-51	
3					1	PLUG - PLAIN		[illegible]	RC 19 26	
2					2	RING - BACK-UP - LEATHER				
1					2	SPECIMEN				

FINISH $\sqrt{}$ 125 UNLESS OTHERWISE SPECIFIED

BREAK SHARP EDGES .01 - .03 UNLESS OTHERWISE INDICATED.

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS MUST BE WITHIN FULL INDICATOR READING SPECIFIED.

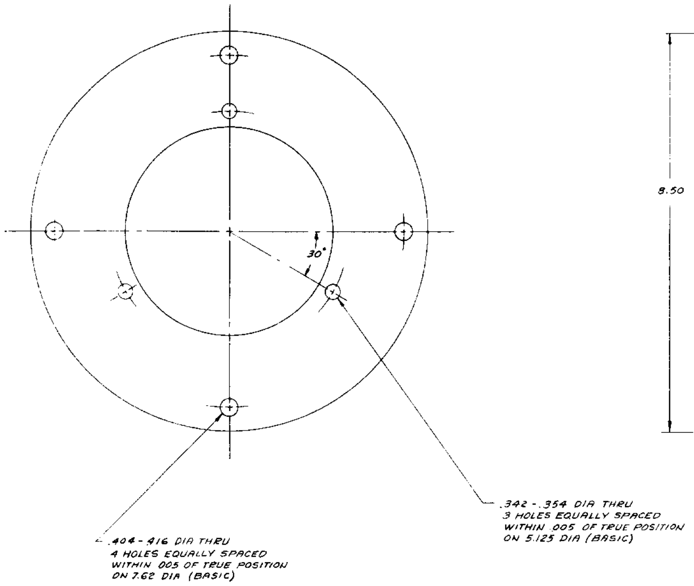
CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

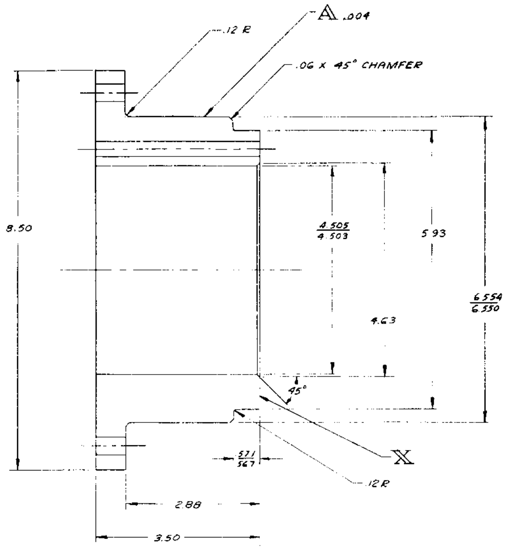
GIRTH WELD RIG
-RE DESIGN-

LS23898

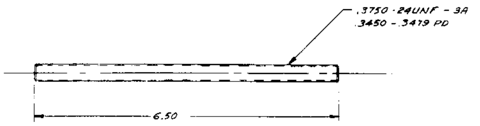
5-20-59
5-22-59
6/1/59
5-28-59

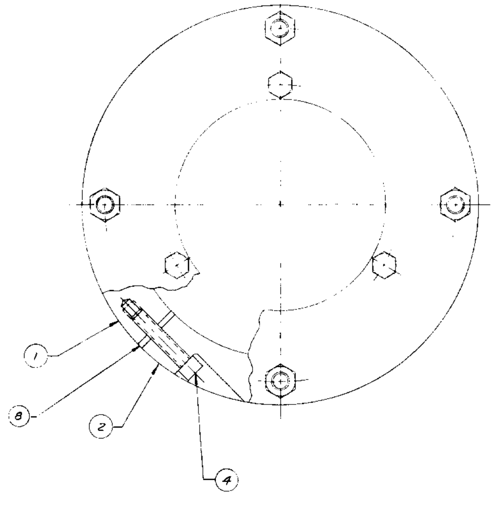
Figure 12

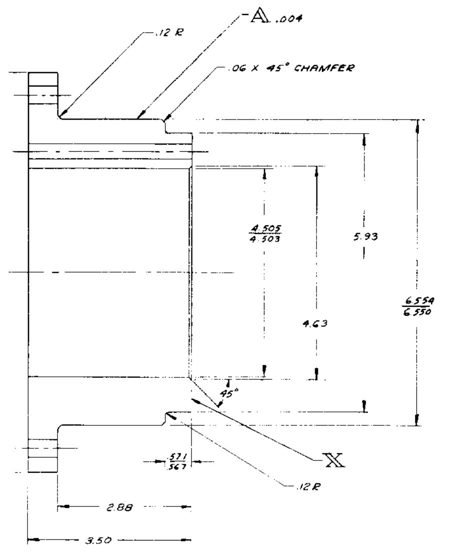

30°
.342 - .354 DIA THRU
3 HOLES EQUALLY SPACED
WITHIN .005 OF TRUE POSITION
ON 5.125 DIA (BASIC)
.404 - .416 DIA THRU
4 HOLES EQUALLY SPACED
WITHIN .005 OF TRUE POSITION
ON 7.62 DIA (BASIC)

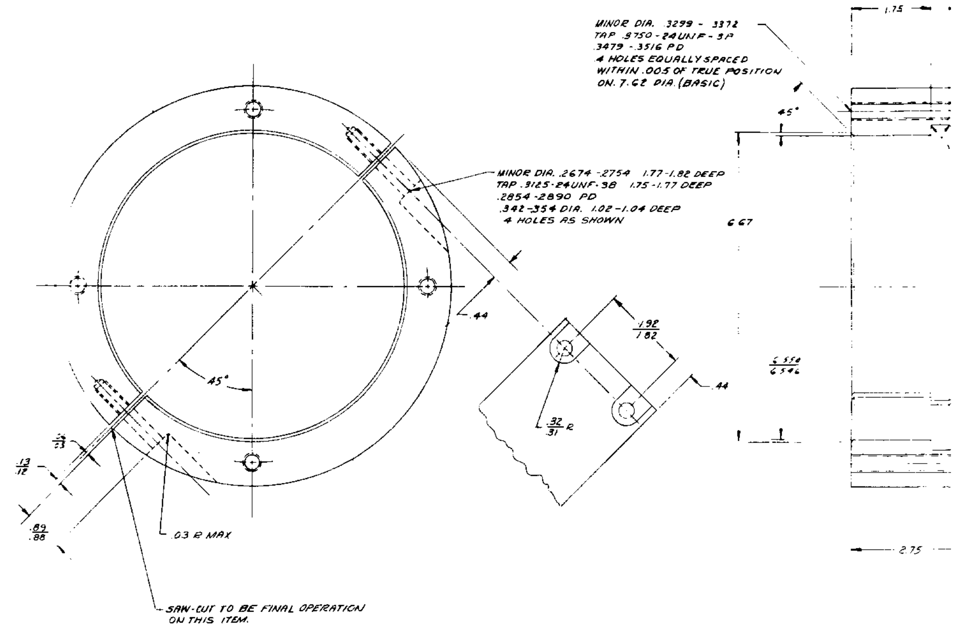

.12 R
A .004
.06 X 45° CHAMFER
8.50
4.505
4.503
5.93
6.554
6.550
4.63
45°
X
.571
.567
.12 R
2.88
3.50

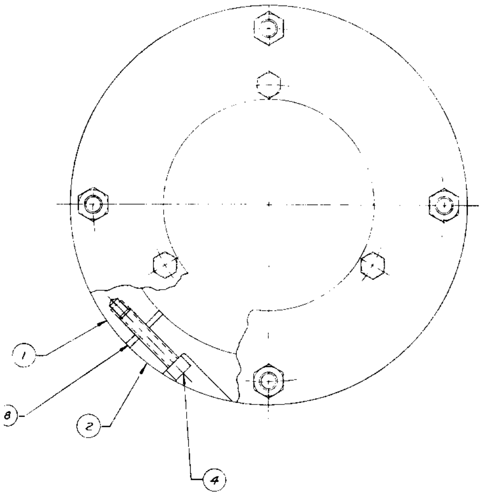

.06
.03
.13
.12
.89
.88

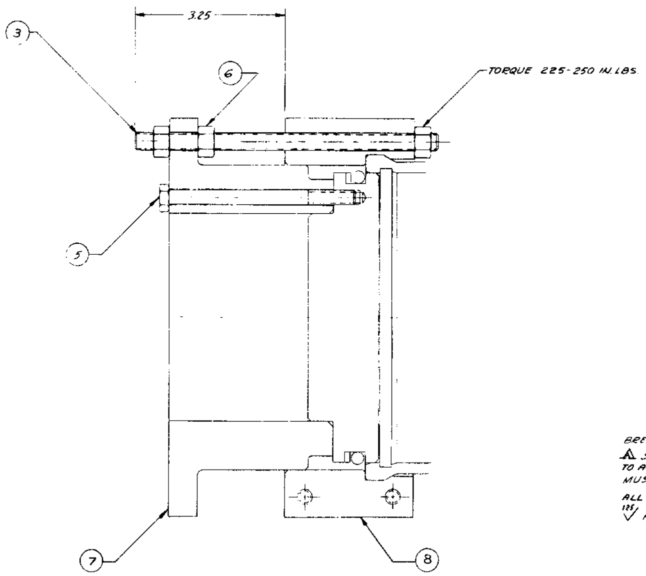

.3750 - 24UNF - 3A
.3450 - .3419 PD
6.50


1
8
2
4





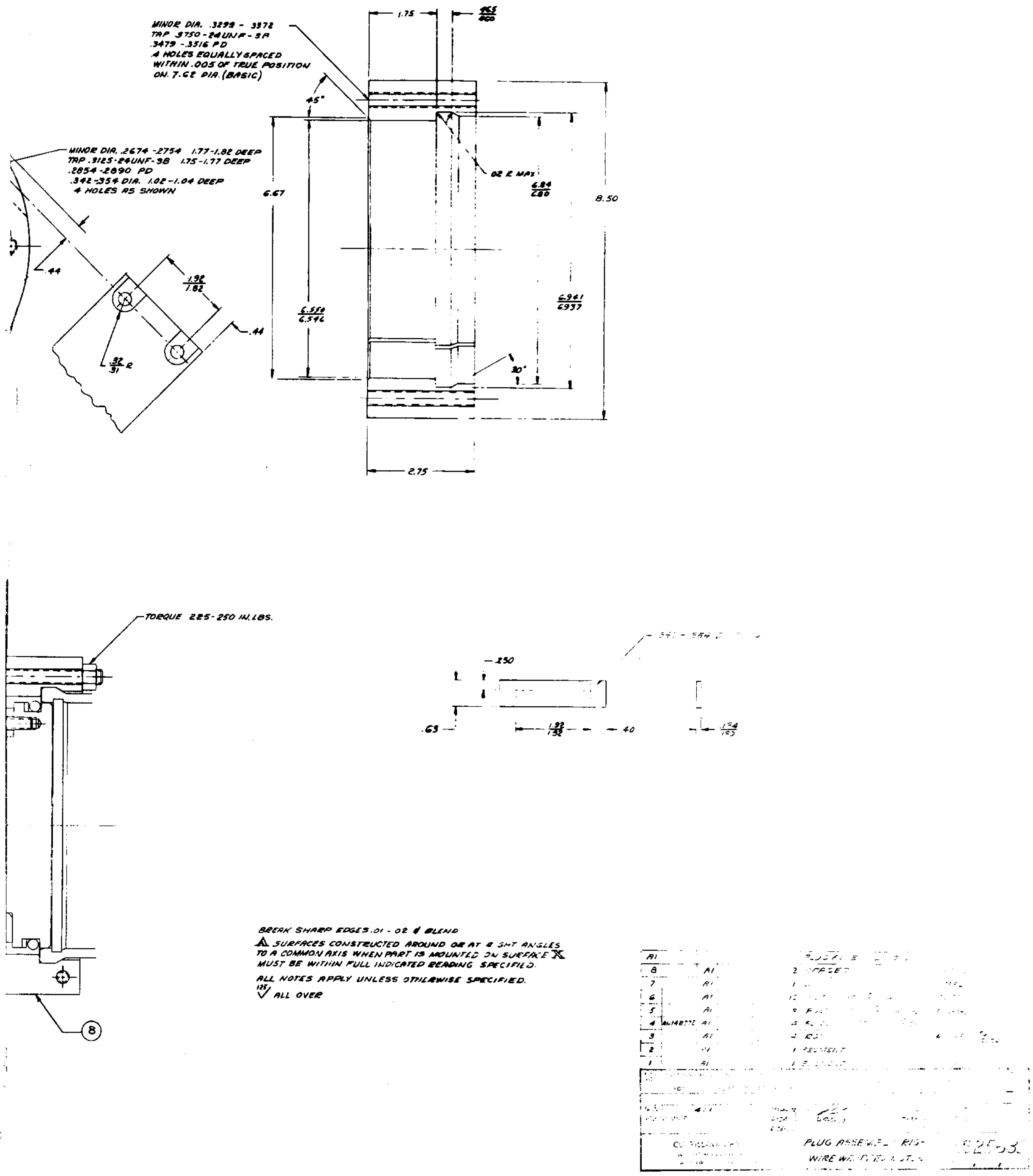




63

BREAK SHARP EDGES .01 - .02 & BLE
A SURFACES CONSTRUCTED AROUND
TO A COMMON AXIS WHEN PART IS MO
MUST BE WITHIN FULL INDICATED REA

ALL NOTES APPLY UNLESS OTHERWI
125 ALL OVER



BREAK SHARP EDGES .01 - .02 & BLEND

A SURFACES CONSTRUCTED AROUND OR AT 8 SHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATED READING SPECIFIED.

ALL NOTES APPLY UNLESS OTHERWISE SPECIFIED.

125 √ ALL OVER

Figure 13

FREEBODY DIAGRAM

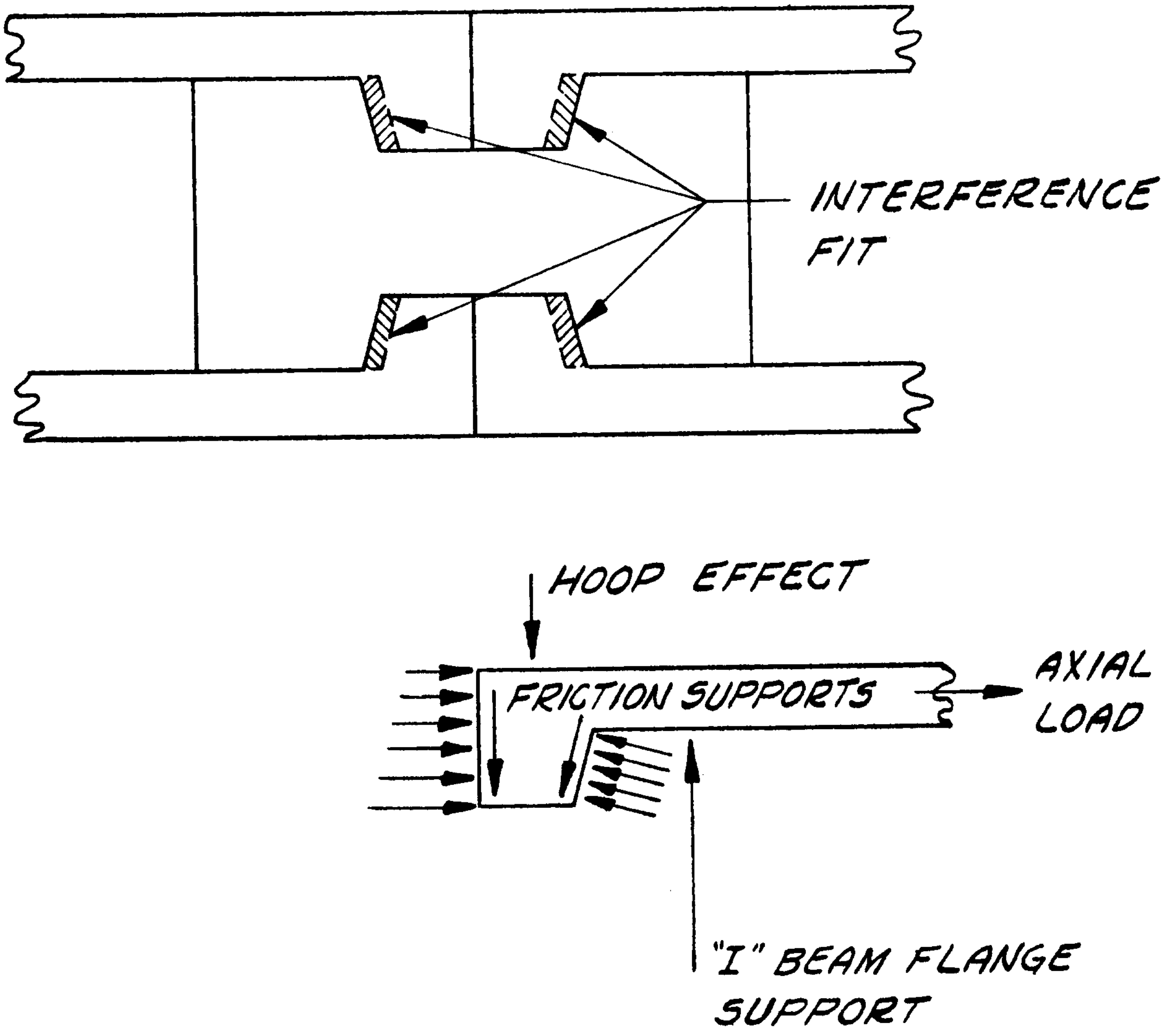
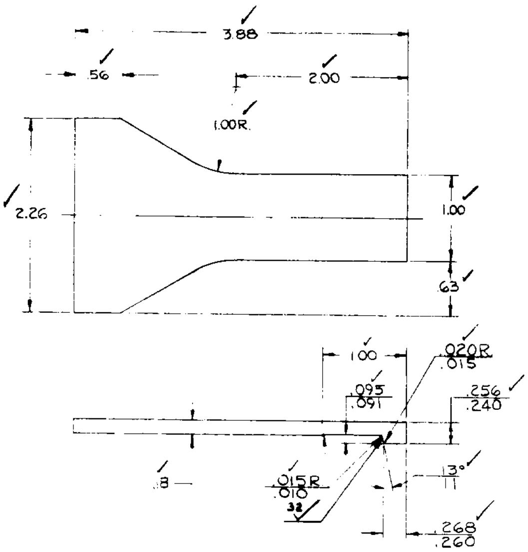
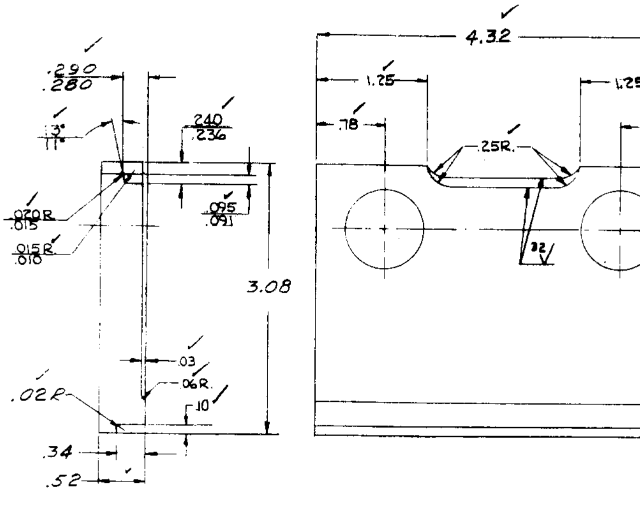


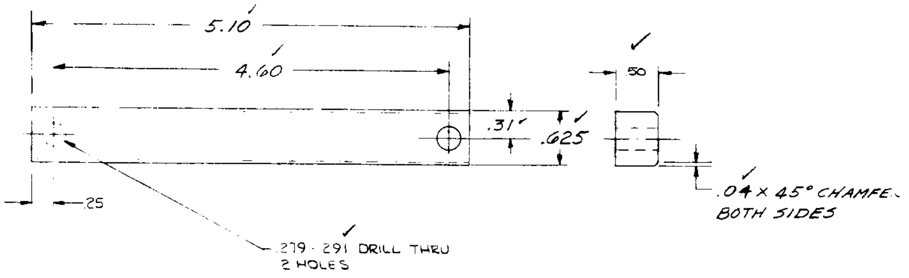
Figure 14



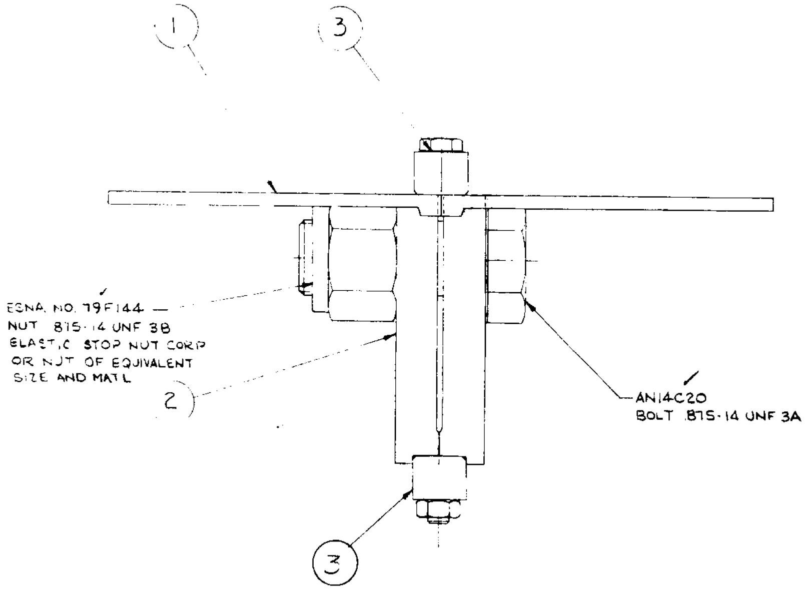
ITEM NO. 1

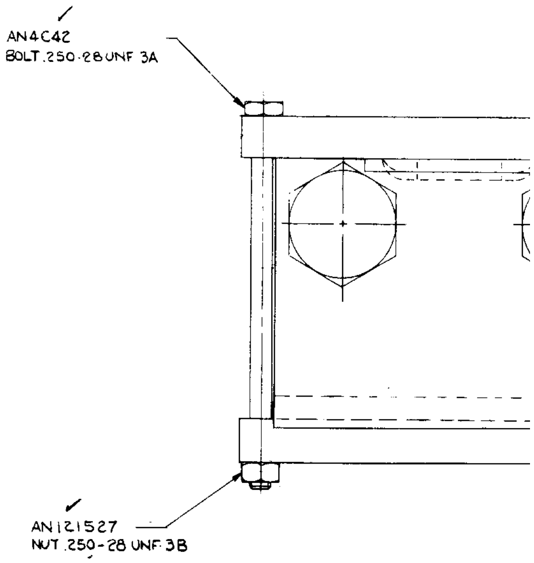


ITEM NO. 2

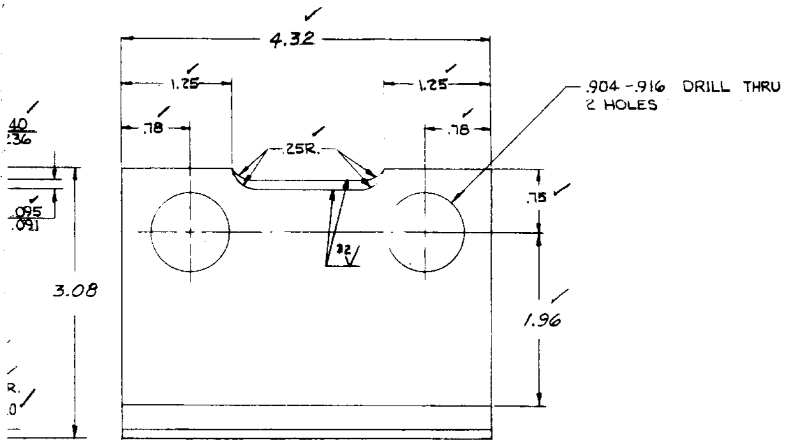


ITEM NO. 3





CHG LTR.	DESCRIPT



ITEM NO. 2

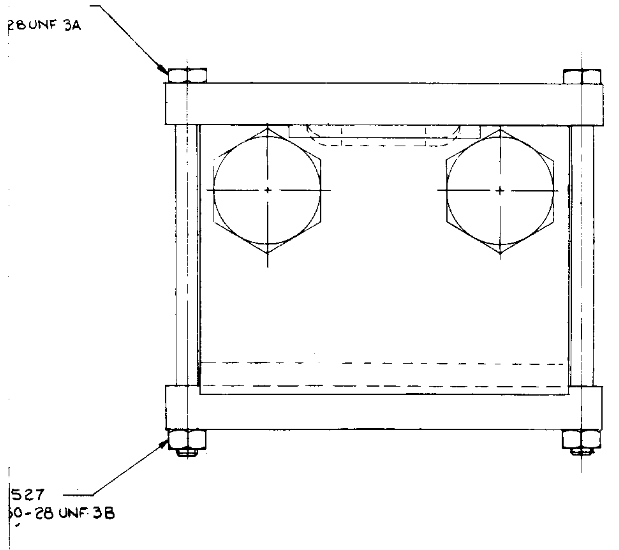
MFE.

FINISH $\sqrt{}^{125}$

BREAK SHARP EDGES
.005-.015 APPROX R

FINISHED DIM. ±.010
ALL ANGLES ± 2°

ALL NOTES APPLY
UNLESS OTHERWISE SPECIFIED



	AN14C20				2	BOLT-.875-14 UNF 3A 2 3/16 LENGTH
	ESNA NO. 79E144 OR EQUIVALENT				2	NUT-.875-14 UNF 3B (SEE NOTE)
	AN4C42				2	BLOT-.250-28 UNF-3A 4 9/32 LENGTH
	AN121527				2	NUT-.250-28 UNF3B
3					2	PLATE - SPECIMEN CLAMP
2					2	CLAMP-"I" BEAM
1					2	SPECIMEN-CHANNEL 10/1 WIRE SIZE
ITEM	PART NO. ADD	ASSY	PART NO. REFERENCE DWG	PART NO.	Q	DESCRIPTION

SCALE FULL
JOB NUMBER 650032

ZAWONSKI 10-25-60
10-27-60

H.H 11-1-60

J.L. 11-1-6

CURTISS

INTER-LOCKING TITANIUM
WIRE CASE -
CHANNEL & "I"-BEAM JOINT RIG

L THRU

REVISIONS			
CHG. LTR.	DESCRIPTION	DATE	ENGRS.

FINISH $\overset{125}{\surd}$

BREAK SHARP EDGES
.005-.015 APPROX R

FINISHED DIM. ±.010
ALL ANGLES ± 2°

ALL NOTES APPLY
UNLESS OTHERWISE SPECIFIED

LS 25810

	AN14C20				2	BOLT-.875-14UNF 3A 2 3/16 LENGTH		CORROSION RESISTANT STEEL		
	ESNA NO. 79E144 OR EQUIVALENT				2	NUT-.875-14UNF 3B (SEE NOTE)		STAINLESS STEEL		
	AN4C42				2	BLOT-.250-28 UNF-3A 4 9/32 LENGTH		CORROSION RESISTANT STEEL		
	AN121527				2	NUT-.250-28UNF3B		CORROSION RESISTANT STEEL		
3					2	PLATE — SPECIMEN CLAMP		AISI 431	RC 32-36	
2					2	CLAMP-"I" BEAM		TITANIUM B120VCA	180,000 Min. yield	
1					2	SPECIMEN-CHANNEL 10/1 WIRE SIZE		TITANIUM B120VCA	180,000 Min. yield	
ITEM	PART NO. ADD	ASSY	PART NO REFERENCE	PART NO CANC.	QTY	DESCRIPTION		MAT'L	OTHER SPECS	FORG CAST W.R.

SCALE FULL
JOB NUMBER 650032

ZAWONSKI 10-25-60
10-27-60

H.H 11-1-60

J.L. 11-1-60

ABF 11/3/60
ENGINEERING MGRS.

CURTISS

INTER-LOCKING TITANIUM
WIRE CASE —
CHANNEL & "I" BEAM JOINT RIG

LS 25810

1 OF 1 SHEETS

Figure 15

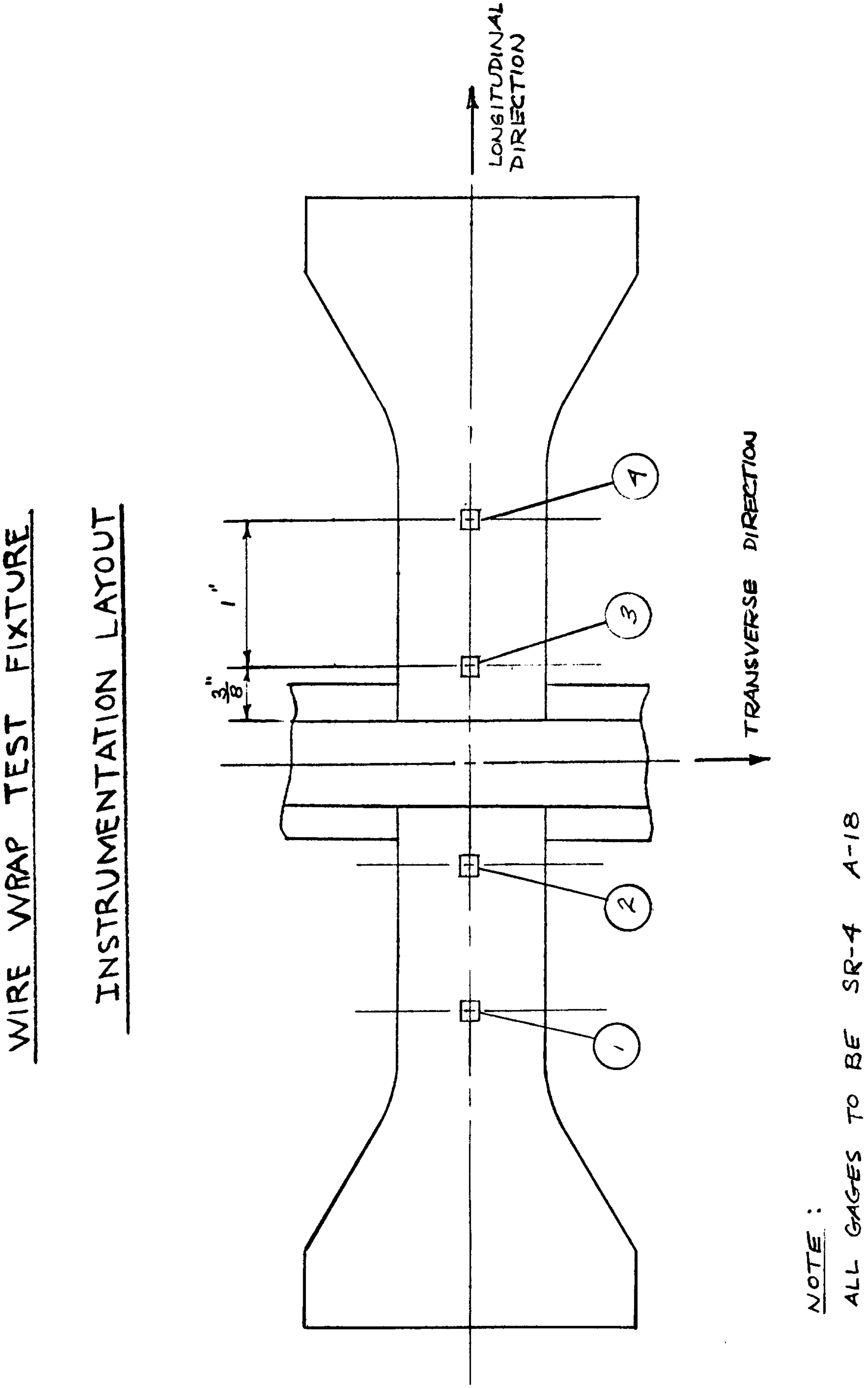
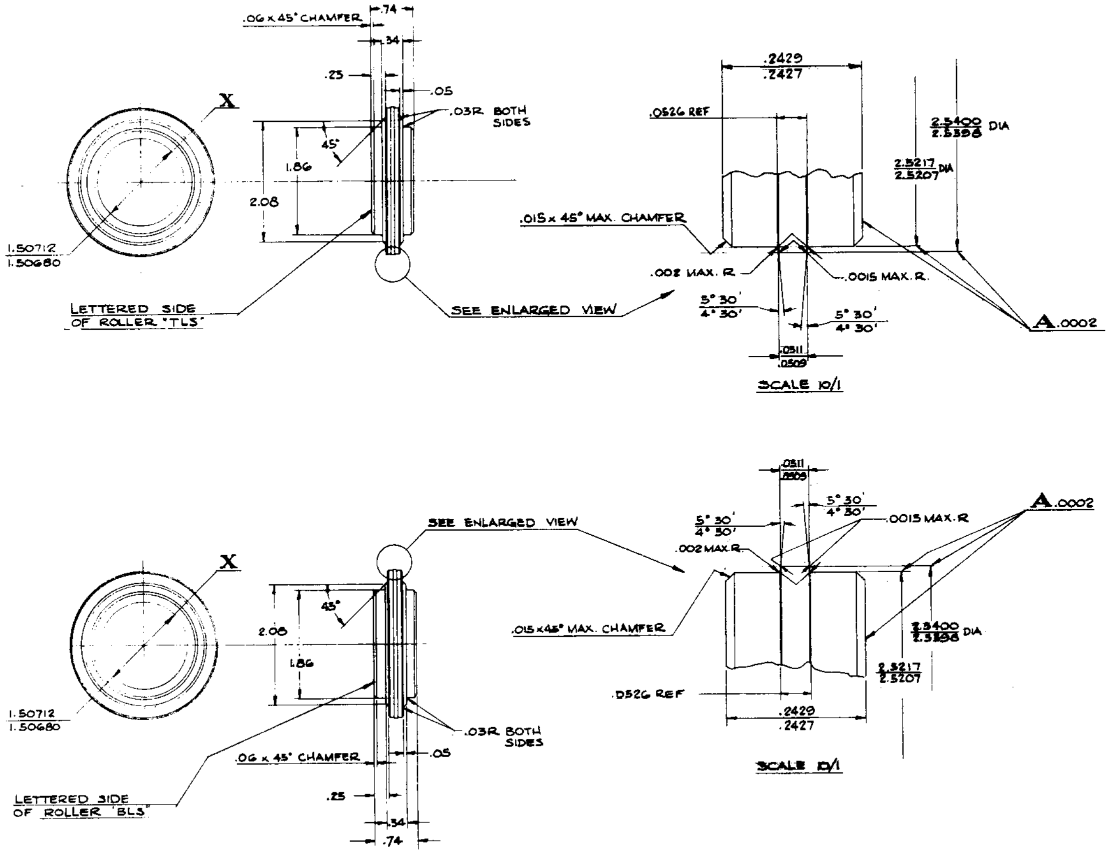
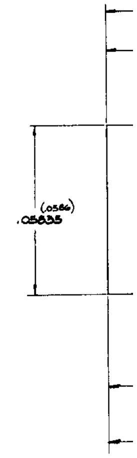

WIRE WRAP TEST FIXTURE
INSTRUMENTATION LAYOUT
LONGITUDINAL DIRECTION
TRANSVERSE DIRECTION
1"
3/8"
1
2
3
4
NOTE:
ALL GAGES TO BE SR-4 A-18

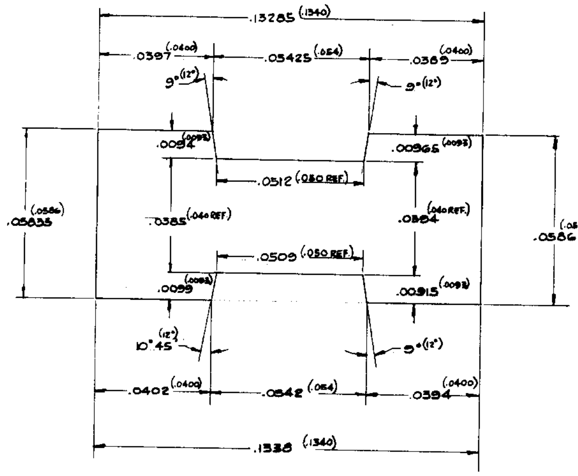
Figure 16


.06 x 45° CHAMFER
.74
.34
.25
.05
.03R BOTH SIDES
X
45°
1.86
2.08
1.50712
1.50680
LETTERED SIDE OF ROLLER "TLS"
SEE ENLARGED VIEW
.2429
.2427
.0526 REF
2.5400
2.5398 DIA
2.5217
2.5207 DIA
.015 x 45° MAX. CHAMFER
.002 MAX. R
.0015 MAX. R.
5° 30'
4° 30'
5° 30'
4° 30'
A .0002
.0511
.0509
SCALE 10/1
.0511
.0509
5° 30'
4° 30'
5° 30'
4° 30'
.0015 MAX. R
A .0002
SEE ENLARGED VIEW
.002 MAX R
X
.015 x 45° MAX. CHAMFER
2.5400
2.5398 DIA
2.5217
2.5207
45°
2.08
1.86
1.50712
1.50680
.0526 REF
.2429
.2427
.03R BOTH SIDES
.06 x 45° CHAMFER
.05
SCALE 10/1
LETTERED SIDE OF ROLLER "BLS"
.25
.34
.74


(.0586)
.05835

A.0002

A.0002



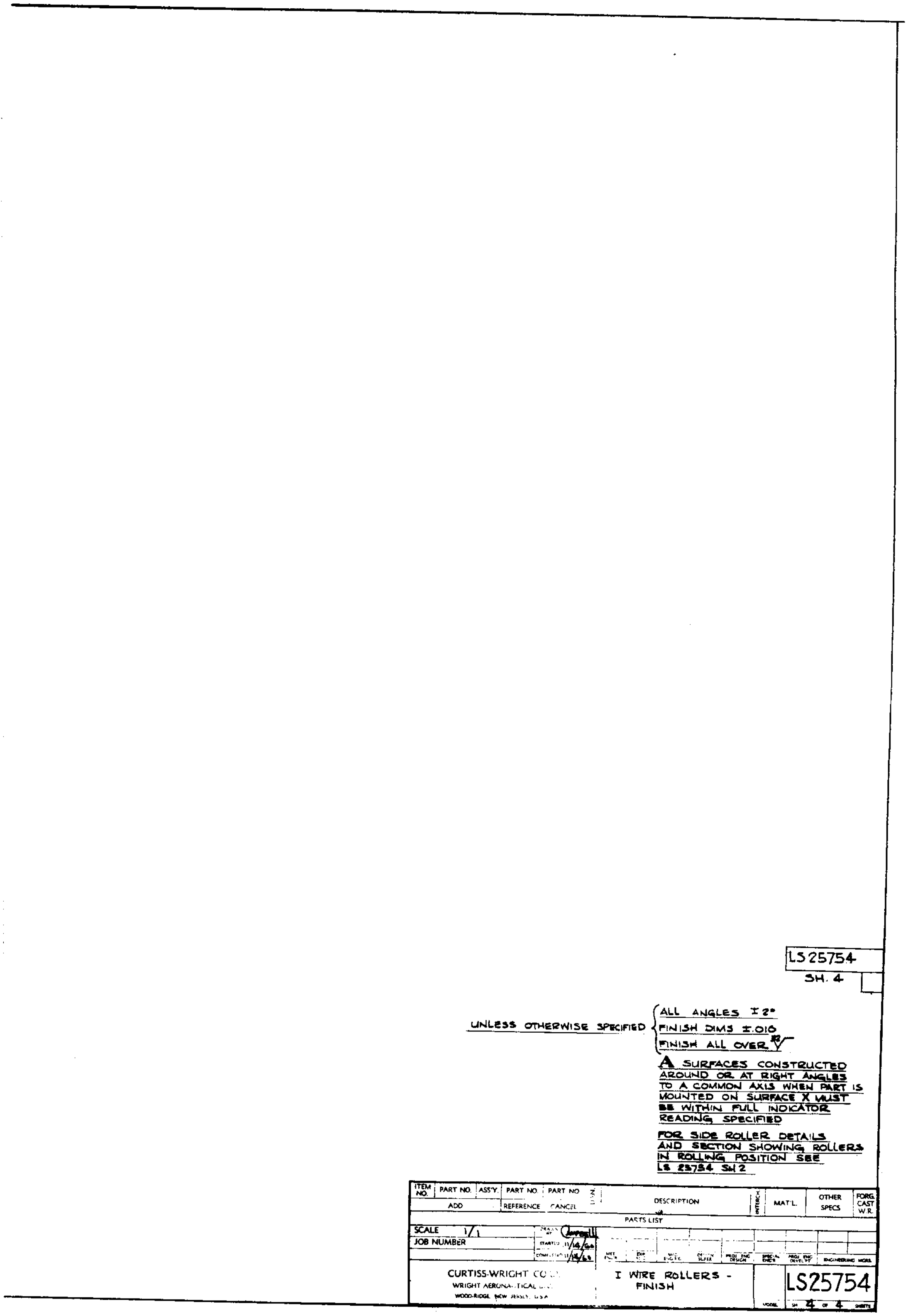
DIMENSIONS OF WIRE SAMPLE MADE
WITH ROLLERS SHOWN AT LEFT
(AVERAGE OF 2 SAMPLES)
DESIRED DIMENSIONS GIVEN IN PARENTHESES
SCALE 50/1

UNLESS OTHERWISE SPECIF

ITEM NO.	PART NO.	ASS'Y.	PART NO.	PART NO
	ADD		REFERENCE	CANCEL

SCALE 1/1
JOB NUMBER
DRAWN BY
STARTED 11/14/64
COMPLETED 11/18/64

CURTISS-WRIGHT CO
WRIGHT AERONAUTICAL D
WOOD-RIDGE, NEW JERSEY, U.S.A.



LS25754
SH. 4

UNLESS OTHERWISE SPECIFIED
- ALL ANGLES ± 2°
- FINISH DIMS ±.010
- FINISH ALL OVER 32√

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25754 SH 2

ITEM NO.	PART NO.	ASS'Y.	PART NO.	PART NO	UNIT	DESCRIPTION	INTERCH.	MAT'L.	OTHER SPECS	FORG. CAST W.R.
	ADD		REFERENCE	CANCEL						

PARTS LIST

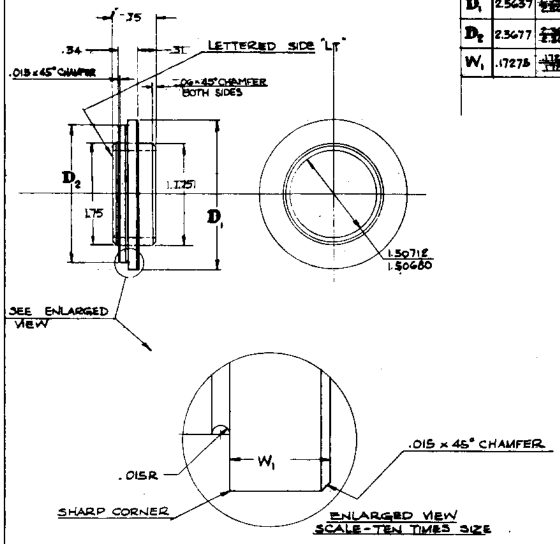
SCALE 1/1
JOB NUMBER
DRAWN BY
STARTED 11/14/64
COMPLETED 11/16/64

CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

I WIRE ROLLERS - FINISH

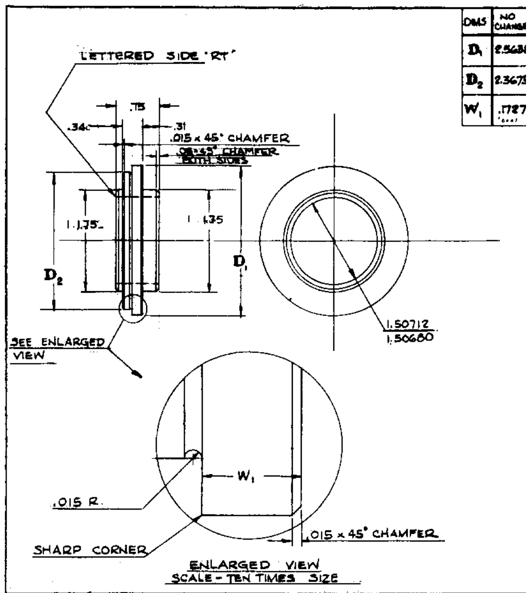
MODEL
LS25754
SH 4 OF 4 SHEETS

Figure 21

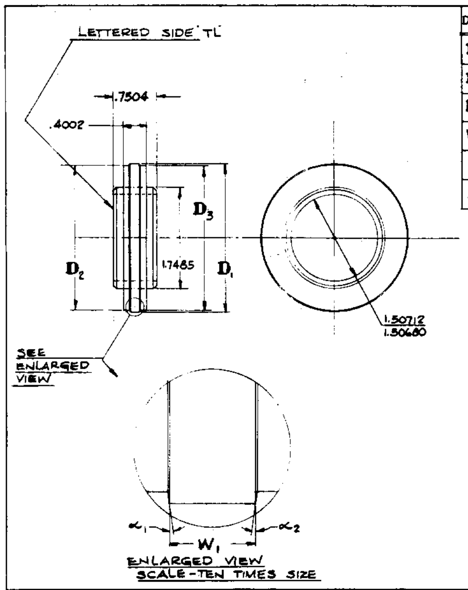


DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5637	2.5639 2.5637	
D_2	2.3677	2.3676 2.3672	
W_1	.17275	.1728 .1726	

CHANNEL FORM ROLLER * XIII



DMS	NO CHANGE
D_1	2.563
D_2	2.367
W_1	.1727



DMS.	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5607 2.5606		
D_2	2.5191		
D_3	2.5191		
W_1	.1462		
α_1	7°30'		
α_2	7°30'		

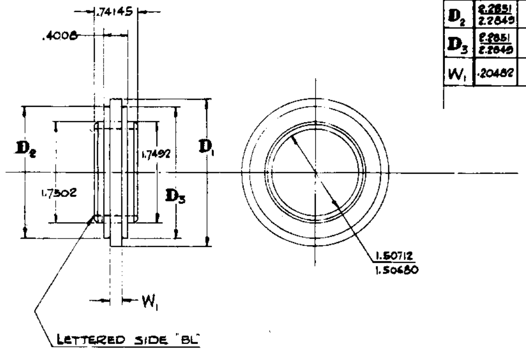
CHANNEL FORM ROLLER * V

LETTER

LETTERED SIDE 'LT'

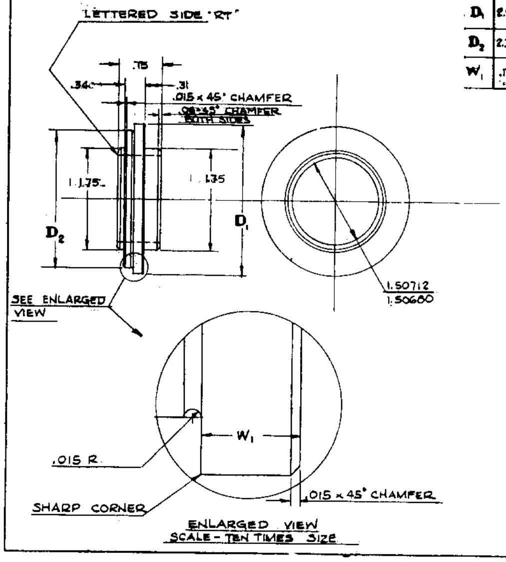
ROLLER *

DMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.56145		
D_2	2.2851 2.2849		
D_3	2.2851 2.2849		
W_1	.20482		



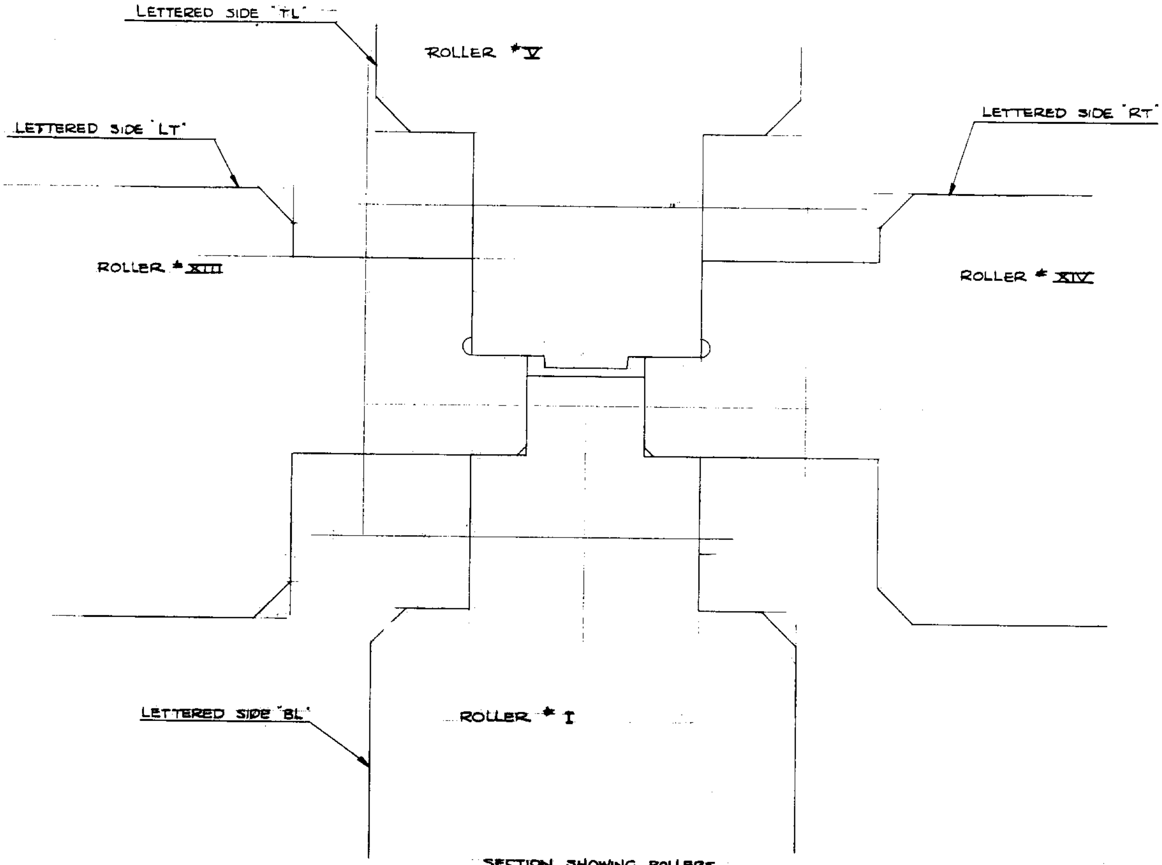
LETT

CHANNEL FORM ROLLER * I

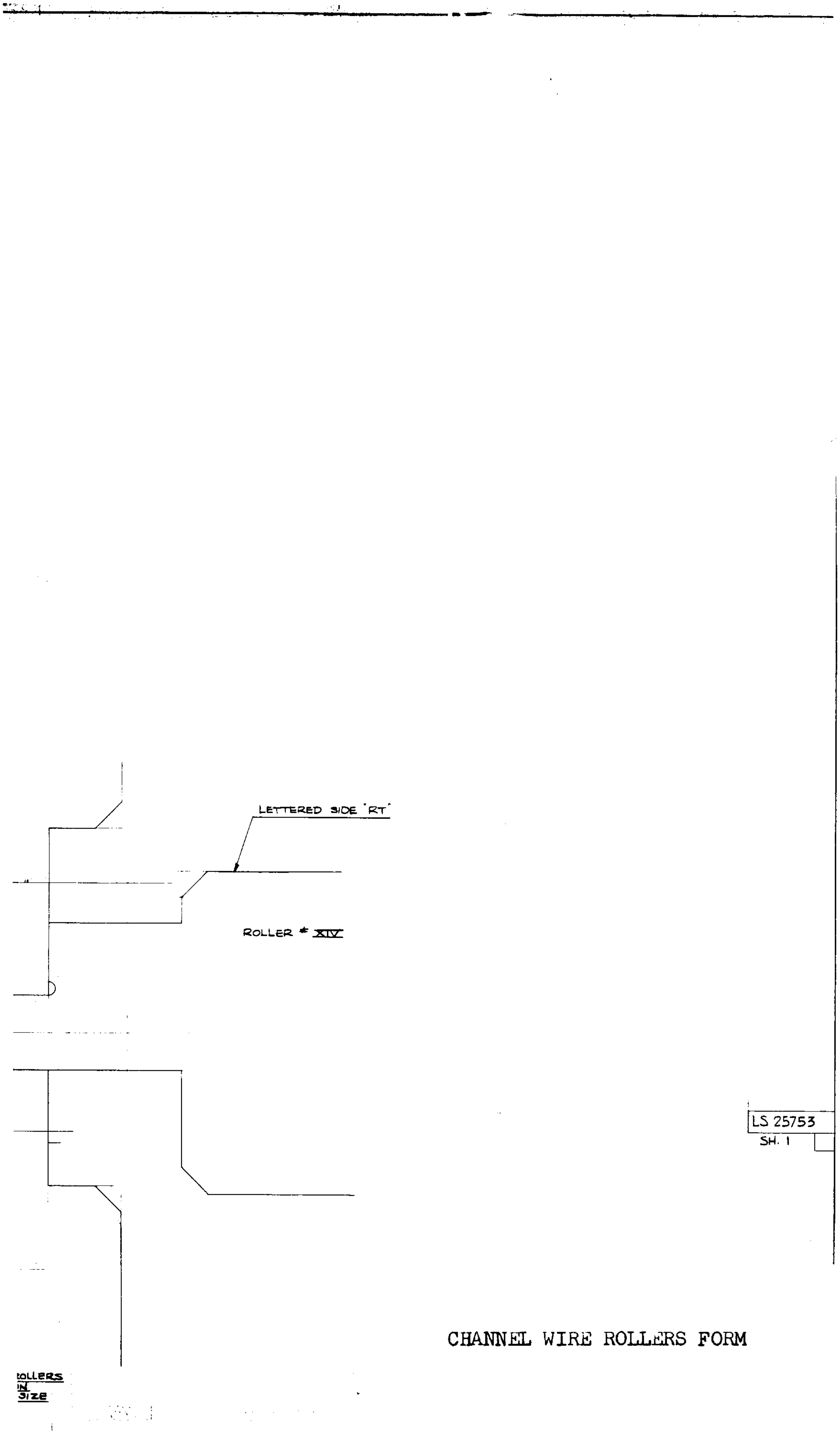


DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5638	2.5639 2.5637	
D_2	2.3675	2.3675 2.3674	
W_1	.1727	.1728 .1726	

CHANNEL FORM ROLLER #XIV



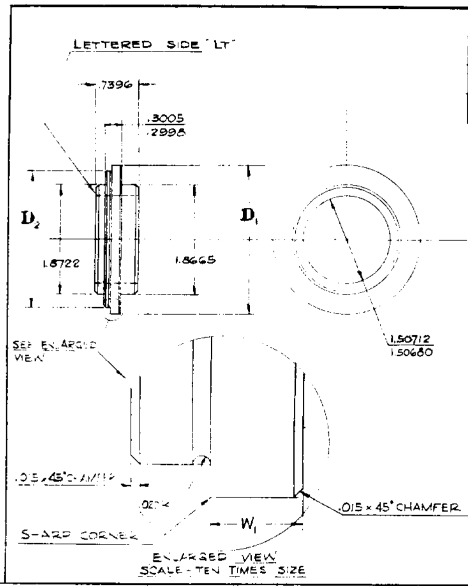
SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE



CHANNEL WIRE ROLLERS FORM

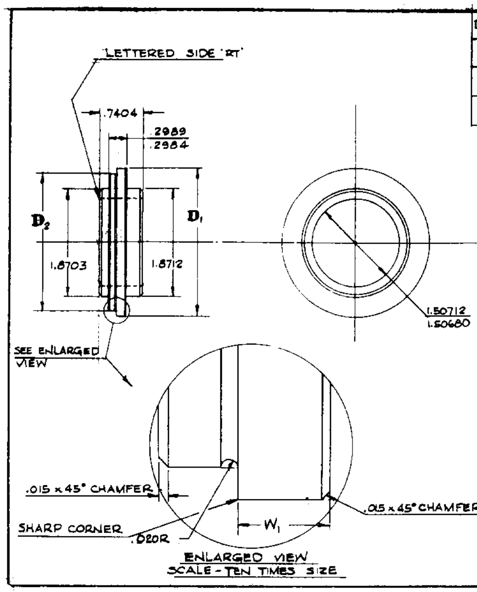
Figure 22

DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5592		
D_2	2.3568		
W_1	.1598		



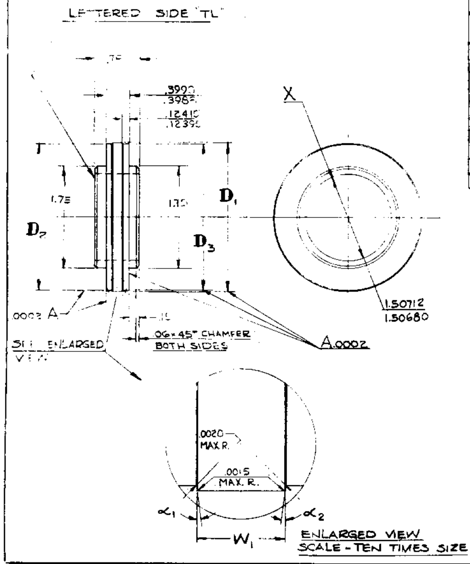
CHANNEL FINISH ROLLER # XVI

DIMS.	NO CHANGE	CH
D_1	2.5568	
D_2	2.3552	
W_1	.1600	



J.L. 10-5-60

DIMS	NO CHANGE	CHANGE	CHANGE
D_1	$\frac{2.5573}{2.5571}$		
D_2	2.5392		
D_3	2.5392		
W_1	.1493		
α_1	7°30'		
α_2	7°30'		



A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

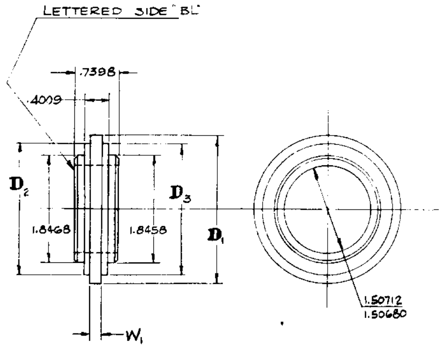
ALL NOTES APPLY UNLESS OTHERWISE SPECIFIED

FINISHED DIM ±.010
ALL ANGLES ± 2°
FINISH ALL OVER 32

LS 25753-4

CHANNEL FINISH ROLLER # IV

DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	$\frac{2.5477}{2.5476}$		
D_2	2.27772		
D_3	2.27772		
W_1	.19995		



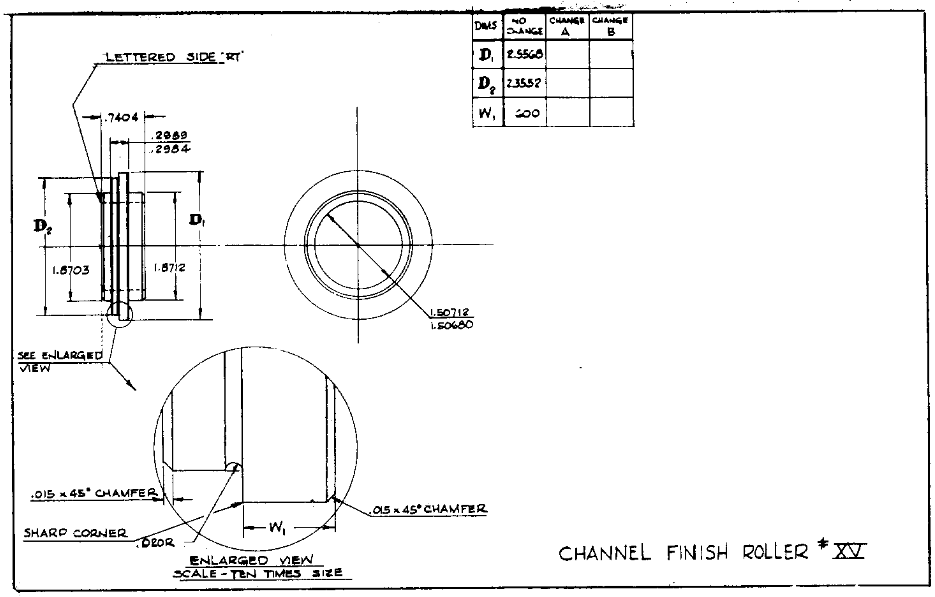
CHANNEL FINISH ROLLER # II

LETTERED SI

LETTERED SIDE "LT"

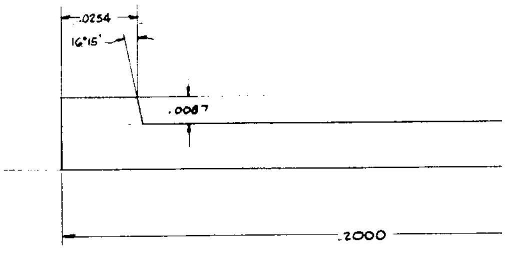
ROLLER #

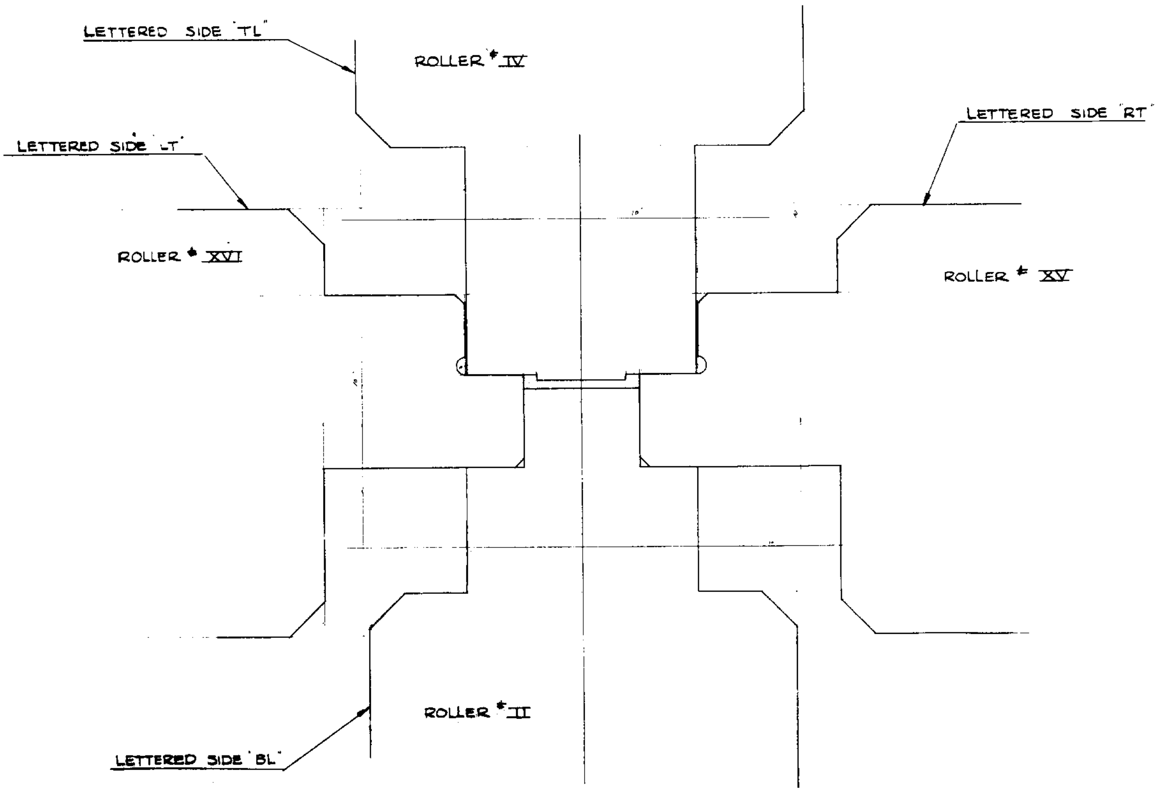
LETTERED S



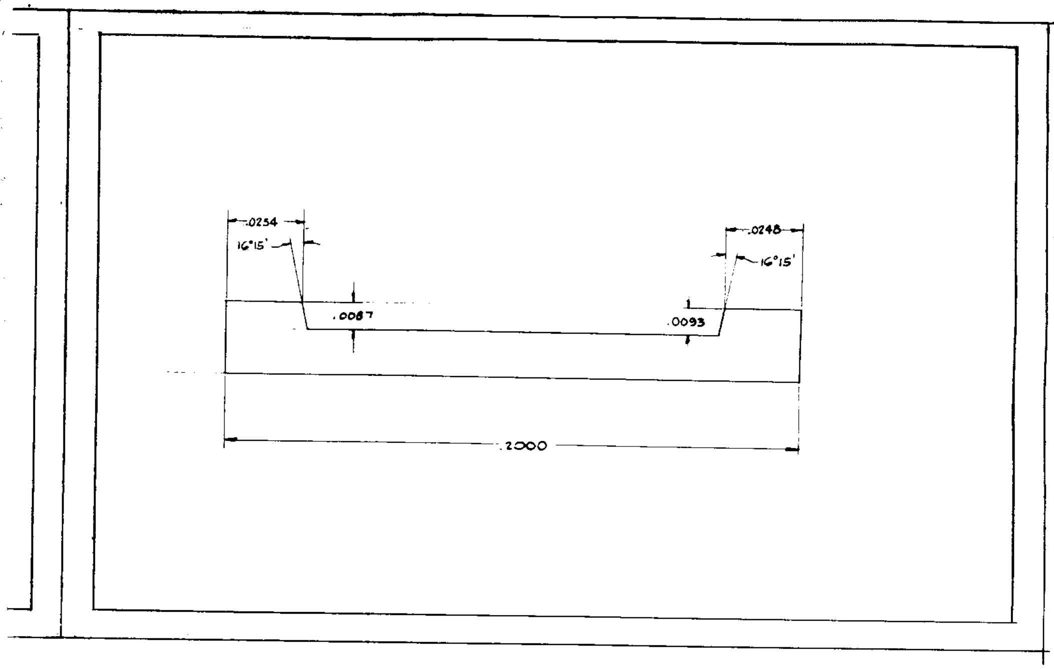
DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5568		
D_2	2.3552		
W_1	200		

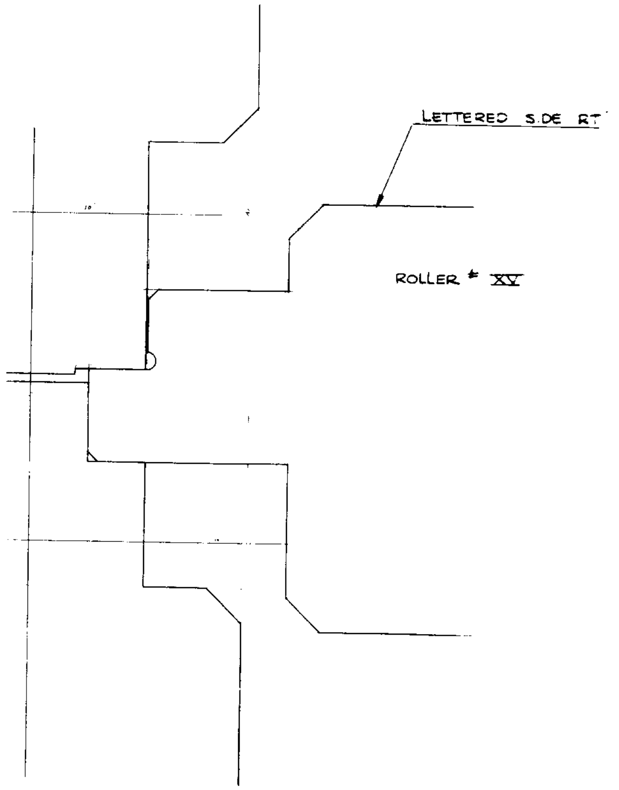
CHANNEL FINISH ROLLER # XV





SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE





LS 25753
SH. 2

OWING ROLLERS
POSITION
TIMES SIZE

ITEM NO.	PART NO.	ASS'Y. PART NO.	PAR	DESCRIPTION		MAT'L.	OTHER SPECS	FORG CAST W.R.
ADD		REFERENCE	CANC'L					

PARTS LIST

SCALE
JOB NUMBER
DRAWN BY Campbell
STARTED 9/14/60
COMPLETED 9/14/60
MET. ENGR
ENG. MFG.
MFG. ENG'R'G.
DESIGN SUPER.
PROJ. ENG DESIGN J. L. 10-5-60
SPECIAL ENGR
PROJ. ENG. DEVELOPT.
ENGINEERING MGRS. 10/5/60

CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

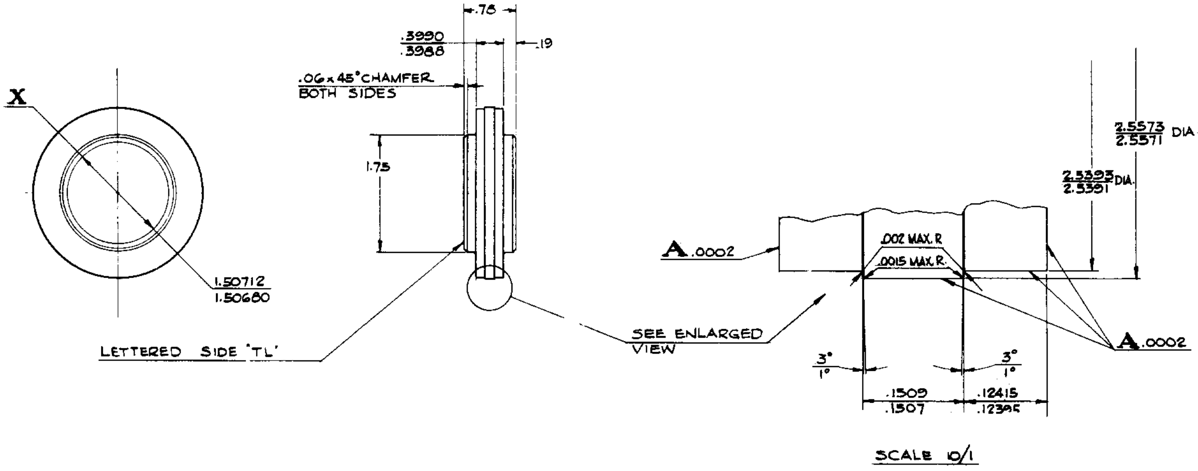
CHANNEL WIRE ROLLERS
(FINISH)

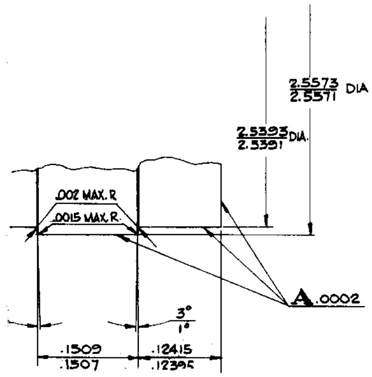
WIRE WRAPPED
TEST RIG
MODEL

LS 25753

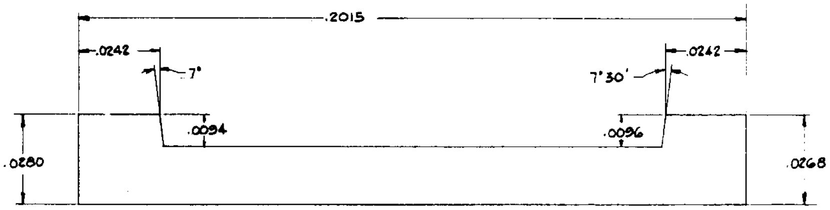
SH. 2 OF 2 SHEETS

Figure 23


X
1.50712
1.50680
.78
.3990
.3988
.19
.06 x 45° CHAMFER
BOTH SIDES
1.75
LETTERED SIDE 'TL'
SEE ENLARGED
VIEW
A .0002
.002 MAX. R
.0015 MAX. R.
2.5573
2.5571 DIA.
2.5393
2.5391 DIA.
A .0002
3°
1°
3°
1°
.1509
.1507
.12415
.12395
SCALE 10/1



SCALE 10/1



UNLESS OTHERWISE SPECIFIED
ALL ANGL
FINISH D
FINISH A

A SURFA
AROUND C
TO A COM
MOUNTED
BE WITHIN
READING

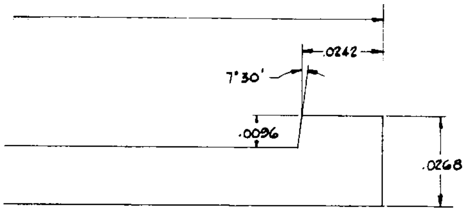
FOR SIDE
DETAILS A
ROLLERS
SEE LS 2

MILITARY SPECIFICATIONS
SPEC NUMBERS
DEVIATIONS

CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

CHANNEL WI
FINIS

Fi



LS 25753
SH. 3

UNLESS OTHERWISE SPECIFIED
- ALL ANGLES ±2°
- FINISH DIMS ±.010
- FINISH ALL OVER $\sqrt{32}$

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25753 SH 2.

MILITARY SPECIFICATIONS
SPEC NUMBERS
DEVIATIONS
Campbell
DRAWN BY
11/14/60
CHECKER
DESIGN SUPER
PROJ. ENG. DESIGN
PROJ. ENG. DEVEL'PT
PROJ. ENG. RESEARCH
STARTED
4/15/60
COMPL'TD
ENGINEERING
ASST. CHIEF ENGINEER
CHIEF ENGINEER

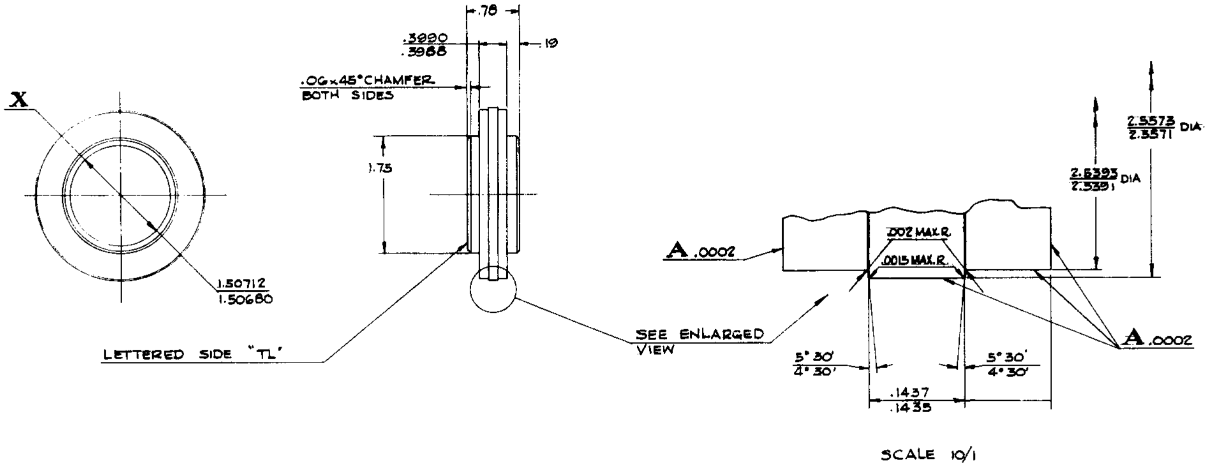
CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.

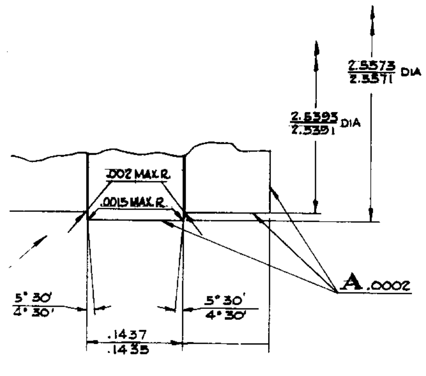
CHANNEL WIRE ROLLERS-FINISH

MODEL

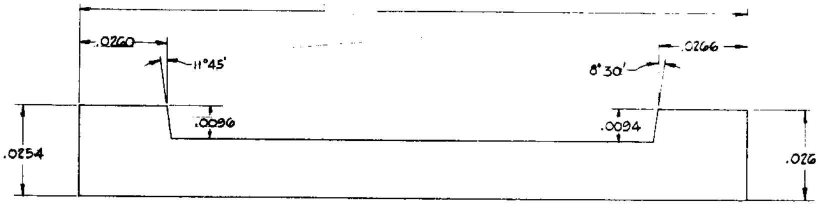
LS25753
SH 3 OF 4 SHEETS

Figure 24


X
1.50712
1.50680
.78
.3990
.3988
.19
.06×45° CHAMFER
BOTH SIDES
1.75
LETTERED SIDE "TL"
SEE ENLARGED VIEW
A .0002
.002 MAX.R.
.0015 MAX.R.
2.5573
2.5571 DIA
2.5393
2.5391 DIA
A .0002
5° 30'
4° 30'
5° 30'
4° 30'
.1437
.1435
SCALE 10/1



SCALE 10/1



UNLESS OTHERWISE SPECIFIED ALL
FINIS
FINIS

A
AROU
TO A
MOUN
BE W
READ

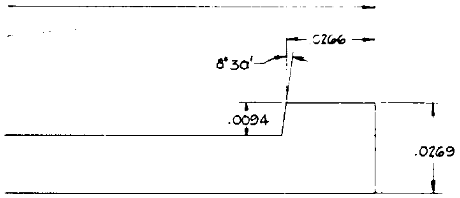
FOR
DETAI
ROLLE
SEE

MILITARY SPECIFICATIONS
DEVIATIONS

CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.

CHAN

Figur
35



LS 25753
SH. 4

UNLESS OTHERWISE SPECIFIED
ALL ANGLES ± 2°
FINISH DIMS ± .010
FINISH ALL OVER $\sqrt{}^{32}$

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25753 SH. 2

MILITARY SPECIFICATIONS							
SPEC NUMBERS	DEVIATIONS	Chappell DRAWN BY 11/17/60	CHECKER	DESIGN SUPER	PROJ. ENG. DESIGN	PROJ. ENG. DEVEL'P'T	PROJ. ENG. RESEARCH
		STARTED 11/17/60 COMPL'T'D	ENGINEERING MGRS.		M. MECH.	ASST. CHIEF ENGINEER	CHIEF ENGINEER

CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.

CHANNEL WIRE ROLLERS-
FINISH

MODEL

LS25753
SH 4 OF 4 SHEETS

Figure 25

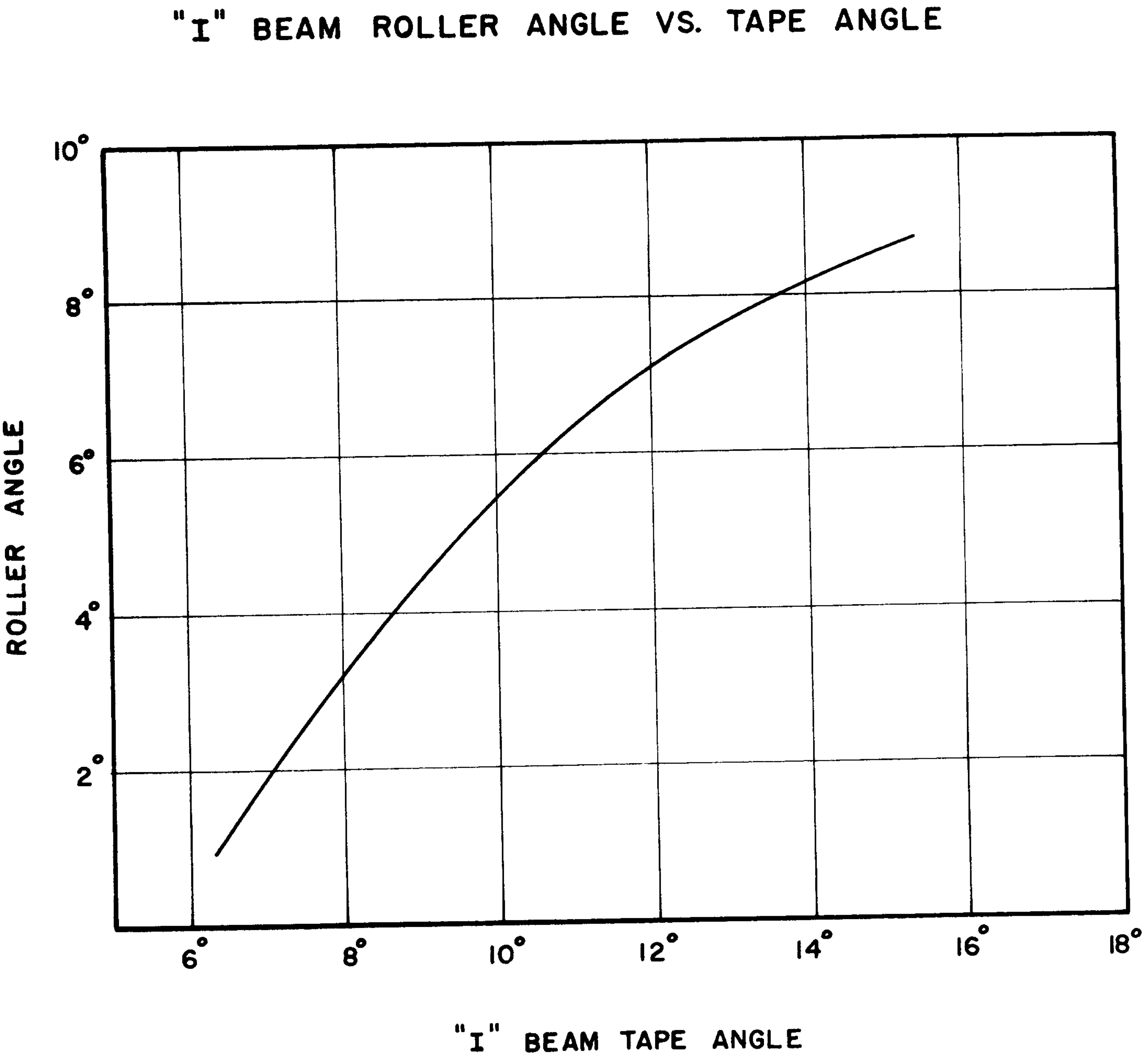
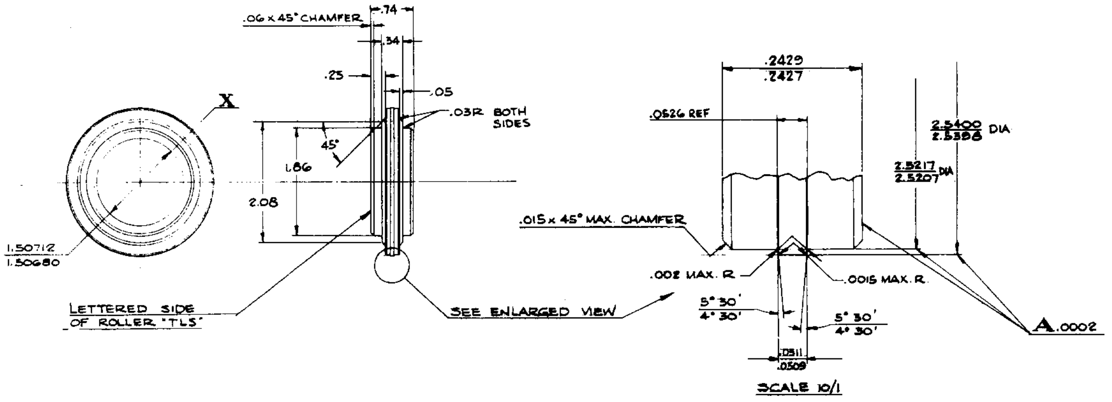
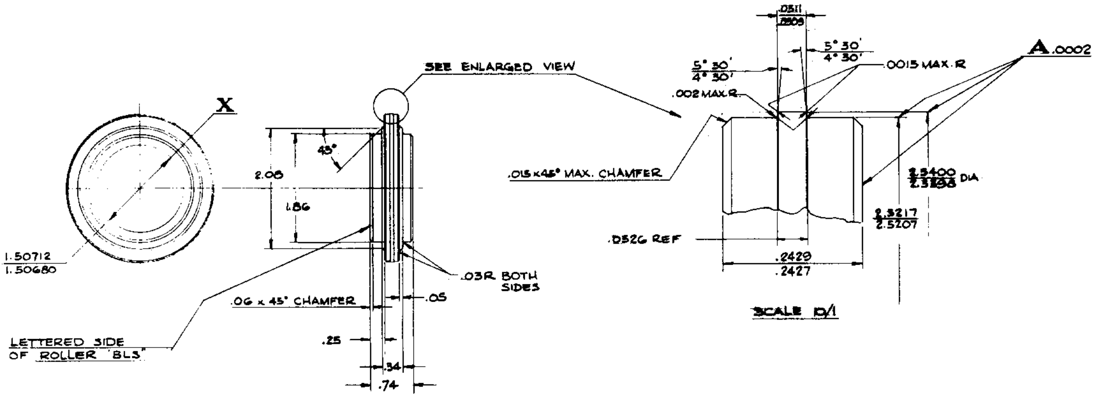

"I" BEAM ROLLER ANGLE VS. TAPE ANGLE
ROLLER ANGLE
10°
8°
6°
4°
2°
6°
8°
10°
12°
14°
16°
18°
"I" BEAM TAPE ANGLE

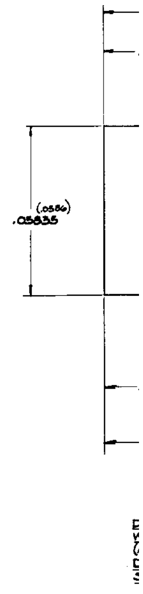
Figure 20



.06 x 45° CHAMFER
.74
.34
.25
.05
.03R BOTH SIDES
X
45°
1.86
2.08
1.50712
1.50680
LETTERED SIDE OF ROLLER "TLS"
SEE ENLARGED VIEW
.2429
.2427
.0526 REF
2.5400
2.5398 DIA
2.5217
2.5207 DIA
.015 x 45° MAX. CHAMFER
.002 MAX. R
.0015 MAX. R
5° 30'
4° 30'
5° 30'
4° 30'
A .0002
.0311
.0309
SCALE 10/1



.0311
.0309
5° 30'
4° 30'
5° 30'
4° 30'
A .0002
.0015 MAX. R
.002 MAX R
SEE ENLARGED VIEW
X
45°
2.08
1.86
.015 x 45° MAX. CHAMFER
2.5400
2.5398 DIA
2.5217
2.5207
.0526 REF
.2429
.2427
1.50712
1.50680
.03R BOTH SIDES
.06 x 45° CHAMFER
.05
LETTERED SIDE OF ROLLER "BLS"
.25
.34
.74
SCALE 10/1

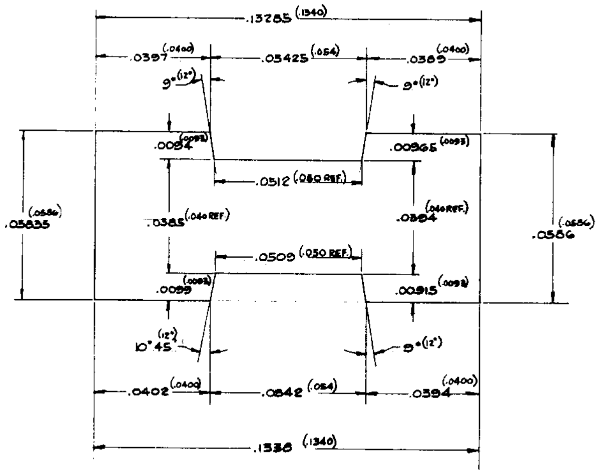


(.0584)
.05835

A

A.0002

A.0002



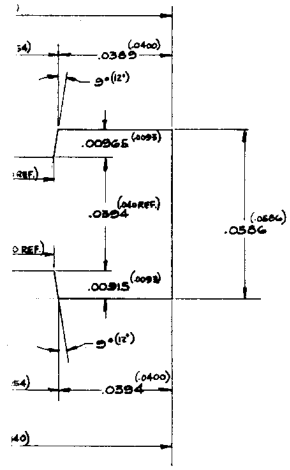
DIMENSIONS OF WIRE SAMPLE MADE
WITH ROLLERS SHOWN AT LEFT
(AVERAGE OF 2 SAMPLES)
DESIRED DIMENSIONS GIVEN IN PARENTHESES
SCALE 50/1

UNLESS OTHERWISE SPECIFI

ITEM NO.	PART NO.	ASS'Y.	PART NO.	PART NO
	ADD		REFERENCE	CANCEL

SCALE 1/1
JOB NUMBER
DRAWN BY
STARTED 11/14/60
COMPLETED 11/18/60
MET. ENG'R

CURTISS-WRIGHT CO
WRIGHT AERONAUTICAL
WOOD-RIDGE, NEW JERSEY, U.S.A.



PLE MADE
AT LEFT

N IN PARENTHESES

LS25754
SH. 4

UNLESS OTHERWISE SPECIFIED
ALL ANGLES ± 2°
FINISH DIMS ±.010
FINISH ALL OVER 32√

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25754 SH 2

ITEM NO.	PART NO. ADD	ASS'Y.	PART NO REFERENCE	PART NO CANCEL	U.S.N.	DESCRIPTION	INTERCH	MAT'L.	OTHER SPECS	FORG. CAST W.R.

PARTS LIST

SCALE 1/1
JOB NUMBER
DRAWN BY Campbell
STARTED 11/14/63
COMPLETED 11/18/63
MET FINISH · EXP MFG · MFG ENG'G · DESIGN SUPER · PROJ ENG DESIGN · SPECIAL ENG'R · PROJ ENG DEVEL'PT · ENGINEERING MGR.

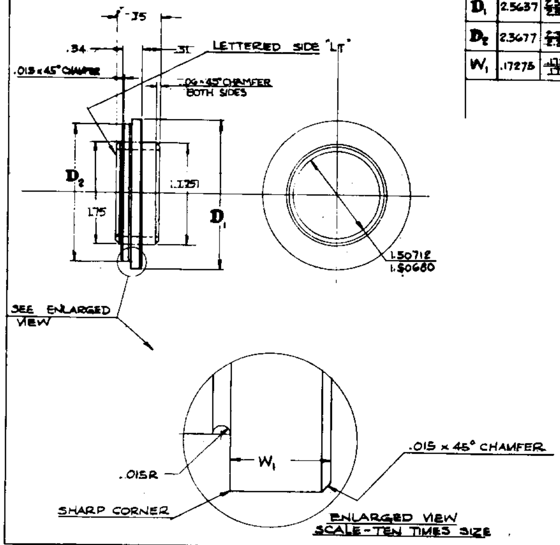
CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

I WIRE ROLLERS - FINISH

MODEL

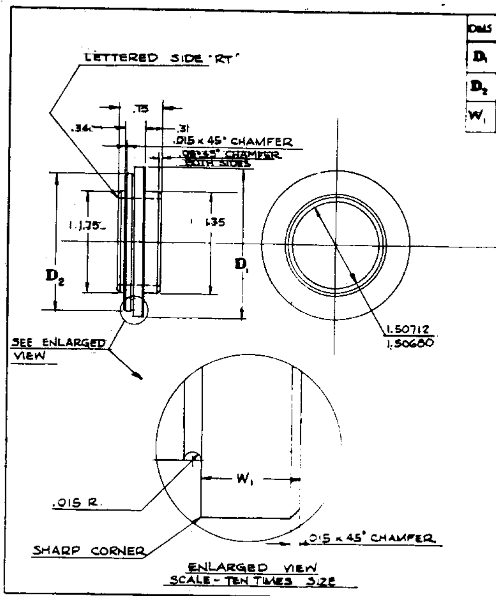
LS25754
SH 4 OF 4 SHEETS

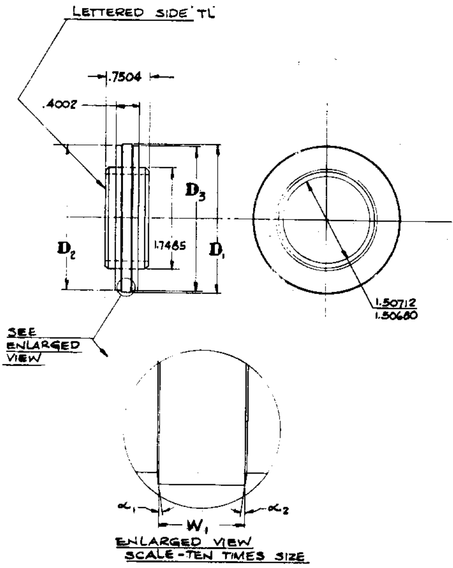
Figure 21



DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5637	2.5639 2.5637	
D_2	2.3677	2.3676 2.3672	
W_1	.17275	.1728 .1726	

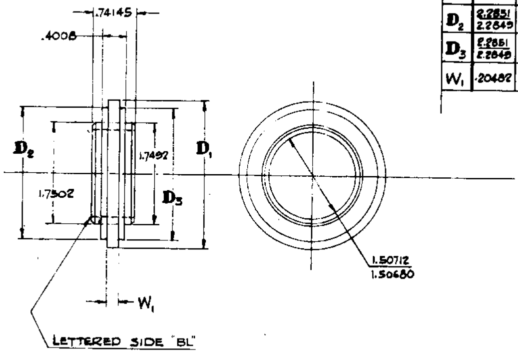
CHANNEL FORM ROLLER * XIII





DIMS.	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5607 2.5606		
D_2	2.5191		
D_3	2.5191		
W_1	.1462		
α_1	7°80'		
α_2	7°30'		

CHANNEL FORM ROLLER * V

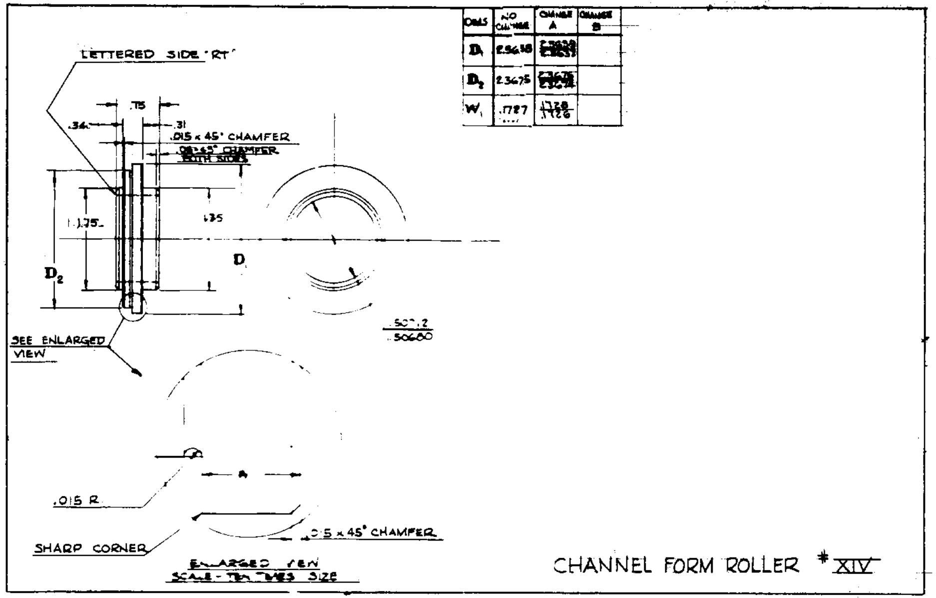


DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.56145		
D_2	2.2851 2.2849		
D_3	2.2851 2.2849		
W_1	.20482		

CHANNEL FORM ROLLER * I

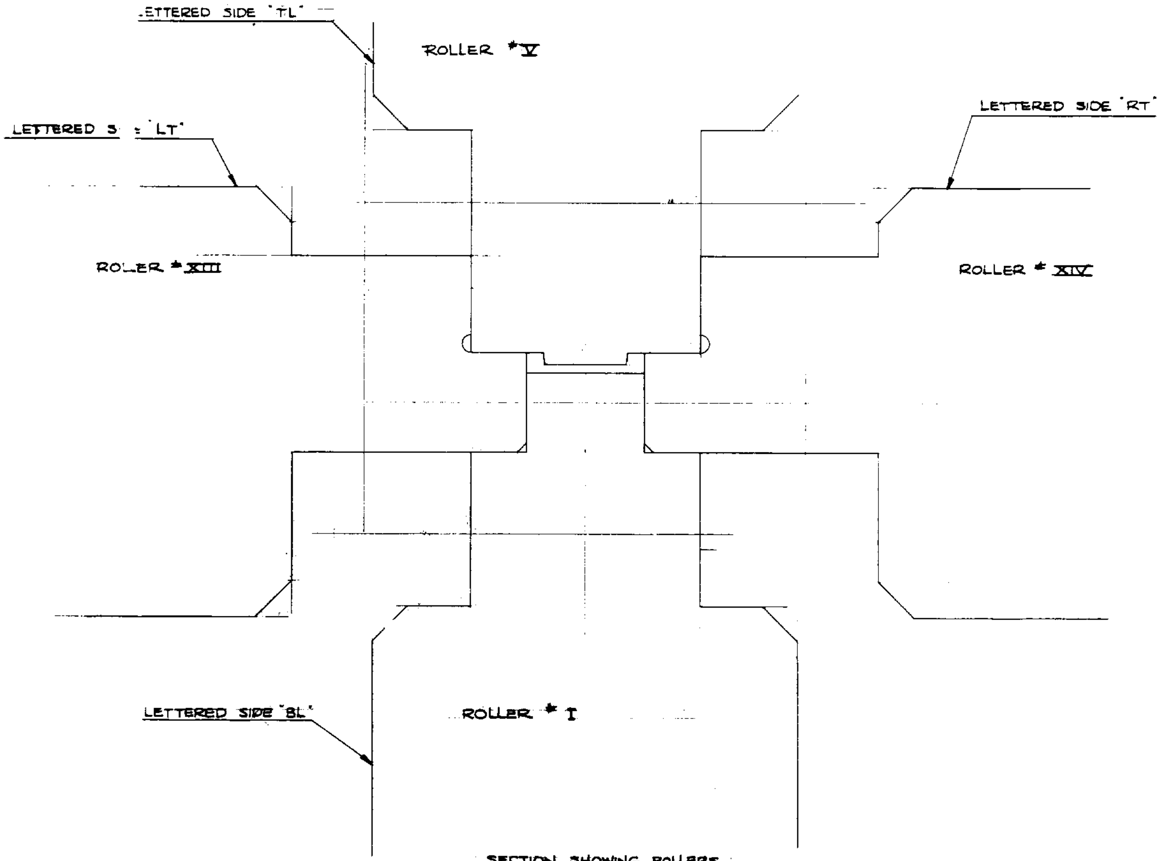
LETTERED S

ROLLER

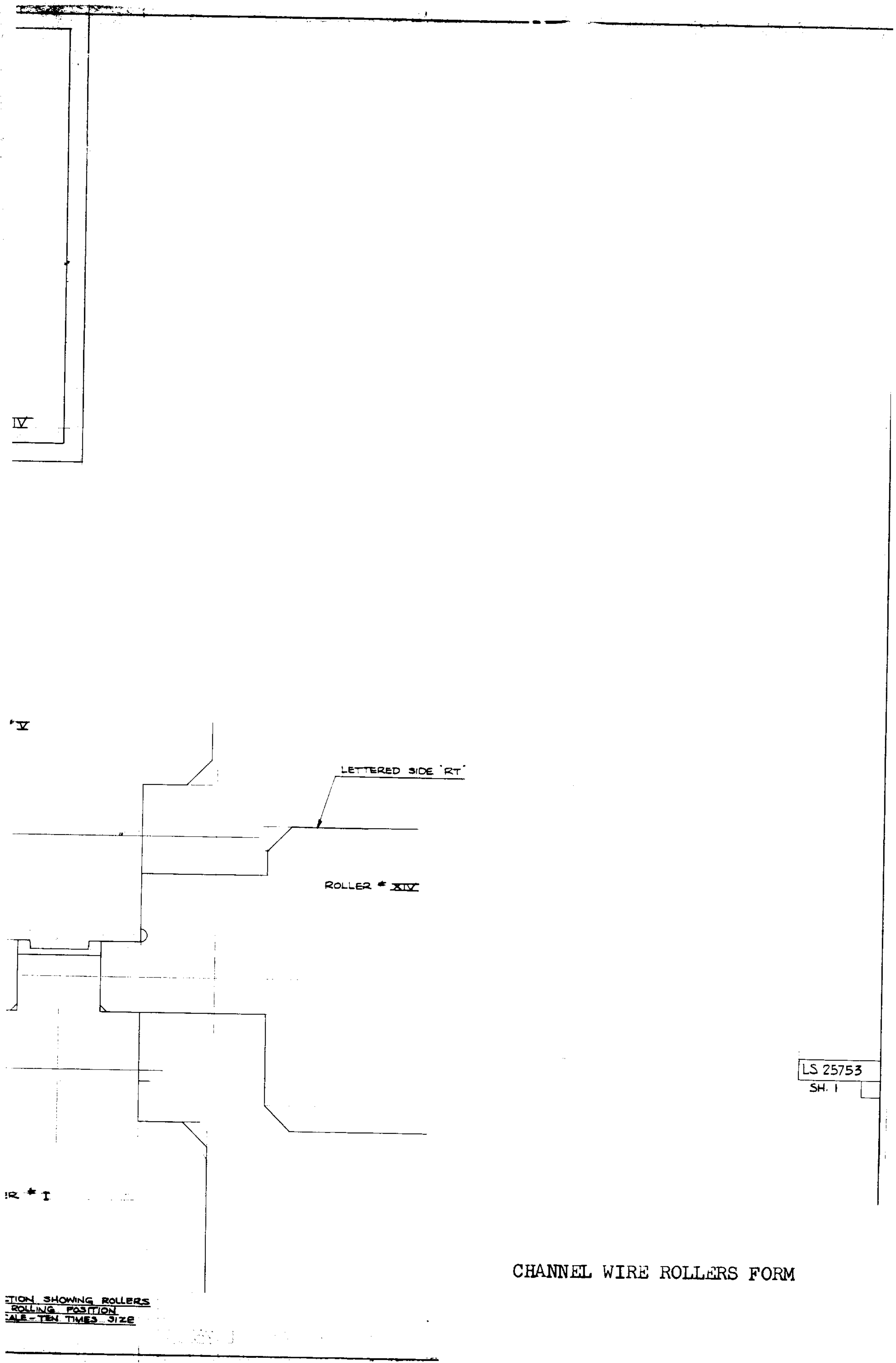


DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5638	2.5638 2.5633	
D_2	2.3675	2.3675 2.3670	
W_1	.1727	.1728 .1726	

CHANNEL FORM ROLLER # XIV



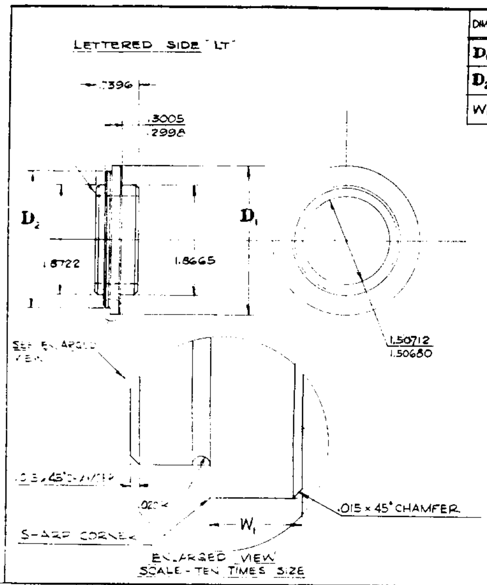
SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE



CHANNEL WIRE ROLLERS FORM

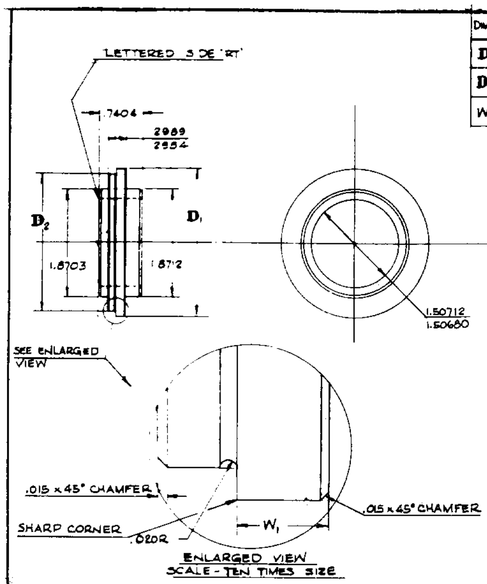
Figure 22

DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5592		
D_2	2.3568		
W_1	.1598		



CHANNEL FINISH ROLLER # XVI

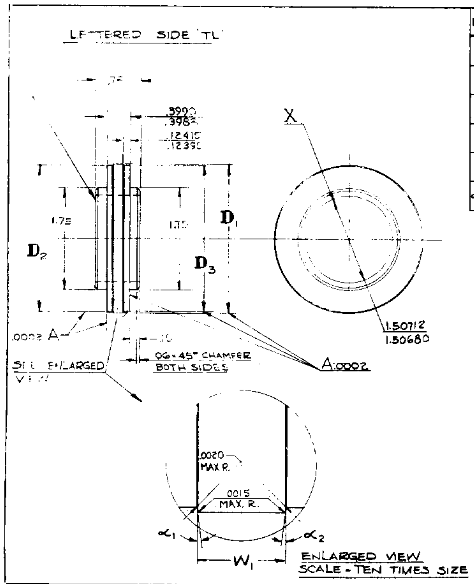
DMS	NO CHANGE	CHA A
D_1	2.5568	
D_2	2.3532	
W_1	.1600	



C

J.L. 10-5-60

DIMS	NO CHANGE	CHANGE	CHANGE
D_1	2.5573 2.5571		
D_2	2.5392		
D_3	2.5392		
W_1	.1493		
α_1	7°30'		
α_2	7°30'		



A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

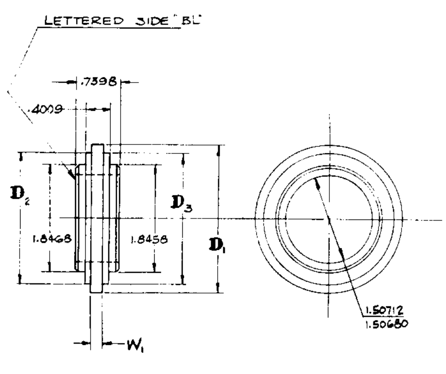
ALL NOTES APPLY UNLESS OTHERWISE SPECIFIED

FINISHED DIM ±.010.
ALL ANGLES ± 2°
FINISH ALL OVER $\overset{32}{\bigtriangledown}$

LS 25753-4

CHANNEL FINISH ROLLER # IV

DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5477 2.5476		
D_2	2.27772		
D_3	2.27772		
W_1	.19995		



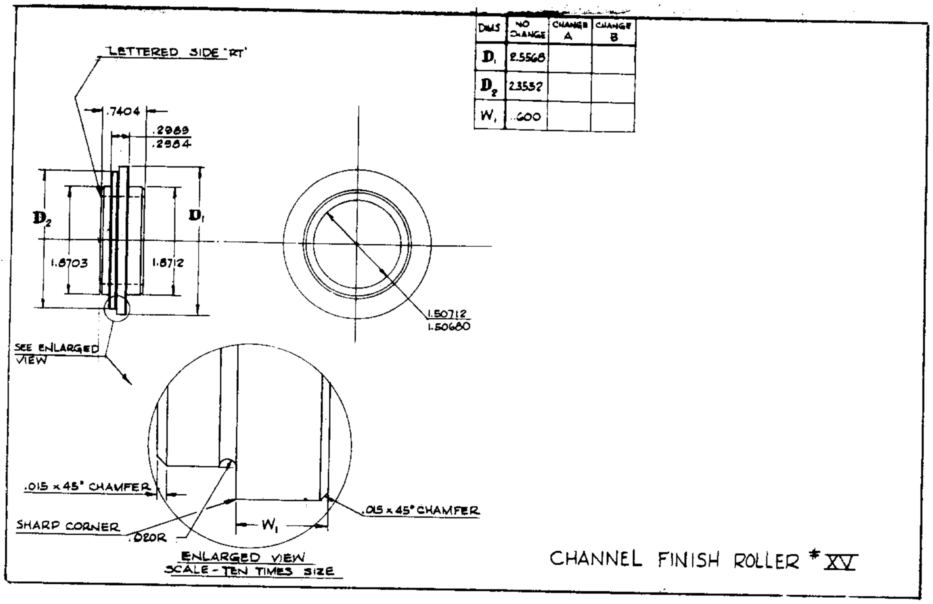
CHANNEL FINISH ROLLER # II

LETTERED SIDE

LETTERED SIDE 'LT'

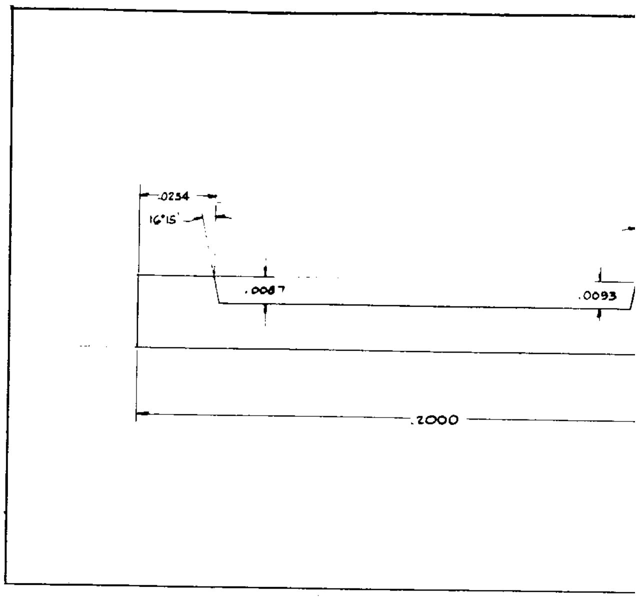
ROLLER # X

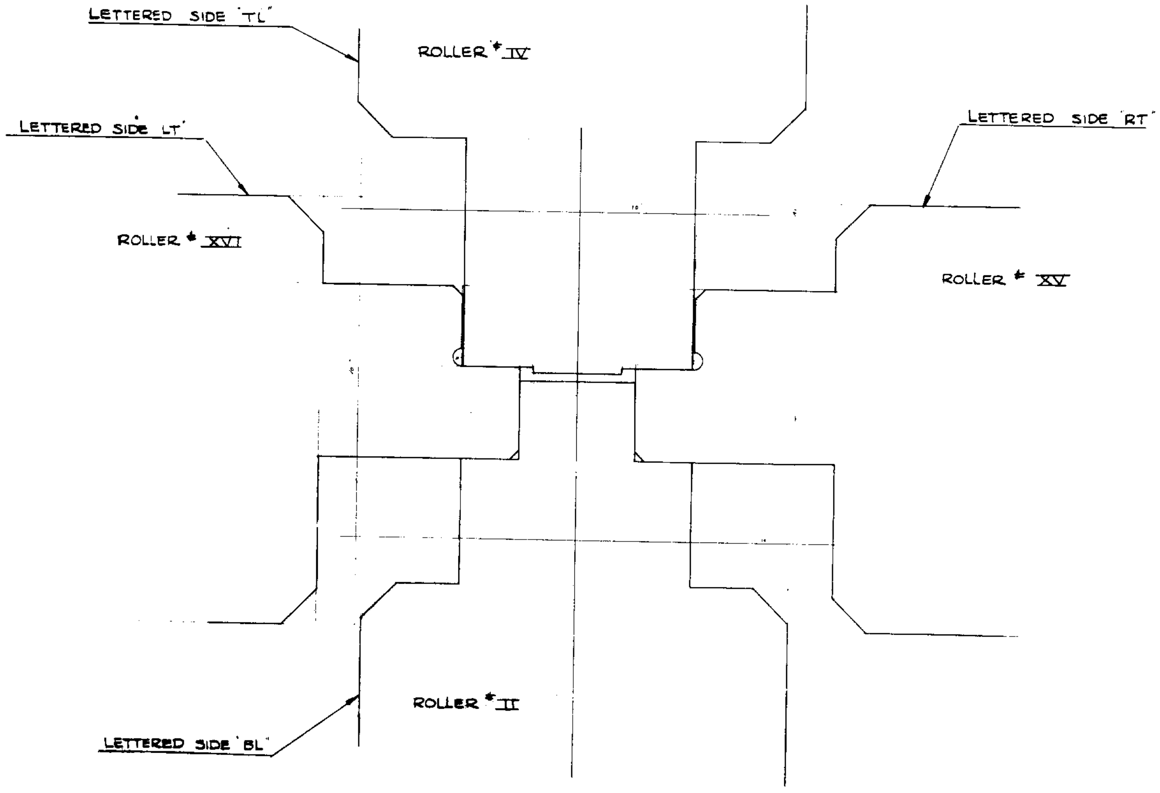
LETTERED SI



DIMS	NO CHANGE	CHANGE A	CHANGE B
D_1	2.5568		
D_2	2.3532		
W_1	.600		

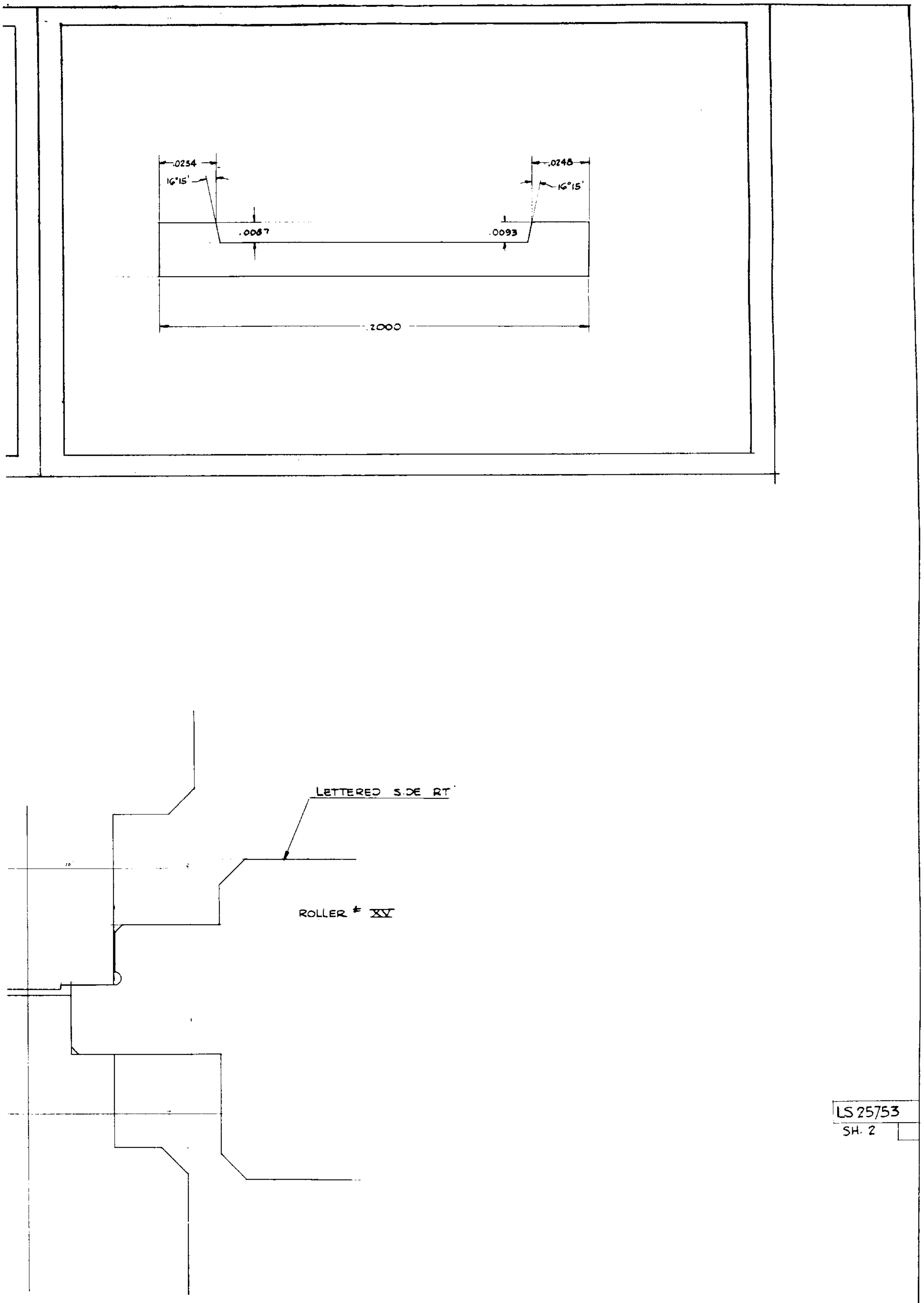
CHANNEL FINISH ROLLER # XV





SECTION SHOWING ROLLERS
IN ROLLING POSITION
SCALE - TEN TIMES SIZE

ITEM NO. | PART NO
ADD
SCALE
JOB NUMBER
CURT
WRIG
WOOD



SHOWING ROLLERS
POSITION
N TIMES SIZE

ITEM NO.	PART NO.	ASS'Y.	PART NO	PAR	DESCRIPTION	INTER.	MAT'L.	OTHER SPECS	FORG CAST W.R.
ADD			REFERENCE	CANCEL					

PARTS LIST

SCALE
JOB NUMBER
DRAWN BY
STARTED 9/16/60
COMPLETED 9/19/60
MET. ENG'R.
EXP. MFG.
MFG. ENG R'G.
DESIGN SUPER.
PROJ. ENG DESIGN 10-5-60
SPECIAL ENG'R.
PROJ. ENG. DEVELOPT.
ENGINEERING MGR. 10/5/60

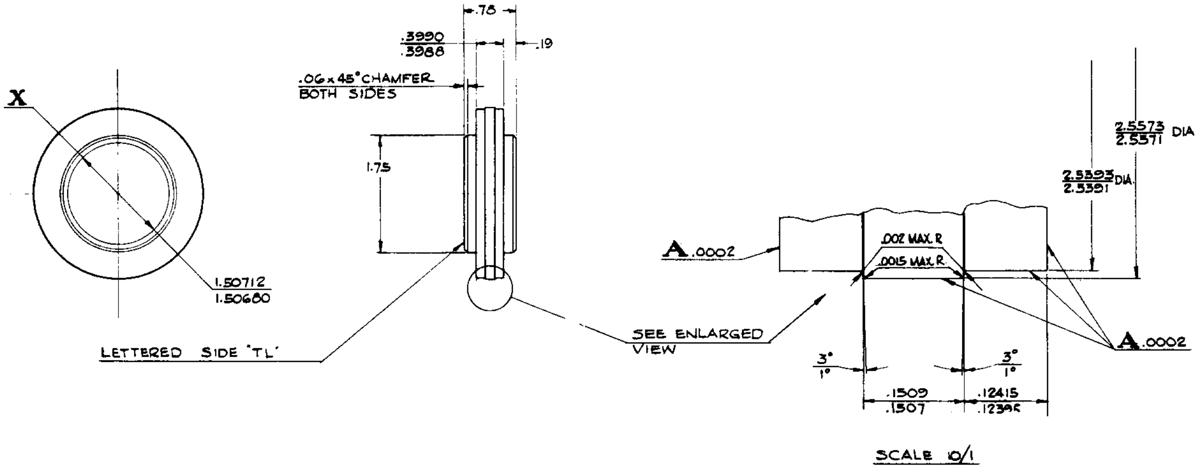
CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U.S.A.

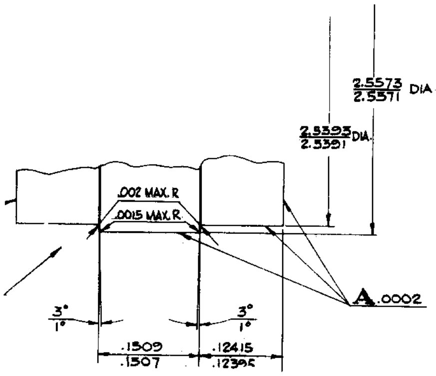
CHANNEL WIRE ROLLERS
(FINISH)

WIRE WRAPPED TEST RIG
MODEL

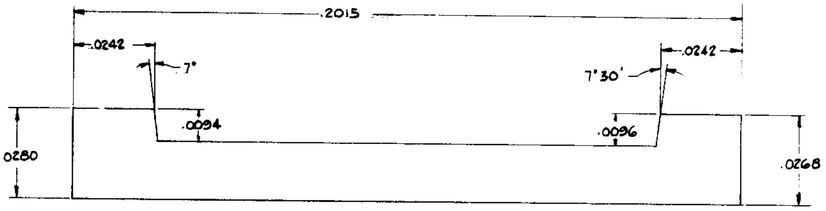
LS 25753
SH 2 OF 2 SHEETS

Figure 23


X
1.50712
1.50680
LETTERED SIDE 'TL'
.78
.3990
.3988
.19
.06×45° CHAMFER
BOTH SIDES
1.75
SEE ENLARGED
VIEW
A.0002
.002 MAX. R
.0015 MAX. R
2.5573
2.5571 DIA
2.5393
2.5391 DIA.
A.0002
3°
1°
3°
1°
.1509
.1507
.12415
.12395
SCALE 10/1

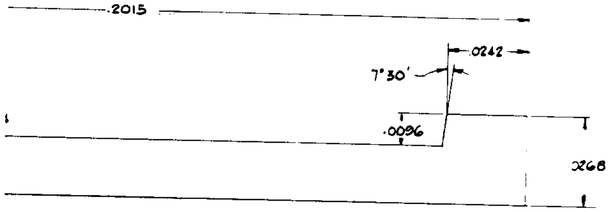


SCALE 10/1



UNLESS OTHERWISE SPECIFIED

CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.



LS 25753
SH. 3

UNLESS OTHERWISE SPECIFIED
- ALL ANGLES ±2°
- FINISH DIMS ±.010
- FINISH ALL OVER $\overset{32}{\nabla}$

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25753 SH 2

MILITARY SPECIFICATIONS
SPEC NUMBER
DEVIATIONS

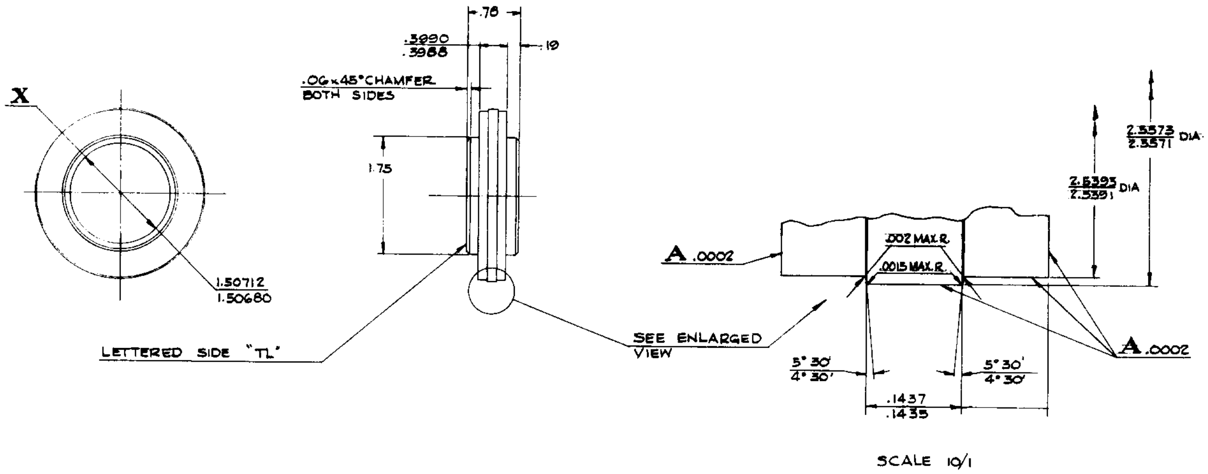
DESIGN BY Q Atwell 11/14/60
STARTED 4/15/60
COMPL'T'D
CHECKER
DESIGN SUPERVISOR
PROJ. ENG. DESIGN
PROJ. ENG. DEVEL'PT
PROJ. ENG. RESEARCH
ENGINEERING
ASST CHIEF ENGINEER
CHIEF ENGINEER

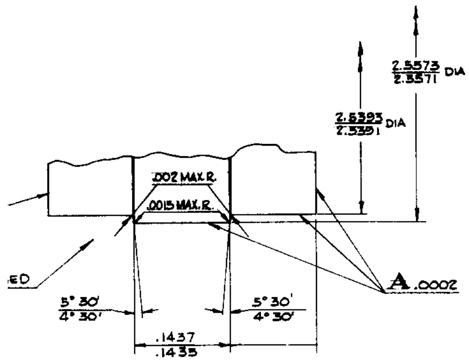
CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.

CHANNEL WIRE ROLLERS-
FINISH

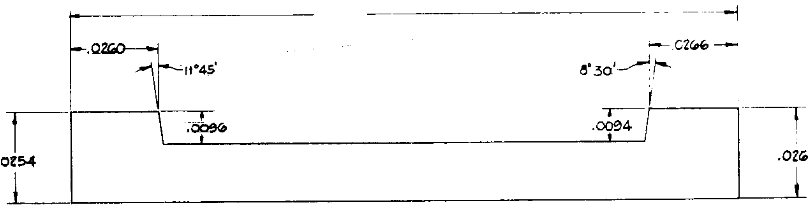
LS25753
MODEL
SH 3 OF 4 SHEETS

Figure 24


X
1.50712
1.50680
.78
.3990
.3988
.19
.06×45°CHAMFER
BOTH SIDES
1.75
LETTERED SIDE "TL"
SEE ENLARGED VIEW
A .0002
.002 MAX.R.
.0015 MAX.R.
2.5393
2.5391 DIA
2.3573
2.3571 DIA
A .0002
5° 30'
4° 30'
5° 30'
4° 30'
.1437
.1435
SCALE 10/1

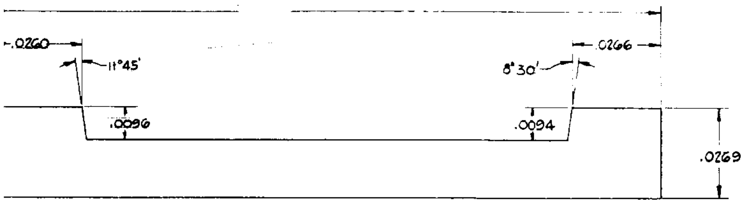


SCALE 10/1



UNLESS OTHERWISE SP

CURTISS-W
WRIGHT AER
WOOD-RIDGE, N



LS 25753
SH. 4

UNLESS OTHERWISE SPECIFIED
ALL ANGLES ± 2°
FINISH DIMS ± .010
FINISH ALL OVER $\overset{32}{\vee}$

A SURFACES CONSTRUCTED AROUND OR AT RIGHT ANGLES TO A COMMON AXIS WHEN PART IS MOUNTED ON SURFACE X MUST BE WITHIN FULL INDICATOR READING SPECIFIED

FOR SIDE ROLLER & BOTTOM ROLLER DETAILS AND SECTION SHOWING ROLLERS IN ROLLING POSITION SEE LS 25753 SH. 2

MILITARY SPECIFICATIONS
SPEC NUMBERS
DEVIATIONS

Campbell DRAWN BY					
11/17/60	CHECKER	DESIGN SUPER	PROJ. ENG. DESIGN	PROJ. ENG. DEVEL'PT	PROJ. ENG. RESEARCH
STARTED 11/17/60					
COMPL'TD	ENGINEERING MGRS		M. MECH.	ASST. CHIEF ENGINEER	CHIEF ENGINEER

CURTISS-WRIGHT CORP
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE, NEW JERSEY, U. S. A.

CHANNEL WIRE ROLLERS-
FINISH

MODEL

LS25753
SH 4 OF 4 SHEETS

Figure 25

CHANNEL ROLLER ANGLE VS TAPE ANGLE

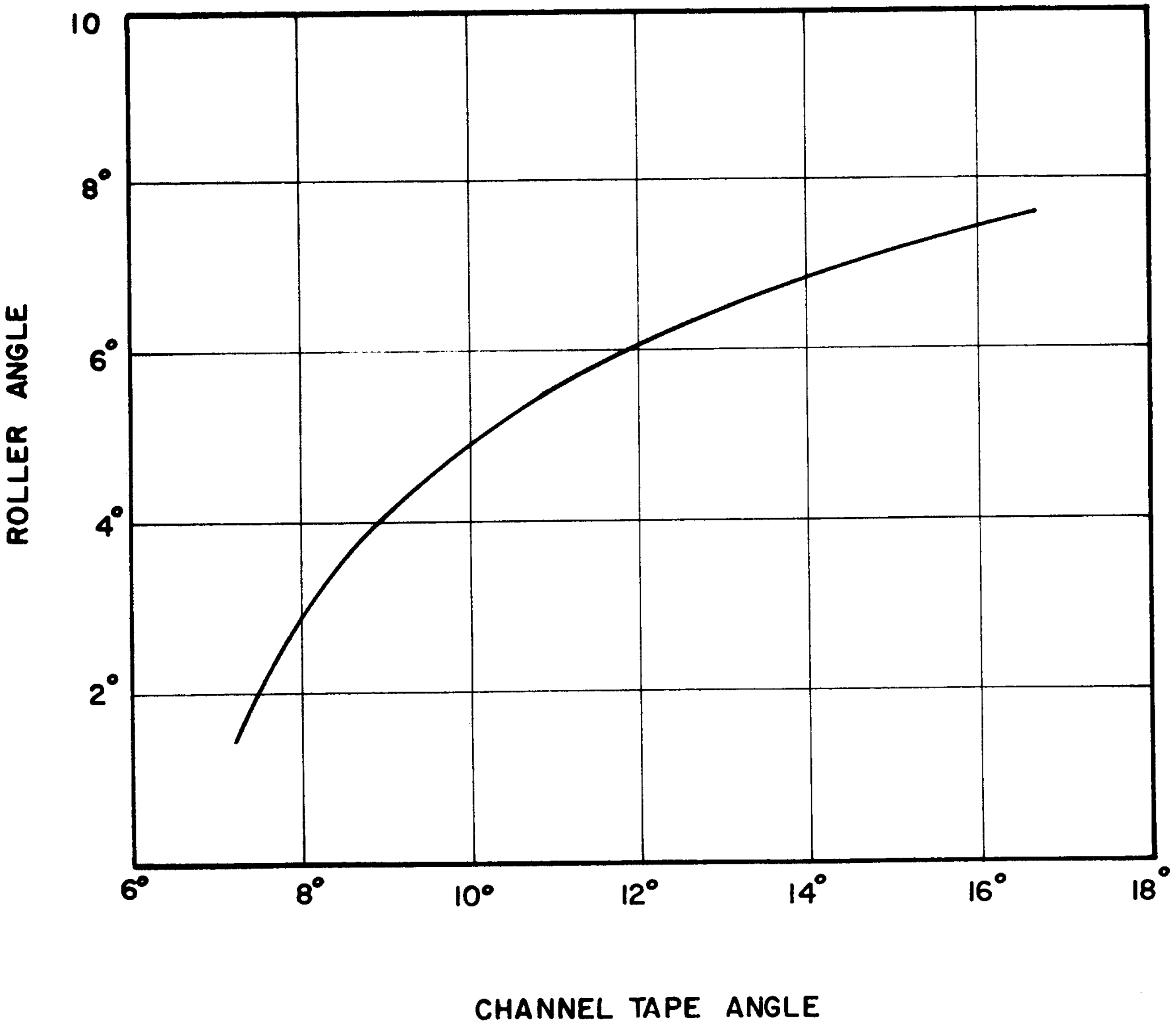


Figure 26

5.0 METALLURGY

5.0 METALLURGY

5.1 Work Statement

Metallurgical work carried out under the present contract includes tape manufacture, development of measuring techniques, measurement of interference fit, development of heat treatment, determination of frictional coefficients, evaluation of liner and bonding methods and a limited number of low temperature tensile tests.

5.2 Starting Material

Commercial B120VCA titanium alloy weld wire produced by centerless grinding and drawing was procured in the mill annealed condition. Two sizes, .154" and .123" were evaluated resulting in the final selection of .123" nominal gage for both shapes. The fabrication of lengths in excess of 100 ft., though successful in some heats, resulted in cracking and rupture in the case of the most recently purchased material. Poor wire surface in "as received" material was observed to contribute to this problem. Superficial pickling, either acid or basic, found effective in improving surface condition was not always found to alleviate the problem. Other possible causes include hydrogen embrittlement, surface contamination, and variances in chemical composition. In order to insure quality and uniformity in future purchases a specification for B120VCA material in the form of coils of wire was prepared. This specification is reproduced in detail in Appendix III.

5.3 Rolling Techniques

5.3.1 Round Wire Breakdown

5.3.1.1 "I" Beam

The round wire discussed in Section 5.2 is cold reduced to a rectangular shape prior to further reduction in the Turks head mill. Originally, a Universal Turks head was used to produce all rectangular shapes. This procedure was abandoned in favor of a more rapid procedure which utilizes power driven rolls. The current breakdown is carried out in a groove mill and a flat mill, and is as follows:

5.3.1.1 "I" Beam (Continued)

Pass No.	Mill	Thickness of Rectangle	Width of Rectangle
1	Groove	.118	.118
2	Groove	.108	.108
3	Groove	.100	.100
4	Flat	.092	.108
5	Flat	.084	.116
6	Flat	.076	.124
7	Flat	.068	.132
8	Flat	.062	.140

5.3.1.2 Channel

The breakdown of round wire into rectangular cross-sections for the channel tape is more complicated since the amount of spread (.121" Dia. to .2165") is much greater. This procedure also requires the use of a groove mill and a flat mill, and is as follows:

Pass No.	Mill	Thickness Rectangle	Width of Rectangle
1	Groove	0.1050	0.1320
2	Groove	0.0990	0.1352
3	Groove	0.0950	0.1395
4	Groove	0.0900	0.1425
5	Groove	0.0855	0.1466
6	Flat	0.0810	0.1510
7	Flat	0.0760	0.1570

5.3.1.2 Channel (Continued)

Pass No.	Mill	Thickness of Rectangle	Width of Rectangle
8	Flat	0.0720	0.1615
9	Flat	0.0590	0.1760
10	Flat	0.0540	0.1816
11	Flat	0.0494	0.1887
12	Flat	0.0443	0.1950
13	Flat	0.0396	0.2030
14	Flat	0.0350	0.2100
15	Flat	0.0310	0.2165

The problem of reducing round wire to the rectangular starting shapes necessary for Turks heading was further complicated by the necessity of avoiding the use of oxide coatings which normally serve as lubricants. Oxide coatings were found to result in embrittlement in the subsequent Turks heading operation.

5.3.2 Turks Heading of Rectangular Wire

Initially, two procedures of cold reducing rectangular B120VCA titanium wire were considered. Use of power driven rolls in a "shell mill" was believed to offer the advantages of spreading rather than elongating the material and allowing heavier reductions per pass because no extremely heavy pull was needed. It was, however, found that the accuracy of the shell mill was not sufficient to maintain the critical internal shapes, particularly the angles. Heavy passes resulted in cracking of the wire. Intermediate annealing was discarded since it lowered the attainable strength of the final product. Emphasis was, therefore, placed on the Turks heading method.

5.3.2 Turks Heading of Rectangular Wire (Continued)

This method, utilizing idling rolls through which wire is drawn, was believed to offer greater flexibility and sensitivity of adjustment, hence, better accuracy. The Turks head mill is an apparatus comprising four rolls which are housed at a 90° angle to one another. Depending on the model, the rolls may be adjusted independently or in pairs. The rolls can move in one direction only, i.e., up or down. A third available model, the "combination" Turks head incorporates the above and in addition, provides means for lateral adjustment.

It was initially thought that by limiting reductions in each pass to a small percentage, large total reductions in area could be obtained. In addition, it appeared advisable to employ one or more intermediate anneals.

Numerous samples were produced by thus "babying" the material, but with varying degrees of success. Intermediate anneals were found to reduce the final attainable strength. It was found that optimum aging response was obtained when the cold worked material after the final pass exhibited a tensile yield strength of 210,000 psi.

Patterning the shaping steps for either the "I" beam or channel shapes after steel mill practice proved unrewarding since the flow characteristics of titanium are totally different. The forming rolls, each taking relatively heavy reductions, were arrived at by trial and error. An extremely heavy finishing pass was necessary in order to avoid steps in the internal walls.

Though the finished dimensions obtained by the heavy reduction method proved superior to those produced by the previously used light reduction method, a number of new problems were introduced. These problems included cracking of the rolls as well as excessive wear of the roll arbors. Changes in the roll materials, heat treatment and chrome plating of arbors, though successful to a limited extent, were not considered satisfactory for rolling long lengths. Consequently, a larger Turks head mill (No. 3TH) was purchased. This resulted in lower Hertz stresses in the rolls and lower bearing stresses in the arbors. A Kerosene-water mixture was used as a lubricant.

5.3.2 Turks Heading of Rectangular Wire (Continued)

The techniques developed for the processing of tape in the small mill were found applicable in the larger mill, resulting in the successful production of the desired shape (Figure 3). Roll design, spring back calculations and modifications of rolls are reported in another portion of the present report (Section 4).

5.3.2.1 "I" Beam

Using the procedure outlined in the above section, the best "I" beam shape was produced in two (2) heavy passes. The first pass reduced the webb to 0.0416 and the overall length to .1370. The final pass reduced the webb to .0395 and the length to 0.134.

5.3.2.2 Channel

The final channel cross-section being smaller, but wider, than the "I" beam required somewhat smaller reductions. The following is the proceudre employed for the manufacture of the channel type.

Pass No.	Channel Webb Thickness	Channel Width
1	.029	.2045
2	.027	.2043
3	.025	.2042
4	.023	.2041
5	.021	.2041
6	.0195	.2040
7	.0185	.2035
8	.0175	.2030
9	.0165	.2000
10	.0155	.2000

Figure 27 illustrates the major steps in the fabrication of the channel shape. As illustrated, shapes K through O contain ridges at the base of the channel which are used to force material to flow upward.

Figures 28 and 29 illustrate both cross sections in the etched and unetched condition. As may be observed from Figure 29, flow lines follow the internal corners indicating favorable flow with respect to the interference fit and final pressure vessel requirements.

5.4 Evaluation of Measuring Techniques

The measurement of both shapes has presented a serious problem due to the close tolerance requirement imposed. An investigation of several measuring methods was carried out. These include measurement by means of a comparator, projection by means of a metallograph, micrometer measurement of external dimensions, measurement of a calcium sulfate mold and use of toolmakers' microscopes and air gages.

The projection of both shapes by means of a comparator resulted in readings differing by as much as .0025 from outside dimensions as measured by a micrometer. This was primarily due to distortion in the tape produced by cutting. Glancing of the comparator beam from a flexed portion of the tape also proved inaccurate because of distortion.

The above attempt also showed that any twist or bend could produce erroneous results. This imposed the requirement that measurement must be made in a perpendicular plane. This was accomplished by copper plating (non-adhering) the tape to a thickness of approximately 0.005 inch. The tape was then placed in special metallographic clamps as illustrated in Figure 30. The specimen was then polished metallographically and photographed at 50X. The photographs were then measured.

Comparison of the results obtained using the above procedure with micrometer measurements revealed a difference much less than those obtained with a comparator. However, this difference (.0005 - .0001 inch) was still considered too great. It was decided that the metallographic method be used to measure only dimensions which could not be measured with a micrometer.

In an effort to obtain greater accuracy a fourth method was attempted whereby a small mold was clamped onto a portion of the tape, and filled with CaSO4· 1/2 H_2O solution. This solution was allowed to set for 2 hours. The impression thus produced was then projected on a comparator and measured. These measurements also did not agree (0.001 inch larger) with micrometer measurements.

External comparators, toolmakers' microscopes, and air gages, in combination, were tried next. A comparison of the dimensions obtained by this method versus those obtained by metallographic and micrometer methods is as follows:

5.4 Evaluation of Measuring Techniques (Continued)

	Width	Height	Groove Depth	∠ 1	∠ 2	∠ 3	∠ 4
"I" Beam							
Non-Metallographic	.1378	.060	.0093			20°	15°
Metallographic	.1343	.0586	.0100	7°30'	6°	16°	15°30'
Channel							
Non-Metallographic	.2025	.0265	.0095	9°	14°		
Metallographic	.2015	.0268	.0095	7°	7°30'		

Note:

∠ 1 = top left side
∠ 2 = top right side
∠ 3 = bottom left side
∠ 4 = bottom right side

The above comparisons show that there is a large discrepancy between the two methods. More significant however, is the fact that the non-metallographic measurements do not agree with succeeding attempts to measure the same tape.

5.5 Interference Fit

It was desired to obtain a measurement of the forces involved to produce an interference fit between the "I" beam and the channel, even though the "I" beam was out of tolerance initially. The test was accomplished in the following manner: Two one inch lengths of channel were butted against each other and the "I" beam placed over the flats. Two more channels were then added to complete the top layer. The assembly was then hydraulically pressed together in a flat position. The gauge pressure was increased from 0 to 3000 psi, to 5000 psi, to 7000 psi and finally to 10,000 psi. At each pressure reading the tapes were polished, etched and photographed. Pressure was maintained on the sample at all times.

This procedure determined the force required to produce an interference fit.

5.5 Interference Fit (Continued)

A determination of the force needed to achieve an interference fit is carried out as part of evaluation of each tape lot produced. Figure 31 shows the results of pressing together the tapes shown in Figure 32. The load was applied in the center of the "I" beam. It may be noted that the center of the "I" beam has deflected before one side has had a chance to seat. This caused a cocking effect resulting in an unsatisfactory interference fit. Another set of channels and an "I" beam were pressed together with the load applied to the "I" beam flanges. The result is illustrated in Figure 33. This loading method eliminated some of the bowing and resulted in better seating of the sides. The lack of good fit is due to the undersized width of the "I" beam groove. Despite this the tapes stayed locked after the load was released.

In order to determine the amount of interference fit from the standpoint of assembled dimensions and force needed for separation, an experiment was carried out whereby the "I" beam and channel tapes shown in Figures 21 and 25 were pressed together (2 layers) and the total thickness measured (from inside of "I" beam to outside of channel) as a function of applied load. The results are given in Figure 34. It can be seen that a 2400 psi force was necessary to initiate a permanent interference fit and a 5000 psi force was necessary to seat the "I" beam on the channel. Figure 36 shows a 3 layer assembly pressed together under a 5000 psi force. Though some separation is still believed to be present, the illustration exaggerates this due to rounding of edges during polishing. This fact is confirmed by observation of strain markings adjacent to "gaps" when the assembly was subjected to higher compressive loads.

In order to estimate the force needed to overcome the interference fit, the fully seated sample was attached to small tensile machine grips by means of wires. Despite non-concentric loading, a load of 14 pounds was required to fail the 1" long assembly. Reseating of the specimen and repetition of the test resulted in a failure load of 11 lbs. A third test of the same specimen yielded a failure load of 6 pounds.

The values obtained are considered sufficient to prevent unwrapping (during vessel assembly) of a partially wrapped layer upon removal of the restraining forces imposed by the wrapping mechanism and drag break. This was verified during trial wrapping of a dummy arbor.

5.6 Tensile Testing Apparatus

All attempts to test both "I" beam and channel shaped tapes in tension have failed to give reproducible values. This is due to the fact that the tapes broke at the grips. Consequently, a rig has been designed whereby the tape is wound on a drum at each end. These drums, in turn, have plates welded to them which are held by the grips. The frictional force created by the wound tape is sufficient to prevent slippage. This apparatus has been constructed and is shown in Figure 36 (LS 25806).

5.7 Heat Treatment

The heat treat proceudre was designed to produce optimum properties in both channel and "I" beam tape, keeping in mind the goal of a 250,000 psi yield strength with 4 percent ductility.

The specimens to be heat treated were first degreased and then capsulated in vacuo. Heat treatment was carried out in a furnace of constant heat zone (± 5°F) for various times ranging from 5 hours to 38 hours at a given temperature. This procedure was repeated at several temperatures until the time and temperature to produce maximum properties was found. The results are presented in the following sections.

5.7.1 Channel Heat Treatment

The results of aging channel tape are presented in Table I and Figure 37. The maximum yield strength was obtained after aging at 700°F for 12.5 hours. The yield strength produced by this treatment was approximately 278 ksi while the ultimate strength was 280 ksi. The elongation was 1.5 percent in an 1" gage length. This heat treatment results in approximately the same properties as the "I" beam heat treatment.

5.7.2 "I" Beam Heat Treatment

The results of aging "I" beam tape are given in Table II and are presented in Figure 38. The maximum yield strength was obtained after aging at 750°F for 25 hours. The ultimate tensile strength produced by this treatment was approximately 279,000 psi and the yield strength was 272,000 psi. The elongation was 1.5 percent (1" gage length).

5.7.3 Metallographic and Hardness Study

The aging response of the channel tape as a function of percent reduction in area and hardness was investigated. This was accomplished by aging samples, having the cross-sections shown in Figure 27 at 750°F for 20 and 46 hours in a vacuo. The resulting microstructures are presented in Figure 39. It may be seen that these microstructures indicate behavior in a normal fashion with evidence of aging taking place at the first Turks head breakdown pass on (a) and (b). The presence of a spheroidal precipitate (probably $TiCr_2$) shown in Figure 39 (c) is indicative of overaging.

A Vickers hardness survey using a 5 kilogram load was taken across the above specimens. The results are shown in Figure 41. The curves indicate an increase in hardness with increasing reductions. The 47 hour-aged hardness is less than the hardness obtained with the 20 hour treatment.

5.8 Elimination of Twist* and Bow **

Twisting and bowing of tapes was found to cause difficulty during the wrapping operation. Twisting resulted in cocking, particularly in the case of the "I" beam, resulting in loss of interference fit. Bowing resulted in a "pre-set" helix causing difficulty during stacking, particularly in the case of the first channel layer.

Both problems are associated with the use of the bull block which supplies the force necessary to draw the tape through the Turks head. In order to eliminate bowing as well as twisting, a specially designed arrangement is being substituted for the presently used bull block.

5.9 Coefficient of Friction

The design of both channel and "I" beam shapes assumed a coefficient of static friction of 0.3-0.5. An investigation to determine the actual value was performed in the following manner:

---

* Twist - Rotation of cross-section about tape axis.

** Bow - Bending of the tape axis parallel to the plane of the web.

5.9 Coefficient of Friction (Continued)

Two titanium channel tapes were mounted back-to-back and clamped with a predetermined load (Figure 41). The channels were then pulled in opposite directions and the load to initiate slippage noted. This experiment was repeated with different clamping loads and the corresponding slippage loads recorded. The results are tabulated in Table III.

An increase in the coefficient of static friction from .270 to .348 as a result of heat treating was observed. Analysis shows the interlock to be effective only when the condition $\tan \theta < \mu$ is satisfied, where θ is the interference fit angle, and μ the coefficient of static friction. Figure 42 shows the derived relationship between the tape angle and coefficient of friction.

5.10 Evaluation of Bonding Methods

In accordance with design requirements, it is essential that the tape be bonded to the adapters. The possibilities considered include brazing, soldering, ultrasonic welding, and the use of resins.

The goal was to obtain a tensile shear strength of 4,500 psi with 0.001" strain.

Brazing was not attempted since the temperatures involved are usually above 1000°F which is in excess of the upper limit of the aging temperature. Low temperature brazing or soldering and ultrasonic welding were found unsatisfactory. Epoxy resins appeared attractive since they are either room temperature curing or cure at slightly elevated temperatures. An evaluation was carried out wherein a piece of steel large enought to contain a piece of B120VCA channel tape was zirconite blasted and degreased. The titanium tape was cleaned in 3 parts HF-30 parts HNO_3 solution for one minute and washed in water. The resin was applied to both parts which were then allowed to come in contact with each other. The specimens were pulled in uniaxial tension using self-aligning grips. A deflectometer was used to measure the cross-head movement. B120VCA channel tape was previously tested and stress-strain curves determined. At given loads a corresponding strain of the tape was subtracted from the total deflection and stress-strain curves for the resins were then drawn. From these curves a modulus of elasticity for each resin was calculated.

5.10 Evaluation of Bonding Methods (Continued)

Tests showed that the resins all had modulli of elasticity in the neighborhood of 10,000 to 25,000. These results are tabulated in Table IV and are illustrated in Figure 43. It was found that Maraset (Marbellette Corporation) had the highest strength and elastic modulus while Bondmaster (Rubber and Asbestos Corporation) was next. Eastman 910 and Goodyear Plibond did not adhere. Since a value of 4,500 psi was required at a 0.001" strain, the material would require a modulus of elasticity of 4.5×10^6. This could not be attained in resins.

5.11 Vessel Liner Evaluation

A test was carried out to determine the adherence and elastic properties of Teflon as a vessel liner. The vessel is so designed that a sharp angle exists where the first tape layer leaves the adapter. For testing purposes two (2) pieces of metal (titanium and steel) were joined together as shown in Figure 44. Teflon was then sprayed over the joint and the metal pieces pulled in tension with a 4500 pound force.

The results of this test showed that Teflon could not be relied upon to fill this corner and provide a leak-tight joint. In view of this, a modified Teflon and vinyl were tried. The results of this evaluation indicated that the modified Teflon flaked when subjected to tensile loading. However, the vinyl coating withstood the required strain (4500 lb. load) without any noticeable cracking or flaking.

5.12 Cryogenic Properties of B120VCA Ti

The results of limited low temperature tensile tests are presented in Figure 45 and shown in Figure 46.

The room temperature smooth sheet specimens had a gage length of 2-1/2" and a width of .400 ± .005". The low temperature smooth sheet specimens were the same except that the specimen width was .250".

The notched specimens were the same as the room temperature smooth specimens, except for a notch with a root radius of 0.010 ± .001", an included angle of 45° and the minimum width was .270 ± .003".

It can be seen from these results that this alloy is not reliable for cryogenic vessels, the notched-to-unnotched tensile strength ratios being 0.34 at -320°F.

Tests run on a second heat and a 0.050" gage thickness produced the same results.

CHANNEL BREAKDOWN

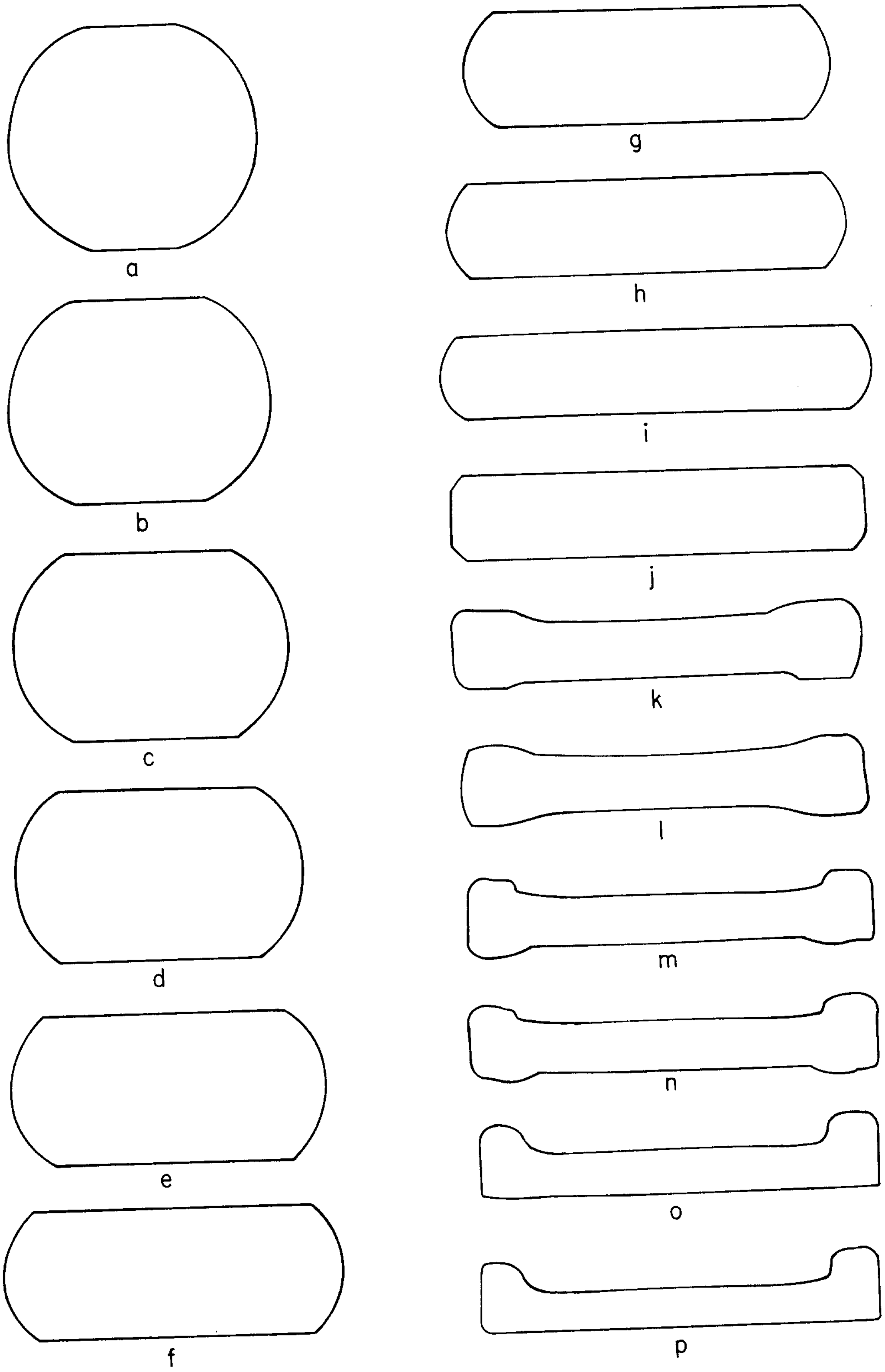
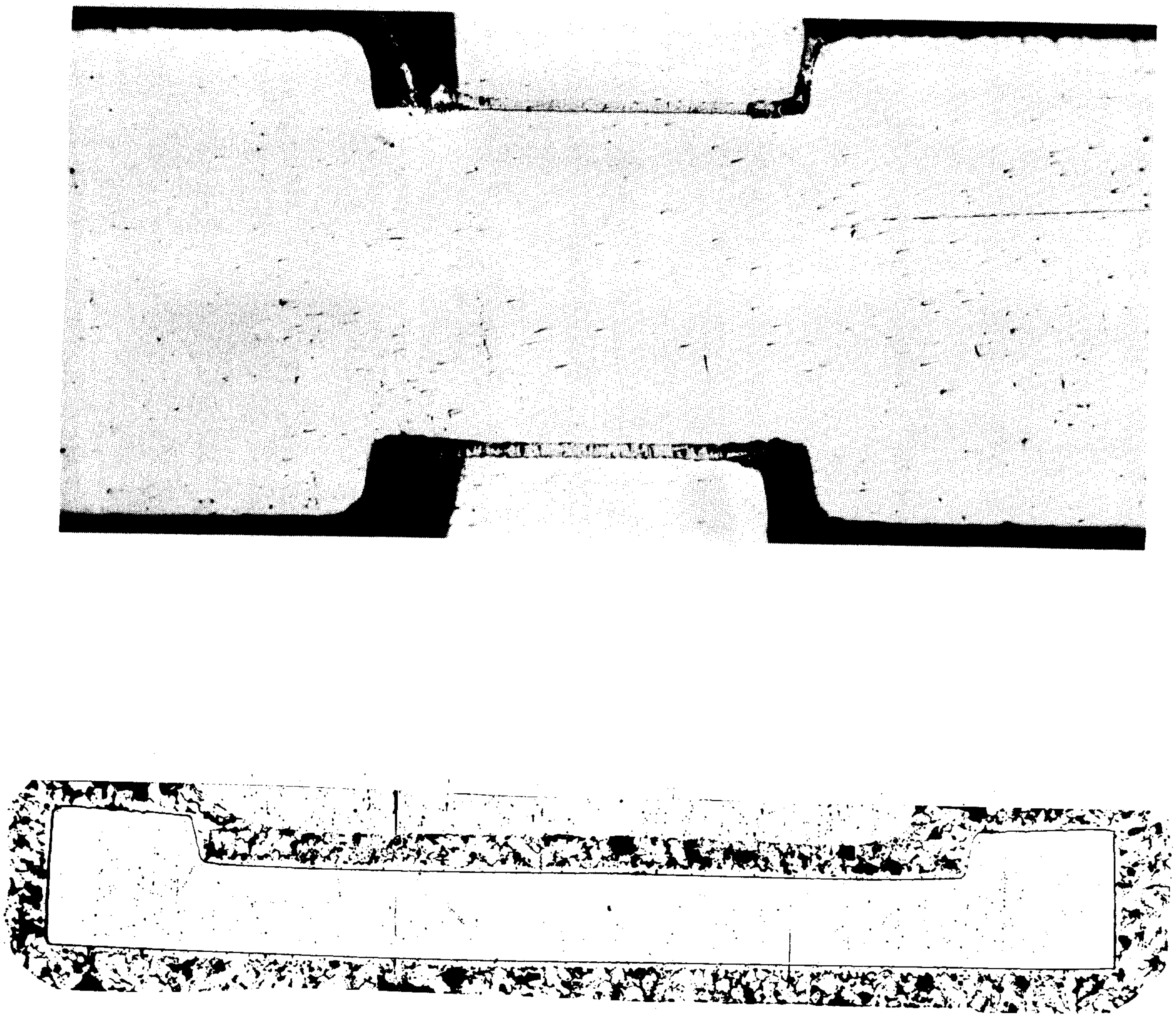
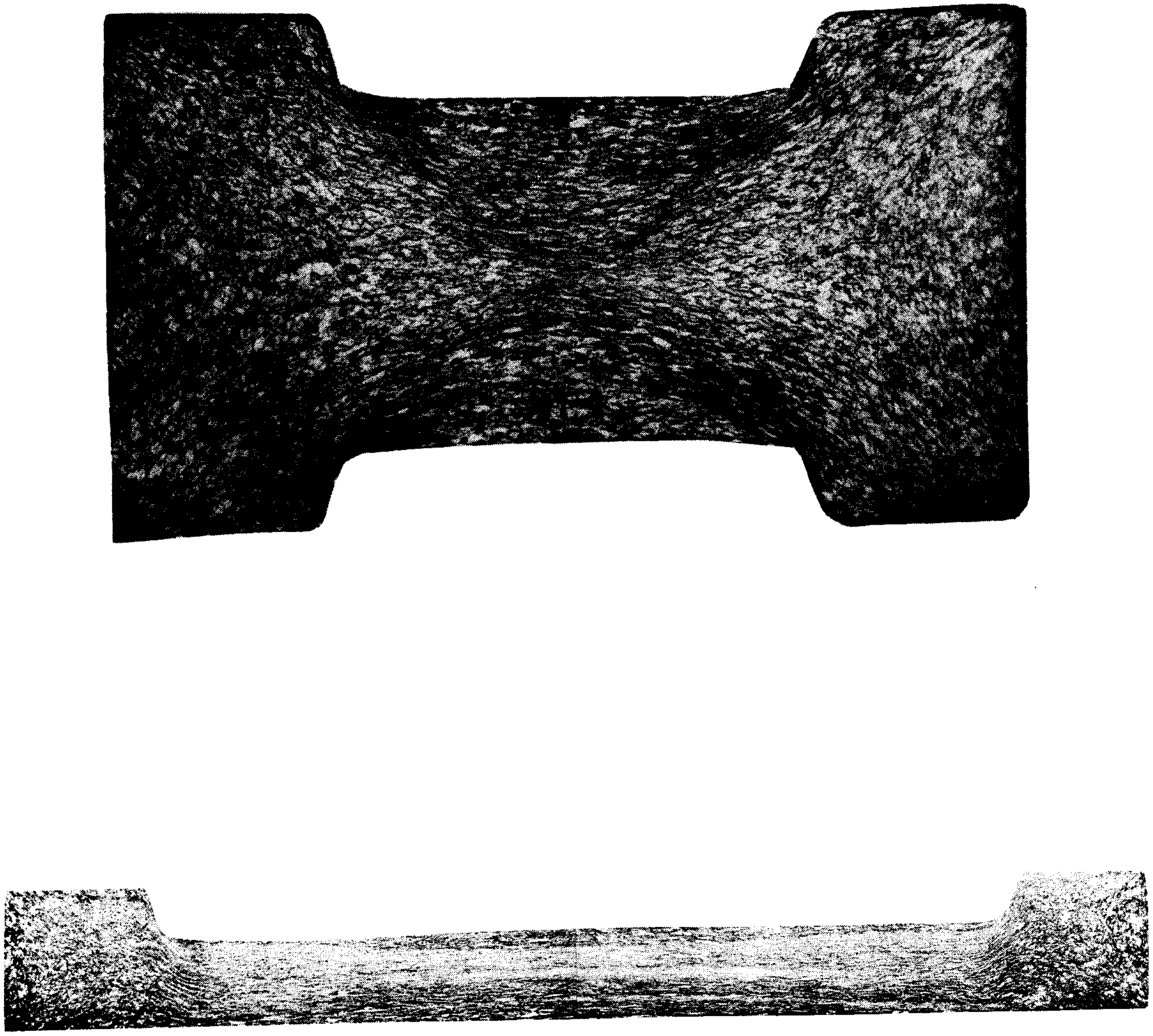


Figure 27



Specimens Mounted for Measurement

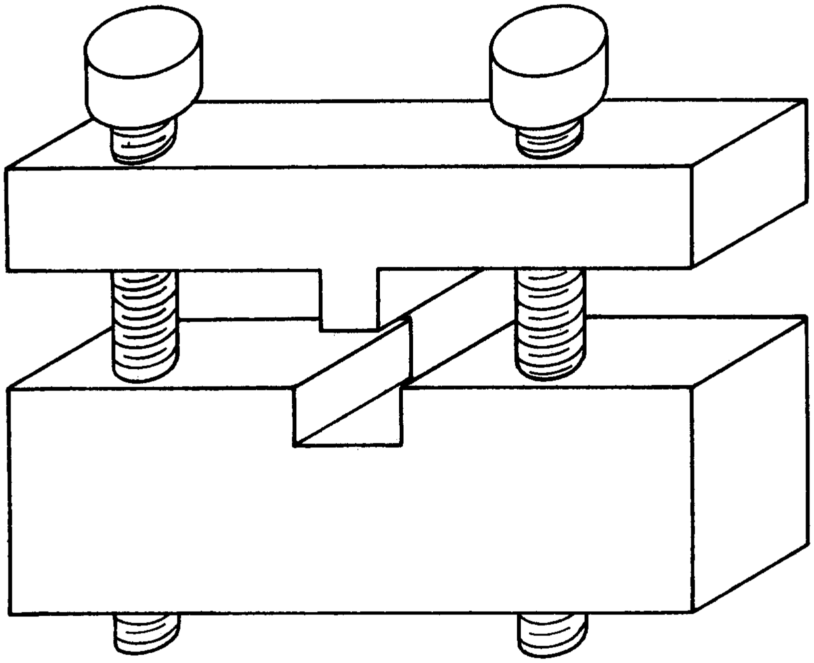
Figure 28



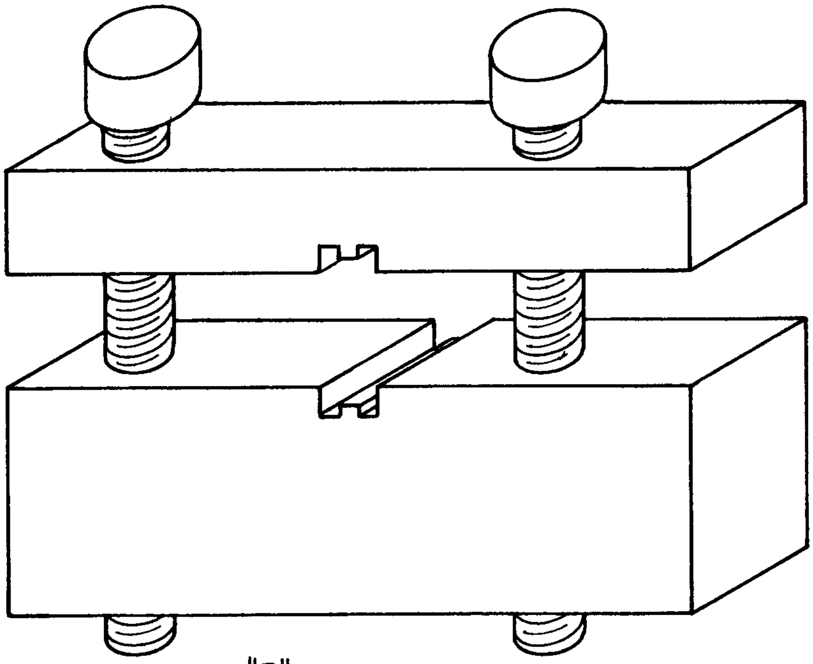
"I"-Beam and Channel Flow Lines

Figure 29

SCHEMATIC ILLUSTRATION OF METALLOGRAPHIC CLAMPS

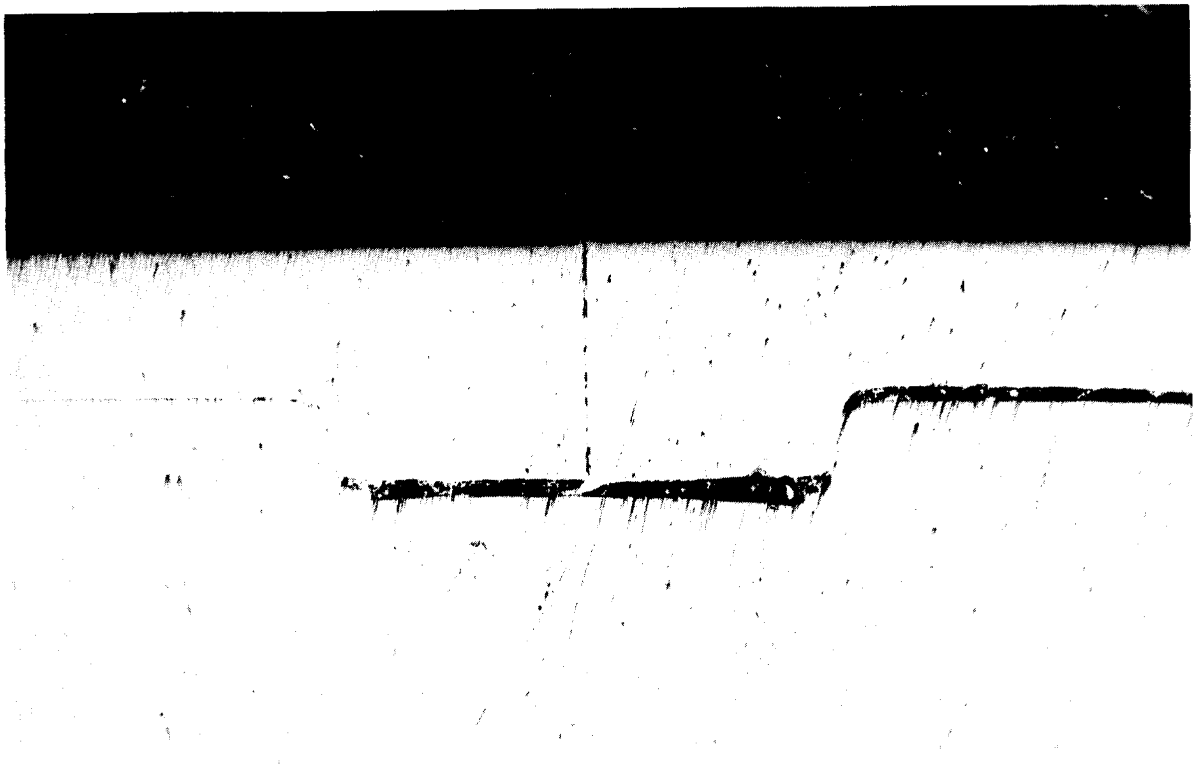


CHANNEL



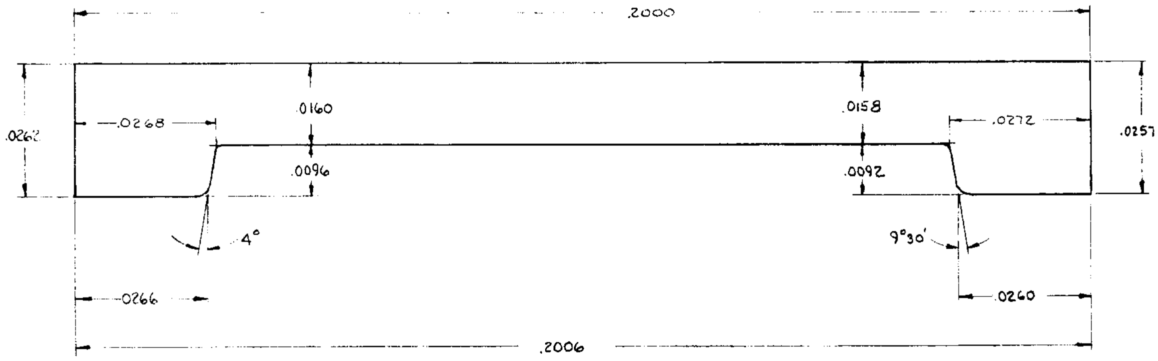
"I" BEAM

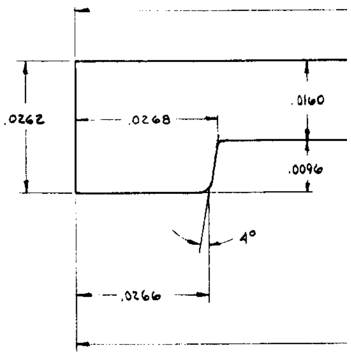
Figure 30



"I"-Beam - Channel - Pressed

Figure 31


.2000
.0262
.0268
.0160
.0096
4°
.0158
.0092
.0272
.0257
9°30'
.0260
.0266
.2006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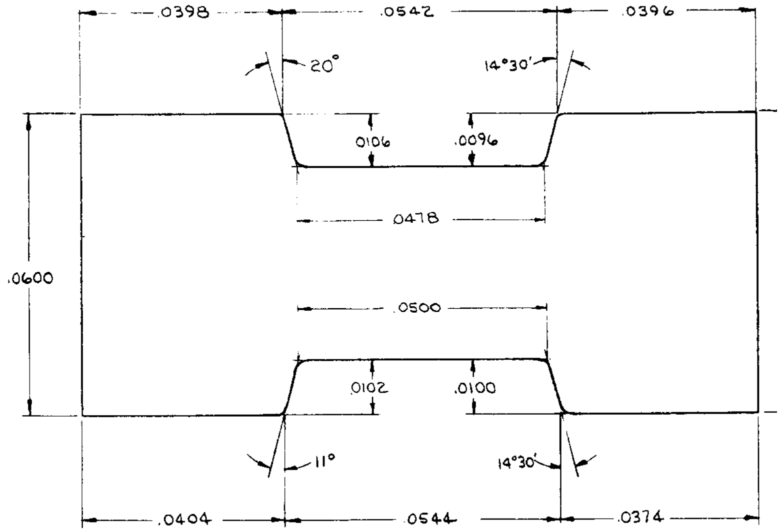
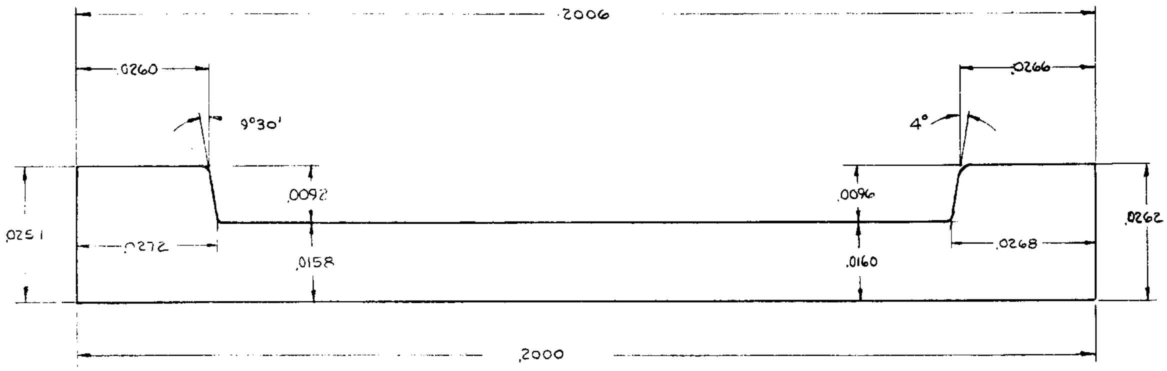
.0266


.0398
.0542
.0396
20°
14°30'
.0106
.0096
.0478
.0600
.0500
.0102
.0100
11°
14°30'
.0404
.0544
.0374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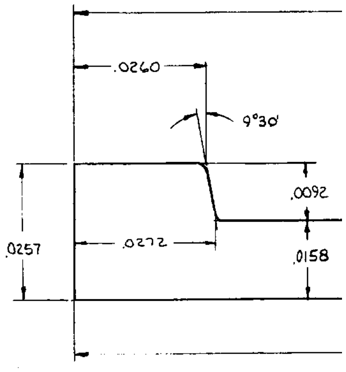
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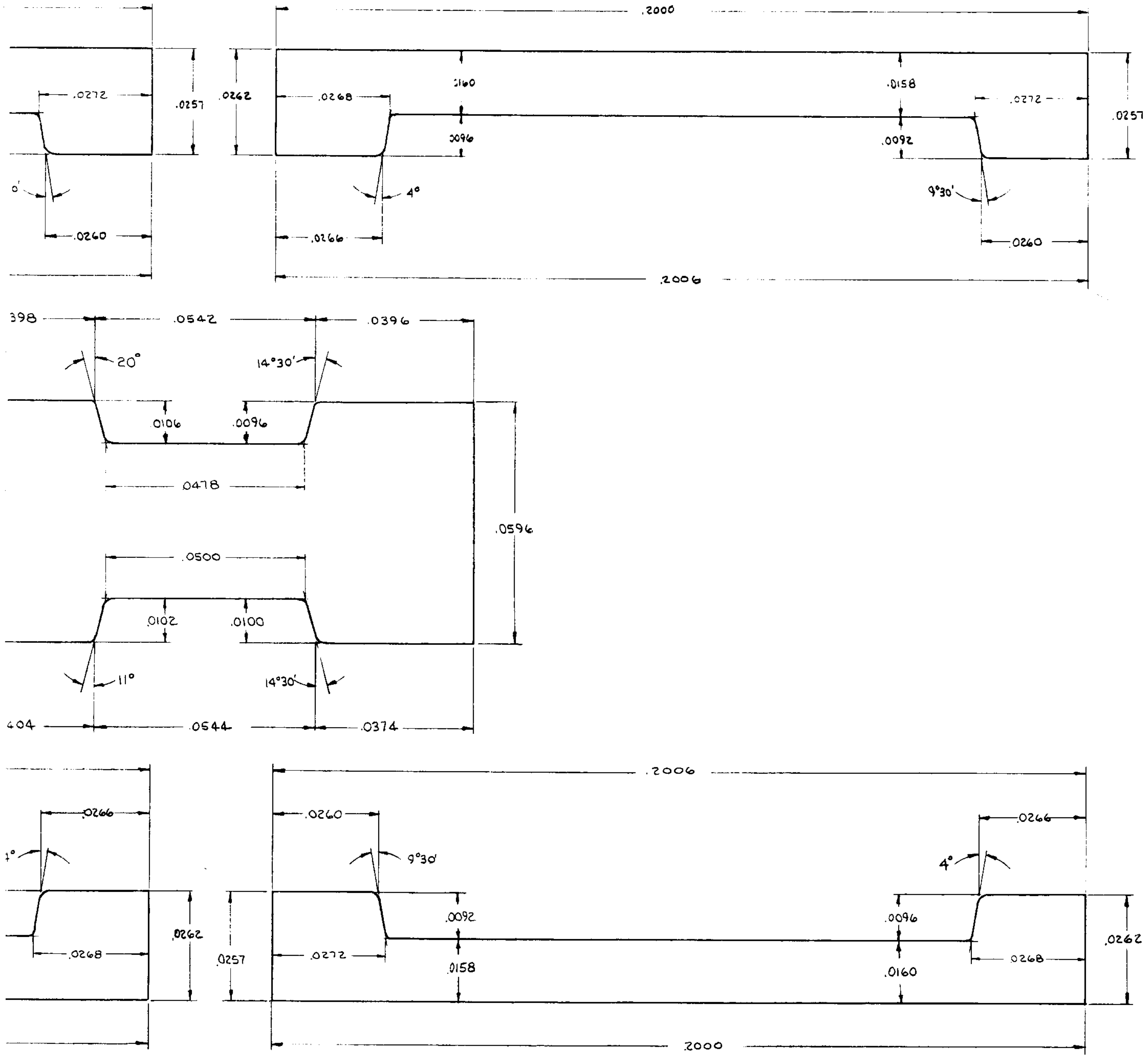
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0'
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.2000
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.160
.0158
.0272
.0257
.0096
.0092
4°
9°30'
.0266
.0260
.2006
398
.0542
.0396
20°
14°30'
.0106
.0096
.0478
.0596
.0500
.0102
.0100
11°
14°30'
404
.0544
.0374
.0266
.0268
.0262
.2006
.0260
9°30'
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4°
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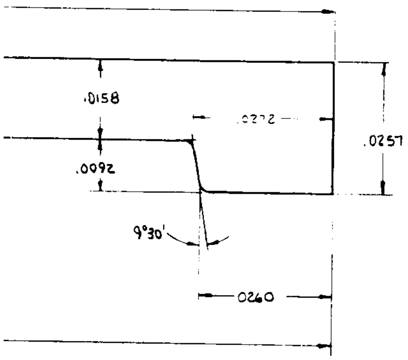
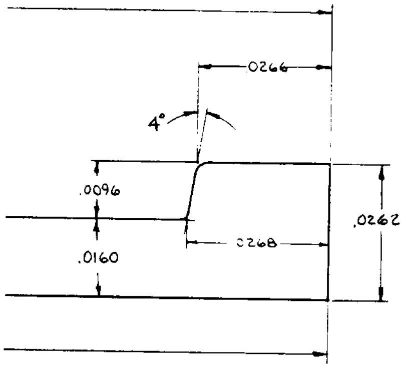
.0160
2000

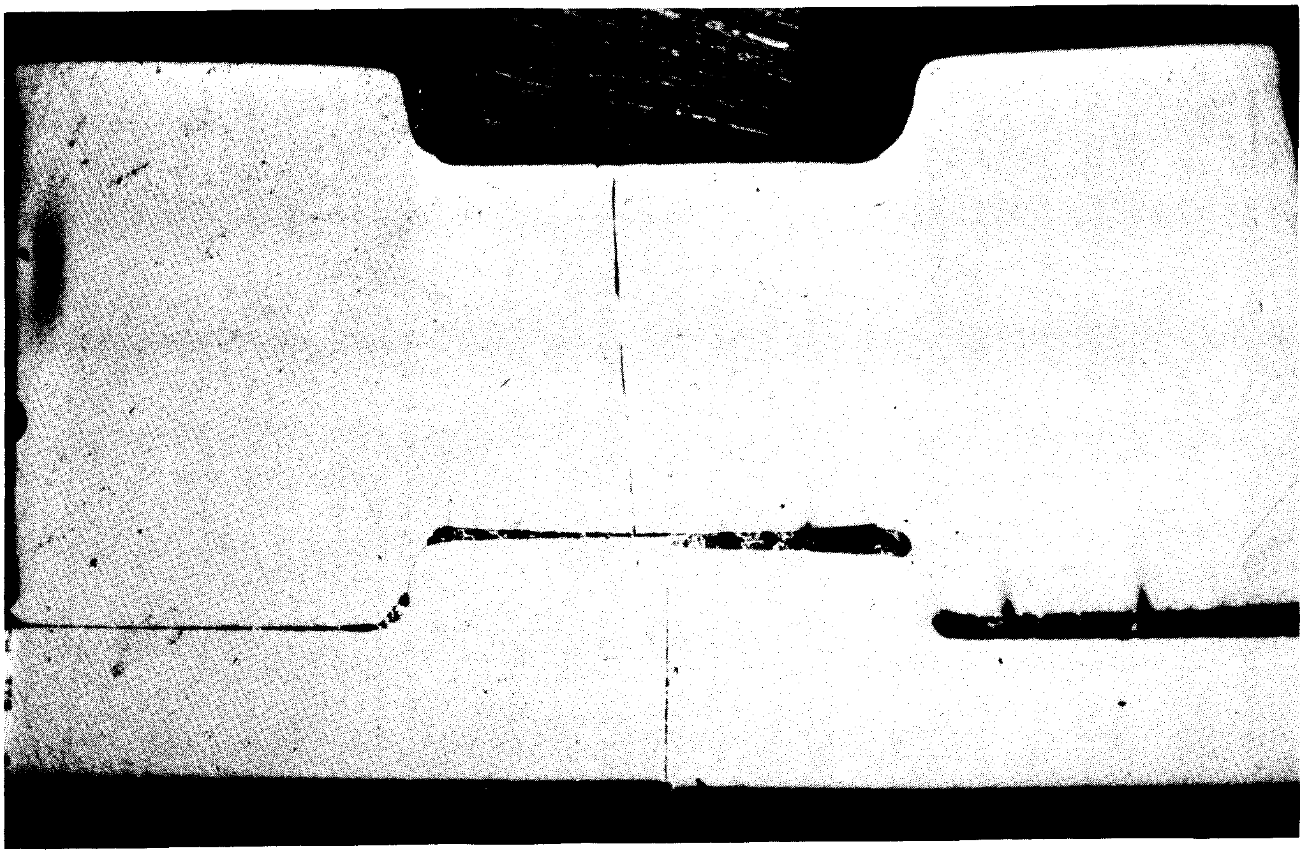




DATE -

DUMBBELL LOAD	LBS.
CHANNEL LOAD	LBS.
YIELD STRENGTH	P.S.I.

Figure 32



"I"-Beam - Channel - Pressed

Figure 33

DEGREE OF INTERFERENCE FIT

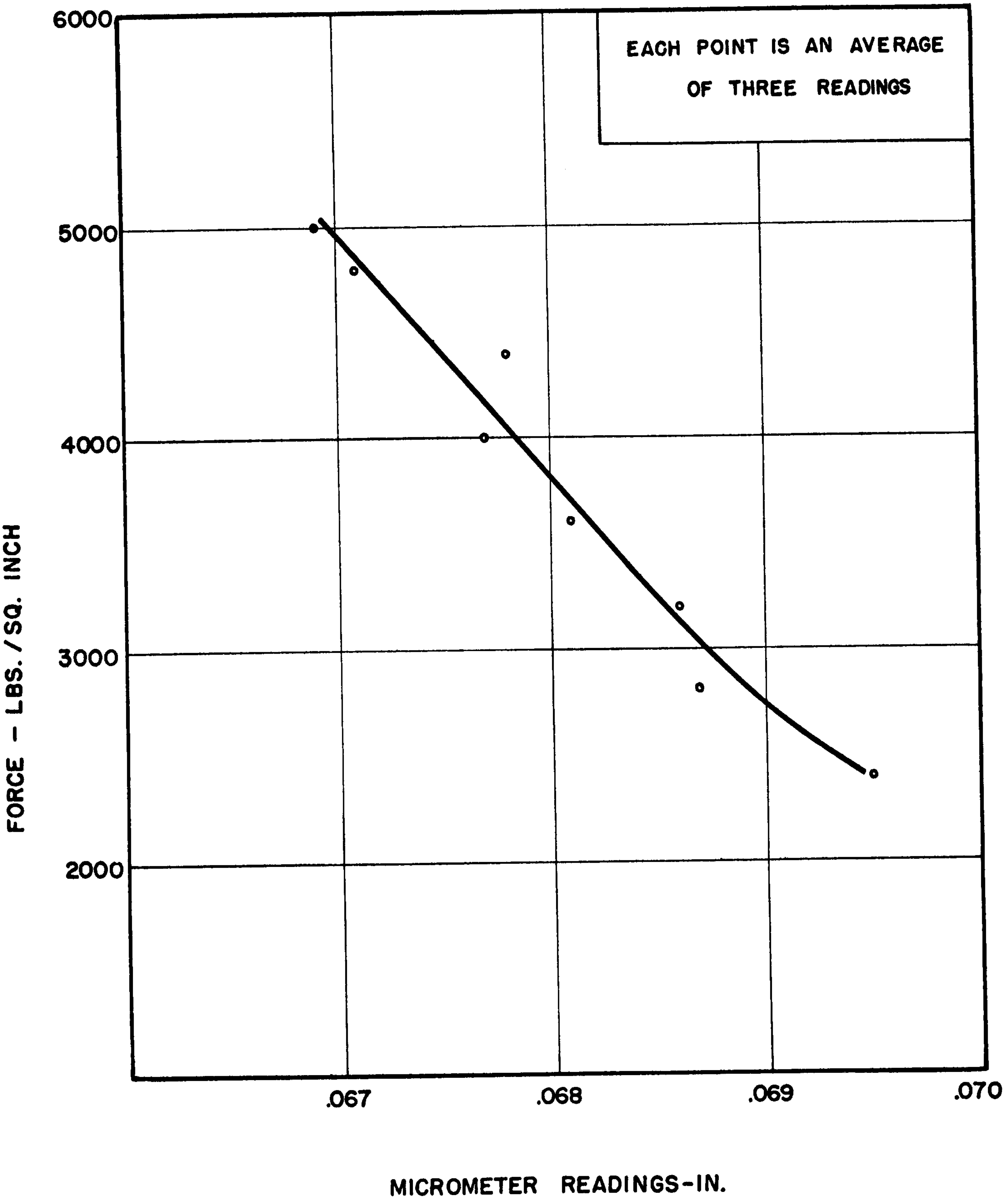
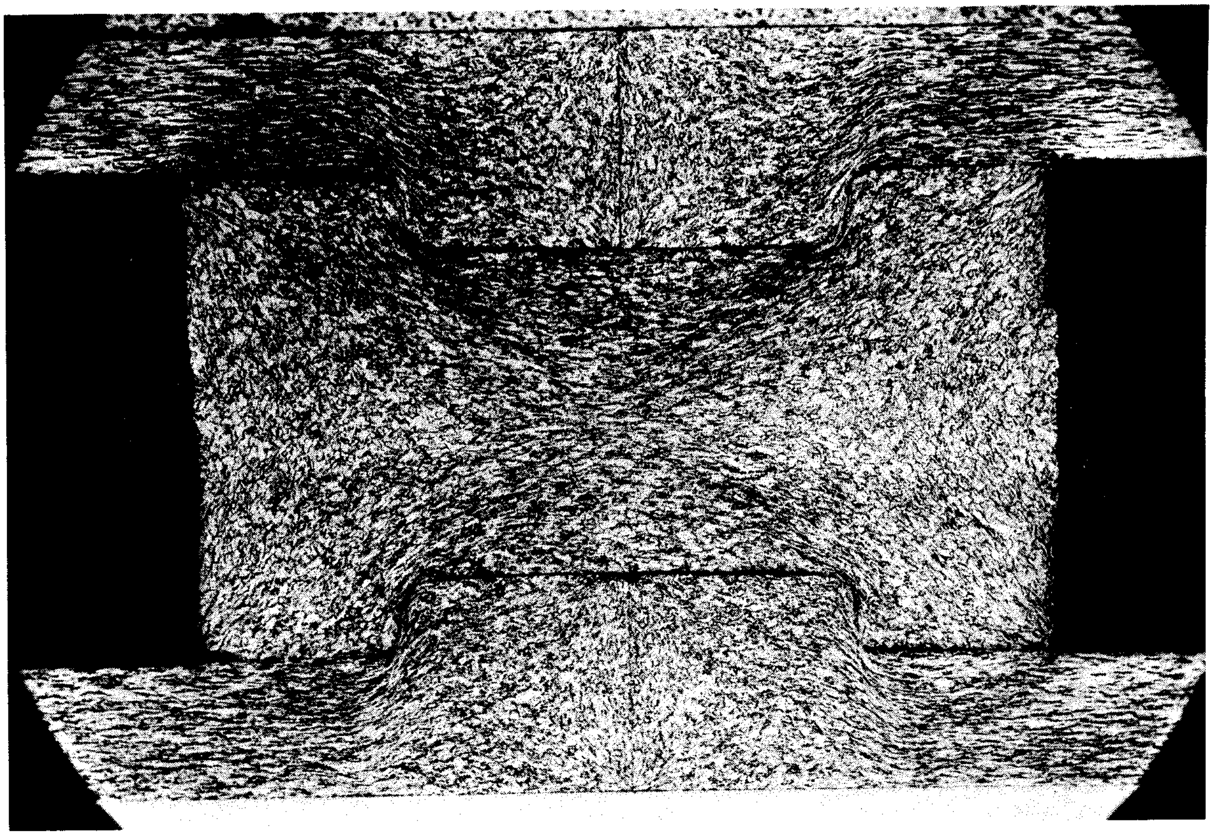
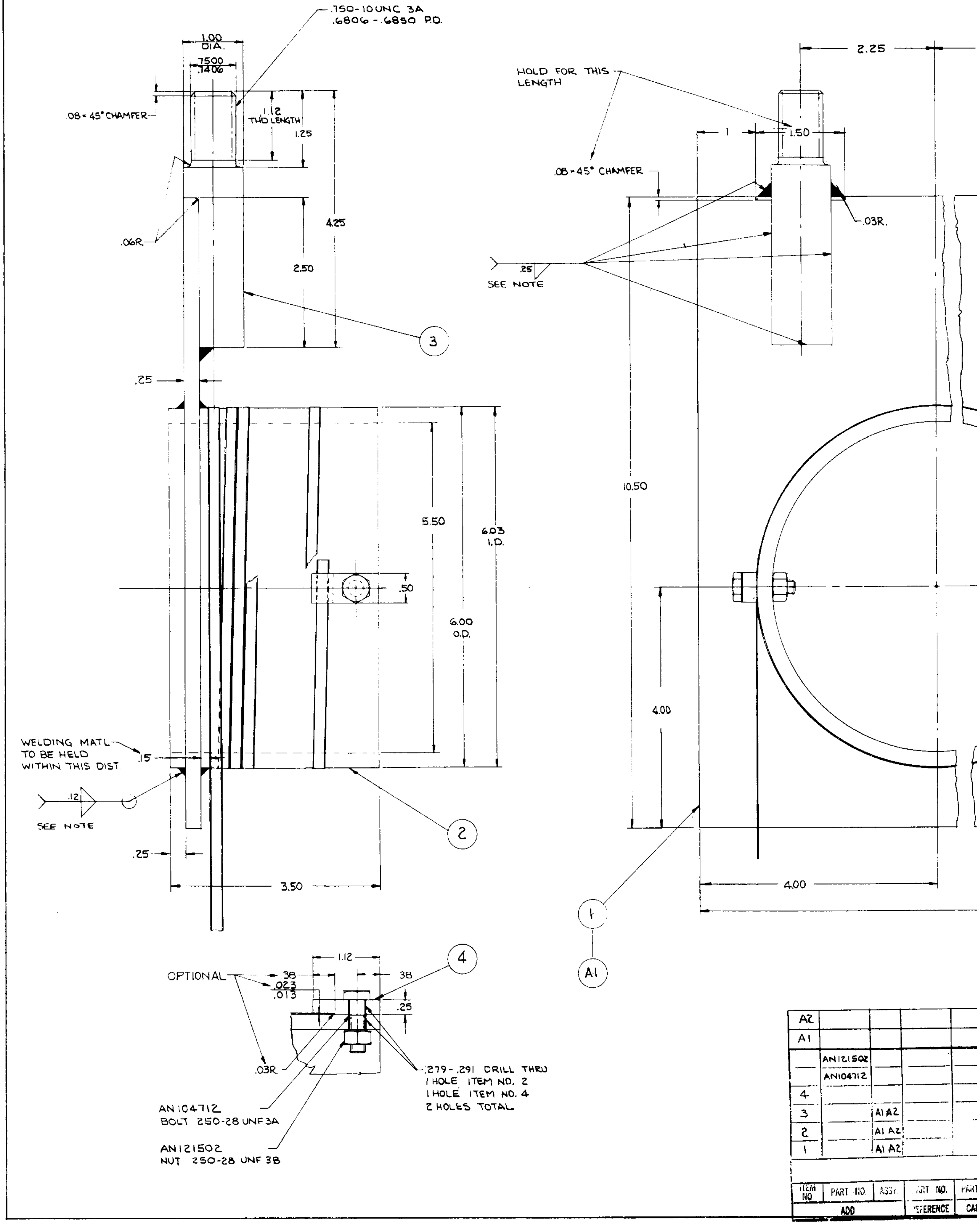


Figure 34



Three Layer Interference Fit

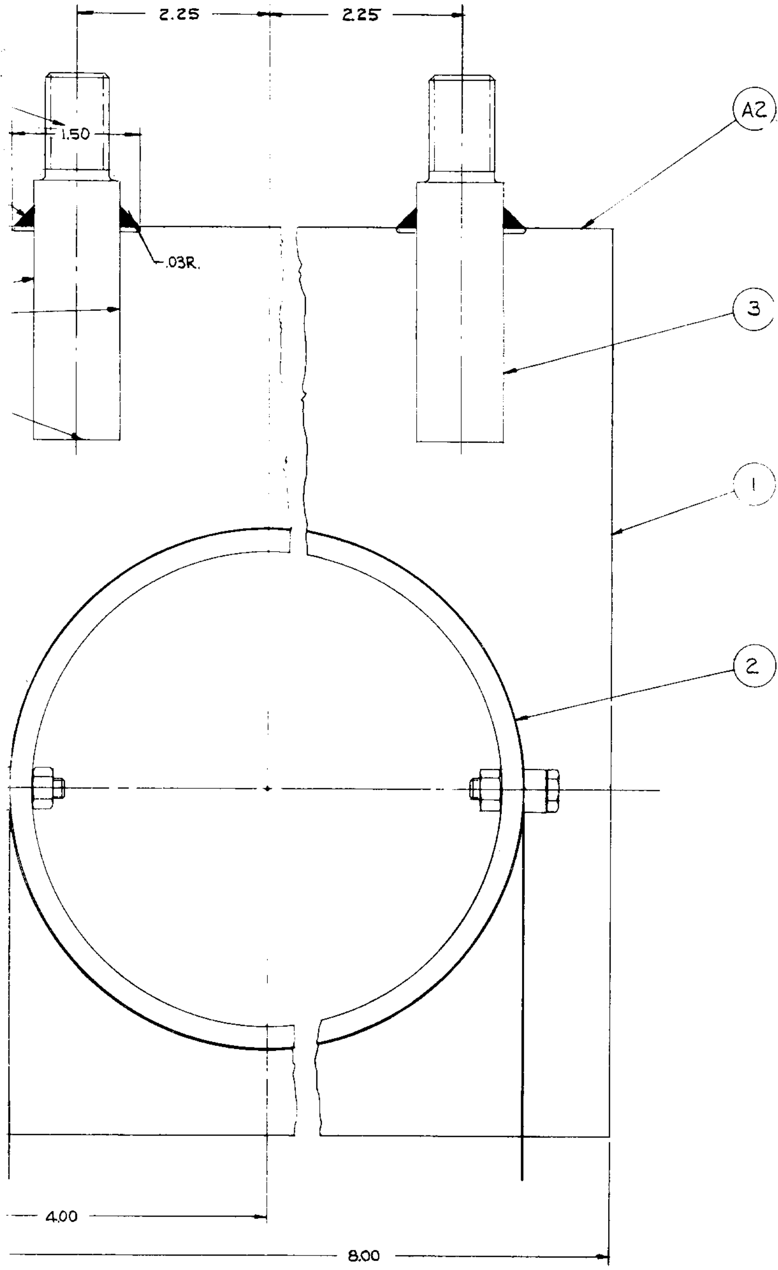
Figure 35



A2				
A1				
	AN121502			
	AN104712			
4				
3		A1 A2		
2		A1 A2		
1		A1 A2		
ITEM NO.	PART NO.	ASSY.	PART NO.	PART
ADD			REFERENCE	CA

REVISIONS

CHG LTR. | DESCRIPTION



SAME AS A1 EXCEPT FOR WELDING POSITION OF ITEM NOS. 2 & 3 AS SHOWN

LS

USE SPEC 8178 WELDING WIRE

BREAK SHARP EDGES .005-.015
APPROX R & BLEND

WELD SIZE & LOC DIM. ±.030
FINISHED DIM. ±.010
ALL ANGLES ±2°

ALL NOTES APPLY
UNLESS OTHERWISE SPECIFIED

A2					1	RIG ASS'Y				
A1					1	RIG ASS'Y				
	AN121502				2	NUT - .250-28 UNF 3B				
	AN104712				2	BOLT - .250-28 UNF 3A - .875 LENGTH				
4					2	FASTENER -		AISI 321		
3		A1 A2			2	LUG -		AISI 321		
2		A1 A2			2	CYLINDER -		AISI 321		
1		A1 A2			2	PLATE -		AISI 321		
ITEM NO.	PART NO.	ASSY.	PART NO.	PART NO.	QUAN.	DESCRIPTION	INTERC.	MATL	OTHER SPECS	FORG CAST WR
	ADD		REFERENCE	CANCEL						

ITEM NO. | PART NO. ASS'Y PART NO. PART NO. | DESCRIPTION | INTERCH. | MATL.
ADD REFERENCE CANCEL
PARTS LIST

SCALE FULL
JOB NUMBER 7491
DRAWN BY Zawonski
STARTED 10-24-60
COMPLETED 10-25-60
APley 10-26-60
J. L. 10-26-60
MET ENGR. | EXP. | MFG ENGRG. | DESIGN SUPER. | PROJ. ENG. DESIGN

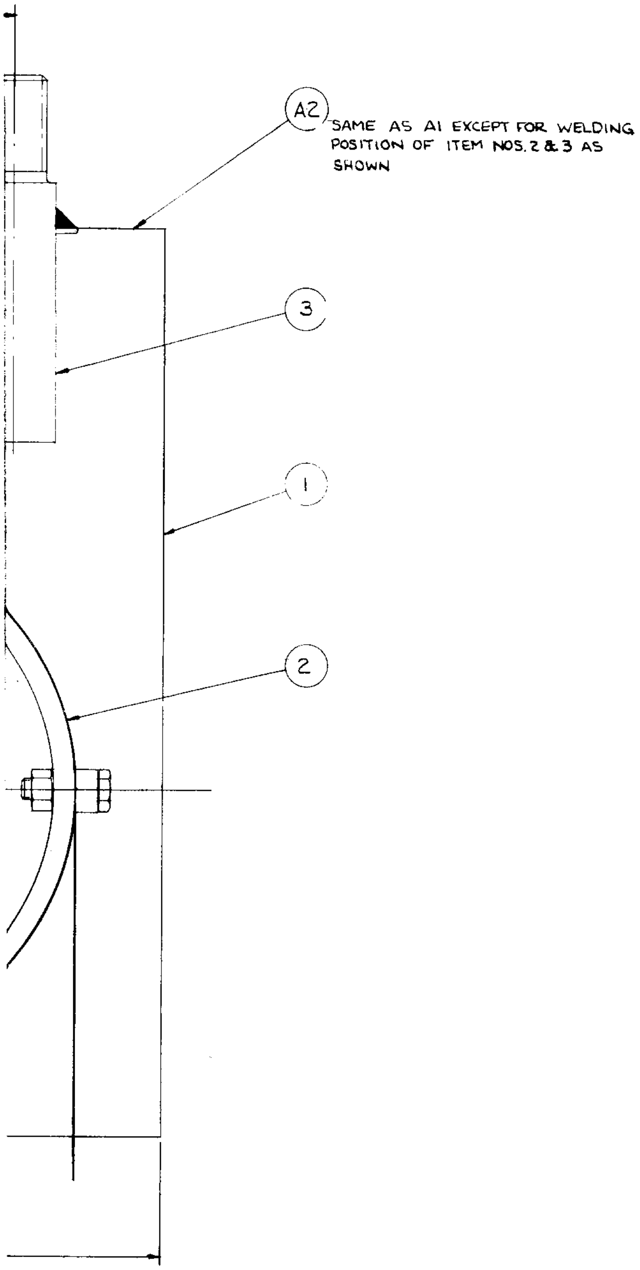
CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE NEW JERSEY U.S.A.

INTER-LOCKING TITANIUM
WIRE CASE -
TENSION RIG

MODEL | SH

Figure 36 Tension Test R

REVISIONS			
CHG LTR.	DESCRIPTION	DATE	ENGRS.



LS 25806

USE SPEC 8178 WELDING WIRE

BREAK SHARP EDGES .005-.015
APPROX R & BLEND

WELD SIZE & LOC DIM.. ±.030
FINISHED DIM. ±.010
ALL ANGLES ±2°

ALL NOTES APPLY
UNLESS OTHERWISE SPECIFIED

S'Y				
S'Y				
.260-28 UNF 3B				
.250-28 UNF 3A -.875 LENGTH				
ER -		AISI 321		
		AISI 321		
ER -		AISI 321		
-		AISI 321		
DESCRIPTION	INTERC.	MATL	OTHER SPECS	FORG CAST WR

ITEM NO.	PART NO. ASS'Y ADD	PART NO. REFERENCE	CANC'L	DESCRIPTION	INTERCH.	MAT'L	OTHER SPECS	FORG. CAST W.R.

PARTS LIST

SCALE FULL
JOB NUMBER 7491
DRAWN BY ZAWONSKI
STARTED 10-24-60
COMPLETED 10-25-60
aBey 10-26-60
J. L. 10-26-60
10/27/60
MET. ENGR. EXP. MFG. ENG'G DESIGN SUPER. PROJ. ENG. DESIGN SPECIAL ENGR. ENGINEERING MGRS.

CURTISS-WRIGHT CORP.
WRIGHT AERONAUTICAL DIV.
WOOD-RIDGE NEW JERSEY, U.S.A.

INTER-LOCKING TITANIUM
WIRE CASE-
TENSION RIG

MODEL
LS 25806
SH. 1 OF 1 SHEETS

Figure 36 Tension Test Rig

TABLE I

AGING RESPONSE OF B120VCA TITANIUM WIRE

ROOM TEMPERATURE TENSILE PROPERTIES OF "CHANNEL" WIRE

Aging Condition		Ultimate Tensile Strength		Yield Strength (.2% Offset)		Elongation in 1"	
		Avg. KSI	Range KSI	Avg. KSI	Range KSI	Avg. %	Range %
As rec'd.	0 hrs.	222.7	221.2-224.2	217.0	215.9-218.1	2.5	2.0-3.0
700°F	10 hrs.	269.0	**267.4-271.0	268.7	***268.5-269.1	1.5	1.5
700°F	15 hrs.	275.9	**274.9-276.9	275.0	***274.4-275.8	1.0	1.0
700°F	20 hrs.	271.5	265.2-277.2	270.0	264.6-275.2	2.0	2.0
700°F	25 hrs.	-	**278.8	-	***280.2	0.75	0.5-1.0
700°F	30 hrs.	291.2	***286.0-296.4	290.0	286.0-293.9	0.75	0.5-1.0
750°F	5 hrs.	265.3	264.9-265.7	262.7	262.4-263.0	1.5	1.0-2.0
750°F	10 hrs.	277.7	277.7	273.8	273.8	1.5	1.5
750°F	15 hrs.	276.2	271.6-280.8	274.5	271.0-278.0	1.0	1.0
750°F	20 hrs.	***					
750°F	25 hrs.	-	**287.2	-	***289.4		0.75
750°F	30 hrs.	-	**283.6	-	***293.9	1.0	1.0

TABLE I (Continued)

Aging Condition		Ultimate Tensile Strength Avg. KSI	Ultimate Tensile Strength Range KSI	Yield Strength (.2% Offset) Avg. KSI	Yield Strength (.2% Offset) Range KSI	Elongation in 1" Avg. %	Elongation in 1" Range %
750°F	38 hrs.	-	**291.1	-	***294.7	0.75	0.5-1.0
800°F	10 hrs.	275.9	273.5-279.7	275.0	274.6-275.5	0.75	0.5-1.0
800°F	15 hrs.	283.0	280.2-285.8	280.5	279.7-281.3	0.75	0.5-1.0
800°F	20 hrs.	269.8	**268.8-**270.8	275.0	***274.4-***275.8	0.5	0.5
800°F	25 hrs.	271.0	271.0	269.1	269.1	1.0	0.5-1.5
800°F	30 hrs.	***					

NOTE: * All wire samples cooled to room temperature in vacuum.

** Sample failed at listed strength which is related to yield strength.

*** Extrapolated value of the yield strength.

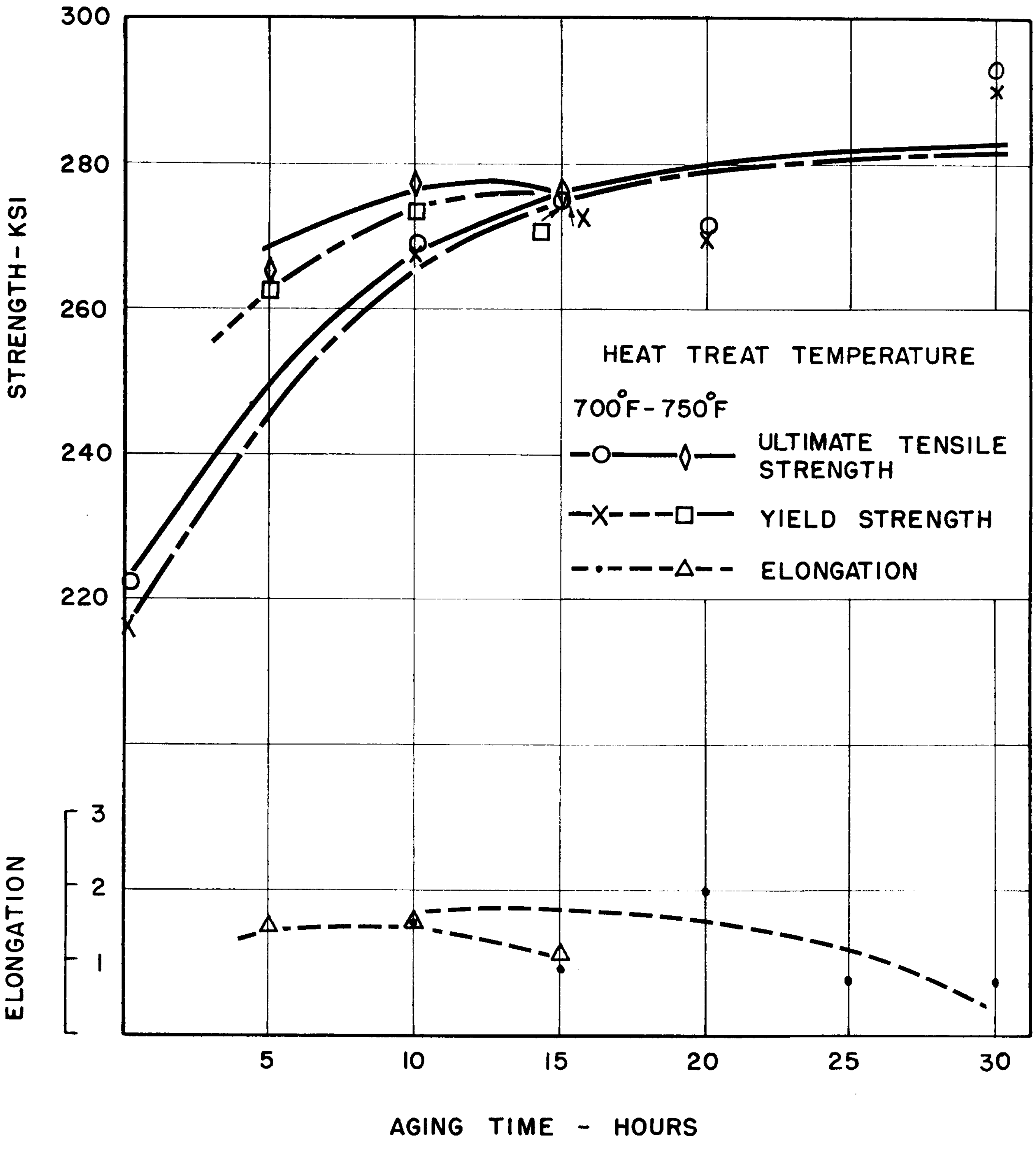

300
280
260
240
220
STRENGTH - KSI
3
2
1
ELONGATION
5
10
15
20
25
30
AGING TIME - HOURS
HEAT TREAT TEMPERATURE
700°F - 750°F
ULTIMATE TENSILE STRENGTH
YIELD STRENGTH
ELONGATION

Figure 37

TABLE II

"I" BEAM SHAPE HAVING CROSS-SECTIONAL AREA = $5.0 \times 10^{-3} IN^2$

Aging Temperature and Time	U.T.S. (ksi)	Y.S. (ksi)	Elongation in 1" (%)
As Received (50% cold work)	211.3	204.2	4.0
800°F - 5 hours	246.2	239.75	2.0
800°F - 10 hours	262.5	252.5	2.25
800°F - 15 hours	265.0	254.0	1.75
800°F - 20 hours	263.0	255.5	1.0
800°F - 25 hours	264.0	259.0	--
800°F - 30 hours	263.0	254.5	--
800°F - 38 hours	255.0	--	--

HEAT TREAT RESPONSE OF "I" BEAM WIRE

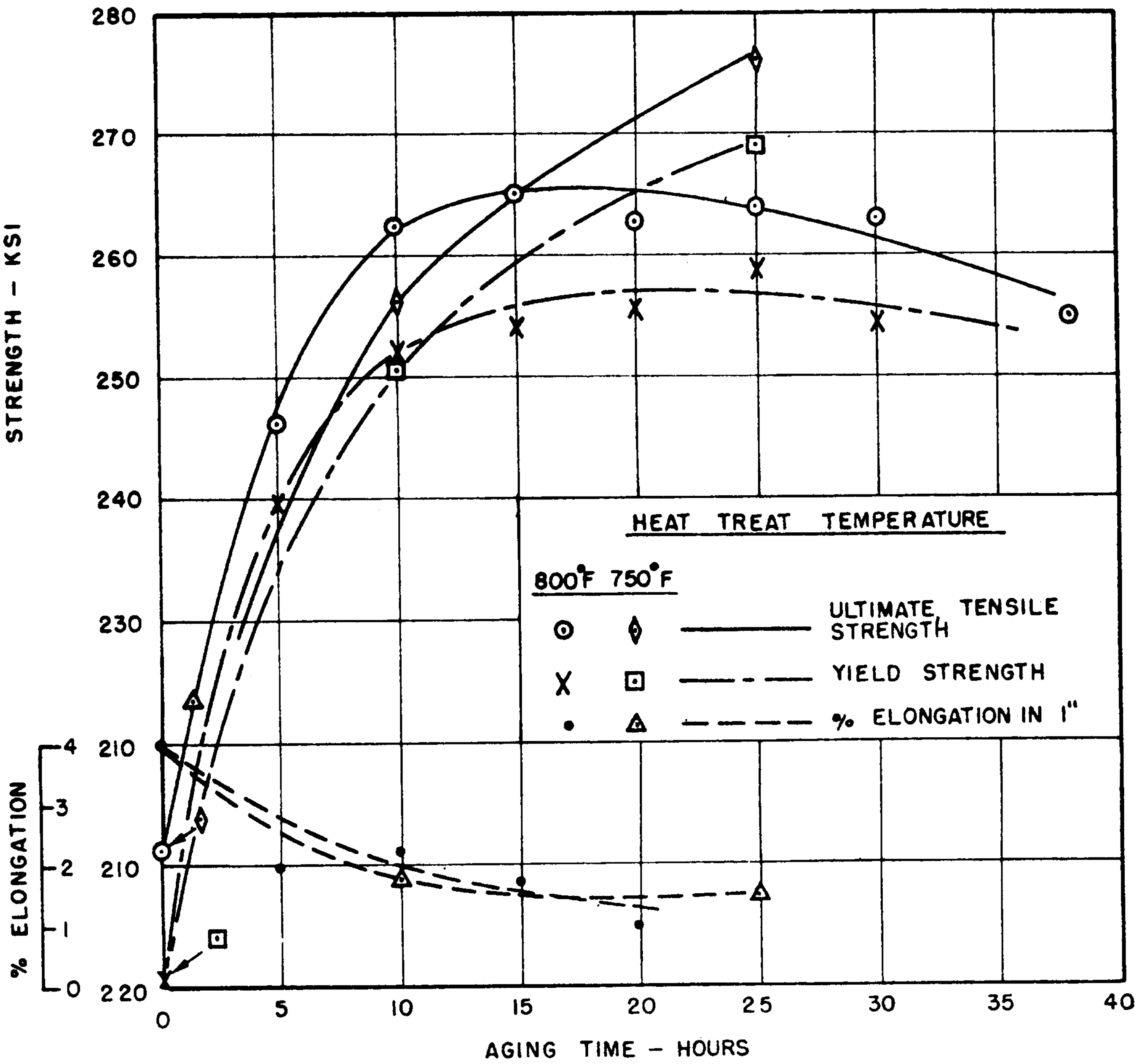
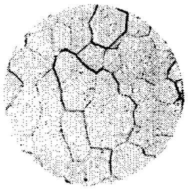
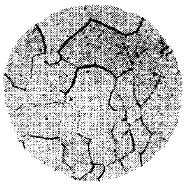
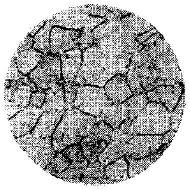
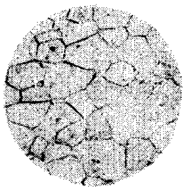
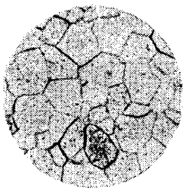
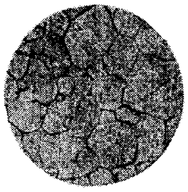
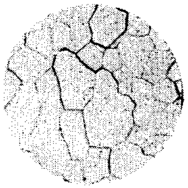
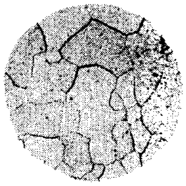
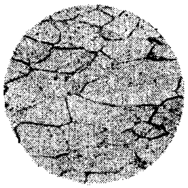
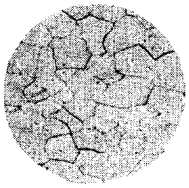
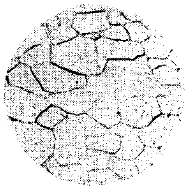
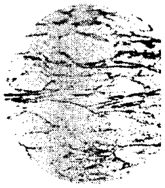
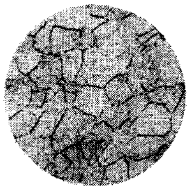
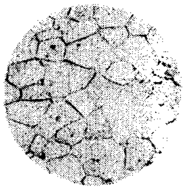
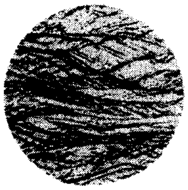
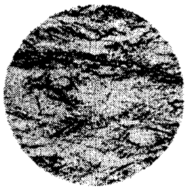
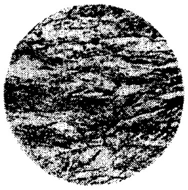
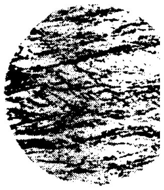
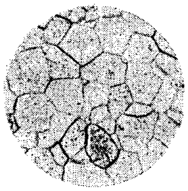
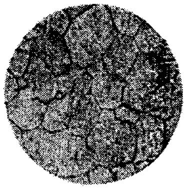
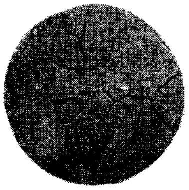
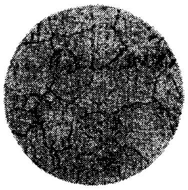
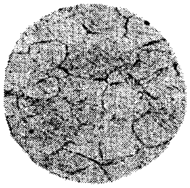
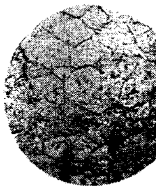


Figure 38

AGING R

MATERIAL CONDITION		
	5.6	5.6
a AS COLD ROLLED		
b AGED 750°F-20 HRS.		
c AGED 750°F-47 HRS.		

AGING RESPONSE VS. % RA

	RA (%)					
	5.6	5.6	11.8	18.9	25.6	30.0
						
						
						

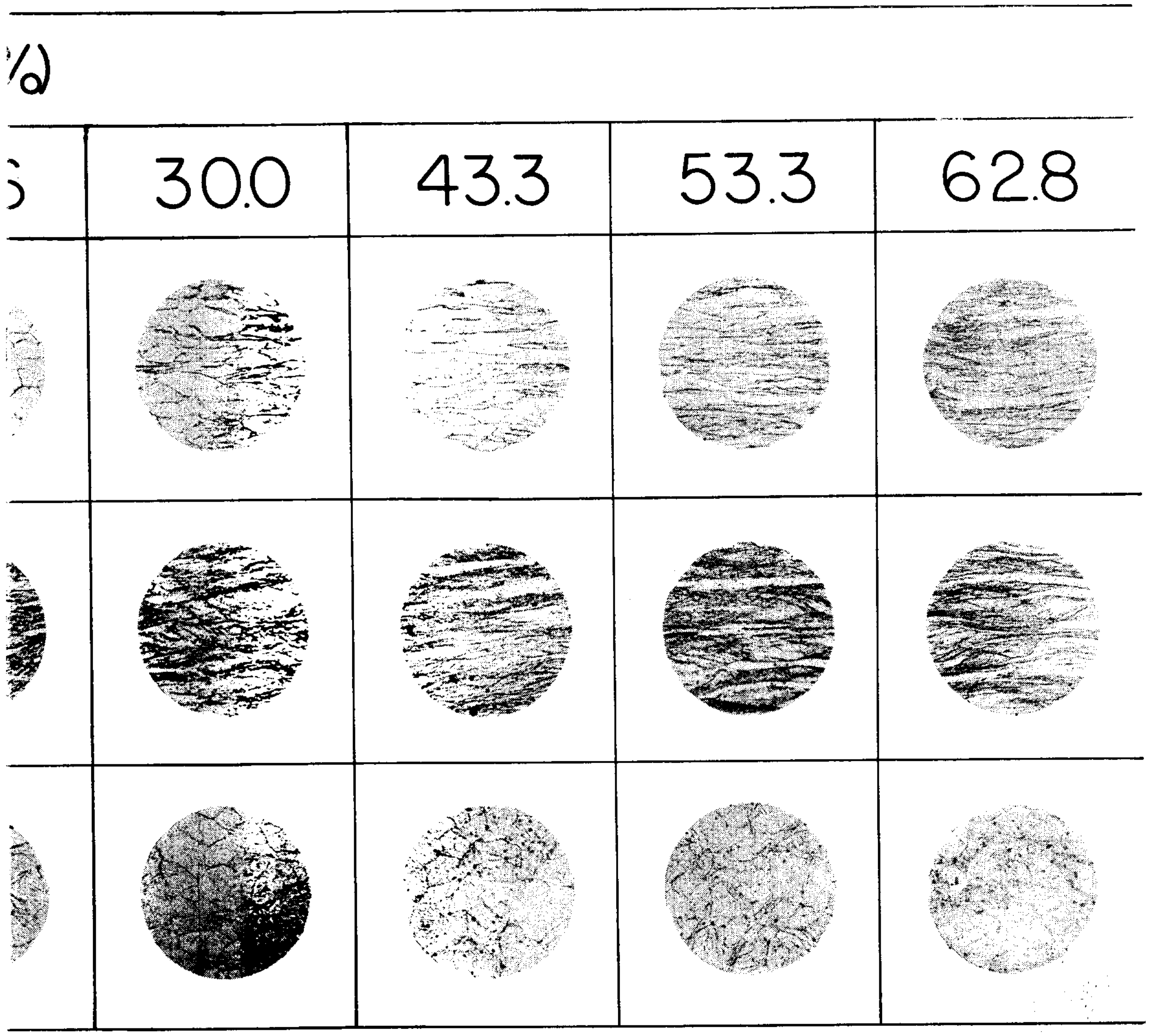


Figure 39

Hardness vs % RA

(750°F Isotherm)

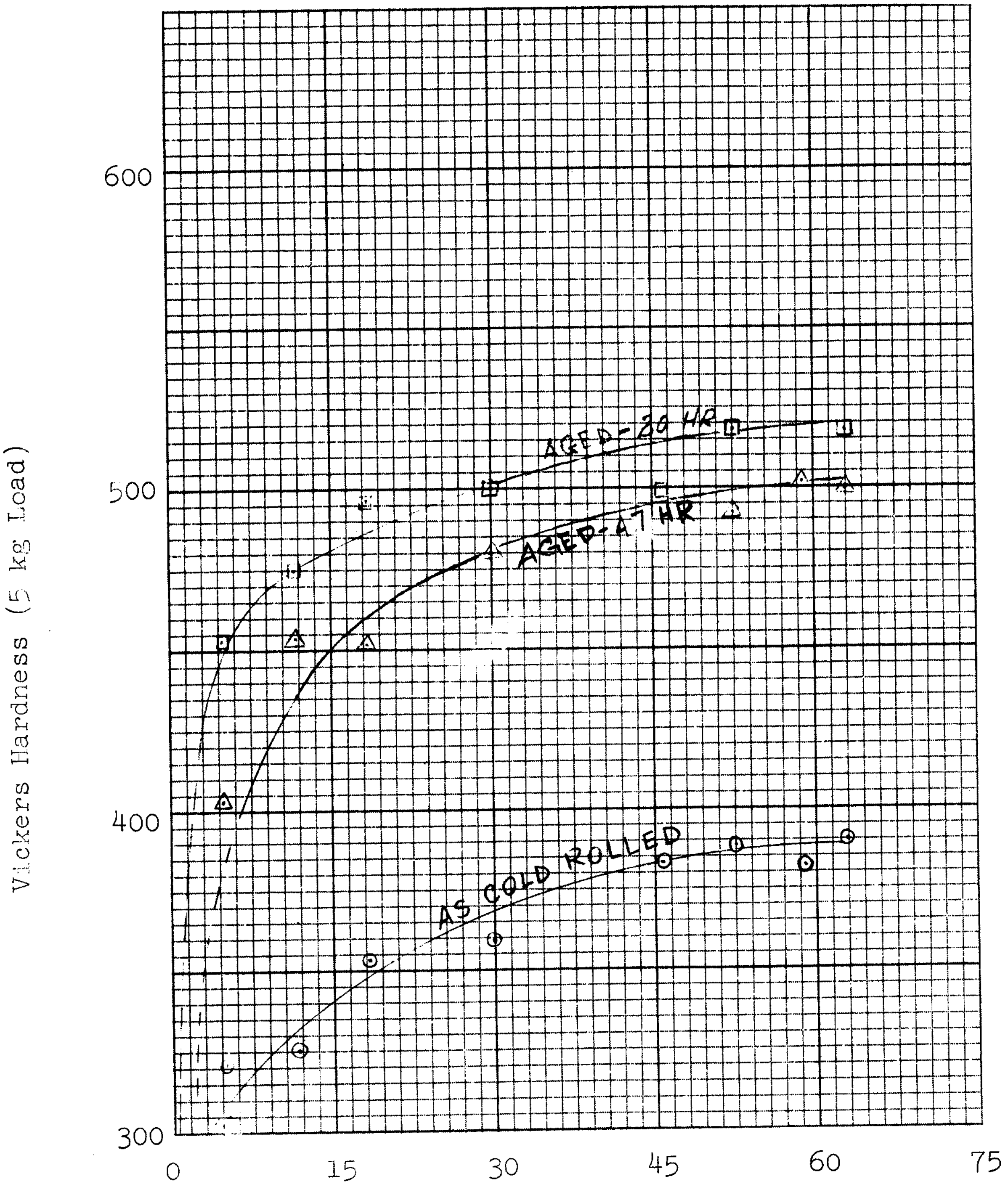
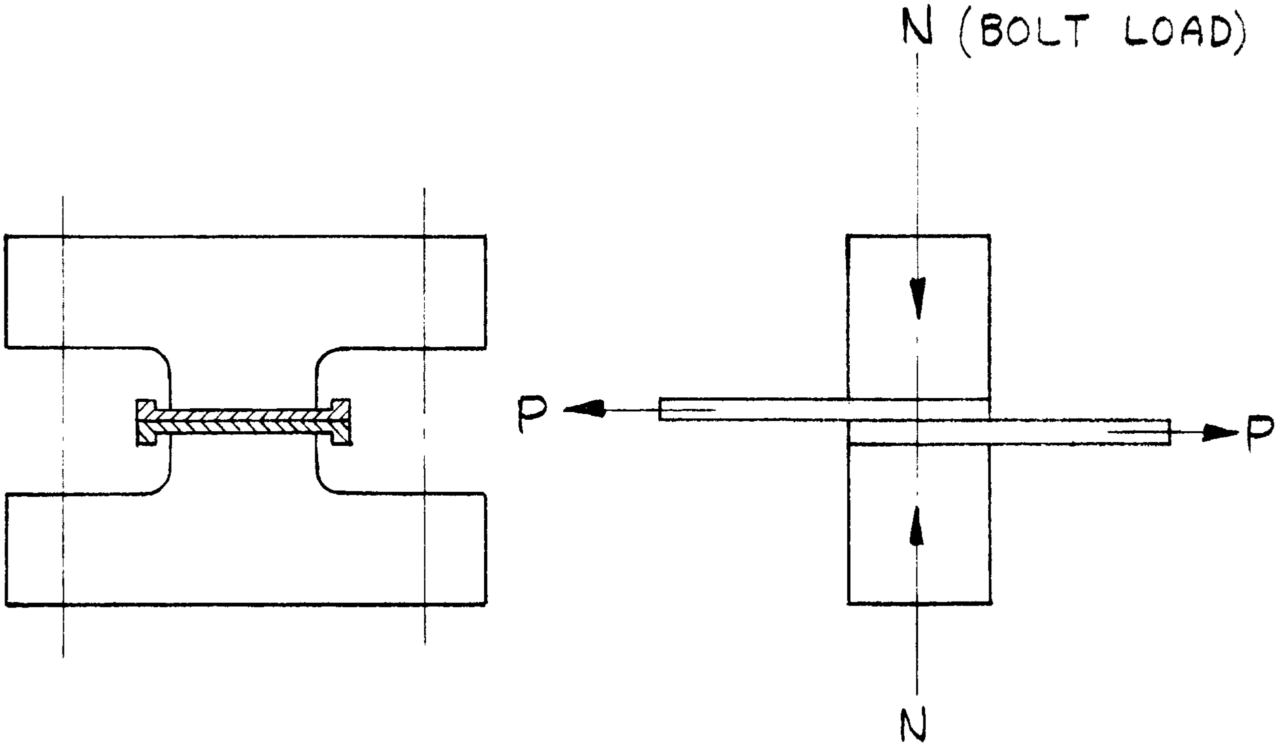


Fig. 40

FRICTION TEST CLAMP



$$\mu = \frac{P}{N}$$

Figure 41

TABLE III

COEFFICIENT OF FRICTION OF B120VCA TITANIUM WIRE

Torque (#)	Nominal Load N (#)	Tensile Load P (#)	Coefficient $\mu = \frac{F}{N}$
	Cold Rolled (Drawn) Wire		
24	1046.9	280	0.267
28	1219.9	360	0.295
34	1480.0	400	0.270
42	1828.2	455	0.249
56	2436.5	660	0.271
			0.270 Avg.
	Cold Rolled, Heat Treated Wire		
24	1046.9	395	0.377
28	1219.9	415	0.340
34	1480.0	510	0.345
42	1828.2	650	0.355
56	2436.5	790	0.324
			0.348 Avg.

RELATIONSHIP BETWEEN THE ANGLE OF WIRE AND COEFFICENT OF FRICTION

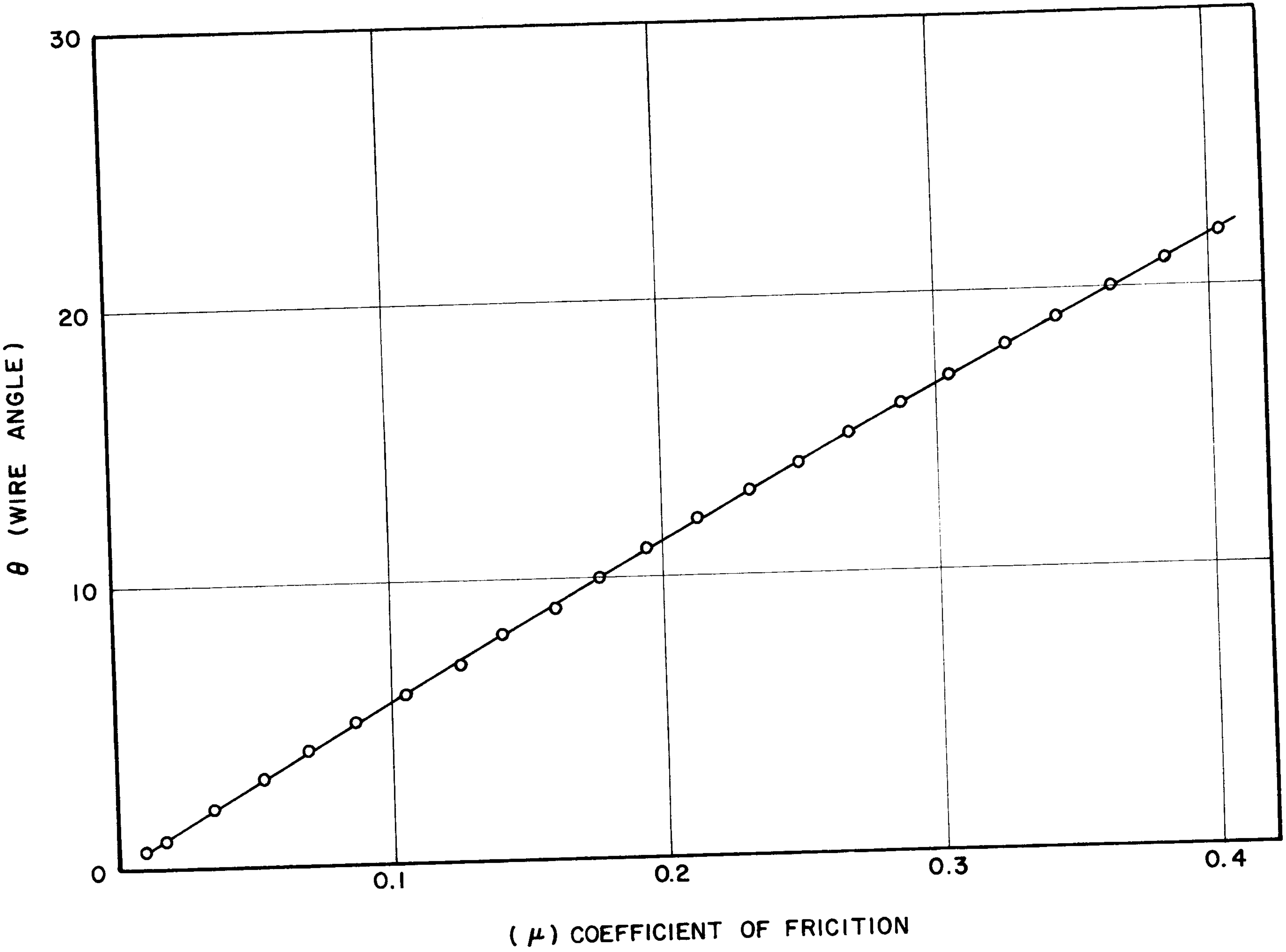
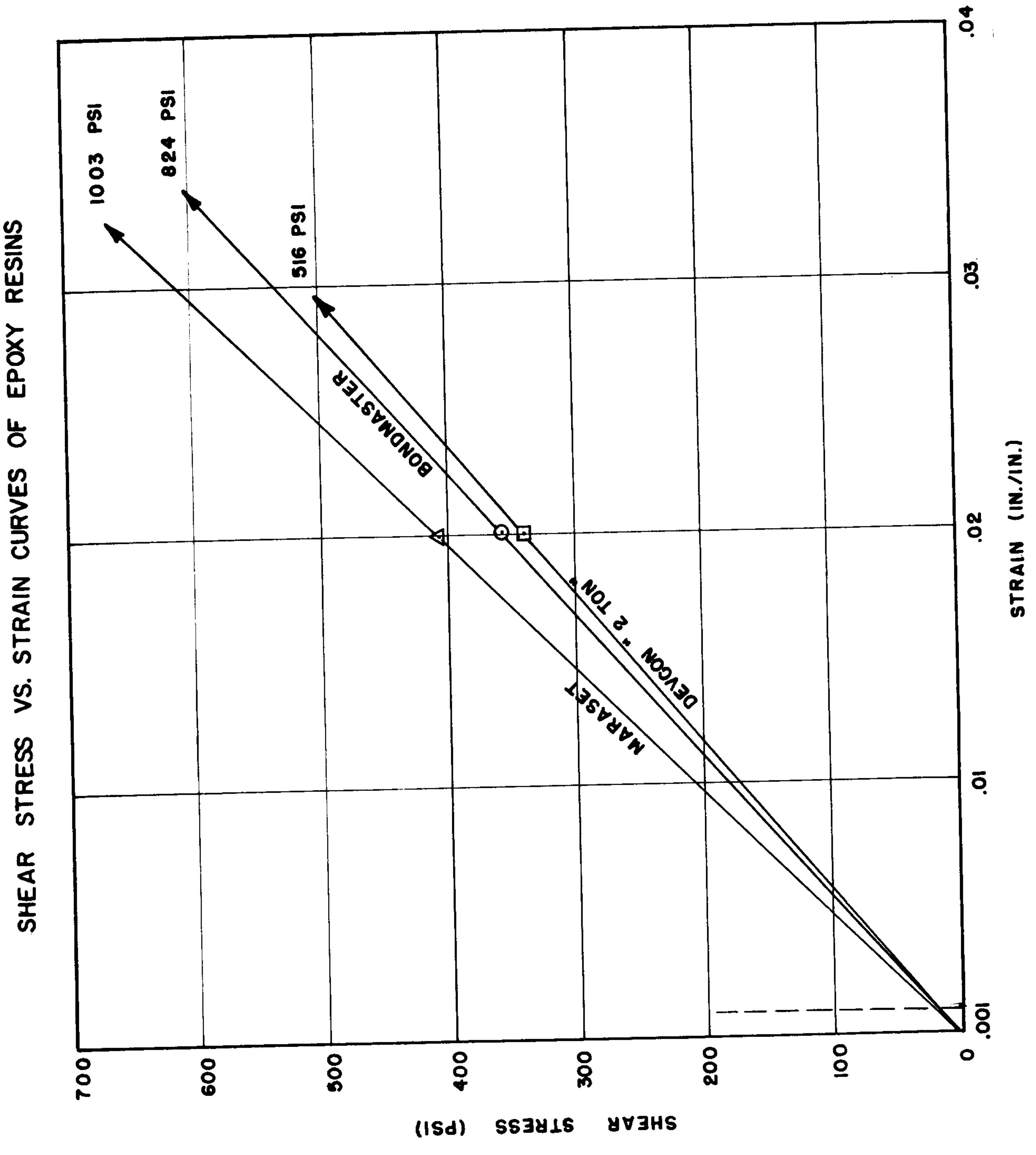


Figure 42

TABLE IV

RESIN EVALUATION

Resin	Shearing Stress (psi)	Modulus of Elasticity $(X10^4)$(psi)
"MARASET" (Marbelette Corp.)	1003	2.04
"BOND MASTER" (Rubber & Asbestos Corp.)	824	1.78
"DEVCON '2 TON'" (Devcon Corp.)	516	1.69



SHEAR STRESS VS. STRAIN CURVES OF EPOXY RESINS

Figure 43

LINER FILM TEST

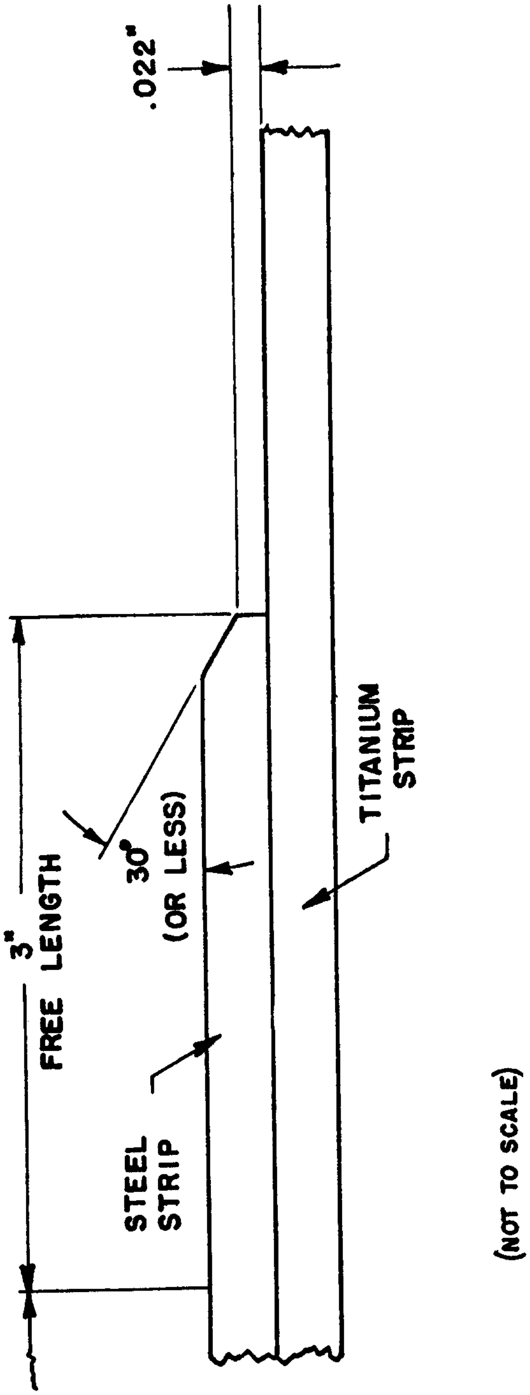
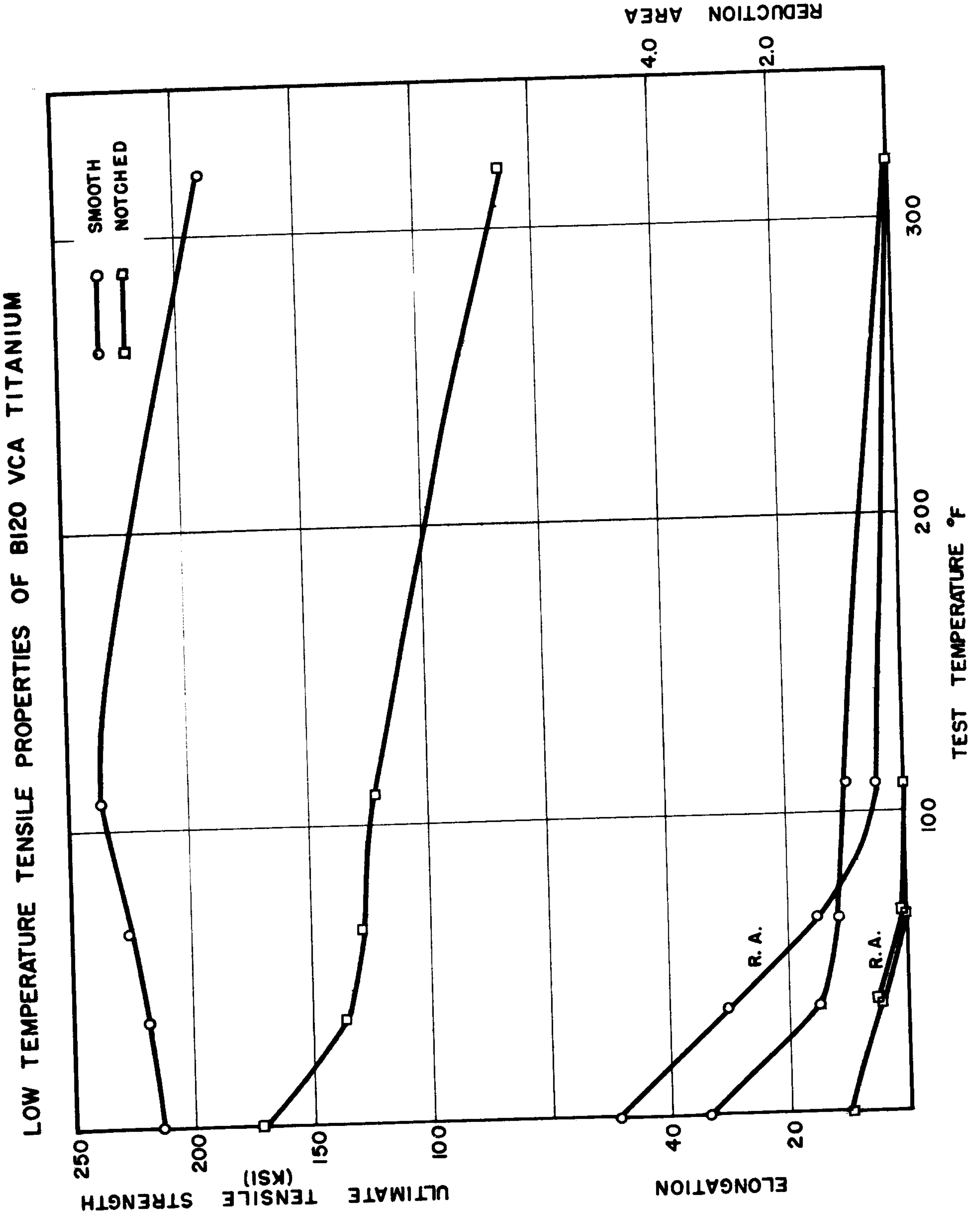


Figure 44

LOW TEMPERATURE TENSILE PROPERTIES
OF
B120VCA Ti - AGED AT 900°F - 75 HRS.
AC (HEAT #F-6236 - GAGE - 0.090")

Test Temperature	Condition	UTS	Elongation in 1" (%)	RA (%)	RATIO: $\frac{\text{Notched UTS}}{\text{Smooth UTS}}$
Room Temperature	Smooth	214.0	3.4	4.9	0.78
	Notched	164.1	1.0		
-35°F	Smooth	220.6	1.5	3.1	0.61
	Notched	135.5	.3	0.5	
-65°F	Smooth	227.2	1.2	1.5	0.57
	Notched	129.5	.05	0.1	
-110°F	Smooth	235.8	1.0	0.5	0.52
	Notched	121.5	0	0	
-320°F	Smooth	190.0	0	0	0.34
	Notched	64.0			

FIG. 45



LOW TEMPERATURE TENSILE PROPERTIES OF BI20 VCA TITANIUM

Figure 46

6.0 EXPERIMENTAL MANUFACTURING

6.0 EXPERIMENTAL MANUFACTURING

The manufacture of two 6.2" I.D. sub-scale vessels, employing the tape configurations illustrated in Figures 3 and 4, was accomplished on a converted lathe shown in Figures 47 and 48. This piece of equipment consists of the following components:

(a) Wrapping Apparatus (6T-60924)

(b) End Adapters (LS-25439-7)

(c) Collapsible Mandrel (6T-60925)

(d) Reel Equipment (6T-60988)

(e) Dummy Arbor (DA-32360)

6.1 Wrapping Apparatus

The wrapping apparatus (Figure 49) rolls over the mandrel assembly (described in the following section) on the ways of the lathe. It is initially supported on three legs. The apparatus is fitted with three equally spaced and free rotating rollers. Two of the rollers are mounted on shafts which are clamped to the frame and the third is mounted on a cylinder. This system is capable of applying a rolling radial force of 2500 pounds on the tape. By application of the rolling force, the apparatus lifts from its legs and centers itself on the mandrel. The roller shafts are axially and angularly adjustable by means of gage blocks and sine bar devices mounted at the shaft ends (Figure 49). This provides a means of tilting the rollers to the wrapping helix angle while maintaining their correct axial positions. A spring loaded guide pushes the tape axially at the point of tangency as the tape is fed on the mandrel. Three sets of rollers are required to wrap a vessel. Each set of rollers is formed to suit the particular tape shape. The apparatus is attached to the compound of the lathe carriage through tie rods for driving through the lathe lead screw. This provides axial and square adjustment of the apparatus while it is engaged in the lead screw pitch. By removing the tie rods, the apparatus may free-track to follow the pitch of a tape lay.

Trail wrapping was attempted with spring loaded tie rods pulling the head in the anti-wrapping direction with forces which are great enough to overcome the friction between the tape and the arbor. The tests were unsuccessful since the

6.1 Wrapping Apparatus (Continued)

rollers pulled out of the tape track. The rollers were subsequently reworked to remove the .010" radii at their edges. Another trial run showed them to still roll out of the tape track. It was then concluded that the head must be able to track freely, uninhibited by external forces.

The tie rods were removed and the same tape was wrapped with the head tracking freely. The roller helix angle or tilt was set for .190" pitch or .010" less than the channel width. As the channel winds on the arbor, it is continuously pushed at the shoulder by the difference in pitch, which causes the tape to slip on the arbor until it butts the previous wrap (Figure 50). After butting is achieved, the roller slips on the tape to make up for the pitch difference. This is a continuous and smooth occurrence since the displacements are achieved in the circumferential length of 20 inches in each turn. The first trial of 14 wraps measured .011" more than 14 times the mean width of the channel. A second trial with a more uniform channel was wrapped 17 turns with a measured length of .0005" more than 17 times the mean tape width. This method of wrapping is considered acceptable for the first layer.

Trial wrapping of the second layer was first attempted with an embrittled tape section which failed under load. A second attempt was made using a unheat-treated length which distorted under a load of 1500 pounds and required 500 pounds to bottom on the first layer. The second layer was wrapped successfully with a 1000 pound radial load, but the interference fit was not sufficient for full interlock.

The third layer was similarly wrapped with a 1000 pound radial load. The three layers shown in Figure 51 were wrapped on the dummy arbor demonstrating that the wrapping technique, except for increased interference fit, is feasible.

6.2 End Adapters

300M and SAE 52100 steel end adapters are rough turned, heat treated, and ground all over. All helical surfaces are ground on a thread grinder in the solid stock. The grinding of the inner tape is done after assembly in order to maintain adapter strength during wrapping and mandrel stripping. The technique developed for grinding the helical surfaces utilizes a set of wheel dressing cams which provides a "V" shaped wheel edge with a 24° included angle. The point is dressed down so that

6.2 End Adapters (Continued)

the wheel grinds a groove of .0544"-.0536" width when fed to a sufficient depth. The adapter is clamped on an arbor (Figure 52) which has angular scribe marks to permit rotation and re-indexing of the adapter relative to the wheel and arbor which are constantly engaged in the machine's .200 pitch. In this manner, control of the pitch is maintained while the same wheel is relatively shifted from position to grind the other groove shapes which are off the pitch lines.

A comparator chart of 62-1/2 magnification was used to check the helical surfaces on an optical comparator.

The grinding of the inner taper is done after assembly in order to maintain adapter strength during wrapping and mandrel stripping. A support tube (Figure 53) was designed and fabricated which clamps the adapters of a finished vessel. This tube supports the vessel during grinding of the tapers and also acts as a protective case for the vessel.

6.3 Collapsible Mandrel

The end adapters are assembled and clamped on a mandrel (Figure 54) which holds them in position and provides a core for wrapping. This mandrel is capable of absorbing the wrapping loads and is collapsible and retractable after wrapping. It consists of a solid stepped shaft (Figure 55) onto which a five-segment shell is assembled. The segments were made from two hardened cylinders which were ground on the I.D. to fit the center shaft and on the O.D. at each end to fit the counterbore in the locating rings. The segments are clamped to the shaft by means of the locating rings which are piloted on the shaft and are in turn clamped in the assembly. The end adapters are assembled on the locating rings and held axially between the segment's shoulders and end plates. The adapters are free to rotate for angular positioning by adjustment of the end plates. In disassembly, the end plates are removed and one locating ring removed by pull-out screws. The assembly is located on a sleeve which permits the pressing out of the shaft which in turn pushes out the second locating ring. The pressing load is opposed by the reaction load passing through the sleeve, the end adapter, and the segments. The segments are then free to be pulled to the center and withdrawn. During wrapping, the mandrel assembly is driven on a lathe between the face plate and a live center (Figure 56).

6.3 Collapsible Mandrel (Continued)

The extraction of the mandrel, after wrapping, required approximately a 10,000 pound force. This was resulted in the draging of the tape causing a "saw-tooth" effect. In view of this, a new inner core was designed and constructed for the collapsible mandrel. The new core incorporates a 1/16 inch thick "Cero Alloy" sleeve which will be melted before extraction of the core, and thus reduce the extraction force.

6.4 Reel Equipment

Reel equipment is mounted on the lathe head and locates the tape reels in the axial location of the mandrel. Each reel (Figure 56) holds enough tape for one layer and spaces it to the wrapping pitch. The reel is mounted on a shaft shich is supported between bearings (Figure 57). A drag brake is mounted at one end of the shaft and is controlled by a potentiometer which can vary the tape tension in a range of 0-400 pounds.

6.5 Dummy Arbor

A dummy arbor (Figure 58) which simulates a mandrel assembly with end adapters has been designed and fabricated. This is a hardened, solid steel arbor which is used in the development of wrapping procedures. Variables due to tape tolerances and assembly of parts are minimized so that the adapters and mandrel are not jeopardized during development.

6.6 Staking

This method of joining the tapes to the adapters includes drilling for pins in the hardened tape and adapter material on a sensitive drill. The drilling must be done at the wrapping machine with a hand drill which presents risk of drill breakage. The drilling of the end adapters requires solid carbide drills which are extremely brittle. The staking pin size has been increased to 1/16" to reduce drill breakage.

6.7 Wrapping Development

Trial wrappings of the first layer were made with the roller helix angles set for .200" pitch and the wrapping head driven by the lathe lead screw. The resulting spacing was erratic. The first layer must be wrapped with channels butting tightly to permit fitting of the second layer interlock. Several modifications were made to the wrapping apparatus primarily for this

6.7 Wrapping Development (Continued)

purpose. The probability of tape width, the head tracking rate, and the lathe lead being exactly the same is remote. Therefore, axial slippage is expected and should be used to advantage. Fixing of the head to the lathe lead screw, as originally contemplated, is not considered practical.

Experiments were then run with the wrapping apparatus on the bare dummy arbor using various roller helix angles and radial loads. An inconsistency in the tracking rate was detected. Eccentricities in the roller shaft assemblies and deflections in the apparatus due to machining tolerances and roller loads were noted. Corrected base line settings on the shaft assemblies were established to minimize the effect of these deviations.

Experiments were also carried out to determine the axial drag force required to overcome the clamping load of the rollers on the bare arbor. The apparatus was set to track the arbor by means of roller tilt and clamping load. Cables, fitted with a spring balance, were attached to the frame and fixed at opposite ends. The apparatus tracked the mandrel until the restraining force of the cables caused slippage between the rollers and the arbor. Coefficients of friction between .120-.126 were realized. A similar test was run with short pieces of channel tape located between the rollers and the arbor, but without rotation of the arbor. The drag force indicated a coefficient of friction of.5, approximately.

A modification was made on the wrapping apparatus which incorporated a third tie rod between the wrapping head and the lathe compound (Figure 59). The three equally spaced rods were fitted with springs and preloaded to pull the head back from the wrapping direction, thereby stacking the first channel tightly with a predetermined load.

In previous trial wraps, the radial forces used were 500, 1000, and 1000 pounds for the first, second, and third layers, respectively. The tape tension remained at 200 pounds.

No problems were encountered during the dummy arbor wrapping of the first layer. The second layer ("I" beam), however, fractured under the 2500 pound load on the first few laps over that portion of the cylinder equivalent to the adapter piece. The load was reduced to 1000 pounds over the adapter portion and then increased to 2500 pounds over the titanium-to-titanium interlocking sections without further cracking. The third layer was wrapped using a 500 pound load on the steel and 2500 pounds on the titanium without difficulties.

6.8 Wrapping Vessel No. 1

Vessel No. 1 (Figures 60 and 61) was wrapped, staked, and the mandrel successfully withdrawn. The force necessary to withdraw this mandrel was 10,000 pounds. This vessel appeared to be rigid and able to withstand handling despite the following condition:

(a) A variation in outside diameters between the end adapters and the mandrel resulting in an adapter to mandrel step. Wrapping difficulties occurred in these zones on all three layers. It is felt that this situation caused a "saw-tooth" effect on the inside of the vessel when the mandrel was extracted.

(b) The tape used (both "I" beam and channel) was slightly out of tolerance.

(c) An incorrect "as-received" helix on the third layer increased the tendency of this tape to eject the staking pins. This incorrect helix also caused the tape to form an "S" shaped curve coming off the wrapping reel. This condition produces difficulty in attaining a tight loop-to-loop (side face) contact. It was learned from these problems that the third layer (channel) must be wrapped during the tape manufacture process onto the drum with the legs facing inward.

Wrapping of the first layer employed the proper shaped rollers loaded to 500 pounds radially with a tensile force on the tape of 200 pounds. These rollers were free-tracking and were set at a retarding pitch of 0.190 inch; the wrapping pitch being 0.200 inch. The proper angular alignment (about its axis) of the terminal end-adapter was accomplished using a "Jo" block of a thickness equivalent to a multiple of the actual channel tape width. A gain of .001 inch in width for each turn due to the compressive deformation of the tape was measured resulting in a cumulative total terminal loss of .043 inch for the complete first layer. No measurable space between turns was observed. An "Indiac" concentricity measuring device showed maximum runout of 0.002 inch except in the adapter-to-mandrel transition areas where the step caused the instrument to run off scale.

The second layer, rolled with wide, plain rollers, cracked under the imposition of the high (2500 pounds) radial force.

6.8 Wrapping Vessel No. 1 (Continued)

A check of the end adapters revealed that the adapter section which fits into the groove of the "I" beam was wider than the tape groove and that sharp edges existed. By breaking these edges, the interference fit was reduced and cracking eliminated. This second layer was removed and, using new tape (having the same cross-section), rewound under a radial force of 1350 pounds.

The third layer (channel) also was confronted with the "step" problem. In addition, the application of the high radial rolling force (2500 pounds) plastically deformed the tape thus increasing the basic width of the channel by .0014 inch. The first few loops were unwound and the tape width reduced to 0.200 inch by hand filing. Pressure tests on subsequent wraps indicated that a gage setting of 45 psi (1300 pounds approximately), applied radially, was the optimum non-deforming force permissible. This setting was used to complete the wrapping of the third layer.

6.9 Wrapping Vessel No. 2

The first layer was successfully wrapped with a radial load of 570 pounds and tensile load of approximately80 pounds.

The second layer bottomed and locked with a radial load of 870 pounds and a tensile load of 80 pounds. A radial load of 1000 pounds caused distortion. Towards the end of the second layer at the terminal point of the first layer, a space developed between the first layer and the end-adapter shoulder. The staking pin for the first layer was removed, the adapter was rotated to close the space and wrapping of the second layer was completed. The space could be caused by a .0002 compression of the channel tape in the interference fit. The tape used in this vessel was not heat treated.

The third layer required a 1200 pound radial load and a 180 pound tensile load. No difficulties were encountered until the channel reached the first groove on the end adapter, at which point it was displaced approximately .005 forward. The last wrap had to be filed to fit.

After completion of wrapping and staking, the collapsible arbor was removed on an arbor press with no difficulty. The arbor extraction force was estimated at 5 tons. The inner tapers on the end adapters were machined to finish the vessel.

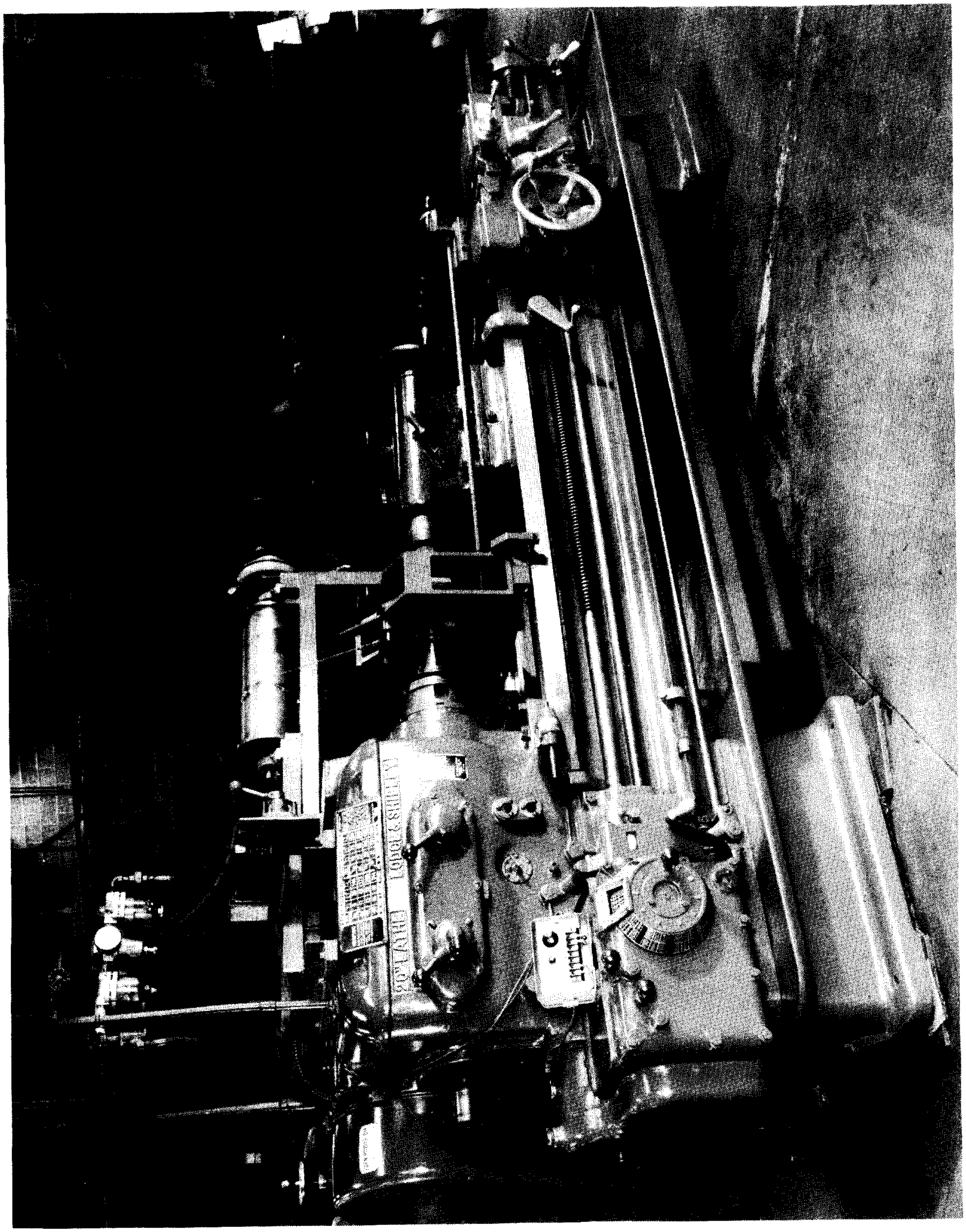
6.9 Wrapping Vessel No. 2 (Continued)

The finished vessel was approximately .020" smaller in diameter at the center than at the ends with .004" total runout of the end faces. The outer diameter remained smooth but the inner bore was slightly stepped in a manner resembling rifling. This indicates that the interlock between the 1st and 2nd layer is incomplete.

Generally, the wrapping was indicative of the feasibility of the technique. Better results are expected with more accurately sized tape with the required strength and ductility.

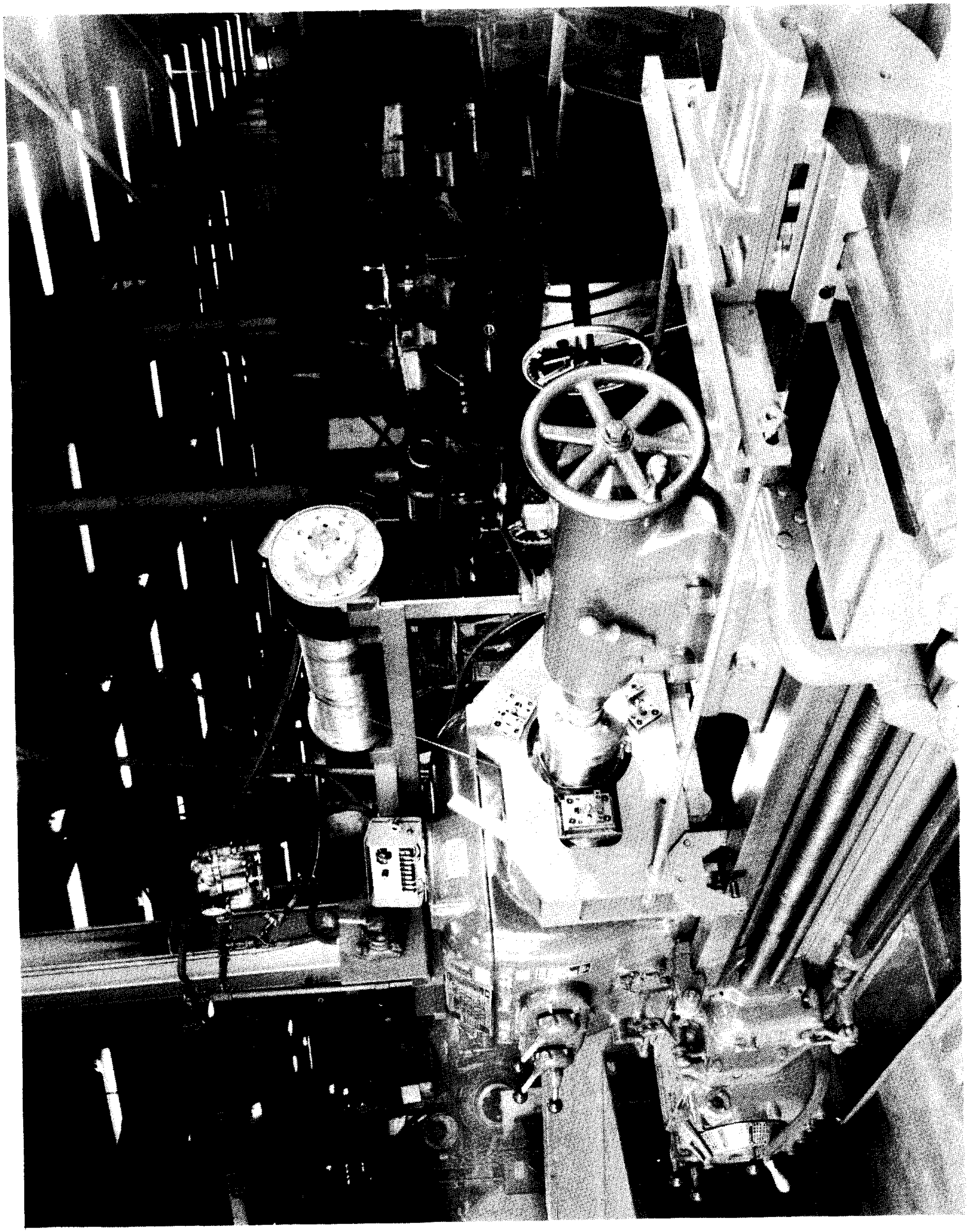
This vessel pressurized and leaked at 30 psig. The leak was caused by a separation of the tapes at one end of the vessel. Since the separation occurred near the edge of the end adapter, it was surmised that the flaw was caused by a compression of the end adapter as the mandrel parts were being withdrawn. The tensile force on the tape during wrapping imposes a hoop stress which is transmitted to the end adapters and the mandrel as a radial compressive force. As each portion of the mandrel is removed, the vessel contracts in that area. The first portion removed is located under the adapter near the point of failure. However, a good interlock between the tape layers should hold the vessel intact until the remainder of the mandrel is withdrawn. A modification on the mandrel could be made to permit a collapse prior to withdrawal.

This separation was plugged by casting an inner and outer shell of a low melting alloy. A second test was conducted which resulted in failure at 50 psig. The vessel separated in the center section far from the end adapters. The tape layers unwound easily indicating a lack of interlock. These sectional radii and the locking angles were enlarged and the 'I" beam was found to be twisted. It appears that after wrapping when the mandrel was withdrawn, the wrapping stresses were relieved by contraction of the vessel. The "I" beam twisted toward its free position (Figure 62) and a stagger "tooth effect" developed on both the O.D. and the I.D. of the vessel. It is suspected that the tape layers were not bottomed and the interlock was insufficient to prevent twisting.



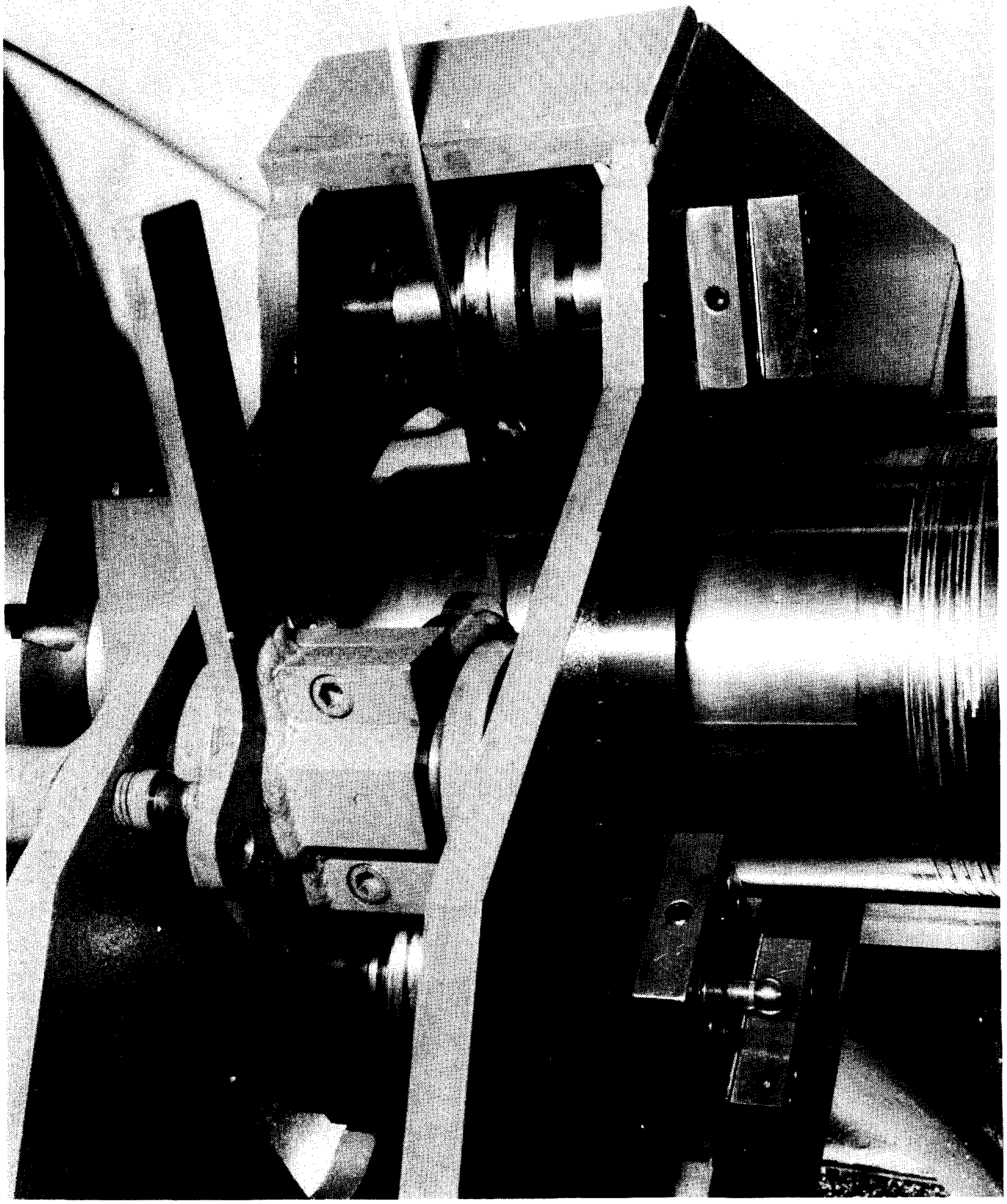
Tape Wrap Machine

Figure 47



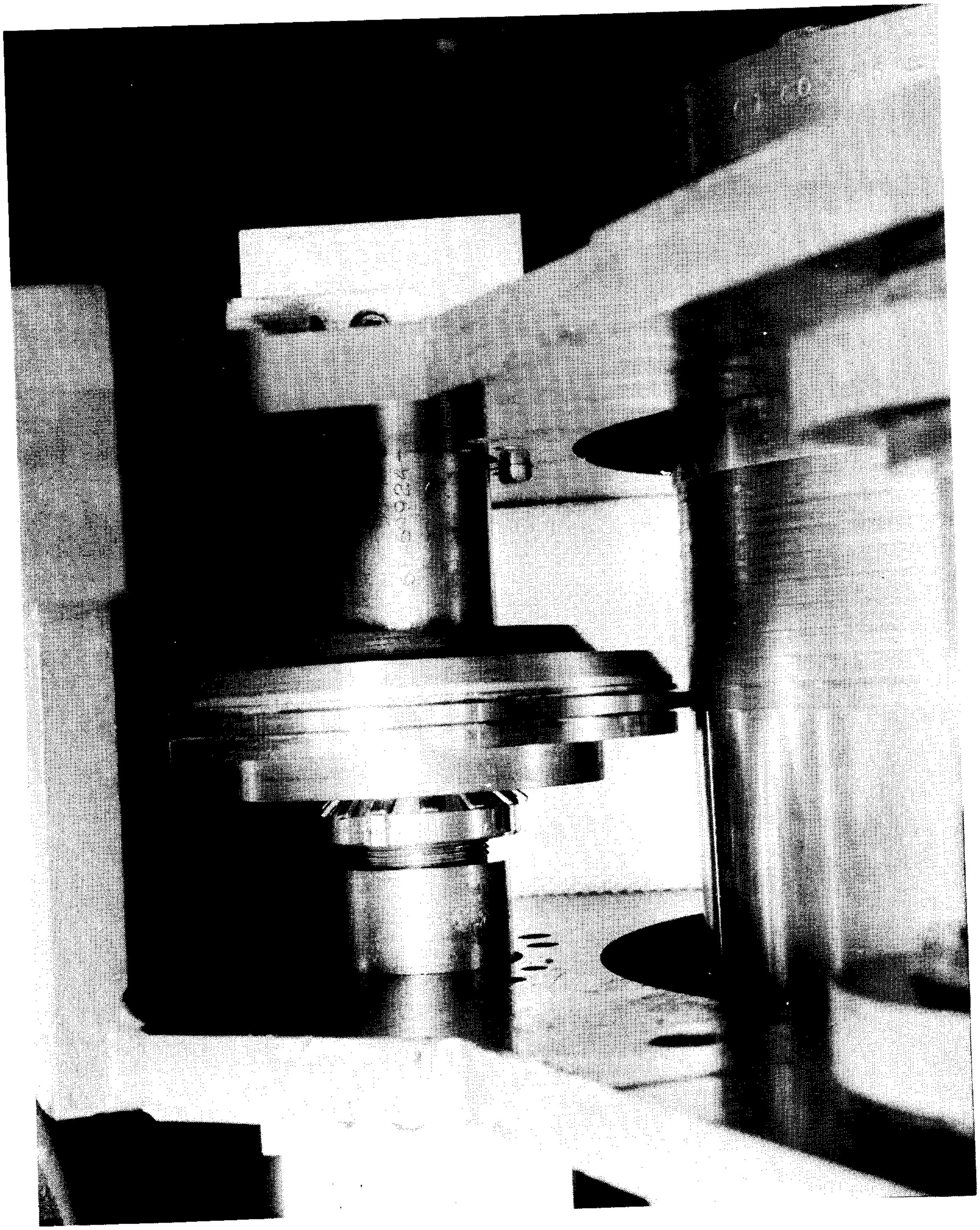
Wrapping Apparatus Close-Up

Figure 48



Wrapping Apparatus

Figure 49

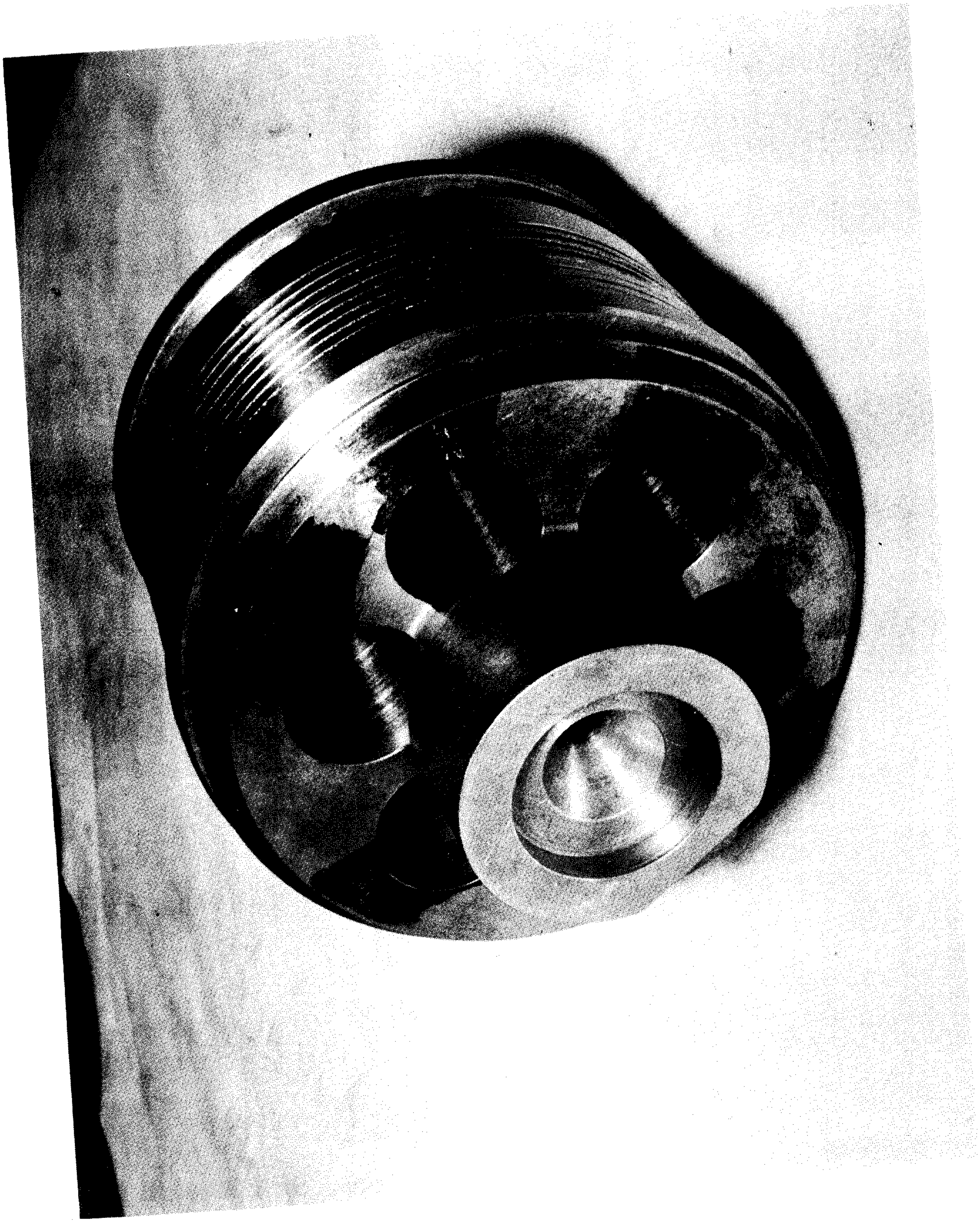


Close Up of Roller on Channel Wire

Figure 50

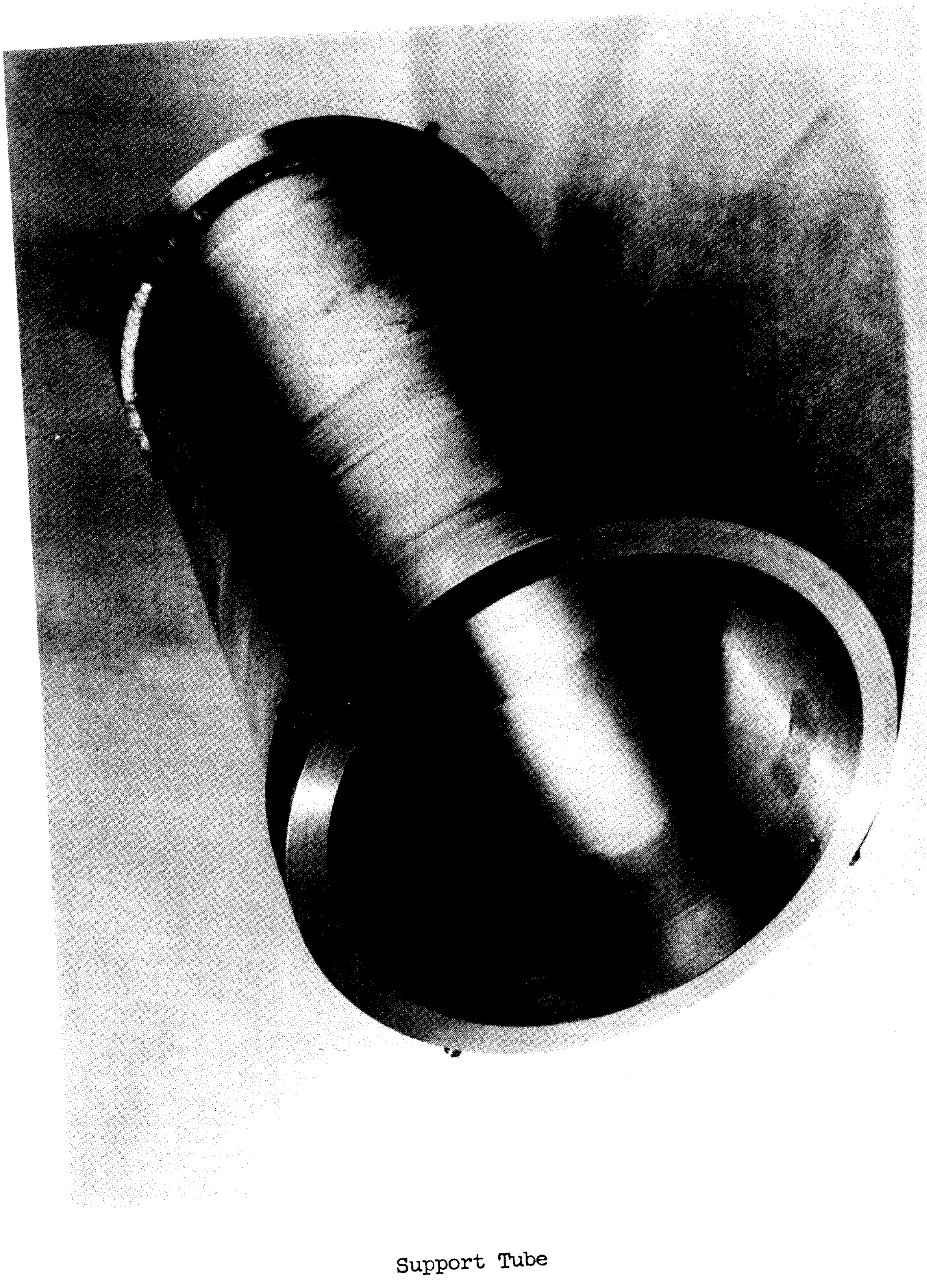
Three Layers Wrapped on Dummy Arbor

Figure 51



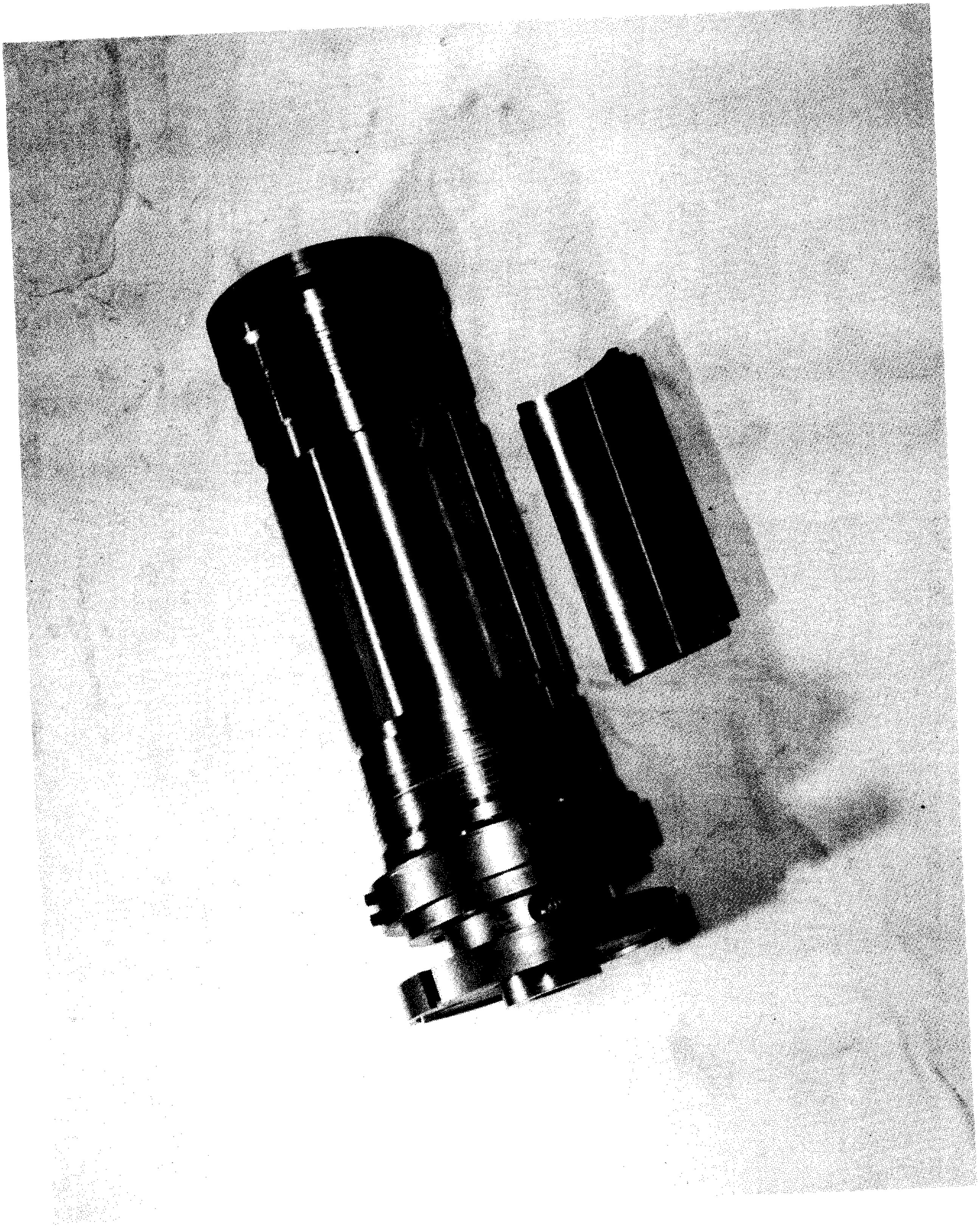
Adapter Clamped to Arbor

Figure 52



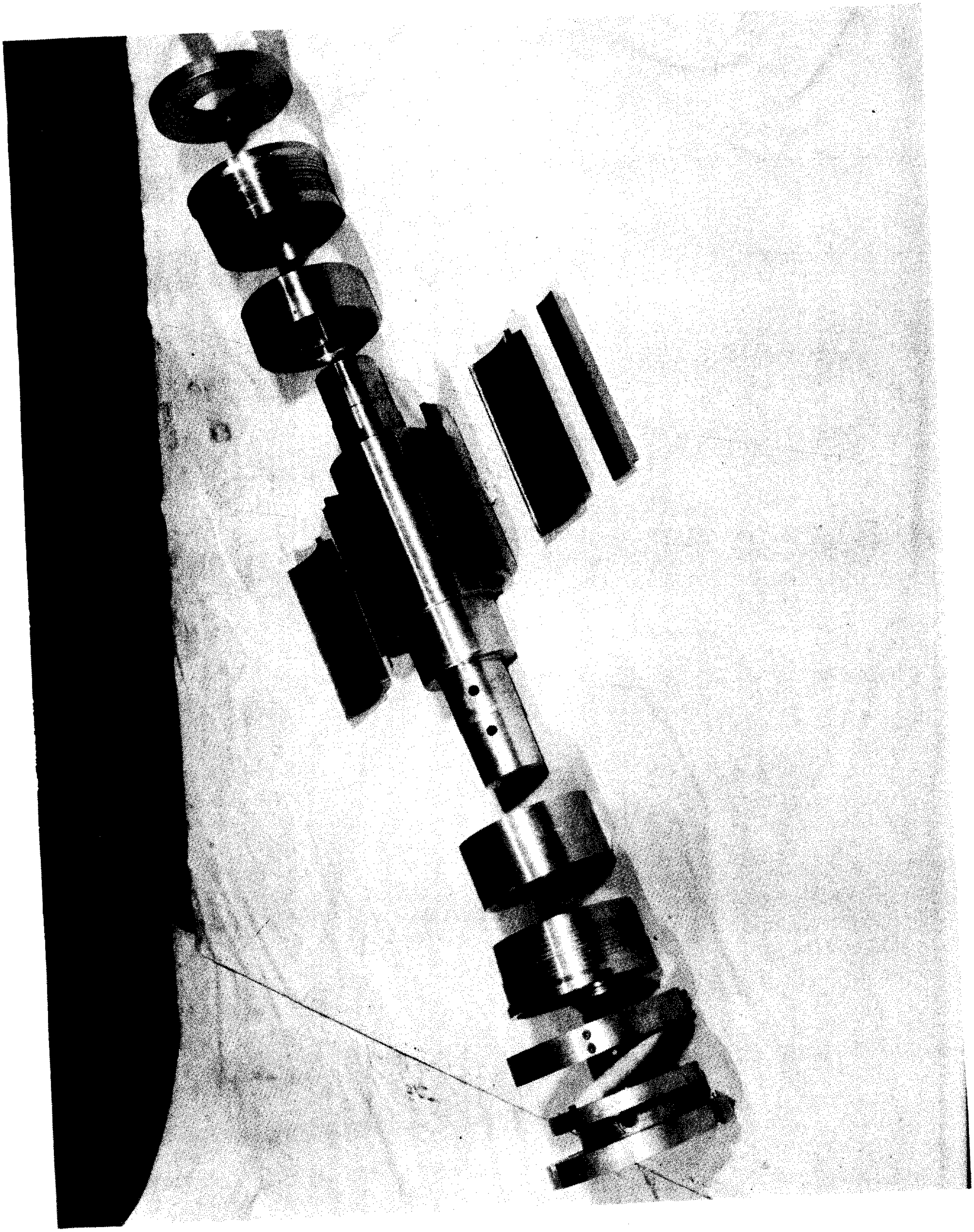
Support Tube

Figure 53



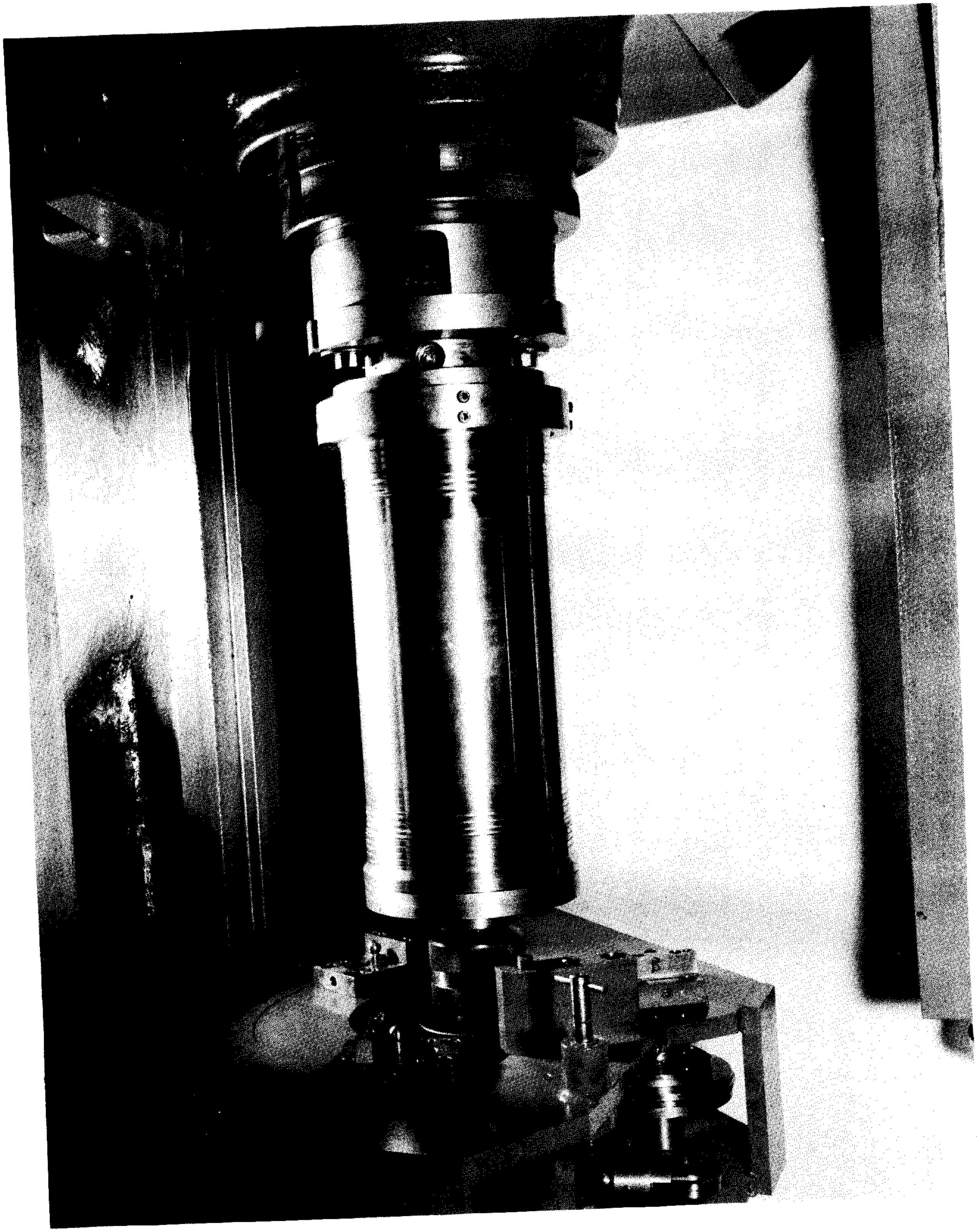
Mandrel Assembled

Figure 54



Exploded View of Mandrel

Figure 55

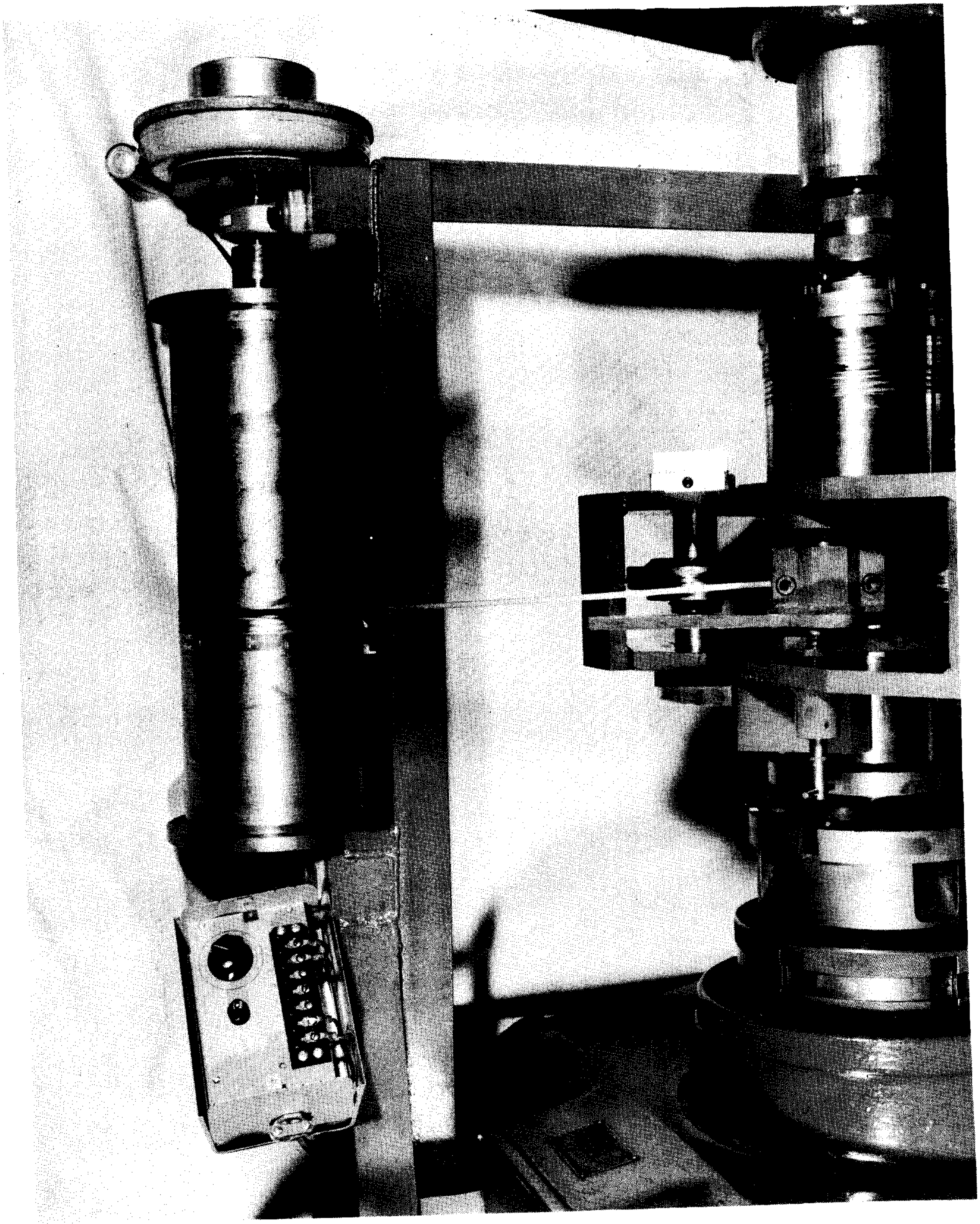


Mandrel Set on Lathe

Figure 56

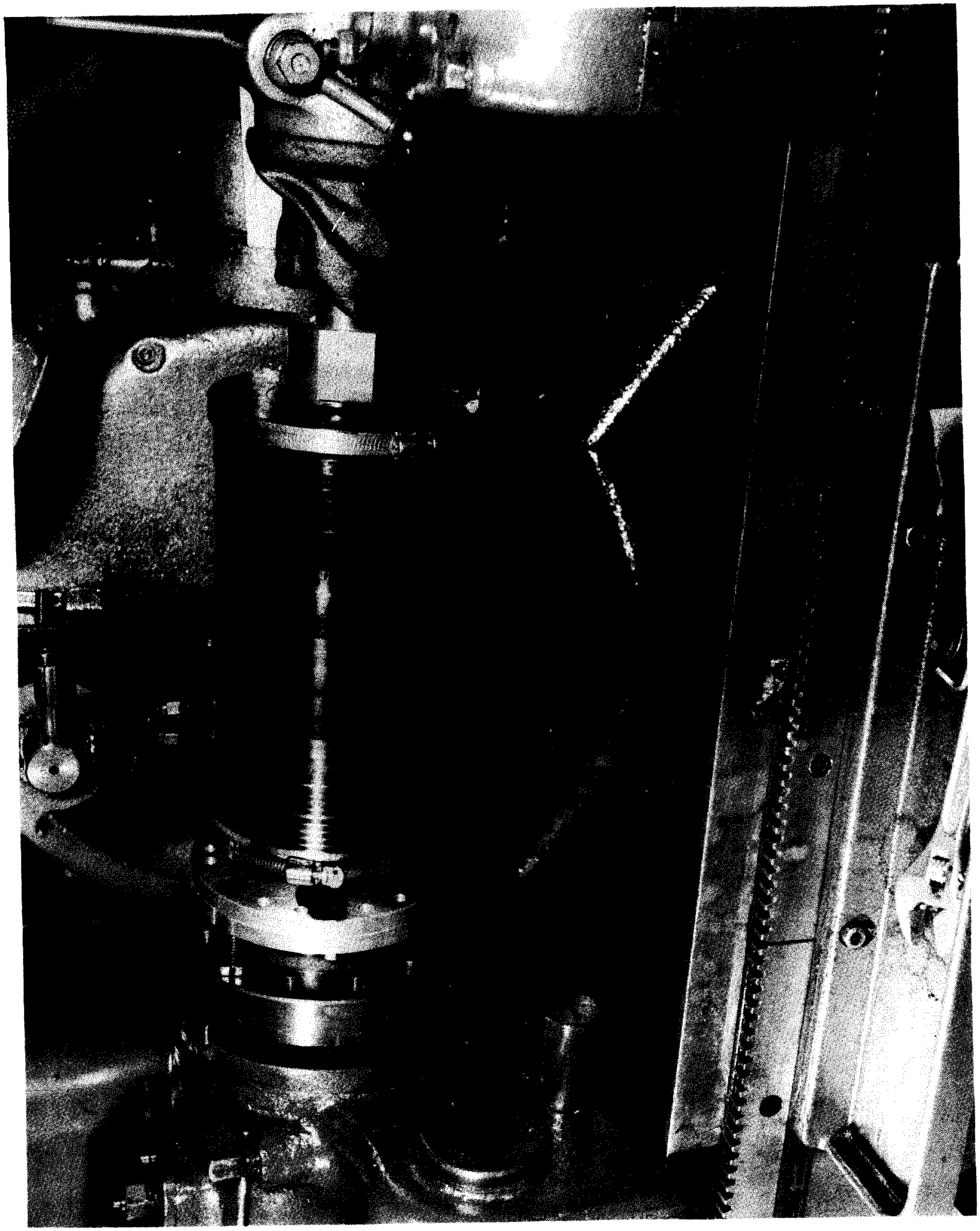
Reels

Figure 57



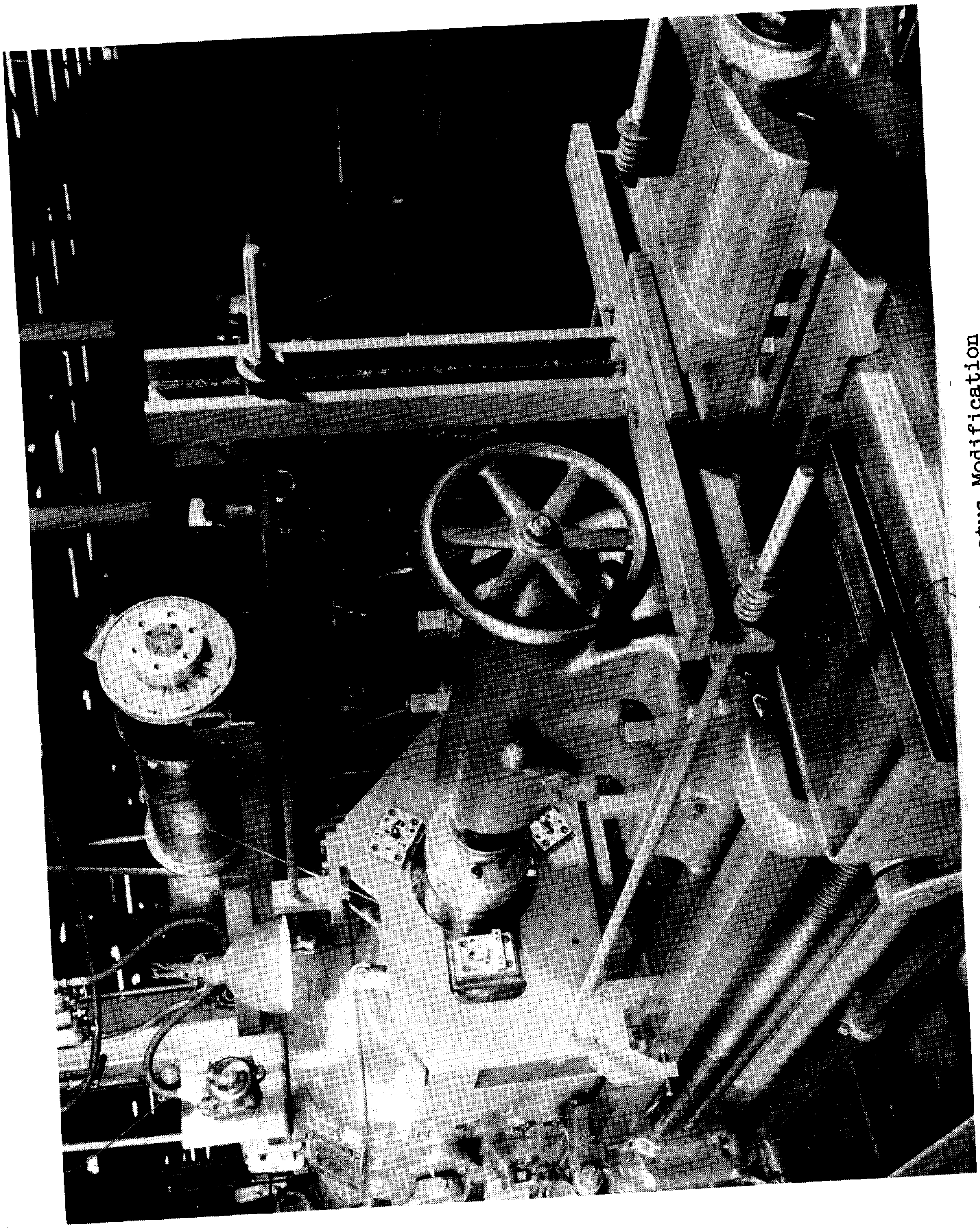
Drag Brake

Figure 58



Dummy Arbor

Figure 59



Wrapping Apparatus Modification

Figure 60

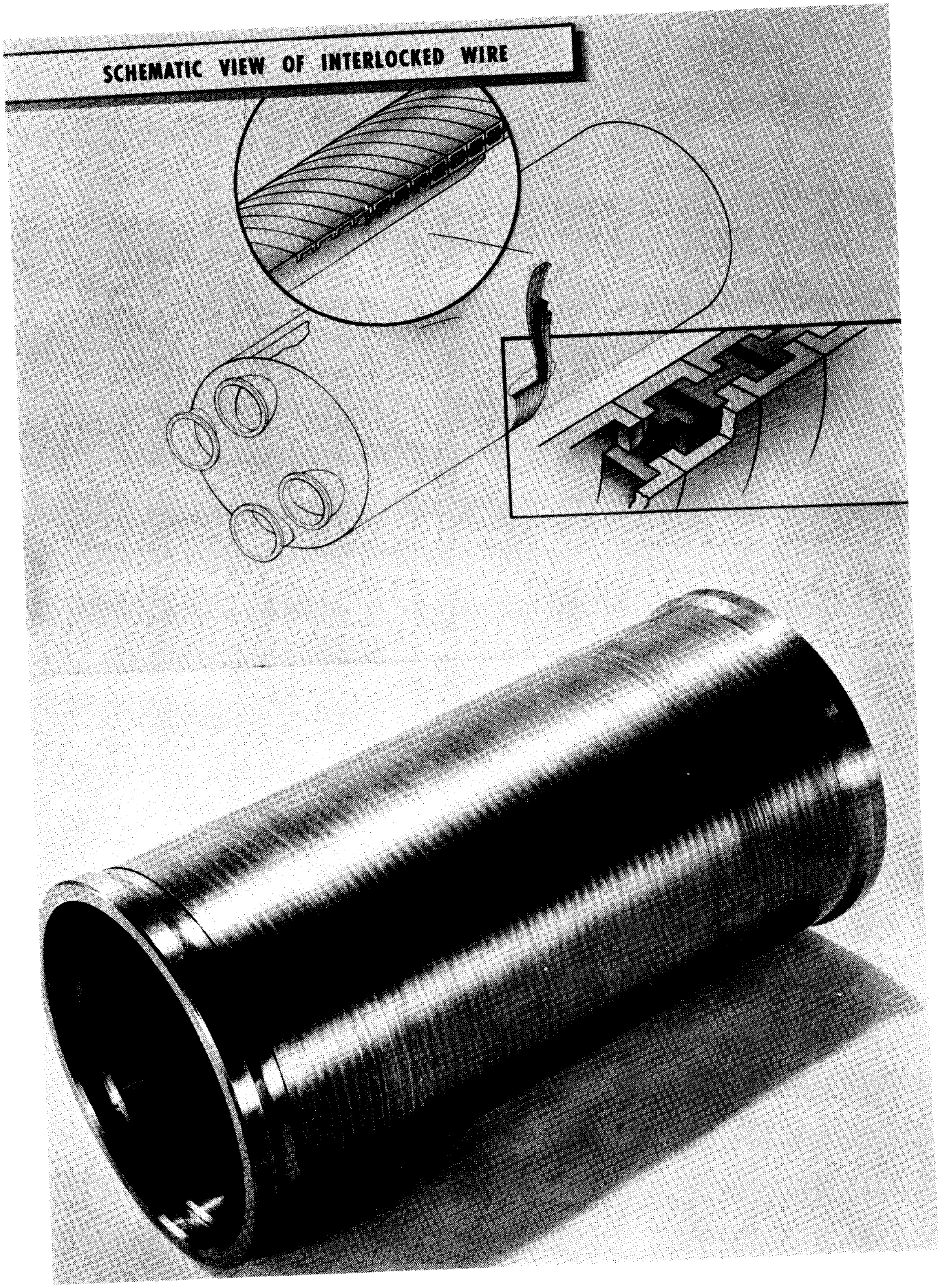
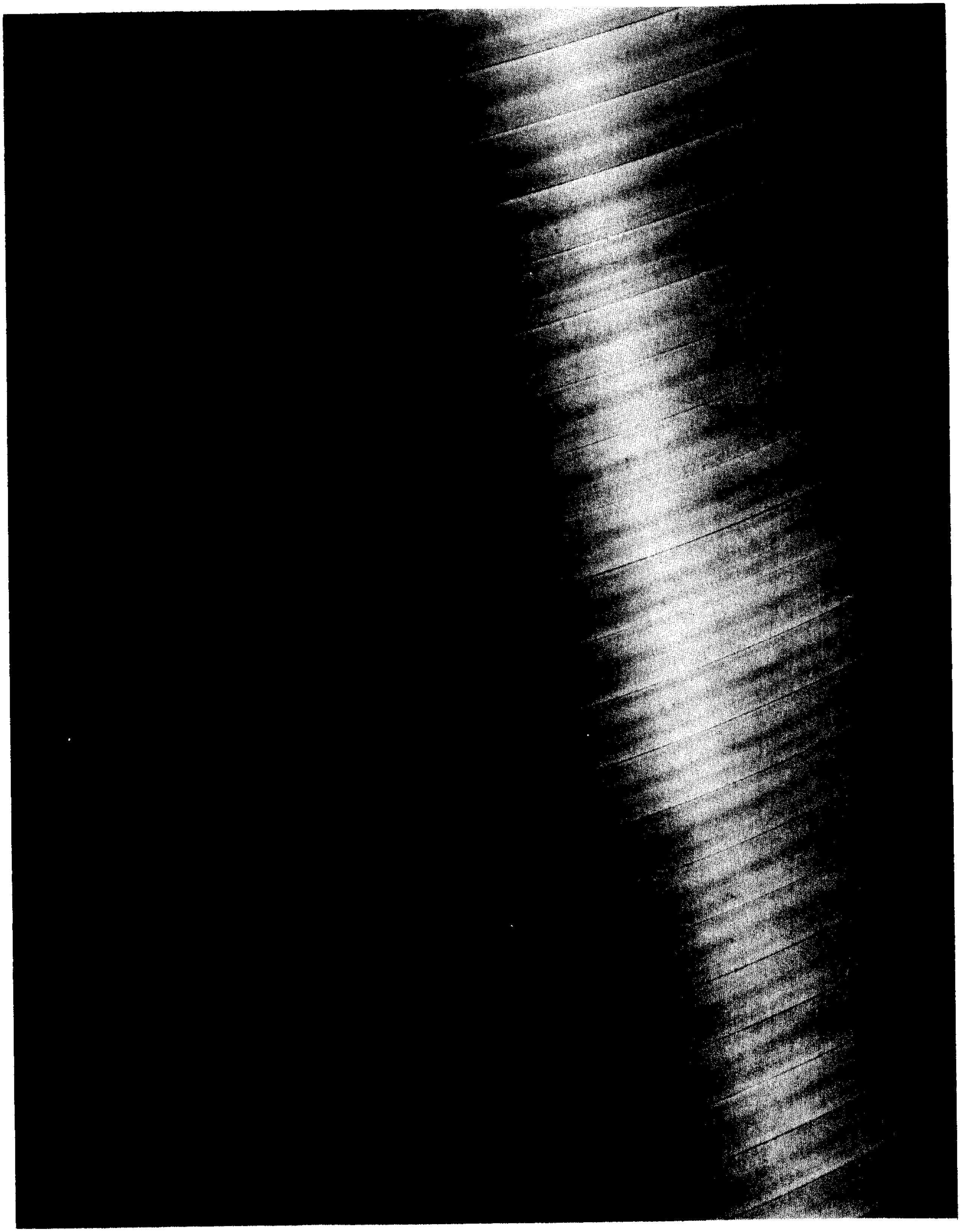


Figure 61



Wrap Vessel Specimen   Close-up

Figure 62

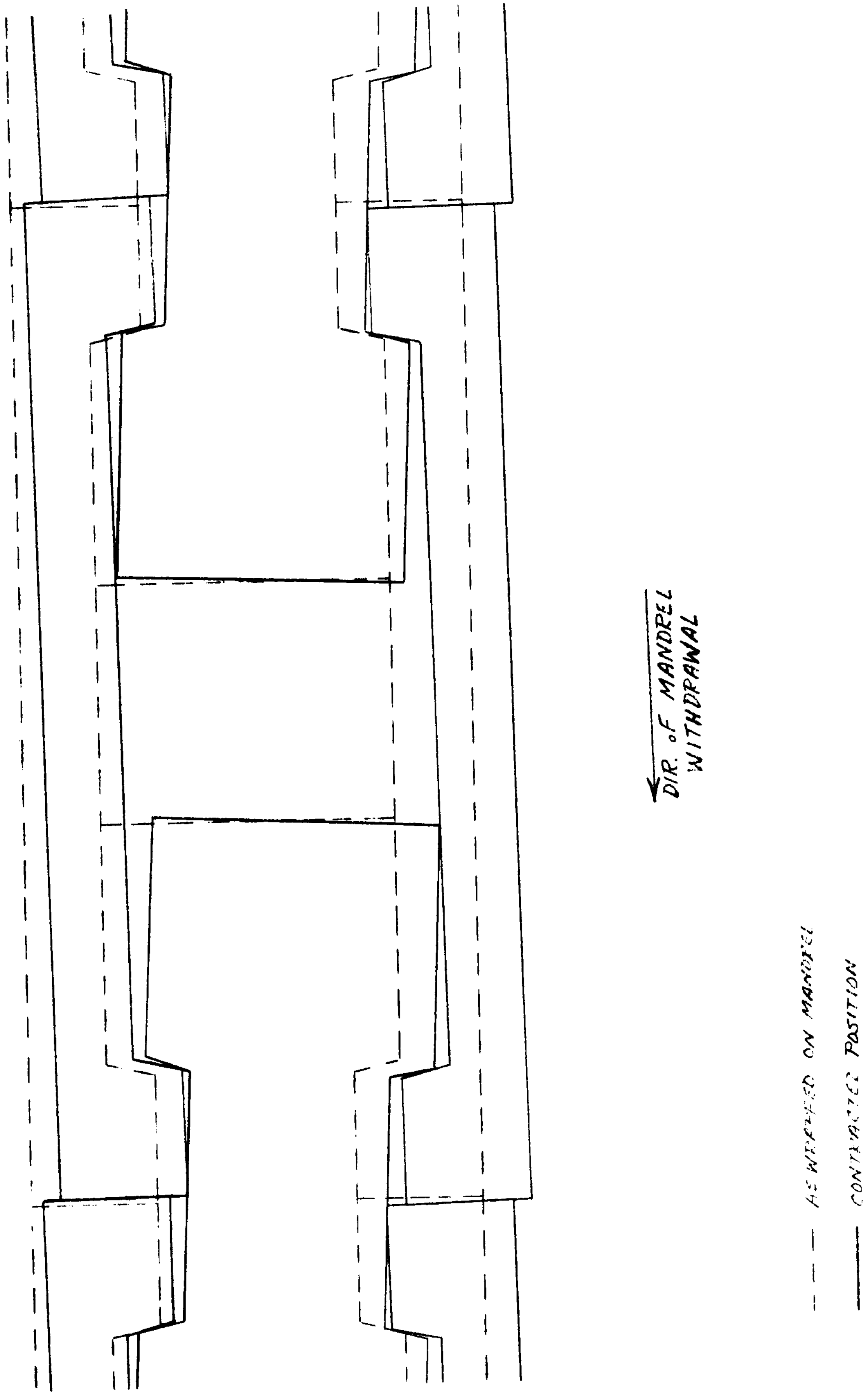

DIR. OF MANDREL WITHDRAWAL
AS WRAPPED ON MANDREL
CONTRACTED POSITION

Figure 63

APPENDIX I

STRESS ANALYSIS

CURTISS - WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET______OF SHEETS______

WRITTEN BY L. SEELEN

APPROVED BY

DATE 7-18-60

ENGINE NO.

JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAP VESSEL

RESULTS, SKETCHES & FORMULAS

APPENDIX A

STRESS ANALYSIS - CALCULATIONS

INTERLOCKING WIRE WRAP VESSEL

CURTISS - WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET a OF SHEETS 28

WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 3-10-60

ENGINE NO.
JOB NO. 51792
SUBJECT:
INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

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CURTISS - WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 1 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

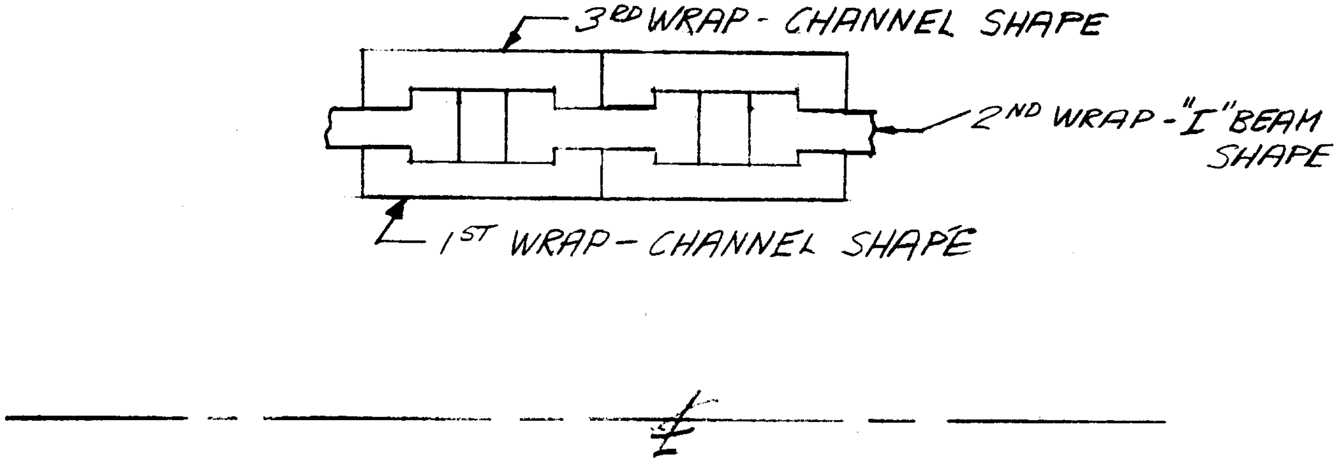
WRITTEN BY L. SEELEN

APPROVED BY WBG

DATE 10-19-59

RESULTS, SKETCHES & FORMULAS

DESIRED CONFIGURATION



VESSEL DIAMETER —— 6.2"

DESIGN PRESSURE —— 5000 psi

MATERIAL

TITANIUM WIRE
B120 VCA

.2% YIELD STRESS
250000 psi (LONGITUDINAL & TRANSVERSE)

MODULUS OF ELASTICITY
15×10^6 psi

ALLOWABLE SHEAR STRESS = .6 x 250000 = 150000 psi

ALLOWABLE BEARING STRESS = $\frac{1.5 \times 250000}{.9}$ = 416000 psi

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 2 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

WRITTEN BY L. SEELEN

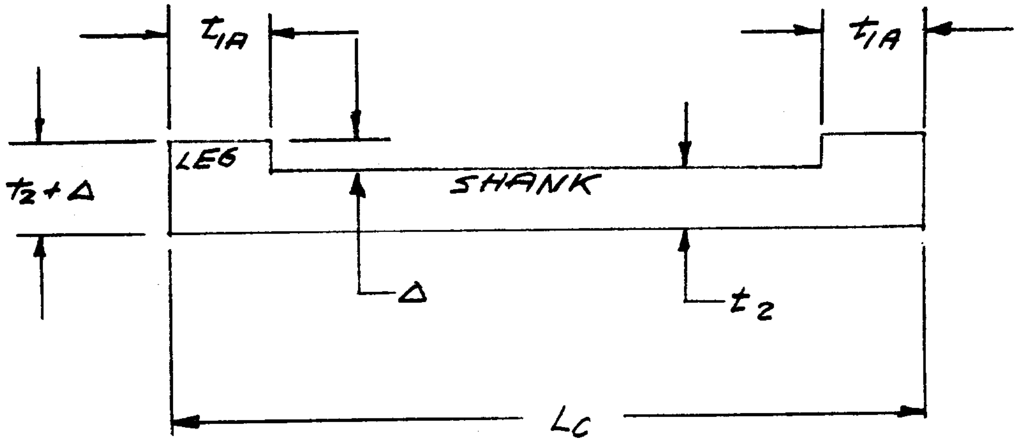
APPROVED BY WBG

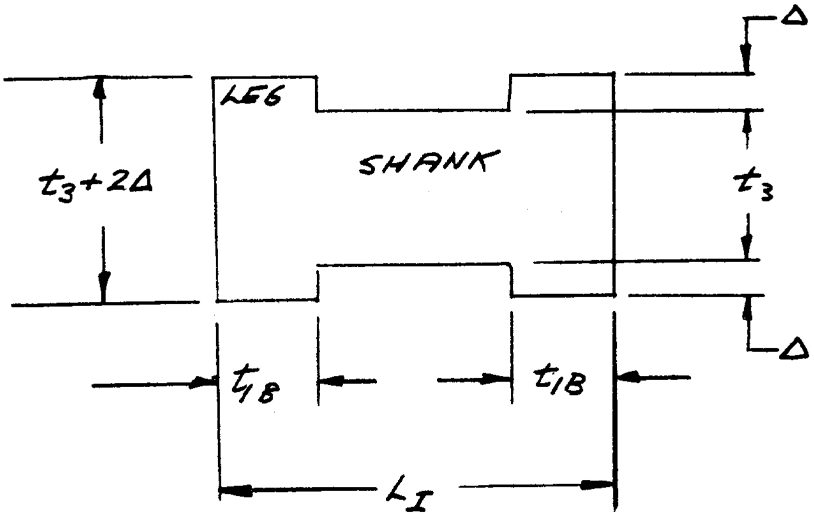
DATE 10-19-59

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

WIRE NOMENCLATURE





RECORD OF ANALYSIS

SHEET 3 OF SHEETS 28

WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-20-59

ENGINE NO.
JOB NO. 51792
SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

LOADING

$p = 5000 psi \quad D = 6.2''$

CIRCUMFERENTIAL LOAD

$$= 5000 \frac{\#}{in^2} \times 3.1 in = 15500 \ \#/in$$

AXIAL LOAD

$$= \frac{5000 \ \#/in^2 \times 3.1 in}{2} = 7750 \ \#/in$$

BASIC DIMENSIONS - BASED ON AXIAL LOADS

CHANNEL SHAPE	DUMBELL SHAPE
$2t_2 = \frac{7750}{250000}$	$t_3 = 2t_2$
$t_2 = .0155 \ in$	$t_3 = .031 \ in$
$2t_{1A} = \frac{7750}{150000}$	$t_{1B} = t_{1A}$
$t_{1A} = .02583$	$t_{1B} = .02583$
$2\Delta = \frac{7750}{416000}$	
$\Delta = .009315$	$\Delta = .009315$

ENGINE NO.

JOB NO. S1792

WRITTEN BY L. SEELEN

APPROVED BY WBG

DATE 10-20-59

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BASIC DIMENSIONS (CONTD) - BASED ON CIRCUMFERENTIAL LOADS

THE AREA OF ONE PITCH MUST CARRY THE LOAD/PITCH

$A_p = 2A_{CHANNEL} + A_{"I"}$

PITCH LENGTH $= L_C$

$$\begin{aligned} AREA_{CHANNEL} &= 2 t_{1A} \Delta + t_2 L_C \\ &= 2 \times .02583 \times .009315 + .0155 L_C \\ &= .0004812 + .0155 L_C \end{aligned}$$

$$\begin{aligned} AREA_{"I" SHAPE} &= 4 t_{1B} \Delta + t_3 L_{"I"} \\ &= .0009624 + .031 L_{"I"} \end{aligned}$$

SETTING $L_C = .200$ in

$A_C = .0004812 + .0031 = .0035812$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 5 OF SHEETS 28

WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-20-59

ENGINE NO.
JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BASIC DIMENSIONS (CONT'D)

$$.2 \times 15500 = 250000\,(.0035812 \times 2 + .0009624 + .0310\,L\text{"I"})$$

$$\frac{3100}{250000} = 0081248 + .0310\,L\text{"I"}$$

$$L\text{"I"} = \frac{.0124 - .0081248}{.031} = \frac{.004275}{.031} = .1379 \text{ in}$$

HOWEVER

THE FIT OF THE CHANNEL LEGS IN THE "I" BEAM IS TO BE A 1 - 4% PRESS FIT

THEREFOR THE "I" BEAM SHANK MUST BE MADE HEAVIER TO TAKE THE PRELOAD

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RECORD OF ANALYSIS

SHEET 6 OF SHEETS 28

WRITTEN BY L. SEELEN

APPROVED BY WBG

DATE 10-20-59

ENGINE NO.

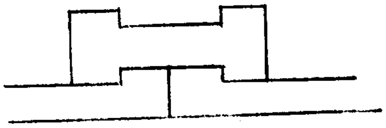
JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

INCREASE t_3 TO .040

1- WRAPPING "I" BEAM LAYER ON 1ST CHANNEL LAYER



TOTAL DEFORMATION = 8 %

COMPRESSION OF CHANNEL LEGS $= \frac{.040}{.040+.0186} \times 8\% = 5.46\ \%$

ELONGATION OF "I" BEAM SHANK $= \frac{.0186}{.040+.0186} \times 8\% = 2.54\ \%$

2- WRAPPING 2ND CHANNEL LAYER ON "I" BEAM LAYER

SINCE THE "I" BEAM SHANK HAS ELONGATED 2.54 %

THE TOTAL DEFORMATION DURING THIS WRAP = 5.46 %

FURTHER ELONGATION OF "I" BEAM SHANK

$= \frac{.0186}{.040+.0186} \times 5.46\% = 1.633\ \%$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 7 OF SHEETS 28

WRITTEN BY L-SEELEN
APPROVED BY WBG
DATE 10-21-59

ENGINE NO.
JOB NO. 51792
SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

TOTAL ELONGATION OF "I" BEAM SHANK

$= (2.54 + 1.633)\% = 4.173\%$

THIS IS WITHIN THE ALLOWABLE VALUE, AND ENSURES AGAINST ANY LOSS OF PRELOAD DUE TO PRESSURIZATION SINCE THE PRESSURE LOAD NEVER EXCEEDS THE PRELOAD, THE CHANNEL LEGS REMAIN BUTTED, AND NEITHER THE CHANNEL LEGS NOR THE "I" BEAM LEGS ARE SUBJECT TO BENDING STRESSES.

RE-SIZE "I" BEAM

ALL DIMENSIONS EXCEPT L_I REMAIN

$$L_I = \frac{.031}{.040} \times .1379 = .1069 \text{ in}$$

RECORD OF ANALYSIS

SHEET 8 OF SHEETS 28

WRITTEN BY L SEELEN

APPROVED BY WBG

DATE 10-21-59

ENGINE NO.

JOB NO. S1792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

FINAL SIZE

CHANNEL

$t_2 = .0155$

$t_{1A} = .026$

$\Delta = .0093$

$L_C = .200$

"I" BEAM

$t_3 = .040$

$t_{1B} = .026$ *

$\Delta = .0093$

$L_I = .1069$

* SEE PP10 & 15, CASE 1B, FOR SUGGESTED INCREASE TO .040 in.

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RECORD OF ANALYSIS

SHEET 9 OF SHEETS 28

WRITTEN BY L-SEELEN

APPROVED BY WBG

DATE 10-21-59

ENGINE NO.

JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

IF THE "I" BEAM SHAPE DOES NOT BOTTOM ON CHANNEL WRAP THE SPAN IS .1472 IN. THE DEFLECTION OF THE CHANNEL .025 IN FROM THE END

$$= \frac{5000 \times .025^2 (.1472 - .025)^2 \times 12}{24 \times 15 \times 10^6 \times .0155^3} = .000417 \text{ IN.}$$

IF THE "I" BEAM LEG HEIGHTS ARE MIN
AND THE CHANNEL LEG HEIGHTS ARE MAX
THE CLEARANCE IS .0004 IN.

DEFORMATION DUE TO THE PRESS FIT CAUSES THE CLEARANCE TO APPROACH ZERO, AND THE ANALYSIS ASSUMING THE DISTANCE BETWEEN "I" BEAMS AS THE CHANNEL SPAN IS ESSENTIALLY CORRECT

A MORE ACCURATE METHOD ASSUMES A FIXED BEAM WITH THE .1472" SPAN LENGTH SIMPLY SUPPORTED .025" FROM EITHER END.

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 10 OF SHEETS 28

WRITTEN BY L. SEELEN

APPROVED BY WPG

DATE 10-21-59

ENGINE NO.

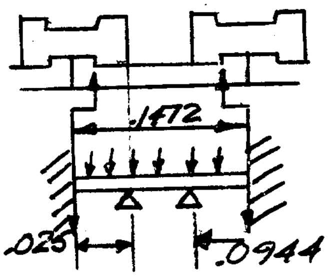
JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAP VESSEL

RESULTS, SKETCHES & FORMULAS

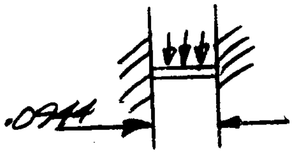
ASSUMED CONFIGURATIONS

CASE 1A — FIXED ENDED - SIMPLY SUPPORTED AT "I" BEAM ENDS



CASE 1B - SAME AS 1A EXCEPT .025 = .040

CASE 2A, 2B FIXED ENDED AT "I" BEAM ENDS



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RECORD OF ANALYSIS

SHEET 11 OF SHEETS 28

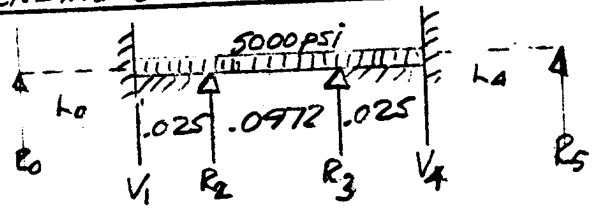
WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-22-59

ENGINE NO.
JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 1a



THREE MOMENT METHOD

SPAN 0-1

① $M_0L_0 + 2M_1(L_0+L_1) + M_2L_1 + \frac{6A_0\bar{a}_0}{L_0} + \frac{6A_1\bar{b}_1}{L_1} = 0$

SPAN 1-2

② $M_1L_1 + 2M_2(L_1+L_2) + M_3L_2 + \frac{6A_1\bar{a}_1}{L_1} + \frac{6A_2\bar{b}^2}{L_2} = 0$

SPAN 2-3

③ $M_2L_2 + 2M_3(L_2+L_3) + M_4L_3 + \frac{6A_2\bar{a}_2}{L_2} + \frac{6A_3\bar{b}_3}{L_3} = 0$

SPAN 3-4

④ $M_3L_3 + 2M_4(L_3+L_4) + M_5L_4 + \frac{6A_3\bar{a}_3}{L_3} + \frac{6A_4\bar{b}_4}{L_4} = 0$

IN APPLYING THESE EQUATION ALL TERMS REFERRING TO THE IMAGINARY SPANS ARE NEGLECTED.

SINGER - STRENGTH OF MATERIALS

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RECORD OF ANALYSIS

SHEET 12 OF SHEETS 28

WRITTEN BY L SEELEN
APPROVED BY WBG
DATE 10-22-59

ENGINE NO.
JOB NO. 51792
SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

$$\frac{6A_1\bar{b}_1}{L_1} = \frac{5000 \times \overline{.025}^{3}}{4} = .01954$$

$$\frac{6A_1\bar{a}_1}{L_1} = \frac{5000 \times \overline{.025}^{3}}{4} = .01954$$

$$\frac{6A_2\bar{b}_2}{L_2} = \frac{5000 \times \overline{.0972}^{3}}{4} = 1.1479$$

$$\frac{6A_2\bar{a}_2}{L_2} = \frac{5000 \times \overline{.0972}^{3}}{4} = 1.1479$$

$$\frac{6A_3\bar{b}_3}{L_3} = \frac{5000 \times \overline{.025}^{3}}{4} = .01954$$

$$\frac{6A_3\bar{a}_3}{L_3} = \frac{5000 \times \overline{.025}^{3}}{4} = .01954$$

① $2M_1(.025) + M_2(.025) + .01954 = 0$

.019

② $M_1(.025) + 2M_2(.1222) + M_3(.0972) + .01954 + 1.1479 = 0$

③ $M_2(.0972) + 2M_3(.1222) + M_4(.025) + .01954 + 1.1479 = 0$

④ $M_3(.025) + 2M_4(.025) + .01954 = 0$

① $.050 M_1 + .025 M_2 + .01954 = 0$

② $.025 M_1 + .2444 M_2 + .0972 M_3 + 1.16744 = 0$

③ $.0972 M_2 + .2444 M_3 + .025 M_4 + 1.16744 = 0$

④ $.025 M_3 + .05 M_4 + .01954 = 0$

CURTISS - WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 13 OF SHEETS 28

WRITTEN BY L. SEELEN

APPROVED BY WBG

DATE 10-22-59

ENGINE NO.

JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

		M_1	M_2	M_3	M_4	K
①		.050	.025			-.01954
2	$\frac{.025}{.050} = .5$	.025	.2444	.0972		-1.16744
3	-.5×①	-.025	-.0125			+.00977
④	②+③	0	.2319	.0972		-1.15767
5			.0972	.2224	.025	-1.16744
6		–	–	–	–	–
7	⑤+⑥ $\frac{.0972}{.2315} = .4192$		.0972	.2444	.025	-1.16744
8	-.4192×④		-.0972	-.0407	–	+.48530
9	⑦+⑧		0	.2037	.025	-.68214
10				.025	.050	-.01954
11		–	–	–	–	–
12	⑩+⑪			.025	.050	-.01954
13		–	–	–	–	–
14	⑫+⑬ $\frac{.025}{.1816} = .1377$			.025	.050	-.01954
15	-.1377×⑨			-.025	-.00344	+.09382
16				0	.04656	.07428

ENGINE NO.
JOB NO. 51792
WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-22-59
SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

$M_4 = .07428/.04656 = +1.5954$

$$M_3 = \frac{-.68214 - .025\times1.5954}{.2037} = -3.5446$$

$$M_2 = \frac{-1.15767 + .0972(3.5446)}{.2319} = -3.5064$$

$$M_1 = \frac{-.01954 + .025(3.5064)}{.050} = +1.3624$$

HOWEVER M_1 SHOULD EQUAL M_4 AND $M_2 = M_3$

THE DISCREPANCY IS DUE TO THE NUMBER OF CALCULATIONS PERFORMED

ASSUME

$$M_1 = M_4 = \frac{1.5954 + 1.3624}{2} = 1.4788 \quad \text{in-lb/in}$$

$$M_2 = M_3 = \frac{-(3.5064+3.5446)}{2} = -3.5255 \quad \text{in-lb/in}$$

$$S_{b_1} = 6\times1.4788/.0155^2 = \underline{36900}$$

$$S_{b_2} = 6\times3.5255/.0155^2 = \underline{\underline{88000}}$$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

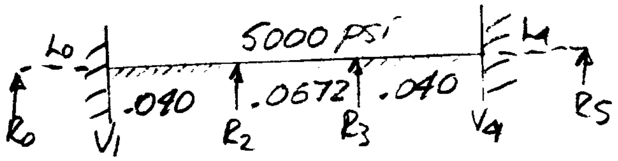
SHEET 15 OF SHEETS 28

WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-23-59

ENGINE NO.
JOB NO. 51792
SUBJECT: INTERLOCKING WIRE WRAPPED MOTOR

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 1b



$$\frac{5000 \times .040^3}{4} = .03$$

$$.03 + .3793 = .4093$$

$$\frac{5000 \times .0672^3}{4} = .3793$$

① $.080 M_1 + .040 M_2 = -.03$

② $.040 M_1 + .2144 M_2 + .0672 M_3 = -.4093$

BY SYMMETRY $M_2 = M_3$

① $.080 M_1 + .040 M_2 = -.03$

② $.040 M_1 + .2816 M_2 = -.4093$

1/2 ③ $.040 M_1 + .0200 M_2 = -.0150$

③ $0 \quad .2616 M_2 = -.3943$

$$M_2 = -\underline{1.507}$$

$$M_1 = \frac{-.03 + .04 \times 1.507}{.08} = \underline{.3785}$$

$$S_{b_1} = \frac{6 \times .3785}{.0155^2} = 9440 \text{ psi}$$

$$S_{b_2} = \frac{6 \times 1.507}{.0155^2} = 37600 \text{ psi}$$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 16 OF SHEETS 28

ENGINE NO.

JOB NO. 51792

SUBJECT:

INTERLOCKING WIRE WRAPPED VESSEL

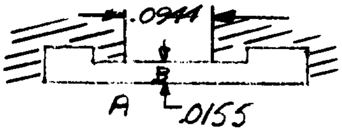
WRITTEN BY L. SEELEN

APPROVED BY WB

DATE 10-23-59

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP DUE TO PRESSURE - CASE 2 a



TREATING THE CHANNEL AS A FIXED ENDED BEAM WHERE "A" IS AT THE SUPPORT AND "B" IS AT THE CENTER.

$M_{"A"} = p\frac{(.0944)^2}{12} = .0007426\ p.$ $\qquad Z = \frac{1 \times .0155^2}{6} = .4 \times 10^{-4}$

$M_{"B"} = p\frac{(.0944)^2}{24} = .0003713\ p$

$S_b "A" = .0007426 p / .00004 = 18.565 p = \underline{93000 \text{ psi}}$

$S_b "B" = .0003713 p / .00004 = 9.283 p = \underline{46500 \text{ psi}}$

WITH A SUBSCALE VESSEL SUCH AS THE ONE CURRENTLY UNDER DEVELOPMENT, THE BENDING STRESSES IN THE 1ST CHANNEL WRAP WILL BE LARGE.

HOWEVER FULL SCALE VESSELS OPERATE AT SUBSTANTIALLY LOWER PRESSURES AND THIS STRESS IS NEGLIGIBLE.

THE CHANGE IN "I" BEAM WIDTH SUGGESTED ON PAGE 15 WILL REDUCE THESE STRESS TO 43000 psi AT THE END AND 21600 psi AT THE CENTER (CASE 2B)

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RECORD OF ANALYSIS

SHEET 17 OF SHEETS 28

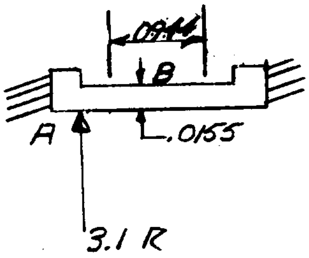
WRITTEN BY L. SEELEN
APPROVED BY WBG
DATE 10-23-59

ENGINE NO.
JOB NO. 51792

SUBJECT: INTERLOCKING WIRE WRAPPED VESSEL

RESULTS, SKETCHES & FORMULAS

BENDING OF 1ST CHANNEL WRAP UNDER PRESSURE - CASE 3



FIXED ENDED BEAM ON ELASTIC FOUNDATION

$$\lambda = 1.285 / \sqrt{3.1 \times .0155} = 5.868$$

$$\lambda L = 5.868 \times .0944 = .55$$

$$\lambda^2 = 34.433$$

$$M_A = \frac{-p}{2\lambda^2}\left[\frac{\sinh \lambda L - \sin \lambda L}{\sinh \lambda L + \sin \lambda L}\right]$$

MOMENT AT ENDS $.2 - \begin{array}{r} .0264 \\ 4 \\ \hline .1056 \end{array} = .0944$

$$M_B = \frac{p}{\lambda^2}\left[\frac{\sin \frac{\lambda L}{2} \cosh \frac{\lambda L}{2} - \cos \frac{\lambda L}{2} \sinh \frac{\lambda L}{2}}{\sinh \lambda L + \sin \lambda L}\right]$$

MOMENT AT CENTER

for $\lambda L = .55$

$$M_A = \frac{-5000}{2 \times 34.333}\left\{\frac{.5782 - .5227}{.5782 + .5227}\right\} = -3.67 \text{ in-lb/in}$$

$$M_B = \frac{-5000}{34.333}\left\{\frac{.2764 \times 1.0395 - .9611 \times .2837}{1.1009}\right\} = 1.93 \text{ in-lb/in}$$

$$\sigma_{M_A} = \frac{6 \times -3.67}{.0155^2} = 91660 \text{ psi}$$

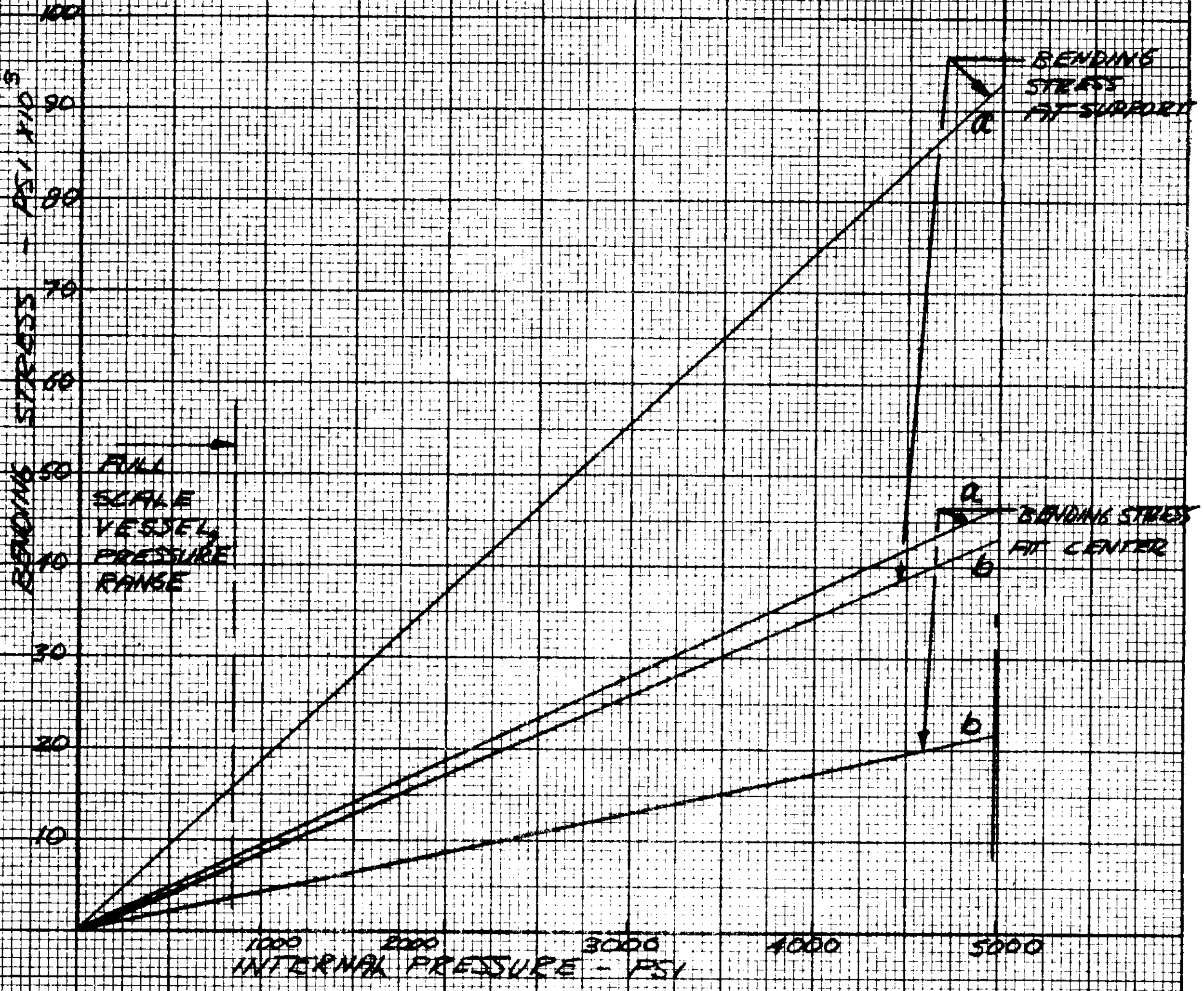
$$\sigma_{M_B} = 48200 \text{ psi}$$

NOTE: COMPARISON OF THESE STRESSES WITH THOSE OF CASE 2b SHOWS A NEGLIGIBLE REDUCTION IN BENDING STRESS RESULTING FROM CONSIDERATION OF VESSEL CURVATURE

M. Hetenyi - Beams on Elastic Foundations

INTERLOCKING WIRE WRAPPED VESSEL →
(6 IN. SUBSCALE)

BENDING OF 1ST CHANNEL WRAP - CASE 2a & 2b



A. SEELEN

10/23/59
WBG

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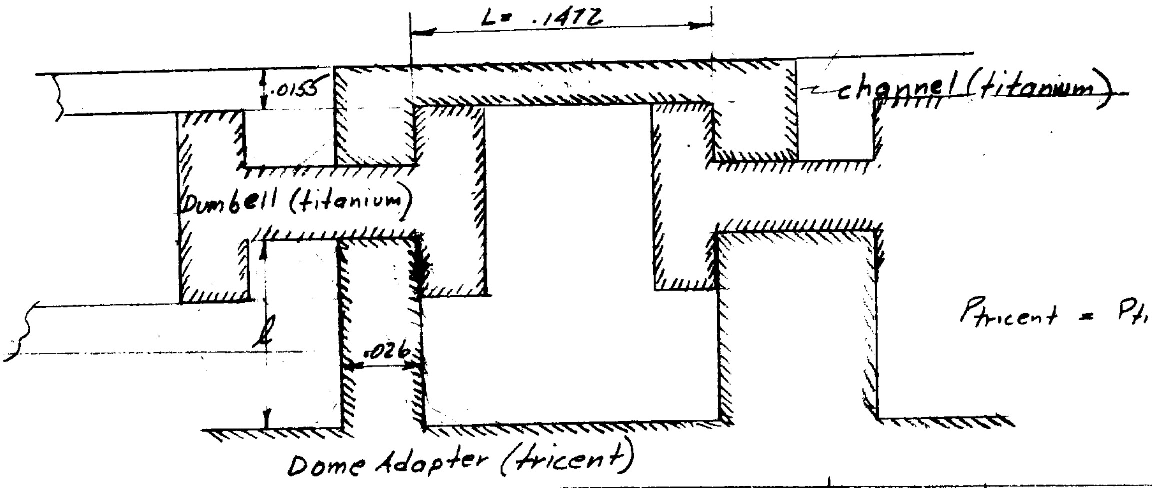
RECORD OF ANALYSIS

SHEET 19 OF SHEETS 28

WRITTEN BY D. Kanowsky
APPROVED BY WBG
DATE 2/19/60

ENGINE NO. Wire Wrap Motor
JOB NO. 51792
SUBJECT: Dome Adapter stresses

RESULTS, SKETCHES & FORMULAS



$P_{tricent} = P_{titanium}$

$$\Sigma \delta_{tr} = \delta_c$$

$$\left(\frac{Pl^3}{3EI} + \frac{6}{5}\frac{Pl}{AG}\right)_{tr} = \left(\frac{PL}{AE}\right)_c$$

	titanium	tricent
A	.0155	.026
E	16×10^6	30×10^6
G		12×10^6
l	.1472	?
I		$\frac{1}{12}(.025)^3 = 1.30\times10^{-6}$

$$\frac{l^3}{3(30)(1.30)} + \frac{6}{5}\frac{l}{(.026)(12\times10^6)} = \frac{.1472}{(.0155)(16\times10^6)}$$

$$.00854 l^3 + 3.85\times10^{-6} l = .594\times10^{-6}$$

$$l^3 + 4.51\times10^{-4} l = .697\times10^{-4}$$

$$l = .037 \quad (\text{say } .035")$$

$P_{total} = 7750$#/in $P_{tr} = P_c = 3875$# ✓

tricent: $M = 3875\times.035 = 136$

$$\frac{I}{c} = \frac{1.30\times10^{-6}}{1.3\times10^{-2}} = 1\times10^{-4}$$

$$\sigma = \frac{136}{1}\times10^4 = \text{HIGH}$$

shear

$$\sigma = \frac{\overset{V}{3875}}{.026} = 149{,}000 \text{ psi}$$ ✓

If tricent is assumed to be prevented from bending, by the abutting channel:

then: $3.85 l = .594$

$\therefore l = .155"$

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RECORD OF ANALYSIS

SHEET 20 OF SHEETS 28

ENGINE NO. Wire Wrap Motor

JOB NO. 51792

SUBJECT: Trial & Error solution for "l"

WRITTEN BY D. Kanowsky

APPROVED BY WBG

DATE 2/19/60

RESULTS, SKETCHES & FORMULAS

$$l^3 + 4.51 \times 10^{-4} l = .697 \times 10^{-4}$$

l	.02	.03	.04	.035	.037	.038
l^3	$.08 \times 10^{-4}$	$.27 \times 10^{-4}$	$.64 \times 10^{-4}$	$.43 \times 10^{-4}$	$.507 \times 10^{-4}$	$.549 \times 10^{-4}$
$+4.51 l \times 10^{-4}$	$.090 \times 10^{-4}$	$.135 \times 10^{-4}$	$.1804 \times 10^{-4}$	$.158 \times 10^{-4}$	$.167 \times 10^{-4}$	$.171 \times 10^{-4}$
$= .697 \times 10^{-4}$	$.17 \times 10^{-4}$	$.405 \times 10^{-4}$	$.82 \times 10^{-4}$	$.588 \times 10^{-4}$	$.674 \times 10^{-4}$	$.720 \times 10^{-4}$

$l = .037$

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RECORD OF ANALYSIS

SHEET 21 OF SHEETS 28

ENGINE NO. Wire Wrap Motor
JOB NO. 51792
SUBJECT: Dome Adapter stress

WRITTEN BY D. Kanowsky
APPROVED BY WBG
DATE 2/19/60

RESULTS, SKETCHES & FORMULAS

$l = .035$:

Tolerance condition when tricent is stiffest:

	titanium	tricent
A	.0145	.0268
E	16×10^6	30×10^6
G		12×10^6
l	.15	.035
I		$\frac{1}{12}(.0268)^3 = \overset{\checkmark}{1.61}\times10^{-6}$

$$P_{t}\left[\frac{(.035)^3}{3(30)(1.61)} + \frac{6\,.035}{5(.0268)(12\times10^6)}\right] = P_c\left(\frac{.15}{(.0145)(16\times10^6)}\right)$$

$$P_{tr}\left[\overset{\checkmark}{.297}\cancel{\times10^{-6}} + \overset{\checkmark}{.130}\cancel{\times10^{-6}}\right] = P_c\left(.648\cancel{\times10^{-6}}\right)$$

$$P_{tr}(.427) = P_c(.648)$$

$$P_{Tr} = 1.52P_c$$

total $P = 7750^{\#}$ $\quad P_{Tr} = 4670^{\#}$

$P_c = 3080^{\#}$

Tricent: $\frac{I}{c} = \frac{1.61\times10^{-6}}{1.34\times10^{-2}} = 1.2\times10^{-4}$

$M = 4670\times.035 = 163$

$\sigma = \frac{163}{1.2}\times10^4 = $ High

Shear $\sigma = \frac{4670}{.0268} = 174,000$ psi

Titanium: $S = \frac{P}{A} = \frac{3080}{.0145} = 210,000$

$$\epsilon = \frac{S}{E} = \frac{210000}{16\times10^6} = \frac{.21}{16} = .013$$

RECORD OF ANALYSIS

SHEET 24 OF SHEETS 28

ENGINE NO.

JOB NO. S1792

SUBJECT: Wire wrapped Motor stress in wire on spool.

WRITTEN BY D. Kanowsky

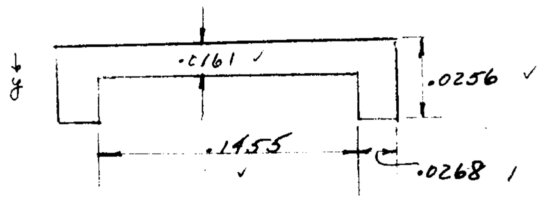
APPROVED BY W.B.G.

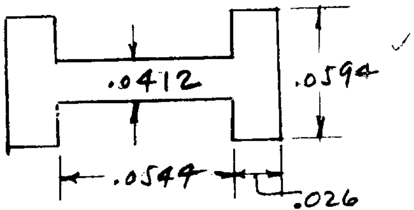
DATE 2/18/60

RESULTS, SKETCHES & FORMULAS

Wire to be unwrapped from 6" spool:

Bending stress:





$$\frac{M}{EI} = \frac{1}{R}$$

$$M = \sigma S = \sigma I/c \qquad \sigma \doteq \frac{cE}{R} \checkmark$$

$$\frac{\sigma I/c}{EI} = \frac{1}{R}$$

channel:

$E = 16 \times 10^6$ psi

$R = 3.1''$

	A	y	Ay
.0161 × .1455 =	.00234 ✓	.0080 ✓	.0000187 ✓
2 × .0256 × .0268 =	.00137 ✓	.0128 ✓	.0000175
	.00371		.0000362

$$\bar{y} = \frac{.0000362}{.00371}$$

$\bar{y} = c_1 = .00974$ ✓

$c_2 = .0256 - .00974$

$c_2 = .0159$ ✓

$$\sigma = \frac{(.0159)\,16 \times 10^6}{3.1}$$

$\sigma = 82{,}000$ psi

<u>NG</u> reduce to 50,000 psi <u>max</u> ✓

$$\sigma = (50{,}000) = \frac{(.0159)\,16 \times 10^6}{R}$$

$$\text{min. } R = \frac{(.0159)\,16 \times 10^6}{50 \times 10^3} = 5.05'' \checkmark$$

10.1" spool ✓

Dumbell.

$C_1 = C_2 = .0297''$ ✓

$$\sigma = \frac{.0297}{.0159} \times 82000 = 153{,}000 \text{ psi}$$

$$\text{min } R \text{ for } 50{,}000 \text{ psi} = \frac{.0297}{.0159} \times 5.05 = 9.43''$$

use 19" spool ✓

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WRIGHT AERONAUTICAL DIVISION

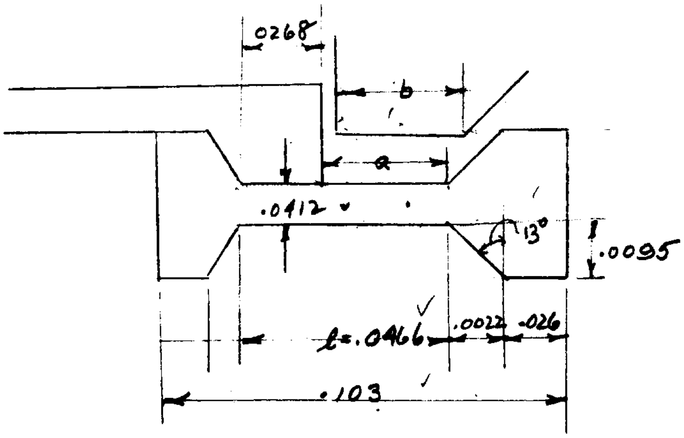
RECORD OF ANALYSIS

SHEET 28 OF SHEETS 28

WRITTEN BY D. Kanowsky
APPROVED BY WBG
DATE 2/18/60

ENGINE NO.
JOB NO. 51792
SUBJECT: Wire Wrapped Motor
Force req'd to place wire

RESULTS, SKETCHES & FORMULAS



$.0095 \tan 13° = .0095(.231)$
$= .0022$

based on worst tolerance condition:

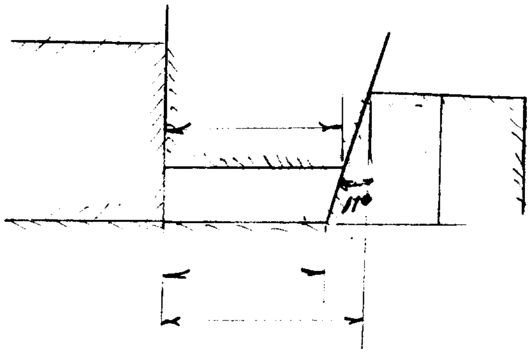
$$\begin{array}{rl} & .103 \\ - & .052 = 2 \times .026 \\ \hline & .051 \\ - & .0044 = 2 \times .002 \\ \hline l = & .0466 \\ - & .0268 \\ \hline & .0198 = a \end{array}$$

$$\begin{array}{l} b = .0268 \\ a = .0198 \\ \hline \delta = .0070'' \end{array}$$

$$\delta = \frac{Pl}{AE} \qquad P = \frac{AE\delta}{l}$$

$$\left[\begin{array}{c}\text{Horizontal}\\ \text{Force}\end{array}\right] P = \frac{(.0412)(16 \times 10^6)(.007)}{.0466} = 98{,}800^{\#}$$

if deformation of other parts are considered, P will be reduced by about 60%. Assume $P = 40{,}000^{\#}$



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WRIGHT AERONAUTICAL DIVISION

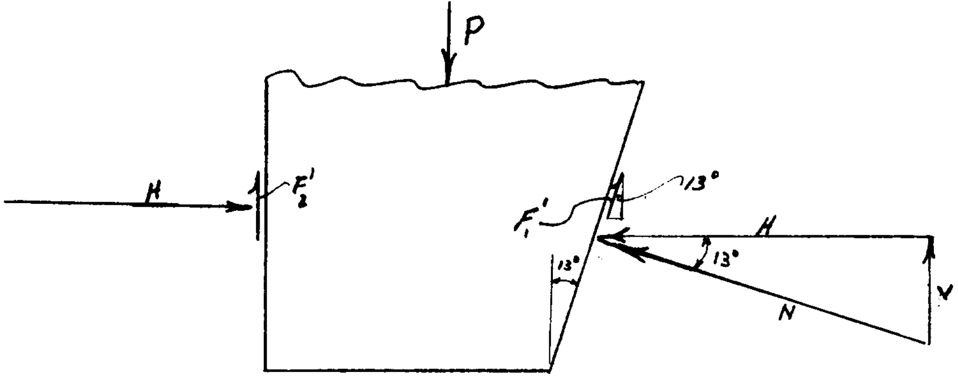
RECORD OF ANALYSIS

SHEET 24 OF SHEETS 28

ENGINE NO. Wire wrap
JOB NO. 51792
SUBJECT: Force req'd to place wire

WRITTEN BY D. Kanowsky
APPROVED BY W. B. G.
DATE 2/23/60

RESULTS, SKETCHES & FORMULAS



$$P = H \tan 13^\circ + F_1' \cos 13^\circ + F_2'$$

$$F_1' = \mu N = \frac{H}{\cos 13^\circ}$$ ✓

$$F_2' = \mu H$$ ✓

$$P = H\left[\tan 13^\circ + 2\mu\right]$$

$H = 40{,}000^{\#}$ per inch circumference

$\mu = .2$ (assumed) ✓

$\tan 13^\circ = .231$ ✓

$\tan 13^\circ = .231$ ✓

$2\mu = \underline{.400}$

$.631 \times 40{,}000$

$P \doteq 25{,}000^{\#}$/inch of circum.

assume length of contact between roller & wire = .1"

$P = .1 \times 25000$

apply $\underline{\underline{P = 2500^{\#}}}$ ✓

RECORD OF ANALYSIS

SHEET 25 OF SHEETS 28

ENGINE NO. Wire Wrap

JOB NO. 51792

SUBJECT: Axial Pull for Wrapping wire

WRITTEN BY D. Kanowsky

APPROVED BY WBG

DATE 3/8/60

RESULTS, SKETCHES & FORMULAS

Spool Diameter 7"

Vessel Diameter 6.5"

$$\frac{M}{EI} = \frac{1}{R}$$

$$\sigma_b = \frac{Mc}{I} = \frac{EI}{R} \cdot \frac{c}{I} = \frac{Ec}{R}$$

Hold σ to $.70\ \sigma_y = .70 \times 250,000 = 175,000$ psi

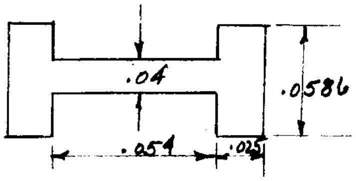
$$\sigma = \sigma_b + \sigma_a$$

$$\underline{\sigma = \frac{Ec}{R} + \frac{P}{A} \leq 175,000}$$

Dumbell

$c = .0297"$

$A = .00509\ \square"$



Area: $.04 \times .054 = .00216$

$+ 2 \times .025 \times .0586 = \underline{.00293}$

$A = .00509$

unwinding: $\frac{Ec}{R} = \frac{16 \times 10^6 \times .0297}{3.5} = 135,500$ psi

$$\frac{P}{A} = 175,000 - 135,500 = 39,500 \text{ psi}$$

$$P \leq 39,500 \times .00509$$

$$\underline{\underline{P \leq 201^{\#}}}$$

channel

max $c = .016"$

$A = .0037\ \square"$

$$\frac{Ec}{R} = \sigma_b = \frac{.016}{.0297} \times 135,500 = 73,000 \text{ psi}$$

$$\frac{P}{A} = 175,000 - 73,000 = 102,000 \text{ psi}$$

$$P \leq 102,000 \times .0037$$

$$\underline{\underline{P \leq 377^{\#}}}$$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 26 OF SHEETS 28

ENGINE NO. Wire Wrap
JOB NO. 51792
SUBJECT: Axial Pull for Wrapping wire

WRITTEN BY D. Konowsky
APPROVED BY WBG
DATE 3/17/60

RESULTS, SKETCHES & FORMULAS

unwrapping wire from 7" spool:

Dumbell $\sigma = 135,500$ psi

channell $\sigma = 73,000$ psi

wire to be rewound on 6.5" diameter vessel

<u>Dumbell:</u>

$$\sigma' = \frac{Ec}{R} = \frac{16 \times 10^6 \times .0297}{3.25} = 146,000 \text{ psi}$$

<u>channel</u>

$$\sigma' = \frac{16 \times 10^6 \times .016}{3.25} = 78,700 \text{ psi}$$

stresses remaining in wire due to wrapping:

<u>Dumbell:</u>

wrap on 6.5"	146,000
unwrap from 7.0"	135,500
net stress	10,500 psi

<u>Channel:</u>

wrap on. 6.5"	78,700
unwrap from 7.0"	73,000
net stress	5,700 psi

To keep total preload in wire below 50,000 psi:

Dumbell $50,000 - 10,500 = 39,500$ use $P \leq 200^{\#}$ as before

channel $50,000 - 5700 = 44,300$

$$44,300 = \frac{P}{A}$$

$$P = 44,300 \times .0037 = 165^{\#}$$

This assumes full axial load will remain in wire.

Recommend max $P = 200^{\#}$ for Dumbell & Channel

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WRIGHT AERONAUTICAL DIVI N

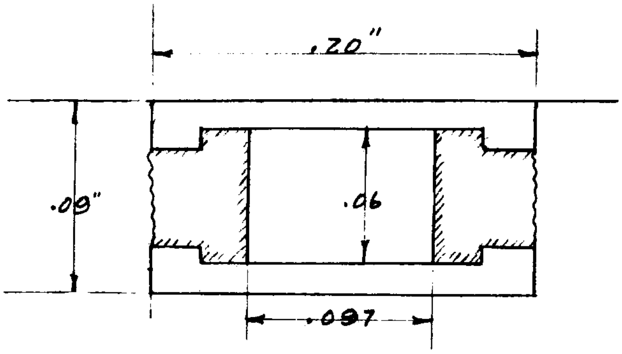
RECORD OF ANALYSIS

SHEET 27 OF SHEETS 28

ENGINE NO. Wire Wrap
JOB NO. 51792
SUBJECT: End Taper on Dome Adapter Piece

WRITTEN BY D. Kanowsky
APPROVED BY WBG
DATE 3/8/40

RESULTS, SKETCHES & FORMULAS



Effective thickness of wire assembly:

Area in .20" length: $.09 \times .20 = .0180$

$- .097 \times .06 = \underline{.0058}$

$.0122$

Area per inch $= .0122 \times \frac{1}{.20} = .061''''$

Effective thickness $= .061''$

use thickness at end of $\overset{\text{tricent}}{\wedge}$ taper: $\underline{\underline{t = .025''}}$

Thickness for yielding of tricent at 5000 psi pressure:

$\frac{pR}{t} = \sigma_y$ $\qquad t = \frac{pR}{\sigma_y}$ $\qquad \sigma_y = 220{,}000$ psi

$$t = \frac{5000 \times 3.25}{220{,}000} = .074 \quad \underline{\underline{\sim .075}}$$

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WRIGHT AERONAUTICAL DIVISION

RECORD OF ANALYSIS

SHEET 28 OF SHEETS 28

ENGINE NO. Wire Wrap

JOB NO. 51792

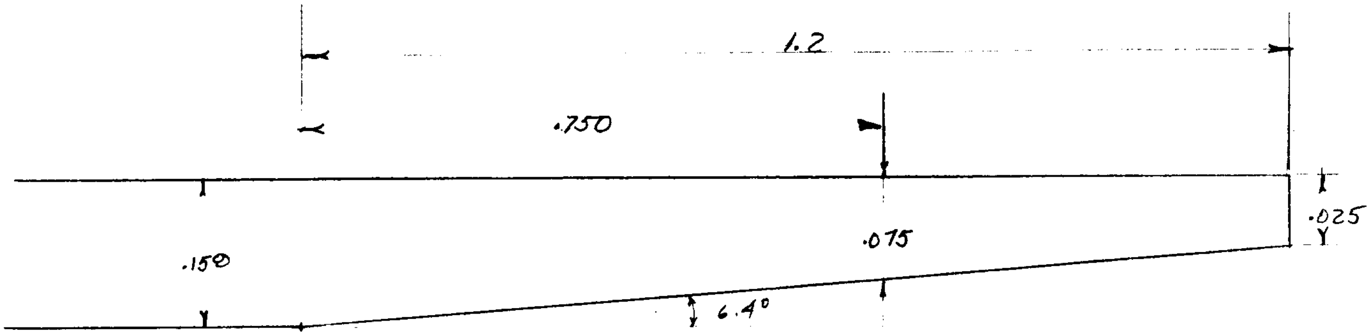
SUBJECT: End Taper on Dome Adapter Piece

WRITTEN BY D. Konowsky

APPROVED BY WBG

DATE 3/8/60

RESULTS, SKETCHES & FORMULAS



$$\frac{.075-.025}{.159-.075} \times .750 = .445$$

$$\frac{.159-.025}{1.2} = \tan\alpha = \frac{.134}{1.2} = .1118$$

$$\alpha = 6.4°$$

The .025 end thickness and .75 length were arbitrarily chosen. The adapter will yield from the .75 length to the .025 end, thus reducing the effects of the interlocking wire wrapped cylinder - adapter discontinuity.

Memo: Leprete to Lersch 2/10/60

APPENDIX II

STRUCTURAL RIG TESTING PROCEDURE

1. Instrument the specimen as shown in Figure 16 and check.

2. Balance all gages. Take a zero and a calibration reading.

3. A combination of three loads is to be applied to the specimen for each reading of strain values. These are the tensile, the longitudinal clamping load from the torquing of the two 7/8 in. side bolts, and the transverse clamping load induced by torquing the two 1/4 in. top bolts. For each combination of pull load and transverse clamping load, three longitudinal clamping loads are applied.

   A typical cycle in applying the loads is as follows:

   (a) Torque 1/4 in. transverse clamping bolts to 4 in. lbs. Apply 4,650 lbs. tensile load to specimen and record strain readings. Release the load.

   (b) Using the same transverse clamping load as in step (a), apply 489 in. lbs. torque on the 7/8 in. longitudinal clamping bolts. Apply the same load as in step (a) and record the strain readings. Release the load. (c) repeat step (c) using 586 in. lbs. torque on the 7/8 in. longitudinal clamping bolts.

4. Tabulation of the test loads and the order of their application are as follows:

APPENDIX II (Continued)

	Longitudinal Clamping Load (lbs.)	Equiv. (Approx.) 7/8 in Bolt Torque (in.lbs.)	Tensile Load (lbs.)	Trans. Clamp Load (lbs.)	Equiv. (Approx.) 1/4 in Bolt Torque (in.lbs.)
(a)	2360	391	4,650	81	4
(b)	2950	489			
(c)	3540	486			
(a)	3930	651	7,750	135	6
(b)	4910	813			
(c)	5880	974			
(a)	5490	909	10,850	189	9
(b)	6860	1136			
(c)	8230	1363			
(a)	7050	1167	13,950	243	11
(b)	8840	1464			
(c)	10600	1755			
(a)	8650	1432	17,050	297	14
(b)	10800	1799			
(c)	12820	2123			
(a)	10250	1697	20,150	351	16
(b)	12750	2111			
(c)	15400	2550			

APPENDIX III

B120VCA TITANIUM WIRE SPECIFICATION

1. ACKNOWLEDGEMENT: Vendor shall mention the specification number and its revision letter in all quotations and when acknowledging purchasing orders.

2. FORM: Coils of wire.

3. COMPOSITION:

		CHECK ANALYSIS	
		Under Min.	or Over Max.
Vanadium	12.5-14.5	0.15	0.15
Chromium	10.00-12.00	0.15	0.15
Aluminum	3.0-4.0	0.40	0.40
Oxygen	0.15-Max.	-	-
Carbon	0.06-Max.	-	0.02
Nitrogren	0.05-Max.	-	0.02
Hydrogen	0.0100-Max.	-	.001
Other Elements	0.060-Max.	-	-
Iron	0.35-Max.	-	0.05
Titanium	balance	-	-

4. CONDITION:

4.1 Uniformly solution annealed after final draw.

4.2 Material shall be free from all surface and sub-surface defects.

4.3 No surface contamination or oxide film.

4.4 Wire shall be coil ground before final draw.

4.5 Wire shall contain no seams, nicks, kinks, bends, breaks, burrs, scratches, or marks due to grinding or drawing.

4.6 Wire surface must be clean and contain no foreign materials and imperfections which may adversely affect the processing or quality of finished articles.

APPENDIX III (Continued)

5. TOLERANCES: Unless otherwise specified, tolerances shall conform to the following:

	Tolerances, Inch	
Diameter Nominal Inch	Plus	Minus
.130 - .200	0.001	0.001
.121 - .130	0.000	0.0005
0.120	0.0005	0.0005

6. TENSILE PROPERTIES:

Tensile strength, psi	130,000 min.
Reduction in area, %	25 min.

7. REPORTS: Unless otherwise specified, the vendor of wire shall furnish with each shipment three copies of a report of the results of tests for chemical composition and tensile strength of each coil in the shipment. This report shall include the purchase order, heat number, material specification number, size, and quantity.

8. PACKAGING: Packaging shall be accomplished in such a manner as to insure that the wire, during shipment and storage, will be protected against mechanical injury.

9. APPROVAL: To assure adequate performance characteristics, wire shall be approved by purchaser before use, unless such approval be waived.

10. REJECTIONS: Material not conforming to this specification or to authorized modifications will be subjected to rejection.

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         CURTISS WRIGHT CORP-WRIGHT AERONAUTICAL DIV
         WIRE WRAP ROCKET CASE DEVELOPMENT DEPT 8612
         SCHEDULE NO 42
         START DATE  EVALUATION DATE
           2011960      02141961
         OPEN SCHEDULE

         MILESTONE   ORIGINAL  CURRENT    DAYS EXPECTED
          ACTIVITY    TARGET PREDICTION   LATE TIME-WKS  VARIANCE
          802000099  02141961  02141961   00.0   049.6      00.

0800100001  DEV OPT HEATTREAT FOR WIRE      8612   1/29/0   7/08/0  112.    4/15/0    54.       1
0800100001             112.00                      1/29/0   7/08/0  112.0 12051960       01.

0800100005  EFF OF SINGLE&DUPL AGING        8612   1/29/0   6/02/0   87.    4/15/0    54. , N   2
0800100005              87.00                      1/29/0   6/02/0   87.0 12051960       01.

0800100010  SELECT PLASTIC                  8612   2/01/0   3/21/0   35.    3/21/0    35.       3
0800100010              35.00                      1/29/0   3/21/0   35.0  6131960       01.

0800100020  DEV ROLLING TECHNIQUES          8612   3/08/0   3/23/0   12.    3/23/0    12.       4
0800100020  0880100020  12.00                      3/04/0   3/22/0   12.0 11231960       01.

0800100025  METHODS DEVEL INSPECT WIRE      8612   3/08/0   4/28/0   27.    5/05/0    43.       5
0800100025  0800100020  27.00                      3/22/0   4/28/0   27.0  1041961       01.

0800200001  PROCURE ROLLS- 2 SHAPES         8612   1/29/0   3/17/0   26.    3/23/0    37.       6
0800200001              26.00                      1/29/0   3/08/0   26.0  6011960       01.

0800200005  PROCURE DIES-CHANNEL SHAPE      8612   1/29/0   3/30/0   42.    3/30/0    42.       7
0800200005              42.00                      1/29/0   3/30/0   42.0  9261960       01.

0800200010  PROC ROUND WIRE-2 VESSELS       8612   2/24/0   3/16/0   15.    3/30/0    25.       8
0800200010  0880200010  15.00                      2/24/0   3/16/0   15.0  9261960       01.

0800200011  PROC O RINGS  MIL-G-5510        8612   3/01/0   4/05/0   25.    5/16/0    53.       9
0800200011  0880200050  25.00                      3/01/0   4/05/0   25.0  1041961       01.

0800200012  PROC LEATHER BACKUP RINGS       8612   3/01/0   4/19/0   28.    5/16/0    53.      10
0800200012  0880200050  28.00                      3/01/0   4/08/0   28.0  1041961       01.

AN104812    0800200013  PROC BOLTS          8612   3/01/0   5/12/0   52.    5/16/0    53.      11
            0800200013  0880200050  52.00          3/01/0   5/12/0   52.0  1041961       01.

AN806-5S    0800200014  PROC FITTINGS       8612   3/01/0   3/31/0   22.    5/16/0    53.      12
            0800200014  0880200050  22.00          3/01/0   3/31/0   22.0 12281960       01.

0800200015  PROD SAMPLE TI WIRE-INTRLK      8612   3/23/0   3/30/0    5.    3/30/0    25.      13
0800200015  0800200001   5.00                      3/23/0   3/30/0    5.0  6081960       01.
0800200015  0880200015   5.00                                         5.0

AN929-5S    0800200016  PROC FITTINGS       8612   3/01/0   3/31/0   22.    5/16/0    53.      14
                                                                                     PAGE    1
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              0800200016   0880200050     22.00                   3/01/0    3/31/0    22.0   1041961             01.
                                                                   3/31/0    4/14/0    10.     4/28/0    10.               15
AN   806 55   0800200017   RWK FITTINGS AN806-55          8420     3/31/0    4/14/0    10.0   1121961            01.
              0800200017   0800200014     10.00
                                                                   4/14/0    4/20/0     4.     5/12/0    10.               16
LS 25439 A1   0800200018   FAB PLUG & FITTING ASSY        8420     4/14/0    4/20/0     4.0   1181961            01.
              0800200018   0800200017      4.00
                                                                                        50.    4/18/0    10.               17
              0800200019   PROD TI CH SAMPLE-10 FT        8612     4/14/0    6/25/0    50.0   9261960            01.
              0800200019   0800200015     50.00                    4/14/0    6/24/0    50.0
              0800200019   0800200021     50.00                                        50.0
              0800200019   0880200019     50.00
                                                                                         .     5/16/0     5.   N           18
              0800200020   H.T.CH WIRE-DUMMY ARBOR        8612     9/21/0    9/21/0      .    12051960           01.
              0800200020   0800100001       .                      9/23/0    9/23/0      .
              0800200020   0800100005       .                                            .
              0800200020   0800200099       .
                                                                                        11.    4/11/0     9.               19
              0800200021   PROC 2 NEW SETS ROLLS          8612     3/30/0    4/14/0    11.0   6231960            01.
              0800200021   0800200015     11.00                    3/30/0    4/14/0
                                                                             5/05/0     .0     4/26/0     8.   N           20
              0800200022   MODIFICATION #3TI WIRE         8612               6/24/0      .    9261960            01.
              0800200022   0800200019       .                      6/24/0
                                                                                        15.0   4/18/0    15.               21
6T 50507      0800200023   PROC 3 GND WHEEL HLD FIX       8612     3/28/0    4/18/0    15.0  10271960            01.
              0800200023   0880200023     15.00                    3/28/0    4/18/0
                                                                                        71.    7/21/0    68.               22
              0800200025   TI I SAMPLE-10 FT              8612     4/14/0    8/16/0    71.0  11011960            01.
              0800200025   0800200015     71.00                    4/14/0    8/16/0    71.0
              0800200025   0800200021     71.00                                        71.0
              0800200025   0880200019     71.00
                                                                                        22.    7/22/0     1.               23
              0800200030   ROLL WIRE-I-DUMMY ARBOR        8612     8/16/0    9/16/0    22.0  12051960            01.
              0800200030   0800200025     22.00                    8/16/0    9/16/0
                                                                                         3.    8/19/0     5.   N           24
              0800200035   H.T.-I-WIRE-DUMMY ARBOR        8612     9/16/0    9/21/0     3.0  12161960            01.
              0800200035   0800100001      3.00                    9/16/0    9/21/0     3.0
              0800200035   0800200030      3.00
                                                                                        48.    5/09/0    28.               25
              0800200099   ROLL WIRE-CH-DUMMY ARBOR       8612     6/24/0    9/23/0    48.0  12051960            01.
              0800200099   0800200001     48.00                    6/24/0    9/23/0    48.0
              0800200099   0800200005     48.00                                        48.0
              0800200099   0800200010     48.00                                        48.0
              0800200099   0800200015     48.00                                        48.0
              0800200099   0800200019     48.00                                        48.0
              0800200099   0800200022     48.00
                                                                                         5.    9/19/0    11.               26
              0800200105   ROLL WIRE #1 VESSEL            8612     9/23/0    9/30/0     5.0  12211960            01.
              0800200105   0800200030      5.00                    9/23/0    9/30/0     5.0
              0800200105   0800200099      5.00
                                                                                         8.    9/29/0     8.   N           27
              0800200110   HEAT TREAT WIRE #1 VESSEL      8612     9/30/0   10/12/0           1041961            01.
                                                                   9/30/0   10/12/0
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0800200110   0800200030     8.00                                                 8.0
0800200110   0800200099     8.00                                                 8.0
0800200110   0800200105     8.00                                                 8.0

0800200120   REPAIR HEAT TREAT FACIL        8612     9/19/0    11/01/0    31.    10/10/0    15.          28
0800200120   0888000005    31.00                     9/19/0    11/01/0    31.0  12281960        01.

0800200125   MFG I-BEAM #7 ROLL             8612    10/05/0    10/21/0    12.    10/17/0     8.          29
0800200125   0888000006    12.00                    10/05/0    10/21/0    12.0  12051960        01.

0800200130   MFG CHANNEL #4 ROLL            8612    10/05/0    10/21/0    12.    10/17/0     8.          30
0800200130   0888000006    12.00                    10/05/0    10/21/0    12.0  11281960        01.

0800200132   MFG SIDE CHANNL FORM ROLLS     8612    10/21/0    10/28/0     5.    10/28/0     5.          31
0800200132   0800200130     5.00                    10/21/0    10/28/0     5.0  12051960        01.

0800200135   EVAL ADD TEFLN&PLASTC RESN     8612    10/14/0    11/10/0    18.    11/01/0    12.          32
0800200135   0800400090    18.00                    10/14/0    11/10/0    18.0   1241961        01.

0800200140   DESIGN CYLINDRICAL GRIPS       8321    10/24/0    10/28/0     4.    10/28/0     4.          33
0800200140   0888000007     4.00                    10/24/0    10/28/0     4.0  12141960        01.

0800200142   SPRAY VES #1                   8612    11/17/0    11/30/0     8.    11/30/0     8.          34
0800200142   0888000008     8.00                    11/17/0    11/30/0     8.0   1181961        01.

0800200145   MFG CYLINDRICAL GRIPS          8420    10/28/0    12/13/0    30.    11/21/0    15.          35
0800200145   0800200140    30.00                    10/28/0    12/13/0    30.0   1271961        01.

0800200148   MFG STRUCTURAL RIG             8420    11/17/0     1/18/1    41.    12/19/0    21.          36
0800200148   0888000008    41.00                    11/17/0     1/18/1    41.0  -1181961        01.

0800200150   TEST WIRE                      8612    12/13/0     1/05/1    15.    12/13/0    15.          37
0800200150   0800200145    15.00                    12/13/0     1/05/1    15.0   2171961        01.

0800200155   MFG NEW ROLL DIE FOR CH/NL     8612    12/19/0     1/03/1     9.    12/23/0     4.          38
0800200155   0888000009     9.00                    12/19/0     1/03/1     9.0   2021961        01.

0800300001   PRODUCE WIRE FOR VES NO.2      8612    10/28/0    11/22/0    16.     6/30/0    33.          39
0800300001   0800200020    16.00                    10/28/0    11/22/0    16.0  12281960        01.
0800300001   0800200030    16.00                                          16.0
0800300001   0800200099    16.00                                          16.0
0800300001   0800200125    16.00                                          16.0
0800300001   0800200130    16.00                                          16.0
0800300001   0800200132    16.00                                          16.0
0800300001   0800400001    16.00                                          16.0

0800300003   HEAT TREAT WIRE VES #2         8612               11/15/0      .    11/07/0     5.   N      40
0800300003   0800200120      .                      11/22/0    11/22/0      .   12281960        01.
0800300003   0800300001      .                                              .

0800300300   ROLL WIRE VES #3               8612     1/03/1     1/18/1    11.    11/07/0     5.          41
0800300300   0800300001    11.00                     1/03/1     1/18/1    11.0   2171961        01.
0800300300   0800200155    11.00                                          11.0
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0800400001  METH DEVEL-PLASTIC APPL      8612   3/21/0   4/07/0   13.     5/10/0   36.   N    42
0800400001  0800100010     13.00                3/21/0   4/07/0   13.0  12051960        01.

0800400070  EVALUATE SOLDER              8612   6/20/0   9/14/0   45.     8/19/0   28.        43
0800400070  0800400099     45.00                6/20/0   9/14/0   45.0   2171961        01.

0800400080  EVAL ULTRASONIC WELDING      8612   6/20/0   8/24/0   31.     8/19/0   28.        44
0800400080  0800400099     31.00                6/20/0   8/24/0   31.0   1041961        01.

0800400090  EVALUATE TEFLON SAMPLES      8612   6/20/0  10/14/0   67.     9/23/0   54.        45
0800400090  0800400099     67.00                6/20/0  10/14/0   67.0  12281960        01.

0800400099  EVAL APPLICATION OF PLSTIC   8612   4/01/0   6/20/0   55.     5/02/0   21.        46
0800400099  0800100010     55.00                4/01/0   6/20/0   55.0   9211960        01.
0800400099  0880400099     55.00                                  55.0

0800500001  STRESS ANAL-CHANNEL WIRE     8325   1/29/0   2/19/0   20.     2/19/0   20.        47
0800500001                 15.00                1/29/0   2/19/0   15.0   9021960        01.

0800500004  STRESS ANAL-DUMBBELL WIRE    8325   1/29/0   2/19/0   20.     2/19/0   20.        48
0800500004                 15.00                1/29/0   2/19/0   15.0   9021960        01.

0800500008  STRESS ANAL-ADAPTERS         8325   2/08/0   3/07/0   19.     3/07/0   19.        49
0800500008  0880500008     19.00                2/08/0   3/07/0   19.0   9021960        01.

0800500010  STRESS ANAL-PIN NO 1         8325   2/08/0   3/07/0   19.     3/07/0   19.        50
0800500010  0880500010     19.00                2/08/0   3/07/0   19.0   9021960        01.

0800500012  STRESS ANAL-PIN NO 2         8325   2/08/0   3/07/0   19.     3/07/0   19.        51
0800500012  0880500012     19.00                2/08/0   3/07/0   19.0   9021960        01.

0800500014  STRESS ANAL-PIN NO 3         8325   2/08/0   3/07/0   19.     3/07/0   19.        52
0800500014  0880500014     19.00                2/08/0   3/07/0   19.0   9021960        01.

0800500030  DESIGN CHANNEL WIRE          8321   1/29/0   3/07/0   25.     3/07/0   25.        53
0800500030                 25.00                1/29/0   3/07/0   25.0   9021960        01.

0800500032  DESIGN DUMBBELL WIRE         8321   1/29/0   3/07/0   25.     3/07/0   25.        54
0800500032                 25.00                1/29/0   3/07/0   25.0   9021960        01.

0800500034  DESIGN ADAPTERS              8321   1/29/0   3/07/0   25.     3/07/0   25.        55
0800500034                 25.00                1/29/0   3/07/0   25.0   9021960        01.

0800500035  RELEASE DESIGN               8612   3/07/0   3/07/0     .     3/07/0     .        56
0800500035  0800500099       .00                3/07/0   3/07/0     .0   9021960        01.

0800500036  DESIGN STAKING PIN NO 1      8321   1/29/0   3/07/0   25.     3/07/0   25.        57
0800500036                 25.00                1/29/0   3/07/0   25.0   9021960        01.

0800500038  DESIGN STAKING PIN NO 2      8321   1/29/0   3/07/0   25.     3/07/0   25.        58
0800500038                 25.00                1/29/0   3/07/0   25.0   9021960        01.

0800500040  DESIGN STAKING PIN NO 3      8321   1/29/0   3/07/0   25.     3/07/0   25.        59
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            0800500040                     25.00              1/29/0   3/07/0   25.0  9021960        01.

            0800500099  COMPLETE DES&STRESS ANAL      8612    3/07/0   3/07/0    .     3/07/0     .  M      60
            0800500C99  0800500001         .00                3/07/0   3/07/0    .0   9021960        01.
            0800500099  0800500004         .00                                   .0
            0800500099  0800500008         .00                                   .0
            0800500099  0800500010         .00                                   .0
            0800500099  0800500012         .00                                   .0
            0800500099  0800500014         .00                                   .0
            0800500099  0800500030         .00                                   .0
            0800500099  0800500032         .00                                   .0
            0800500099  0800500034         .00                                   .0
            0800500099  0800500036         .00                                   .0
            0800500099  0800500038         .00                                   .0
            0800500099  0800500040         .00                                   .0

 6150SAE    0800510001  PROC BOLTS RND HD DR STUD     8612    3/07/0   3/31/0   18.    5/13/0   50.           61
            0800510001  0800500035     18.00                  3/07/0   3/31/0   18.0  1041961        01.

 6150SAE    0800510002  PROC BOLTS GROOV PIN TYPE3    8612    3/07/0   3/31/0   18.    5/13/0   50.           62
            0800510002  0800500035     18.00                  3/07/0   3/31/0   18.0  1041961        01.

            0800600001  EVAL MACH METHODS-ADAPTERS    8420    3/01/0   3/15/0   10.    3/15/0   10.           63
            0800600001  0880600001     10.00                  3/01/0   3/15/0   10.0  9161960        01.

            0800600005  METHODS DEVELOP-ADAPTERS      8420    3/15/0   3/30/0   11.    3/30/0   11.           64
            0800600005  0800600001     11.00                  3/15/0   3/30/0   11.0  10031960       01.

            0800700001  PROC ADAPTER MATERIAL         8612    1/29/0   3/07/0   25.    3/07/0   25.           65
            0800700001                 25.00                  1/29/0   3/07/0   25.0  10271960       01.

            0800700002  PROC ADDIT ADAPTER MATL       8612    3/15/0   5/02/0   34.    5/03/0   35.           66
            0800700002  0800600001     34.00                  3/15/0   5/02/0   34.0  1041961        01.

 6T 60925   0800700004  TOOL DESIGN MANDREL           8420    3/14/0   3/23/0    7.    3/21/0   10.           67
            0800700004  0800700021      7.00                  3/14/0   3/23/0    7.0  9261960        01.

            0800700006  TOOL SHEETS MANDREL           8420    3/23/0   3/23/0    .     3/28/0    5.           68
            0800700006  0800700004       .00                  3/23/0   3/23/0    .0   9261960        01.

            0800700010  FABRICATE MANDREL             8420    3/23/0   6/13/0   57.    5/02/0   25.           69
            0800700010  0800700004     57.00                  3/23/0   6/13/0   57.0  12161960       01.
            0800700010  0800700006     57.00                                    57.0
            0800700010  0880700010     57.00                                    57.0

 6T 60926   0800700012  TOOL DESIGN END ADAPTERS      8420    3/14/0   3/25/0    9.    3/21/0   10.           70
            0800700012  0800700021      9.00                  3/14/0   3/25/0    9.0  9301960        01.

            0800700014  TOOL SHEETS END ADAPTERS      8420    3/25/0   3/28/0    1.    3/28/0    5.           71
            0800700014  0800700012      1.00                  3/25/0   3/28/0    1.0  10031960       01.

            0800700018  TOOL FAB END ADAPTERS         8420    3/28/0   4/25/0   18.    4/17/0   15.           ,2
                                                              3/30/0   4/25/0         10271960       01.
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	0800700018	0800600005	18.00				18.0				
	0800700018	0800700014	18.00				18.0				
	0800700018	0880700018	18.00				18.0				
LS 25439 7	0800700020	PART SHEETS ADAPTERS		8420	3/11/0	3/22/0	7.	3/25/0	10.		73
	0800700020	0800500099	7.00		3/11/0	3/22/0	7.0	10271960		01.	
	0800700020	0880700020	7.00				7.0				
	0800700021	E033177 RELEASE DESIGN		8241	3/09/0	3/11/0	3.	3/11/0	3.		74
	0800700021	0800500035	5.00		3/07/0	3/14/0	5.0	9121960		01.	
LS 25439 7	0800700022	FABRICATE ADAPTERS		8420	4/25/0	6/28/0	45.	5/09/0	15.		75
	0800700022	0800200023	45.00		4/25/0	6/28/0	45.0	1041961		01.	
	0800700022	0800500035	45.00				45.0				
	0800700022	0800700001	45.00				45.0				
	0800700022	0800700018	45.00				45.0				
	0800700022	0800700020	45.00				45.0				
	0800700022	0800700021	45.00				45.0				
	0800700022	0880700022	45.00				45.0				
DA 32360	0800700030	SHEETS-DUMMY ARBOR		8420	3 18 0	3 24 0	4.	3 24 0	4.		76
	0800700030	0880700030	4.00		3/18/0	3/24/0	4.0	6151960		01.	
DA 32360	0800700035	FABR-DUMMY ARBOR		8420	3 24 0	7 18 0	80.	3 29 0	5.		77
	0800700035	0800700030	80.00		3/24/0	7/18/0	80.0	10281960		01.	
	0800800001	METHODS DEVELOPMT STAKING		8420	3/30/0	4/11/0	8.	4/11/0	8.		78
	0800800001	0800500099	8.00		3/30/0	4/11/0	8.0	12161960		01.	
	0800800001	0880800001	8.00				8.0				
	0800800005	METHODS DEVELOPMT WRAPPING		8420	7/18/0	10/10/0	44.	5/16/0	33.		79
	0800800005	0800200019	44.00		7/18/0	10/10/0	44.0	1041961		01.	
	0800800005	0800500099	44.00				44.0				
	0800800005	0800700035	44.00				44.0				
	0800800005	0880800001	44.00				44.0				
6T 60924	0800800010	TOOL DESIGN WRAPPING MACH		8420	3/14/0	4/13/0	22.	3/28/0	15.		80
	0800800010	0800700021	22.00		3/14/0	4/13/0	22.0	10121960		01.	
	0800800015	TOOL SHEETS WRAPPING MACH		8420	4/13/0	4/18/0	3.	4/01/0	4.		81
	0800800015	0800800010	3.00		4/13/0	4/18/0	3.0	10171960		01.	
	0800800018	TOOL FAB WRAPPING MACH		8420	4/18/0	6/16/0	42.	5/09/0	26.		82
	0800800018	0800800015	42.00		4/18/0	6/16/0	42.0	12161960		01.	
	0800800020	WRAP & STAKE CYL SAMPLE		8420	9/23/0	10/10/0	11.	5/16/0	5.		83
	0800800020	0800200020	11.00		9/23/0	10/10/0	11.0	1041961		01.	
	0800800020	0800200035	11.00				11.0				
	0800800020	0800200099	11.00				11.0				
	0800800020	0800400099	11.00				11.0				
	0800800020	0800700010	11.00				11.0				
	0800800020	0800700018	11.00				11.0				
	0800800020	0800700035	11.00				11.0				

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                                                                                      11.0
            0800800020   0800800001      11.00                                        11.0
            0800800020   0800800018      11.00                                        11.0
            0800800020   0800800030      11.00                                        11.0
            0800800020   0800800040      11.00                                        11.0
            0800800020   0800800045      11.00
                                                       8420    4/18/0     4/21/0      3.     4/21/0       8.          84
6T 60982    0800800025   DESIGN ROLLERS                        4/18/0     4/21/0      3.0  10271960          01.
            0800800025   0800800015        3.00
                                                       8420    4/21/0     6/09/0     34.     5/17/0      18.          85
6T 60982    0800800030   PROCURE ROLLERS                       4/21/0     6/09/0     34.0  12161960          01.
            0800800030   0800800025       34.00
                                                       8420    4/13/0     4/25/0      8.     4/22/0       7.          86
6T 60988    0800800035   DESIGN REEL EQUIP                     4/13/0     4/25/0      8.0  10241960          01.
            0800800035   0800800010        8.00
                                                       8420    4/25/0     6/16/0     37.     5/17/0      17.          87
6T 60988    0800800040   FAB REEL EQUIP                        4/25/0     6/16/0     37.0  12161960          01.
            0800800040   0800800035       37.00
                                                       8612    7/05/0     8/15/0     14.     7/21/0      13.          88
            0800800042   FRICTION TEST-TI WIRE                 7/05/0     8/15/0     14.0  11111960          01.
            0800800042   0888000001       14.00
                                                       8612    8/16/0     9/20/0     24.     7/18/0      11.          89
            0800800045   DET COMPR LD TO LOCK SAMPL            8/16/0     9/20/0     24.0  12161960          01.
            0800800045   0800200019       24.00                                      24.0
            0800800045   0800200025       24.00                                      24.0
            0800800045   0800800042       24.00                                      24.0
            0800800045   0880800045       24.00
                                                       8413    7/18/0     9/14/0     27.     9/06/0      21.   N      90
            0800800050   PROCURE LIN POT                       7/15/0     9/14/0     27.0   1041961          01.
            0800800050   0888000003       27.00
                                                       8413    9/06/0     9/23/0     13.     9/09/0       3.          91
            0800800055   DES CONCNTRCTY MEAS DEV               9/06/0     9/23/0     13.0  12201960          01.
            0800800055   0888000004       13.00
                                                       8413    9/23/0    10/03/0      6.     9/16/0       5.          92
            0800800060   FAB CONCNTRCTY MEAS DEV               9/23/0    10/03/0      6.0  12291960          01.
            0800800060   0800800055        6.00
                                                       8413   10/03/0    10/06/0      3.     9/20/0       2.          93
            0800800065   MNT CONCNTRCTY MEAS DEV              10/03/0    10/06/0      3.0   1041961          01.
            0800800065   0800800060        3.00
                                                       8420   10/12/0    10/19/0      5.     6/20/0      24.   M      94
            0800900001   WRAP VESSEL NO 1                     10/12/0    10/19/0      5.0   1111961          01.
            0800900001   0800100025        5.00                                       5.0
            0800900001   0800200011        5.00                                       5.0
            0800900001   0800200012        5.00                                       5.0
            0800900001   0800200013        5.00                                       5.0
            0800900001   0800200014        5.00                                       5.0
            0800900001   0800200016        5.00                                       5.0
            0800900001   0800200020        5.00                                       5.0
            0800900001   0800200110        5.00                                       5.0
            0800900001   0800400080        5.00                                       5.0
            0800900001   0800510001        5.00                                       5.0
            0800900001   0800510002        5.00                                       5.0
            0800900001   0800700002        5.00                                       5.0
            0800900001   0800700010        5.00
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0800900001   0800700018      5.00                                            5.0
0800900001   0800700022      5.00                                            5.0
0800900001   0800800001      5.00                                            5.0
0800900001   0800800005      5.00                                            5.0
0800900001   0800800020      5.00                                            5.0
0800900001   0800800050      5.00                                            5.0
0800900001   0800800065      5.00                                            5.0

0800900002   FAB JACK-PISTON RIG          8423     7/11/0     9/09/0     28.    11/02/0     68.               95
0800900002   0888000002     28.00                  7/11/0     9/09/0     28.0   1181961          01.

0800900003   FAB SEGMENTS-PISTON RIG      8423     7/11/0     9/12/0     29.    11/02/0     68.               96
0800900003   0888000002     29.00                  7/11/0     9/12/0     29.0   1181961          01.

0800900005   INSP&TEFLON SPRAY 1ST VES    8612                10/11/0     .      6/23/0      3.    N          97
0800900005   0800900001        .                  10/19/0    10/19/0      .     1181961          01.
0800900005   0800900002        .                                          .
0800900005   0800900003        .                                          .
0800900005   0800400090        .                                          .

0800900010   WRAP ARBOR,VESSEL #2 WIRE    8420    11/22/0    11/30/0      5.    11/17/0      5.               98
0800900010   0800300003      5.00                 11/22/0    11/30/0      5.0   1051961          01.

0800900011   2ND WRAP ARBOR VESSEL#2 WI   8420    11/30/0    12/06/0      4.    12/06/0      4.               99
0800900011   0800900010      4.00                 11/30/0    12/06/0      4.0   1111961          01.

0801000001   WRAP VESSEL NO 2             8420    12/06/0    12/13/0      5.     7/15/0     10.              100
0801000001   0800300001      5.00                 12/06/0    12/13/0      5.0   1181961          01.
0801000001   0800300003      5.00                                         5.0
0801000001   0800700010      5.00                                         5.0
0801000001   0800700018      5.00                                         5.0
0801000001   0800700022      5.00                                         5.0
0801000001   0800800001      5.00                                         5.0
0801000001   0800800005      5.00                                         5.0
0801000001   0800900001      5.00                                         5.0
0801000001   0800900011      5.00                                         5.0
0801000001   0881000001      5.00                                         5.0

0801000005   INSPECT&VINYL SPRAY VES 2    8612    12/13/0    12/23/0      8.    10/11/0      6.              101
0801000005   0800200135      8.00                 12/13/0    12/23/0      8.0   2031961          01.
0801000005   0801000001      8.00                                         8.0

0801100001   INSTRUMENT VESSEL NO 1       8413               10/11/0      .      6/24/0      1.    N         102
0801100001   0800200018        .                  10/19/0    10/19/0      .     1181961          01.
0801100001   0800900001        .                                          .
0801100001   0800900005        .                                          .

0801100005   TEST VESSEL NO 1             8413               10/11/0      .      6/28/0      1.    N         103
0801100005   0801100001        .                  10/19/0    10/19/0      .     1181961          01.

0801100010   DATA REDUCTION VESSEL NO 1   8413               10/11/0      .      6/29/0      1.    N         104
0801100010   0801100005        .                  10/19/0    10/19/0      .     1181961          01.

0801100015   EVALUATE TEST DATA V NO 1    8325               10/11/0      .      7/06/0      5.    N         105
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                                                            10/19/0   10/19/0     .   1181961      01.
0801100015  0801100010     .                                                                             106
                                                  8413      12/23/0   12/29/0    3.    7/21/0    1.
0801200001  INSTRUMENT VESSEL NO 2                          12/23/0   12/29/0    3.0  2081961        01.
0801200001  0801000001     3.00                                                  3.0
0801200001  0801000005     3.00                                                  3.0
0801200001  0801100015     3.00
                                                                                                         107
                                                  8413      12/29/0   1/10/1     7.    7/22/0    1.
0801200005  TEST VESSEL NO 2                                12/29/0   1/10/1     7.0  2171961        01.
0801200005  0801200001     7.00                                                                          108
                                                  8612      7/15/0    7/22/0     5.    7/22/0    6.
0801300010  MONTHLY REPORT NO. 1                            7/15/0    7/22/0     5.0  9301960        01.
0801300010  0888000003     5.00                                                                          109
                                                  8612      7/22/0    8/31/0    13.    8/22/0    6.
0801300020  MONTHLY REPORT NO. 2                            7/22/0    8/31/0    13.0  10191960       01.
0801300020  0801300010    13.00                                                                          110
                                                  8612      8/31/0    9/30/0    21.    9/22/0    22.
0801300030  MONTHLY REPORT NO. 3                            8/31/0    9/30/0    21.0  11181960       01.
0801300030  0801300020    21.00                                                                          111
                                                  8612      9/30/0    10/24/0   16.   10/21/0    21.
0802000040  COMPILE REPORT NO 4 INFO                        9/30/0    10/24/0   16.0  12131960       01.
0802000040  0801300030    16.00                                                                          112
                                                  8612      10/24/0   10/31/0    5.   10/31/0    5.
0802000045  ISSUE MONTHLY REPORT NO 4                       10/24/0   10/31/0    5.0  12201960       01.
0802000045  0802000040     5.00                                                                          113
                                                  8612      10/31/0   11/23/0   16.   11/22/0    21.
0802000050  COMPILE REPORT NO 5 INFO                        10/31/0   11/23/0   16.0  1131961        01.
0802000050  0802000045    16.00                                                                          114
                                                  8612      11/23/0   11/30/0    4.   11/30/0    4.
0802000055  ISSUE MONTHLY REPORT NO 5                       11/23/0   11/30/0    4.0  1191961        01.
0802000055  0802000050     4.00                                                                          115
                                                  8612      11/30/0   12/23/0   17.   12/22/0    21.
0802000060  COMPILE REPORT NO 6 INFO                        11/30/0   12/23/0   17.0  2131961        01.
0802000060  0802000055    17.00                                                                          116
                                                  8612      12/23/0   12/30/0    4.   12/30/0    4.
0802000065  ISSUE MONTHLY REPORT NO 6                       12/23/0   12/30/0    4.0  2171961        01.
0802000065  0802000060     4.00                                                                          117
                                                  8612      1/03/1    1/17/1    10.    1/17/1    10.
0802000068  TEST TITAN.MIN.35-MIN.65 F                      1/03/1    1/17/1    10.0  1181961        01.
0802000068  0888000010    10.00                                                                          118
                                                  8612      1/18/1    2/14/1    19.   10/04/0    35.  M
0802000099  FINAL REPORT                                    1/18/1    2/14/1    19.0  -2141961       01.
0802000099  0800100001    19.00                                                 19.0
0802000099  0800100005    19.00                                                 19.0
0802000099  0800100010    19.00                                                 19.0
0802000099  0800200142    19.00                                                 19.0
0802000099  0800200148    19.00                                                 19.0
0802000099  0800200099    19.00                                                 19.0
0802000099  0800300001    19.00                                                 19.0
0802000099  0800400099    19.00                                                 19.0
0802000099  0800500099    19.00                                                 19.0
0802000099  0800900001    19.00                                                 19.0
0802000099  0800900005    19.00                                                 19.0
0802000099  0801000001    19.00
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                                                          19.0
0802000099  0801100015     19.00                          19.0
0802000099  0802000068     19.00

                                                 /  /     24.                   24.        119
0880100020  DUMMY JOB 1-20               1/29/0  3/04/0   24.0   11041960            01.
0880100020                 24.00

                                                 /  /     17.                   17.        120
0880200010  DUMMY JOB 2-10               1/29/0  2/24/0   17.0   9021960             01.
0880200010                 17.00

                                                 /  /     37.                   17.        121
0880200015  DUMMY JOB 2-15               1/29/0  3/23/0   37.0   6011960             01.
0880200015                 37.00

                                         2/01/0  4/04/0   45.    4/04/0         45.        122
0880200019  DUMMY JOB 2-19               1/29/0  4/04/0   45.0   6231960             01.
0880200019                 45.00

                                         1/29/0  3/28/0   40.0   3/28/0         40.        123
0880200023  DUMMY JOB NO. 2-23           1/29/0  3/28/0   40.0   10061960            01.
0880200023                 40.00

                                                 /  /     21.                   21.        124
0880200050  DUMMY JOB 2-50               1/29/0  3/01/0   21.0   10181960            01.
0880200050                 21.00

                                                 /  /      .                    44.        125
0880400099  DUMMY JOB 4-99               1/29/0  4/01/0   44.0   6131960             01.
0880400099                 44.00

                                                 /  /     6.                    6.         126
0880500008  DUMMY JOB 5-08               1/29/0  2/08/0   6.0    7181960             01.
0880500008                 6.00

                                                 /  /     6.                    6.         127
0880500010  DUMMY JOB 5-10               1/29/0  2/08/0   6.0    7181960             01.
0880500010                 6.00

                                                 /  /     6.                    6.         128
0880500012  DUMMY JOB 5-12               1/29/0  2/08/0   6.0    7181960             01.
0880500012                 6.00

                                                 /  /     6.                    6.         129
0880500014  DUMMY JOB 5-14               1/29/0  2/08/0   6.0    7181960             01.
0880500014                 6.00

                                                 /  /     21.                   21.        130
0880600001  DUMMY JOB 6-01               1/29/0  3/01/0   21.0   9011960             01.
0880600001                 21.00

                                                 /  /     35.                   35.        131
0880700010  DUMMY JOB 7-10               1/29/0  3/21/0   35.0   9261960             01.
0880700010                 35.00

                                                 /  /      .                    42.        132
0880700018  DUMMY JOB 7-18               1/29/0  3/30/0   42.0   10031960            01.
0880700018                 42.00

                                                 /  /     29.                   29.        133
0880700020  DUMMY JOB 7-20               1/29/0  3/11/0   29.0   10181960            01.
0880700020                 29.00

                                                 /  /     35.                   35.        134
0880700022  DUMMY JOB 7-22               1/29/0  3/21/0   35.0   10271960            01.
0880700022                 35.00

                                                 /  /     34.                   34.        135
0880700030  DUMMY JOB 7-30               1/29/0  3/18/0          6091960             01.
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                                                                        34.0
0880700030                 34.00                                                             42.       136
                                                      /  /      .
0880800001    DUMMY JOB 8-01                 1/29/0   3/30/0   42.0  10281960                    01.
0880800001                 42.00
                                             2/01/0   7/01/0   108.     7/01/0     108.             137
0880800045    DUMMY JOB                      1/29/0   7/01/0   108.0 11111960              01.
0880800045                108.00
                                                      6/30/0   107.                107.             138
0881000001    DUMMY JOB 10-1                 1/29/0   6/30/0   107.0  1111961              01.
0881000001                 107.00
                                             1/29/0   7/05/0   109.     7/05/0     109.             139
0888000001    DUMMY JOB                      1/29/0   7/05/0   109.0 10211960              01.
0888000001                 109.00
                                             1/29/0   7/11/0   113.     7/11/0     113.             140
0888000002    DUMMY JOB                      1/29/0   7/11/0   113.0 12061960              01.
0888000002                 113.00
                                             1/29/0   7/15/0   117.     7/15/0     117.             141
0888000003    DUMMY JOB                      1/29/0   7/15/0   117.0  9231960              01.
0888000003                 117.00
                                             1/29/0   9/06/0   138.     9/06/0     138.             142
0888000004    DUMMY JOB                      1/29/0   9/06/0   138.0 12011960              01.
0888000004                 138.00
                                             1/29/0   9/19/0   147.     9/19/0     147.             143
0888000005    DUMMY JOB                      1/29/0   9/19/0   147.0 11111960              01.
0888000005                 147.00
                                             1/29/0  10/05/0   159.    10/05/0     159.             144
0888000006    DUMMY JOB                      1/29/0  10/05/0   159.0 11091960              01.
0888000006                 159.00
                                             1/29/0  10/24/0   172.    10/24/0     172.             145
0888000007    DUMMY JOB                      1/29/0  10/24/0   172.0 12081960              01.
0888000007                 172.00
                                             1/29/0  11/17/0   189.    11/17/0     189.             146
0888000008    DUMMY JOB                      1/29/0  11/17/0   189.0 -11171960             01.
0888000008                 189.00
                                      8612   1/29/0  12/19/0   210.    12/19/0     210.             147
0888000009    DUMMY JOB                      1/29/0  12/19/0   210.0  1201961              01.
0888000009                 210.00
                                      8612   1/29/0   1/03/1   219.     1/03/1     219.             148
0888000010    DUMMY JOB                      1/29/0   1/03/1   219.0  1041961              01.
0888000010                 219.00
                                             2/14/1   2/14/1     .                   .              149
9999999999    DUMMY END JOB FOR PROJECT      2/14/1   2/14/1     .   -2141961              01.
9999999999    0800200150    .                                    .
9999999999    0800300300    .                                    .
9999999999    0800400070    .                                    .
9999999999    0801000001    .                                    .
9999999999    0801200005    .                                    .
9999999999    0802000065    .                                    .
9999999999    0802000099    .
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