AGE FORMING of CENTER PIECE HEAD S-IC

By Robert W. Lightstone

Final Report

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THE BOEING COMPANY

Wichita Branch

Wichita, Kansas 67210

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Table of Contents

	Page
SUMMARY OR ABSTRACT	1
LIST OF APPENDIX ITEMS AND FIGURES	2
FOREWORD	3
SCOPE OF WORK	4
WORK PERFORMED	5-7
Introduction	5
Test Program	5
Test Parts and Tooling Configuration	6
Test Procedure	7
EVALUATION OF RESULTS	8-11
Material	8
General Considerations	8-11
Conclusions	11
Recommendations	11
APPENDIX AND FIGURES	

SUMMARY OR ABSTRACT

189/3

The primary objective of this investigation was to determine the capabilities of age forming 2219-T37 aluminum to a compound curved form in the configuration as represented by the Saturn S-1C Bulkhead Center Piece. The geometric shape of the part is a segment of an ellipsoidal shell.

The fact that the shell segment was located at the Y axis pole and of very small curvature compared to the full ellipsoid permitted substitution of a spherical form as the test configuration.

A fixture was designed and fabricated with interchangeable die and punch inserts so that variables of thickness and depth of curvature could be investigated, using one aging fixture. Age formed test parts were measured to establish amount of curvature retention, effect of grain direction, and growth of the alloy.

The data was analyzed and evaluated to obtain practical parameters which were used to design and fabricate tooling to age form sculptured blanks having a predetermined form after age forming.

Four important conclusions were obtained:

1. The age forming of compound contoured configuration proved feasible and repetitive for consistent manufacturing capability. Three sculptured centerpieces were age formed within tolerances set forth in MSFC Dwg. MR&T-SK-714.

2. The percent of retention varies with thickness.

3. The percent of retention is greater in the longitudinal grain direction than in the transverse grain direction and varies at the same rate with respect to material thickness.

4. Material growth occurs in all directions and varies to a limited extent with grain direction and thickness.

Author

LIST OF APPENDIX ITEMS AND FIGURES

Appendix

A Empirical Method for Symmetrical Overform

B Comparison of $\frac{X^2 + 2Y^2}{198^2} = 1$ with $\frac{X^2 + Y^2}{279.238^2} = 1$

C Mechanical Properties Report 2219-T37

D Mechanical Properties Report 2219-T87

E Stress Calculations on MIT-RSC-MR&T-SK-714

F Data Sheet - Summation of Work Sheets

Figure

1 MSFC Drawing MR&T-SK-714
2 Sketch of Scribe Lines for Test Parts
3 Graph of Ratio R_f to R_p
4 Graph Showing Lineal Growth in Age Forming
5 MR&T-SK-714 Center Piece Blank - Adjusted for Material Growth
6 MR&T-SK-714 Part No. 1 Material Growth
7 MR&T-SK-714 Part No. 2 Material Growth
8 MR&T-SK-714 Part No. 3 Material Growth
9 Deviation from 279.3" R MR&T-SK-714, Part No. 1
10 Deviation from 279.3" R MR&T-SK-714, Part No. 2
11 Deviation from 279.3" R MR&T-SK-714, Part No. 3
12 MIT-RSC-MR&T-SK-714 Age Forming Fixture
13 Measurement with Part Supported on Flat Surface
14 Curvature Measurement with Blank Supported on Rubber Pad at Center of Concave Side
15 R&D Master In Open Fixture for Forming to 181" Radius Die
16 Sculptured MR&T-SK-714 Center Piece Without 8" Diam. Center Hole - Prior to Age Forming
17 Sculptured MR&T-SK-714 Center Piece with 8" Diam. Cutout - Prior to Age Forming
18 R&D Master Reinforced to Hold Developed Configuration During Plaster Casting
19 Plaster Die Pattern & R&D Master Ready for Casting of Plaster Punch Pattern
20 Plaster Punch Pattern
21 Plaster Die Pattern
22 Completed Part Contour Compared to 279.3" Radius Template
23 Age Formed MR&T-SK-714 Part Nos. 1, 2, 3

FOREWORD

This final technical report covers the work performed from June 26, 1965, through December 22, 1964, under George C. Marshall Space Flight Center Contract NAS 8-11717 dated June 25, 1964.

This contract was conducted by The Boeing Company, Airplane Division - Wichita Branch. The work was performed under the direction of Virgil Gerstner (Manager) and R. E. Layton (Unit Chief, Tooling-Metalworking-Metallurgy) Manufacturing Development Section, by Robert W. Lightstone, Project Engineer.

The contract was initiated by Program R&D Branch of Marshall Space Flight Center and was administered by C. H. Maroney, Technical Representative, and L. A. Bowers, Alternate, Industrial Support Branch, Manufacturing Engineering Laboratory.

SCOPE OF WORK

Contract NAS 8-11717 was initiated to determine the feasibility of age forming double contoured parts to a configuration as represented by the S-1C Bulkhead Center Piece as shown on MSFC Sketch MR&T-SK-714 dated March 27, 1964, and revised July 30, 1964, Appendix Figure 1, and to resolve problems associated with this operation.

The work included design and fabrication of a tool in which 2219 aluminum alloy in T37 condition could be age formed to the T87 condition. The tool was to be of sufficient strength and durability to hold the blanks to a predetermined shape during the aging process and to accommodate thermal expansion and expected material growth. The one tooling fixture was to be suitable for age forming parts of various constant thickness in two different contours and also to age form the MR&T-SK-714 sculptured parts by the use of removable die and punch holding inserts.

The scope of the work covered forming of 2219-T37 aluminum alloy blanks of a 55" diameter in constant thickness of .250", .500", and .900" to a basic contour of $\frac{X^2 + 2Y^2}{198^2} = 1$ and in the same thicknesses to a .650" symetrical overform of the basic equation. Three test parts of each thickness and of each contour were to be age formed. Three parts, from presculptured blanks per MSFC Sketch MR&T-SK-714, were to be age formed in a holding die and punch adjusted to compensate for parameter variables determined from test forming as follows:

1. The effect of blank thickness on the formed part.
2. The relationship of depth of forming to final contour of the part.
3. The effect of sculptured pattern on the contour.
4. The effect of direction of rolling of blank on final contour.

WORK PERFORMED

Introduction

The Boeing Company - Wichita Branch developed the original technique for age forming contours into single curvature circumferential radii type configurations. This "age forming" process has the unique capability of forming age hardenable alloys without working in the plastic range or exceeding the yield point of the material.

The parameters for manufacturing of single curve configurations have been well established and are being used in production. However, preliminary research has indicated that in the age forming of compound contoured parts the grain direction as produced by the rolling process used in sheet and plate manufacture would produce variations in curvature directly related to the grain direction.

The effort under this contract was to determine the feasibility of age forming compound contours. The approach was to test age form a sufficient number of compound contoured parts to determine and evaluate the characteristics which could be used to establish the compound contour age forming parameters for aluminum alloy 2219-T37.

Test Program

The test program was set up to age form a series of 2219-T37 aluminum panels as follows:

1. Three .250" thick, three .500" thick, and three .900" thick 55" diam. blanks age-formed to a segment of an ellipsoid described by the rotation of an ellipse $\frac{X^2 + 2Y^2}{198^2} = 1$ from X = -27.5 to X = 27.5 about the Y axis.
2. Three .250" thick, three .500" thick, and three .900" thick 55" dia. blanks age formed with a .650" symetrical overform of the ellipse equation $\frac{X^2 + 2Y^2}{198^2} = 1$.
3. Three blanks sculptured to produce a part to conform with the S-IC Center Piece as called for by MSFC Dwg. MR&T-SK-714 (Appendix Fig. 1).

Measurements were made of the age formed constant thickness part to determine the radius of curvature, with and across the grain direction, and material growth resulting from the aging forming process. The measured data was analyzed to set up parameters to be used to compensate for springback and material growth in the age forming of the sculptured parts.

Test Parts and Tooling Configuration

The constant thickness test blanks were machined both sides to the required thickness and were cut to a diameter of 55.099" +.125/-.000 inches. Light scribe lines were made on one surface, consisting of four diametrical lines, indexed to the grain direction, and five concentric circles were scribed with 5-inch to 25-inch radii in 5-inch increments and one circle with a radius of 27.549 inches. (See Appendix Figure 2). This gridding was used to locate measuring points. The blanks were age formed so that the grid appeared on the convex surface of the part.

Mechanical properties of the test part material in T37 condition were determined by laboratory tests on sample coupons from part trim. Test coupons were cut from one constant thickness part in each thickness after the age forming process to provde mechanical property data for the T87 condition. Results of these tests are found in Appendices C and D.

The aging fixture MIT-RSC-MR&T-SK-714 was designed in a two-piece octagonal box shape with radial internal reinforced structure. Each sectionpiece supported a removable die or punch insert. Eight slotted latches were used to lock the fixture under pressure during the aging process (Appendix Figure 12). The structure was stress calculated for a closing and holding load of 152,000 lb. (Appendix E).

Welded 6061-T6 aluminum was used throughout the structure in order to maintain equal thermal expansion rates in the fixture and the test parts. The die and punch inserts used with the sculptured parts were fabricated from kirksite in order to permit an economy in the technique used to obtain the desired punch and die configuration. Production inserts of cast aluminum are equally feasible.

The die and punches used to hold the constant thickness test parts were shaped to conform in cross-section to the section of a circle with the equation of $\frac{X^2 + Y^2}{279.283^2} = 1$. This configuration does not vary from the ellipse equation $\frac{X^2 + 2Y^2}{198^2} = 1$ more than .002 inch over the interval of X = -27.5 to X = 27.5 and permitted conventional machining operations (Appendix B).

The .650" symmetrical overform was established by adding a percentage of the total overform to the vertical distance from a horizontal line, through the pole of the arc, to any point on the arc at the same rate as the ratio as this distance was to the total chord height (Appendix A).

Test Procedure

The test parts were age formed by placing the flat blanks between the punch and die inserts and closing the fixture in a hydraulic press. The fixture was then locked in a closed position by driving wedges in the slotted latches while under pressure of 152,000 lb. The aging fixture was then transferred to a heat treating oven where the test part was aged for twenty-four hours at a temperature of 325°F. ±10°F. This heat treating process transformed the aluminum part from 2219-T37 to a T87 condition. The furnace used for the aging process was a conventional furnace which is certified for temperature uniformity, etc., per established quality control procedures. Certification data is on file in the Quality Control Department of Boeing-Wichita.

After cooling to a maximum of 125°F. the part was removed from the fixture and the chord height at 1" intervals of the chord length were measured along each of the diametrical scribed lines. The increase in surface length over the diametrical length of each concentric scribed circle was measured to determine material growth. Material thickness growth measurements were made on selected test parts in each thickness.

The measurements of the test parts were made with the part supported on a 10" diameter rubber disc at the center of the concave side. This method gave a near free standing part and eliminated distortion induced by the part weight and irregularities when supported on the edge, or in a fixture (Appendix Figures 13 & 14). Material growth was measured by a scale with .010" divisions and estimated to the nearest .005". Thickness growth was measured by micrometer and by Vidigaging.

Test Part No. 6 was age formed with an eight-inch diameter center cut-out in order to observe the effect on growth and springback. One test part in each thickness and each fixture curvature was subjected to closing and then opening of the fixture after which it was measured to determine presence of any permanent set. No permanent deformation was incurred in any of the test parts.

Two of the sculptured parts MR&T-SK-714 Nos. 1 & 2 were age formed without the center 8" dia. hole to permit observation of consistency with constant thickness parts (Figures 16 and 17). Part MR&T-SK-714 No. 3 was age-formed with the 8" dia. center hole. Also an 8" diameter hole was machined in the MR&T-SK-714 No. 1 part after age forming and measuring to determine effects of the center cut-out.

EVALUATION OF RESULTS

Material

Aluminum Alloy 2219 in T37 condition was the material used for the test blanks. The age forming operation of heat treating at 325°F. for a period of 24 hours produced the T87 condition in the age formed part. Analysis of the mechanical properties of the material used in this investigation is shown by Appendices C and D.

A comparison with the standard minimum average tensile yield and ultimate strength reveals that age forming produces no detrimental effects on the material strength, in fact there is an indication of a slight increase in mechanical properties.

General Considerations

The most important parameter effecting the ability to age form to a required configuration is the amount of overform that will be required in the aging fixture to overcome the inability of the material to retain the full configuration of the fixture. The segment of an approximate spherical shell shape of the S-IC polar cap places the spherical radii as the basic measurement for data accumulation and evaluation. The data assembled from work sheets (Appendix F) showed that in the compound contour of the test shape, the retention of radii in the longitudinal grain direction were greater than the retention of radii in the transverse grain direction. The radius of the developed part was calculated by measuring the chord height along lines parallel to the grain and perpendicular to the grain direction and using the equation $R = \frac{4CH^2 + CL^2}{8CH}$ where CH = chord height, CL = chord length, and R = radius. The percent of retention was based on the residual strain in the part as calculated from the equation, percent retention $= \frac{S_p}{S_f} \times 100$, with S = calculated from strain $(S) = \frac{T}{2R}$ where T = thickness and the subscripts "p" and "f" represent the developed part and the fixture respectively.

A graph was prepared (Figure 3) using the fixture radius as the ordinate and the developed radius as the abscissa. The average of the radii in the transverse and in the logitudinal grain direction for each material thickness for the two fixture radii were used to establish the points on the graph. Several important parameters were shown by the graph. The rate of change in the ratio of the R_p to R_f for longitudinal grain direction decreases slightly as the thickness increases. The rate of change in the transverse grain direction did not vary consistently as the thickness varied; the .250" and .900" thickness rates of change are similar while the value of change of the .500" thickness increases with increase of radius. The surface growth also is found to increase with increase in material thickness (Figure 4). This is understood because of the relationship between S & T in the equation $S = \frac{T}{2R}$. Material thickness also increases during the age forming process. This factor was used to calculate a blank size.

To achieve the final objective of the project, the forming of the sculptured part of various thickness to a spherical shape, corrective measures were required to provide for the material growth and for the difference in the amount of corrective retention in the transverse grain direction and in the longitudinal direction. The growth factor was compensated for by re-dimensioning the part blank as shown in Figure 5.

The adjustment for the differences in percent of curvature retention require a fixture having a surface configuration produced by the trace of an arc rotated about its pole, with the radius cycling from a maximum to a minimum and back to a maximum during 180° of rotation.

Looking toward the production future of age forming as well as the direct fabrication of the MR&T-SK-714 test specimens, alternate methods were considered. A method was sought that could avoid the initial preparations for numerical control machining or could avoid the numerous coordinated template-type hand-formed fixture approach.

A unique and novel method was developed by which the desired configuration could be fabricated using only conventional machines and manufacturing techniques and requiring a nominal manhour expenditure.

This tooling concept was developed as follows:

1. Using the Fixture Radius / Developed Part Radius Graph (Figure 3) it was found that to produce a developed radius of 279.238" (MR&T-SK-714 spherical radius) the fixture would require 238" radius in the part longitudinal direction and 206" radius in the part transverse direction.

2. Using the graph again and using the 238" radius in the transverse direction and 206" R in the longitudinal direction the fixture radius is determined as 181".

3. A die and punch fixture was then machined to the 181" spherical radius and a blank called the R&D Master was age formed (Figure 15). The radii of the R&D Master was 238" and 206" as required and antipated (Figure 15).

4. Plaster patterns were made of the convex side and of the concave side of the R&D Master. Grain direction was indexed on the patterns (Figures 18 thru 21).

5. In turn the plaster patterns were used to cast a kirksite die and punch set for the aging fixture. The grain indexing was maintained on the kirksite punch and die set.

6. The MR&T-SK-714 sculptured part was then placed in the aging fixture but with the part grain direction rotated 90° from that of the die and punch. This operation was required to adjust for the grain reversal occurring between Steps 2 and 3 above.

7. Age forming of the part clamped in the fixture produced the required 279.3" spherical radius part within tolerance requirement.

Parts MR&T-SK-714 No. 1 and No. 2 were age formed from sculptured blanks without the 8" diameter center cut-out. Part MR&T-SK-714 No. 3 blank was machined with the 8" dia. cut-out prior to age forming with the exception of the 8" center diameter of the Parts No. 1 & No. 2. All three parts were very close to the required basic contour and all within the .060" deviation allowance. The rate of change did not exceed the .050" in 10" in any part with the exception of a local area within the 8" center area of Parts No. 1 & No. 2 (Appendix Figures 6 thru 11).

There is a slight turn up on the edge of the parts and an underform in the center 8" dia. area on all parts. This condition was expected as the forming parameters were selected on the basis of an average thickness. Complete corrections could have been accomplished by selecting separate radii for each different thickness and machining the punch with the multiple radii configuration.

Conclusions

1. The effect of grain direction and material thickness is consistent and can be predicted from tables established with accuracy sufficient for normal tolerance requirements.

2. The effects of sculpturing in a symmetrical pattern can be predicted and balanced by adjustments in the holding fixture design.

3. The age forming of double contoured configuration in the form of a symmetrical shell segment is feasible and within the normal manufacturing capabilities.

4. By taking advantage of the effects of grain direction upon age formed contours an economical two-stage method of tool fabrication was developed that will reduce production tool and part fabrication costs and use conventional machines (See Page 10).

Recommendations

1. It is recommended that further research be done on compound contoured symmetrical shell configurations. The contours should not be so near spherical but should have a shorter distance between foci and also have greater eccentricity.

2. An investigation to determine the parameters of various age hardenable metal alloys should be conducted in single and compound contoured configurations. Included should be the fusion weldable aluminum alloys 7002, 7039, & X7106.

3. A wider selection of material thickness age formed in a more than one degree of overform should be studied.

4. It is further recommended that the nature of residual stresses in both surfaces of the age formed parts be investigated and compared with similar stresses developed by conventional forming.

Empirical Method for Symetrical Overform

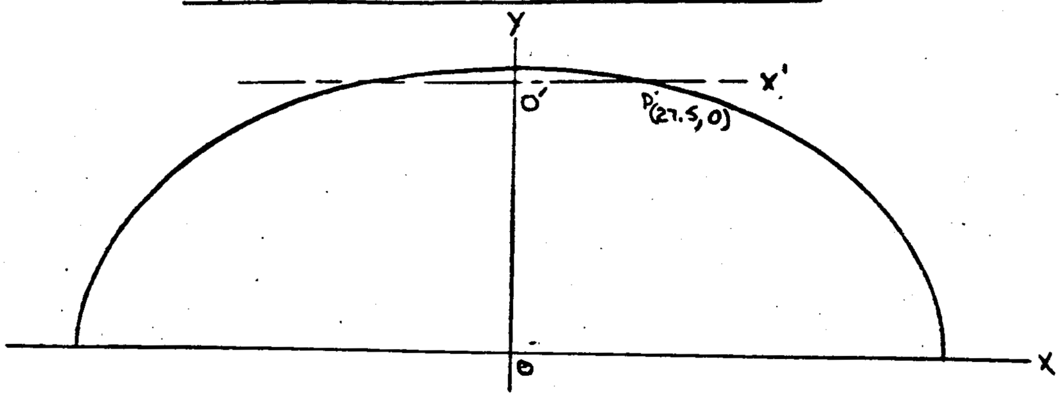


FIG. 1 Translation of Ellipse

$$\frac{X^2 + 2Y^2}{198^2}$$

The X Axis of the Ellipse $\frac{X^2 + 2Y^2}{198^2} = 1$ is translated to coincide with the Chord of the Curve at X = 27.5

$$\text{At } X = 27.5 \quad Y = -\sqrt{\frac{198^2 - 27.5}{2}}$$

$$Y = 138.650$$

Translating the Curve Equation becomes

$$Y + 138.650 = -\sqrt{\frac{198^2 - X^2}{2}}$$

$$Y = -\sqrt{\frac{198^2 - X^2}{2}} - 138.650$$

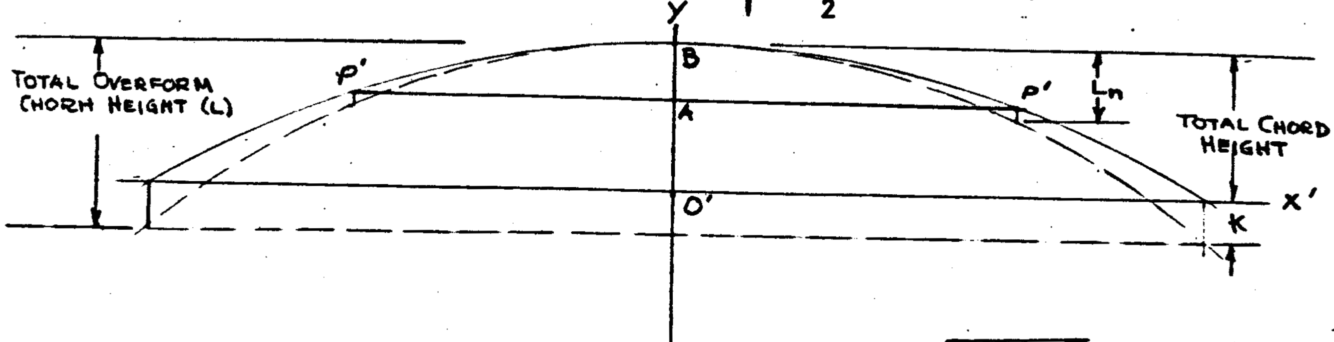


FIG. 2 $Y = -\sqrt{\frac{198^2 - X^2}{2}} - 138.650$

$$O'B = \text{Total Chord Height } (X=0) = \sqrt{\frac{39204}{2}} - 138.650$$

$$O'B = 1.357 \qquad (1)$$

For Point P

$$O'A = \sqrt{\frac{39204 - X_n^2}{2}} - 138.650 \qquad (2)$$

Chord Height of Chord Thru P' = AB = O'B - O'A.

The Empirical Devised for Symetrical Overform is to Add to the Chord Height (AB) at any Point P' the same percent of Maximum Overform K as the percent of the Chord Height (AB) at that point is to the Total Chord Height (O'B).

The Empirical Equation for the above becomes Total Overform Chord Height

(At X_n)

$$L_n = K\left[\frac{O'B - O'A}{O'B}\right] + O'B - O'A$$

Substituting Equations (1), (2)

$$L_n = K\left[\frac{1.357 - \left(\sqrt{\frac{39204 - X_n^2}{2}} - 138.650\right)}{1.357}\right] + 1.357 - \left(\sqrt{\frac{39204 - X_n^2}{2}} - 138.650\right)$$

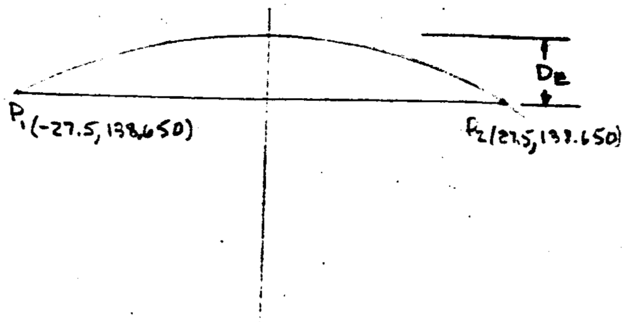
$$L_n = \frac{K}{1.357}\left[1.357 - \left(\sqrt{\frac{39204 - X_n^2}{2}} - 138.650\right)\right] + 1.357 - \left(\sqrt{\frac{39204 - X_n^2}{2}} - 138.650\right)$$

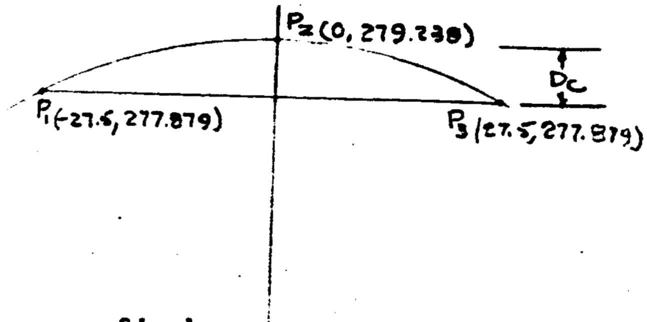
$$L_n = \left(\frac{K}{1.357} + 1\right)\cdot\left(140.007 - \sqrt{\frac{39204 - X_n^2}{2}}\right)$$

For K = .650 $\quad L_n = 1.479\left(140.007 - \sqrt{\frac{39204 - X_n^2}{2}}\right)$

Variations of Ellipse $\frac{X^2 + 2Y^2}{198^2} = 1$ and Circle $\frac{X^2 + T^2}{279.738^2} = 1$ from

$X = -27.5$ to 27.5





Ellipse

$$D_E = 140.007 - \sqrt{\frac{198^2 - X_n^2}{2}}$$

Circle

$$D_C = 279.238 - \sqrt{279.238^2 - X_n^2}$$

X_n	D_E	D_C
0	0	0
1	.002	.002
2	.007	.007
3	.016	.016
4	.029	.029
5	.043	.043
6	.065	.065
7	.088	.088
8	.115	.114
9	.145	.145
10	.179	.179
11	.217	.217
12	.258	.258
13	.303	.302
14	.351	.350
15	.403	.402
16	.460	.458
17	.518	.517
18	.582	.581
19	.647	.646
20	.717	.716
21	.791	.790
22	.869	.867
23	.949	.948
24	1.033	1.032
25	1.122	1.121
26	1.213	1.213
27	1.309	1.308
27.5	1.359	1.357

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THE BOEING COMPANY
AIRPLANE DIVISION - WICHITA BRANCH
WICHITA 1, KANSAS

QUALITY CONTROL LABORATORY REPORT Q 28682

Date 8-27-64 Submitted by 3070 - R. Layton (DEPT. NO. / INSP. OR SHOP SUPV.) Prepared by 3070 - R. Lightstone 3452 (DEPT. NO. / NAME / PHONE)

Description: R.N. ______ Part No. MR & T-SK-714 P.O. ______ Quantity Rec'd ______

Material 2219-T37 Aluminum Vendor ______

No. of Samples 30 No. of Pieces 30 Spec. No. Fed. T.M. 151 Copies to 3070 - RLayton 1cc
3070 - RLightstone 1cc
USAF - Chief, Q.C. 1cc

Information Requested Tensile test, ultimate strength, yield, elongation, and reduction in area.

HS:mm

The 2219-T37 specimens were tensile tested with results as follow:

SAMPLE NUMBER	DIMENSIONS	AREA SQ. IN.	YIELD LOAD LB.	ULTIMATE LOAD LB.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONG. %	REDUCTION IN AREA %
130-5812								
L1	0.5044 x 0.2520	0.1271	5,870	7,220	46,200	56,800	19	42.9
L2	0.5048 x 0.2514	0.1269	6,050	7,290	47,700	57,400	19	38.1
L3	0.5038 x 0.2507	0.1263	5,880	7,230	46,600	57,200	19	41.1
T1	0.5053 x 0.2522	0.1274	5,370	7,340	42,100	57,600	17	37.2
T2	0.5041 x 0.2520	0.1270	5,350	7,280	42,100	57,300	16	35.0
T3	0.5029 x 0.2524	0.1269	5,220	7,240	41,100	57,100	18	38.5
13-1903								
L1	0.5040 x 0.5010	0.2525	12,020	14,200	47,600	56,200	21	40.2
L2	0.5020 x 0.4988	0.2504	12,360	14,520	49,100	58,000	22	45.3
L3	0.5028 x 0.5004	0.2516	11,980	13,980	47,600	55,600	22	40.0
L4	0.5032 x 0.5003	0.2518	12,500	14,560	49,600	57,800	23	45.6
T1	0.5028 x 0.5011	0.2520	10,340	14,200	41,000	56,300	22	40.1
T2	0.5031 x 0.5008	0.2520	10,800	14,600	42,900	57,900	21	36.5
13-1904								
L1	0.5050 x 0.4986	0.2518	11,860	14,560	47,100	57,800	21	38.8
L2	0.5032 x 0.4997	0.2514	12,120	14,260	48,200	56,700	23	42.3
L3	0.5024 x 0.5002	0.2513	11,600	14,280	46,200	56,800	22	42.3
L4	0.5030 x 0.5004	0.2517	12,160	14,300	48,300	56,800	21	38.4
T1	0.5038 x 0.5018	0.2528	10,660	14,720	42,200	58,200	22	37.5
T2	0.5034 x 0.4978	0.2506	10,920	14,720	43,600	58,700	20	39.7

- Continued -

Prepared by ______ Approved by ______

SAMPLE NUMBER	DIMENSIONS	AREA SQ. IN.	YIELD LOAD LB.	ULTIMATE LOAD LB.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONG. %	REDUCTION IN AREA %
181-113								
L1	0.5065	0.2015	9,280	11,250	46,100	55,800	20	43.5
L2	0.5078	0.2025	9,290	11,330	45,900	56,000	21	44.2
L3	0.5079	0.2026	9,280	11,330	45,800	55,900	22	44.2
T1	0.5073	0.2021	8,330	11,520	41,200	57,000	17	32.8
T2	0.5059	0.2010	8,240	11,400	41,000	56,700	18	34.9
T3	0.5042	0.1996	8,130	11,350	40,700	56,900	18	35.8
181-114								
L1	0.5071	0.2020	9,560	11,520	47,300	57,000	20	40.4
L2	0.5039	0.1994	9,430	11,340	47,300	56,900	20	42.0
T1	0.5032	0.1989	8,340	11,540	41,900	58,000	18	34.5
T2	0.5051	0.2004	8,500	11,710	42,400	58,400	16	33.5
T3	0.5046	0.2000	8,370	11,640	41,900	58,200	17	34.5
T4	0.5037	0.1993	8,340	11,540	41,800	57,900	17	35.8

The samples were destroyed in testing and the remnants disposed of as scrap.

Prepared by H. Shapley **Approved by** O.R. Borngesser

Original signed by PAUL C. KISSER

HMS 420 W R12

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WICHITA, KANSAS 67210

QUALITY CONTROL LABORATORY REPORT Q 34671

Date 12-10-64 Submitted by 3070 - R. Layton (DEPT. NO. / INSP. OR SHOP SUPV.) Prepared by 3070 - R. Lightstone 3452 (DEPT. NO. / NAME / PHONE)

Description: R.N. ____ Part No. ____ P.O. ____ Quantity Rec'd ____

Material 2219-T87 Vendor ____

No. of Samples 3 No. of Pieces 3 Spec. No. ____ Copies to 3070 - RLayton 1cc (DEPT. NO. / NAME)
USAF - Chief, Q.C. 1cc

Information Requested Please make check in longitudinal and transverse grain direction, for mechanical properties on yield strength, ultimate tensile strength, percent elongation. Samples may be destroyed, return remnants.

BJW:mm

Sample Nos.			
-3	Part I	All F2 Samples - 1/4" Plate
131-903-7	Part II	All R3 Samples - 1/2" Plate
181-114-13	Part III	All R1 Samples - 3/4" Plate

Test results were as shown by the following data:

SAMPLE NUMBER	DIMENSIONS	AREA SQ. IN.	YIELD LOAD LB.	ULTIMATE LOAD LB.	YIELD STRENGTH PSI	TENSILE STRENGTH PSI	ELONG. %
L-1-1	0.5053 x 0.2577	0.1302	7,250	8,750	55,700	67,200	12
L-1-2	0.5048 x 0.2590	0.1307	7,250	8,770	55,500	67,100	12
T-1-1	0.5052 x 0.2575	0.1301	7,210	8,770	55,400	67,400	12
T-1-2	0.5014 x 0.2570	0.1289	7,160	8,680	55,500	67,300	11
L-2-1	0.2540	0.0507	2,880	3,490	56,800	68,800	12
L-2-2	0.2540	0.0507	2,840	3,440	56,000	67,800	12
T-2-1	0.2535	0.0505	2,850	3,470	56,400	68,700	11
T-2-2	0.2542	0.0508	2,850	3,470	56,100	68,300	11
L-3-1	0.5100	0.2043	11,660	14,320	57,100	70,100	12
L-3-2	0.5111	0.2051	11,740	14,400	57,200	70,200	12
T-3-1	0.5095	0.2039	11,580	14,320	56,800	70,200	11
T-3-2	0.5080	0.2027	11,520	14,260	56,800	70,400	11

Prepared by B.J. Wade Approved by O.R. Borngesser

FIND DEFLECTION DUE TO
STRESS at CENTER = 49,000 psi (YIELD PT. OF 2219T AL)

$$s = \frac{Et^2}{a^2}\left[\frac{1.238}{1-\nu}\left(\frac{y}{t}\right) + .294\left(\frac{y}{t}\right)^2\right] *$$

$$4.9 \cdot 10^4 = \frac{(10.6 \cdot 10^6)(.9)^2}{(27.5)^2}\left[\frac{1.238}{1-.36}\left(\frac{y}{.9}\right) + .294\left(\frac{y}{.9}\right)^2\right]$$

$$0 = .413y^2 + 2.44y - 4.9 = 0$$

$$y = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

or $y = +1.60$ in.

FORCE WITH WHICH MAT'L REACTS AGAINST CLAMPING -

$$\frac{wa^4}{Et^4} = \frac{64}{63(1-\nu)}\left(\frac{y}{t}\right) + .376\left(\frac{y}{t}\right)^3 \quad *$$

$$\frac{w(27.5)^4}{(10.6 \cdot 10^6)(.9)^4} = \frac{64}{63(1-.36)}\left(\frac{1.60}{.9}\right) + .376\left(\frac{1.60}{.9}\right)^3$$

$w = 64$ psi [1]

TOTAL LOAD = 152,000 lb.

LOAD PER BEAM = 38,000 lb.

MOMENT OF INERTIA NECESSARY TO WITHSTAND LOADING:

$$y = \frac{3}{320}\frac{Wl^3}{EI}$$

$$5 \cdot 10^{-3} = \frac{3}{3.2 \cdot 10^2}\frac{(3.8 \cdot 10^4)(68)^3}{(10.6 \cdot 10^6)(I)}$$

$I = 2110$ in.^{4}

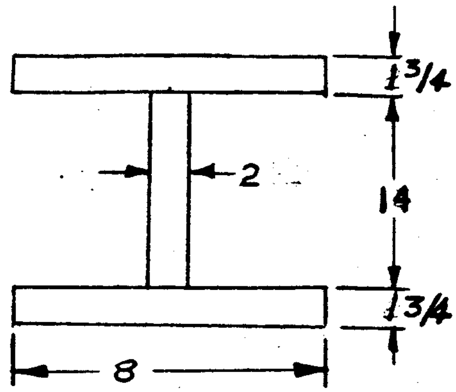
1. FORCE WITH WHICH MAT'L. REACTS AGAINST BEING HELD.

* FROM ROARK, R. J., "FORMULAS FOR STRESS & STRAIN" CHAP. 10, PAGE 220

CALC	TWKS	7/22/64	REVISED	DATE	MIT-RSC-MR&T-SK-714
CHECK					
APR	K. Knightstone	7/28/64			THE BOEING COMPANY — AIRPLANE DIVISION - WICHITA BRANCH — WICHITA, KANSAS, 67210
APR					
CONTRACT NO.					STRESS CALCULATIONS

E 1196 R4

MOMENT OF INERTIA (TYP. SECTION):



$$I_{TOTAL} = \Sigma \frac{bh^3}{12} + \Sigma A d^2$$

$$= 2\left[\frac{(8)(1\tfrac{3}{4})^3}{12} + (8)(2)(7.875)^2\right] + \frac{(2.00)(14)^3}{12}$$

$$= 2193 \text{ IN}^4$$

WELD LENGTH TO WITHSTAND 19,000 lb. at CLAMPS:

$P = 9.6\,DL$

$19 = 9.6\,(1/2)(L)$

$L = 3.76$ IN.

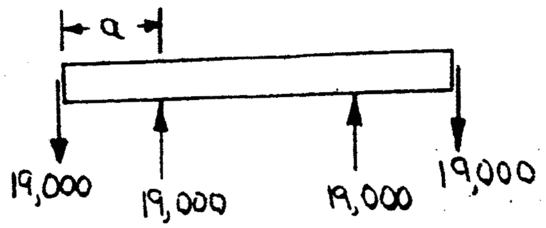
P = LOAD IN KIPS
L = WELD LENGTH
D = WELD SIZE

R.

CALC	Twiss	7/22/64	REVISED	DATE	MIT-RSC-MR & T-SK-7A
CHECK			Lightstone	8/4/64	
APR	R. Lightstone	7/23/64			THE BOEING COMPANY
APR					AIRPLANE DIVISION - WICHITA BRANCH WICHITA, KANSAS 67210
CONTRACT NO.					STRESS CALCULATIONS

E 1196 R4

MOMENT OF INERTIA FOR UPPER PLATE:



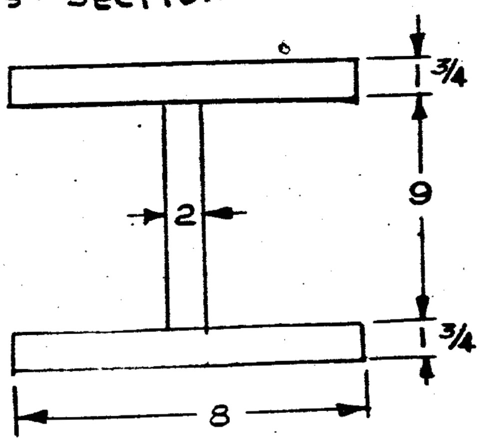
P = TOTAL LOAD
l = LENGTH OF BEAM

$$y = -\frac{Pa^2}{12EI}(3l - 4a)^*$$

$$-5 \cdot 10^{-3} = -\frac{(38,000)(9)^2}{(12)(10.6 \cdot 10^6)I}(3 \cdot 73 - 4 \cdot 9)$$

$$I = 888 \text{ IN}^4$$

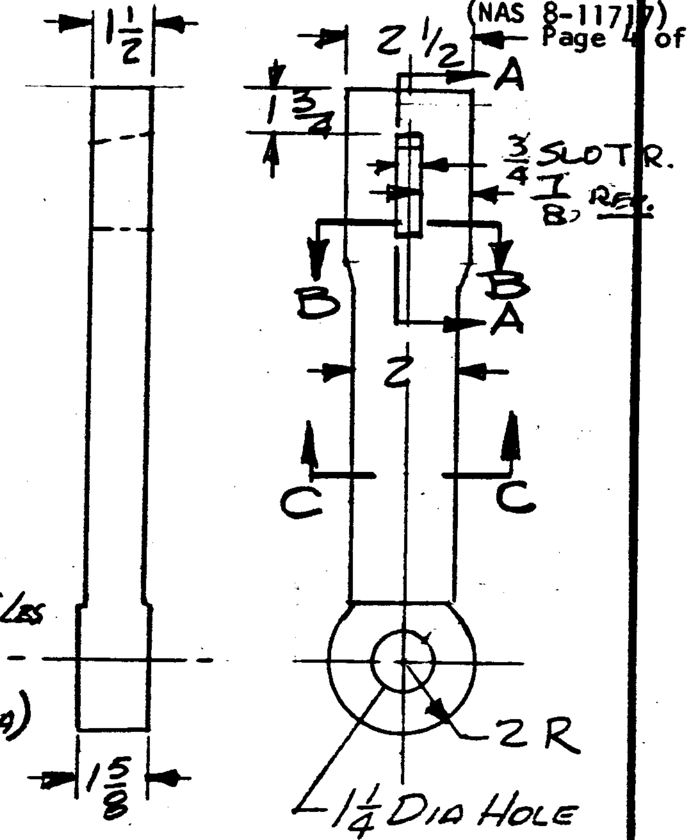
TYP. CROSS-SECTION:



$$I = \frac{bh^3}{12} + Ad^2$$

$$= 2\left[\frac{(8)(1\,3/4)^3}{12} + (1\,3/4)(8)(5.375)^2\right] + \frac{(2)(9)^3}{12}$$

$$= 937.12 \text{ IN}^4$$



MATERIAL: 6061-T6 AL.

ALLOWABLE STRESSES:

TENSILE = 10,000 PSI

COMP = 10,000 PSI

SHEAR = 15,000 PSI

① SHEAR LOAD AT A-A:

$L = \frac{19000\ LB}{2} = 9500\ LB.$

ALLOWABLE LOAD AT A-A

$L = 1.5 \times 1.75 \times 15000\ LB = 39,375\ LBS$

② TENSILE LOAD AT B-B: (MIN AREA)

$L = \frac{19000\ LB}{2} = 9500\ LBS$

ALLOWABLE LOAD = $.875 \times 1.5 \times 10,000\ PSI = 13,125\ LB$ Rev.

③ TENSILE LOAD AT C-C:

$L = 19000\ LBS$

ALLOWABLE LOAD AT C-C = $2 \times 1.5 \times 10,000\ PSI = 30,000\ LBS$

④ COMPRESSIVE STRESS AT PIN:

t = THICKNESS d = DIAMETER

COMPRESSIVE AREA = $td = 1.63 \times 1.25 = 2.0375$

COMPRESSIVE STRESS = $\frac{19000}{2.0375} = 9,327\ LB$

			REVISED	DATE	
CALC	C. Nelson	8/4/64			MIT-RSC-MR&T-SK-714
CHECK			Lightstone	8/7/64	
APR	R. Lightstone	8/4/64	"	8/11/64	
APR					THE BOEING COMPANY
					AIRPLANE DIVISION - WICHITA BRANCH WICHITA, KANSAS, 67210
CONTRACT NO.					STRESS CALCULATIONS

E 1196 R4

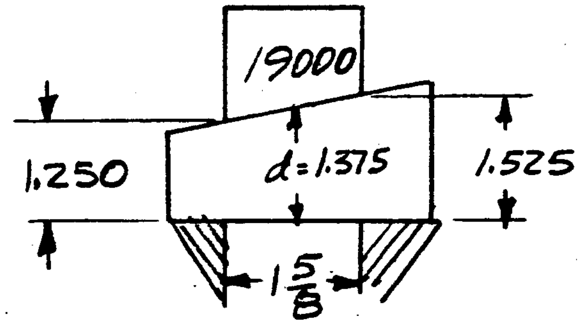
CALCULATIONS FOR LOCK WEDGE

MAT'L = 6061-T6 AL.

LOAD P = 19000 LBS

SPAN L = 1.63

R SAFETY FACTOR = 2



$$M_0 = \frac{PL}{8} = \frac{19000 \times 1.625}{8} = \frac{31,825}{8} = 3978 \text{ IN/LBS}$$

WEDGE THICKNESS b = .500

$$S_0 = \frac{Mc}{I} = M\frac{6}{bd^2}$$

$$R \quad 20\,000 = 3978 \text{ IN/LB} \; \frac{6}{.5 \times d^2}$$

$$R \quad d = \sqrt{\frac{3978 \times 6}{20000 \times .75}} = \sqrt{1.591}$$

$$R.. \quad d = 1.265$$

$$d \text{ (ACTUAL)} = 1.375$$

MAXIMUM SHEAR LOAD = 19000 LB

ALLOWABLE SHEAR LOAD =

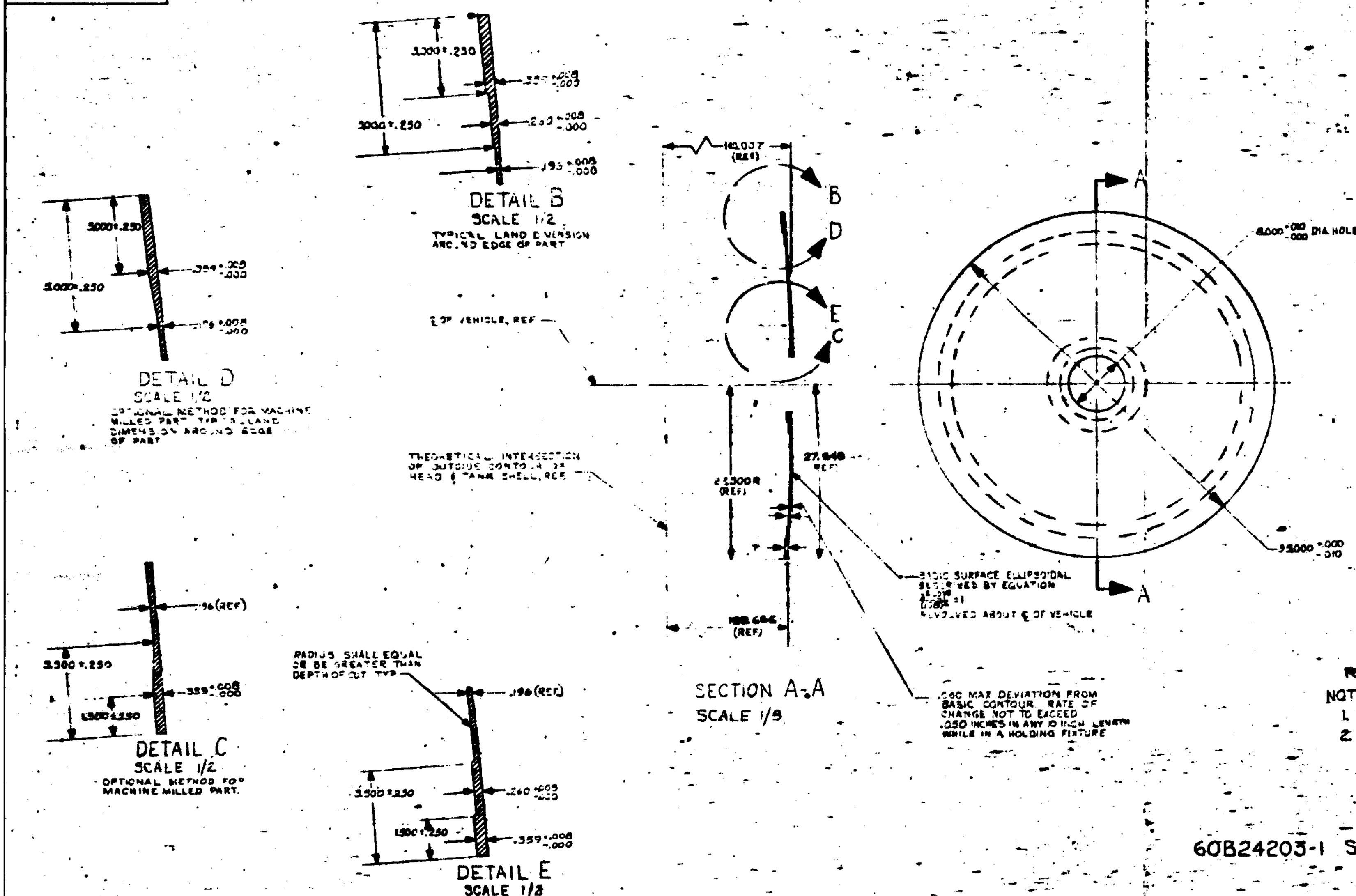
$$(.5 \times 1.250 + .5 \times 1.525)(15000) = 20,813 \text{ LBS}$$

			REVISED	DATE	
CALC	C. NELSON	8/4/64			
CHECK			Lightstone	8/7/64	MIT-RSC-MR&T-SK-714
APR	Lightstone	8/4/64			
APR					THE BOEING COMPANY AIRPLANE DIVISION - WICHITA BRANCH WICHITA, KANSAS, 67210
CONTRACT NO.					STRESS CALCULATIONS

E 1196 R4

Part No.	Thickness T	Contour	Grain Direction	Chord Height CH	Chord Length CL	$R_p = \frac{4CH^2+CL^2}{8(CH)}$	$S_p = \frac{T}{2R}$	Rf (Fixture)	Sf (Fixture)	Retention % $\frac{S_p}{S_f}$X100	Retention % $\frac{CH_p}{CH_f}$X100	Arc Length at 50" CL	Lineal Growth In./In.	Thick. Growth In./In.
1	.250"	Std.	Long.	1.109	54	329.22	.000380	279.238	.000448	84.8	84.79	50.055	.0011	
	.250"	Std.	Trans	.896	54	407.255	.000307	279.238	.000448	68.57	68.50	50.080	.0016	
2	.250"	Std.	Long.	1.016	54	359.268	.000348	279.238	.000448	77.68	77.68	50.090		THIS PANEL DATA IS IN OBVIOUS ERROR.
	.250"	Std.	Trans	1.020	54	357.863	.000349	279.238	.000448	77.90	77.98	50.095		REASON HAS NOT BEEN DETERMINED - (1ST PART FORMED)
3	.250"	Std.	Long.	1.101	54	331.610	.000377	279.238	.000448	84.15	84.17	50.065	.0013	
	.250"	Std.	Trans	.917	54	397.950	.000314	279.238	.000448	70.09	70.11	50.085	.0017	
4	.250"	65"O.F.	Long.	1.653	54	221.335	.00057	189.340	.00066	86.36	85.42	50.100	.0020	
	.250"	65"O.F.	Trans	1.521	54	240.405	.00052	189.340	.00066	78.79	78.60	50.115	.0023	
5	.250"	65"O.F.	Long.	1.752	54	208.924	.000598	189.340	.00066	90.60	90.54	50.113	.00236	
	.250"	65"O.F.	Trans	1.459	54	250.558	.000499	189.340	.00066	75.61	75.40	50.115	.0023	
6	.250"	65"O.F.	Long	1.752	54	219.620	.000569	189.340	.00066	86.21	86.10	50.120	.0024	.0024
	.250"	65"O.F.	Trans	1.506	54	242.785	.000515	189.340	.00066	78.03	77.83	50.120	.0024	.0036
7	.500"	Std.	Long.	1.065	54	345.699	.000723	279.238	.000895	80.78	80.42	50.110	.0022	
	.500"	Std.	Trans	.916	54	397.086	.000630	279.238	.000895	70.39	70.26	50.120	.0024	
8	.500"	Std.	Long.	1.020	54	357.863	.000699	279.238	.000895	78.10	77.98	50.110	.0022	
	.500"	Std.	Trans	.936	54	389.890	.000641	279.238	.000895	71.62	71.95	50.120	.0024	
9	.500"	Std.	Long.	1.086	54	336.178	.000744	279.238	.000895	83.13	83.03	50.110	.0022	
	.500"	Std.	Trans	.922	54	395.369	.000632	279.238	.000895	70.61	70.48	50.115	.0023	
10	.500"	65"O.F.	Long.	1.652	54	221.464	.001123	189.340	.001320	85.53	85.37	50.140	.0028	
	.500"	65"O.F.	Trans	1.426	54	256.323	.000975	189.340	.001320	73.86	73.69	50.145	.0029	
11	.500"	65"O.F.	Long.	1.669	54	219.229	.001140	189.340	.001320	86.36	86.25	50.145	.0029	.0020
	.500"	65"O.F.	Trans	1.447	54	252.623	.000990	189.340	.001320	75.00	74.78	50.145	.0029	.0026
12	.500"	65"O.F.	Long.	1.660	54	220.408	.001134	189.340	.001320	85.91	86.25	50.145	.0029	
	.500"	65"O.F.	Trans	1.448	54	252.451	.00099	189.340	.001320	75.00	74.78	50.145	.0029	
13	.900"	Std.	Long.	1.035	54	352.691	.001276	279.238	.001612	79.16	79.13	50.135	.0027	.0017
	.900"	Std.	Trans.	.926	54	394.518	.00114	279.238	.001612	70.72	70.80	50.142	.0028	.0019
14	.900"	Std.	Long.	.980	54	372.429	.001208	279.238	.001612	74.94	74.92	50.130	.0026	.0019
	.900"	Std.	Trans.	.886	54	411.843	.001093	279.238	.001612	67.80	67.74	50.135	.0027	.0020
15	.900"	Std.	Long.	.980	54	372.429	.001208	279.238	.001612	74.94	74.92	50.135	.0027	
	.900"	Std.	Trans.	.880	54	414.645	.001085	279.238	.001612	67.31	67.28	50.130	.0026	
16	.900"	65"O.F.	Long.	1.624	54	225.258	.001998	189.340	.002377	84.06	84.93	50.180	.0036	
	.900"	65"O.F.	Trans.	1.469	54	248.863	.001800	189.340	.002377	76.06	75.92	50.185	.0037	
17	.900"	65"O.F.	Long.	1.560	54	234.434	.001920	189.340	.002377	80.77	80.98	50.165	.0033	
	.900"	65"O.F.	Trans.	1.416	54	258.123	.001743	189.340	.002377	73.33	73.18	50.175	.0035	
18	.900"	65"O.F.	Long.	1.612	54	226.923	.001983	189.340	.002377	83.42	83.30	50.172	.0035	
	.900"	65"O.F.	Trans.	1.478	54	247.356	.001819	189.340	.002377	76.53	76.38	50.170	.0034	

SUMMATION OF WORK SHEETS ---- NAS 8-11717



REVISED - 30 JULY 1964

NOTES:

1. T=MATERIAL THICKNESS
2. BLANKS WILL BE AS SHOWN PLUS SOME OF UNIFORM THICKNESS. UNIFORM THICKNESS BLANKS WILL BE FROM 0.250" TO 0.900"

60B24203-1 SHOWN-

NAS 8-11717
FIG. I

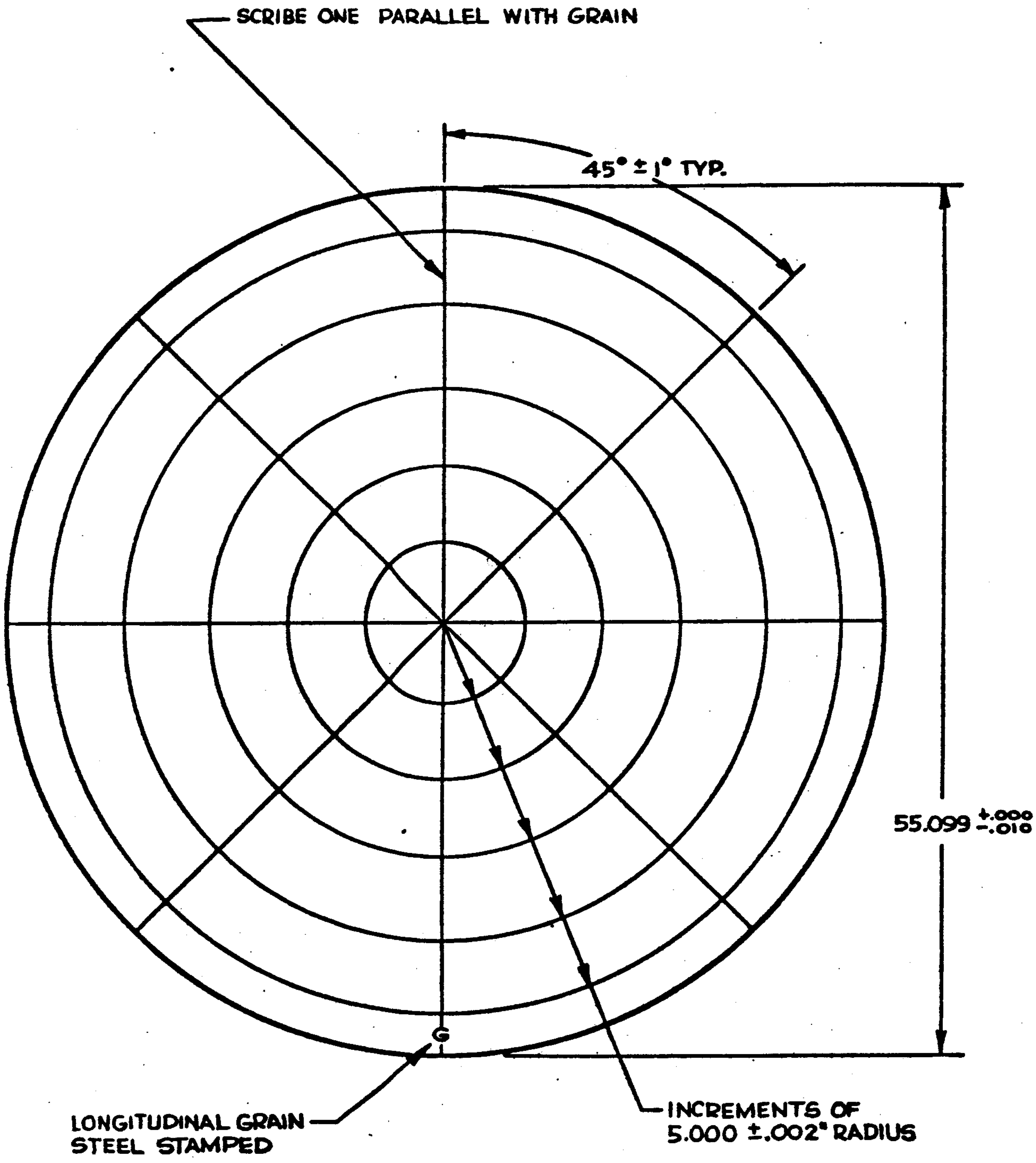
CENTER PIECE
LOWER HEAD
FUEL TANK

MATERIAL 2219 AL ALLOY

SCALE 1/4

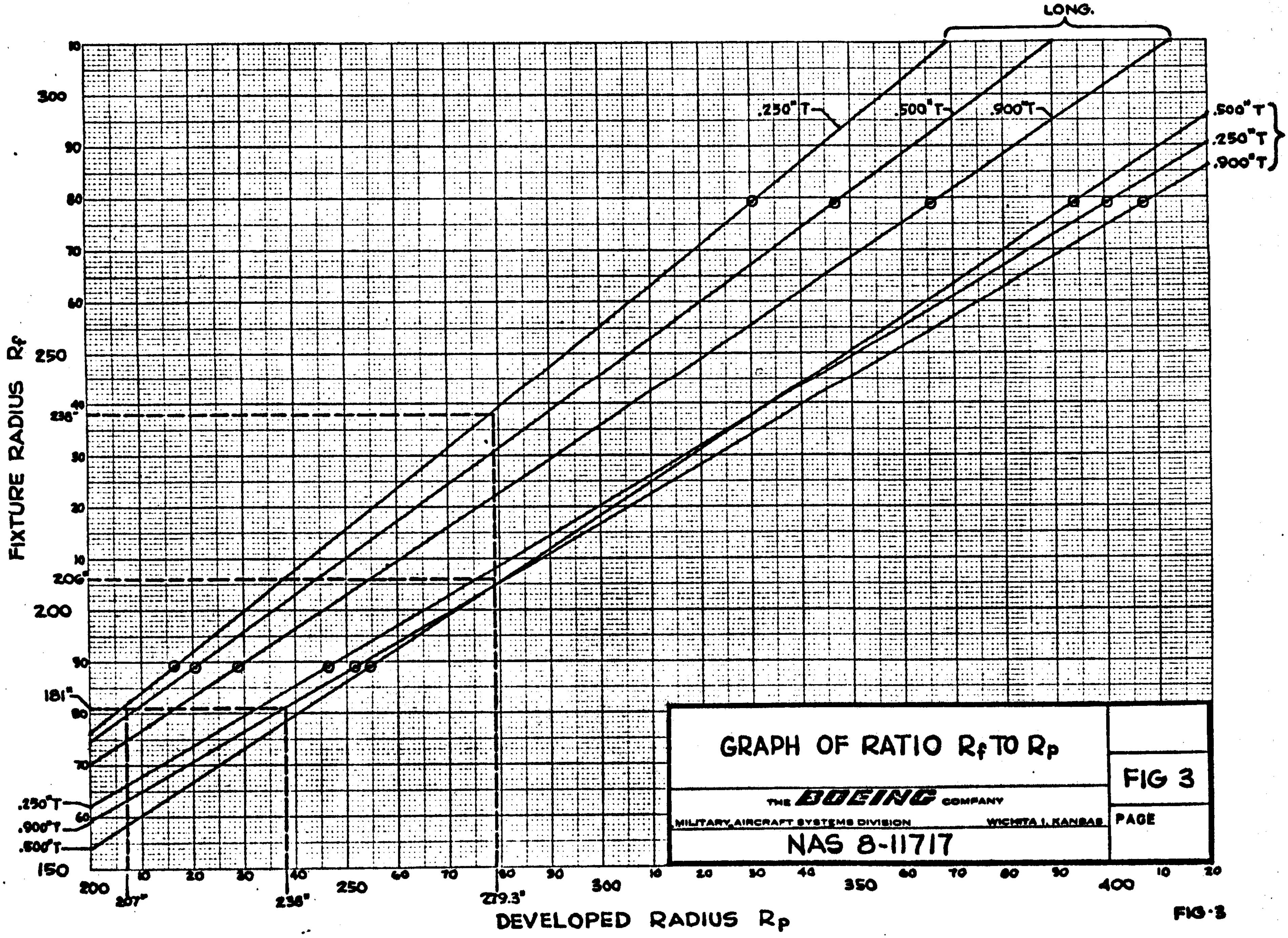
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

D MR|T SK 74



CALC			REVISED	DATE	GRID PATTERN	
CHECK						
APR						FIG. 2
APR					THE BOEING COMPANY AIRPLANE DIVISION · WICHITA BRANCH	
						PAGE
CONTRACT NO. NAS 8-11717						

E-582 R4



GRAPH OF RATIO R_f TO R_p

THE BOEING COMPANY

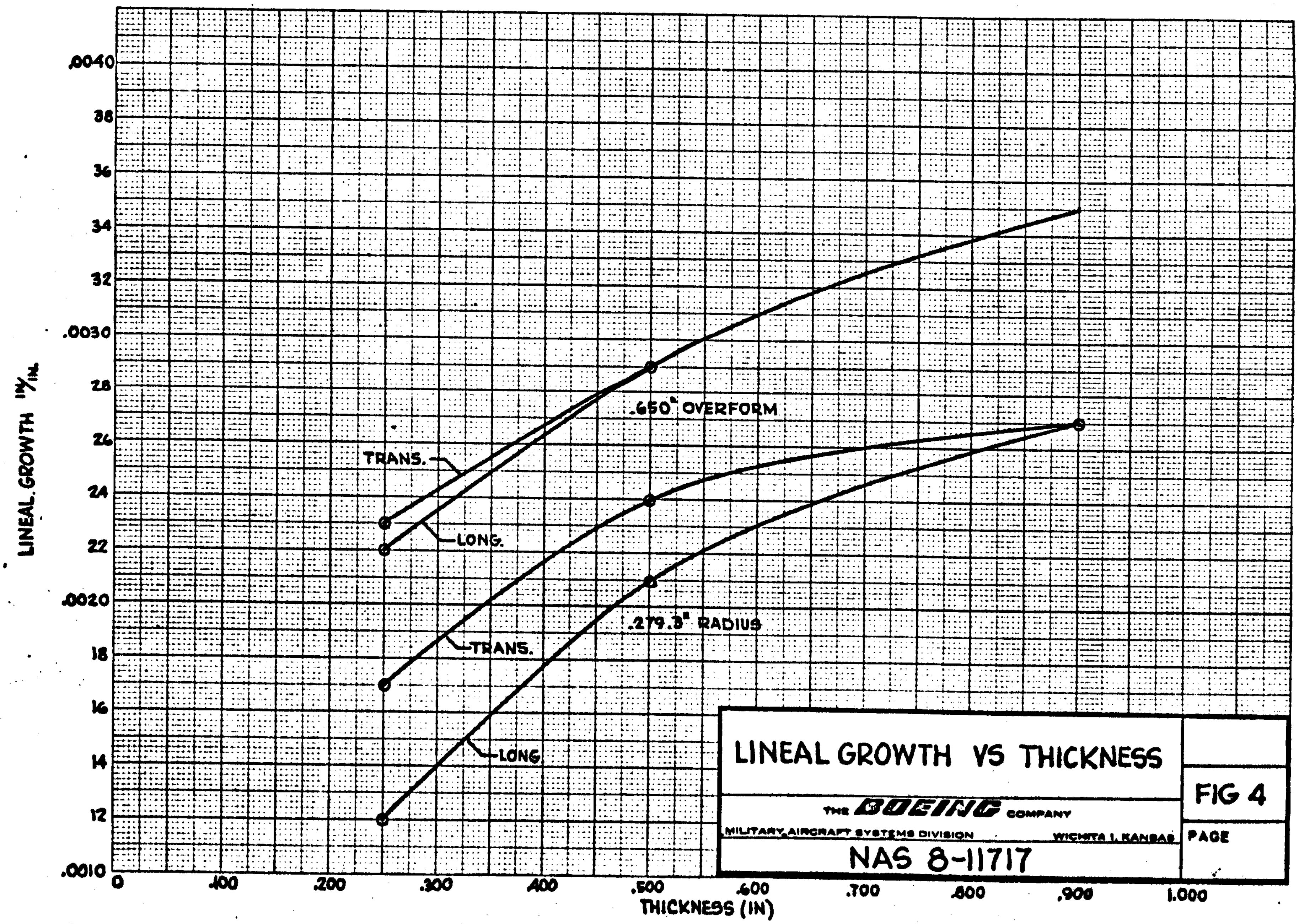
MILITARY AIRCRAFT SYSTEMS DIVISION WICHITA 1, KANSAS

NAS 8-11717

FIG 3

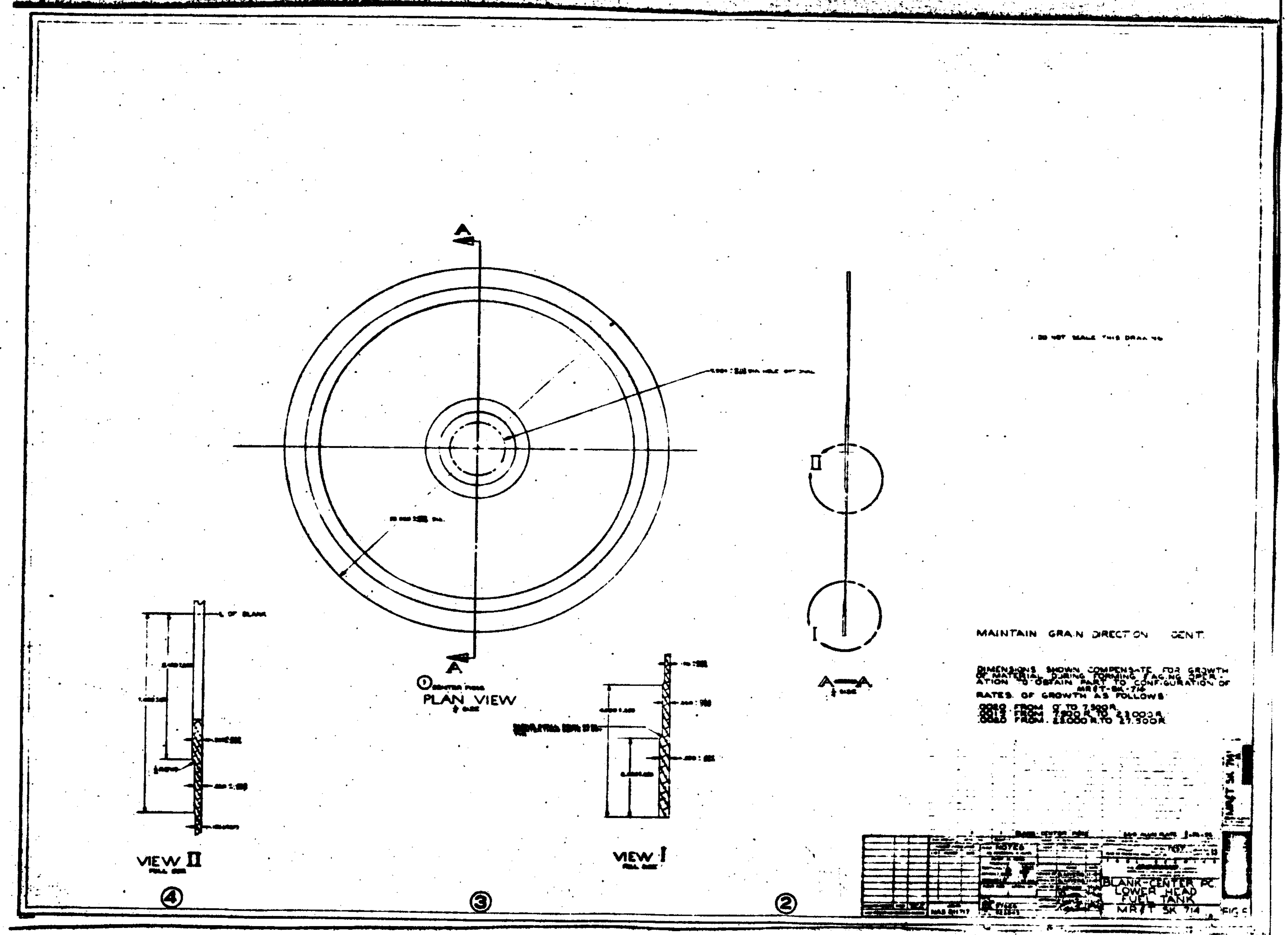
PAGE

FIG · 3

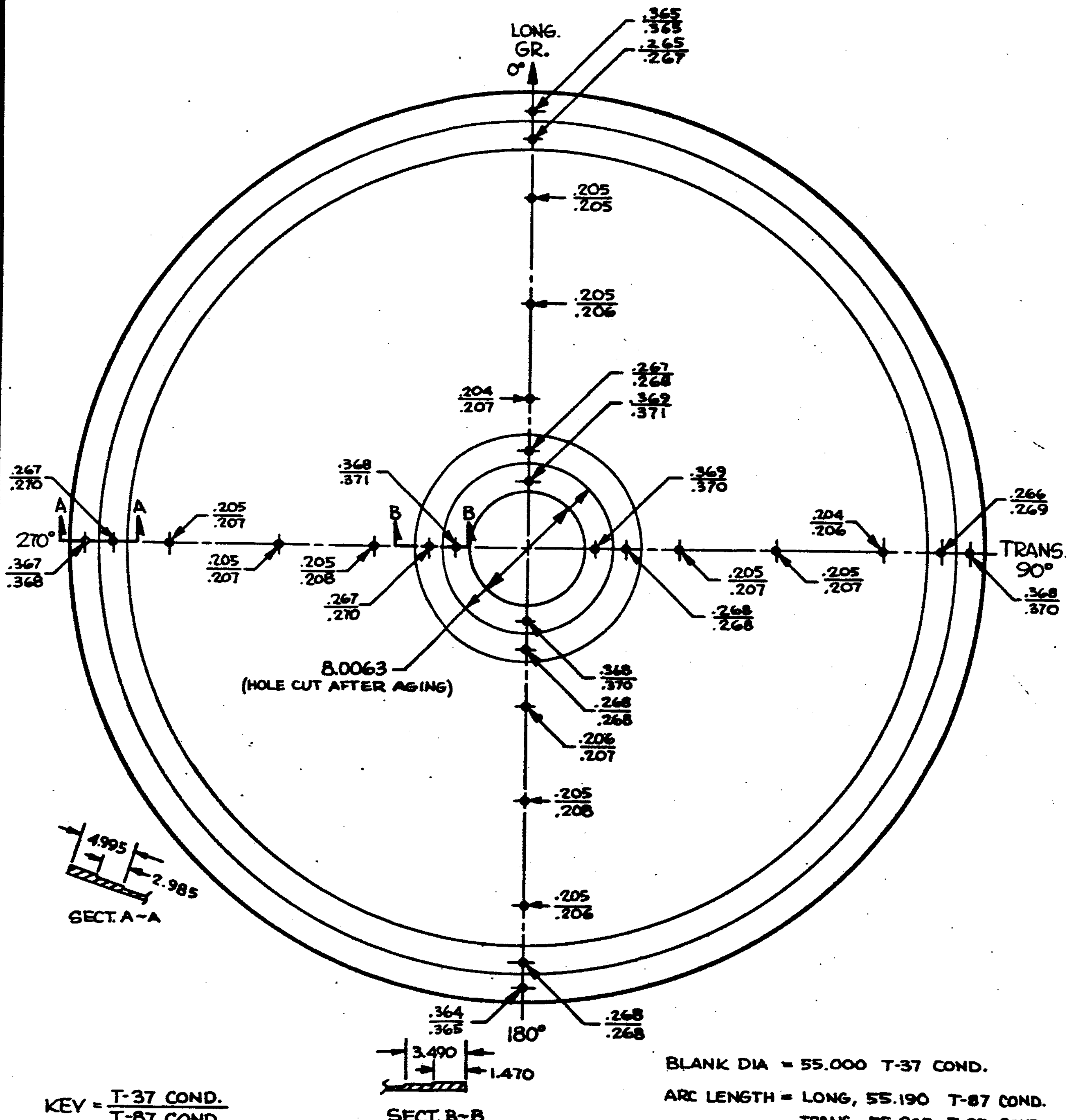


LINEAL GROWTH

FIG.4



A
A
PLAN VIEW
A—A
VIEW I
VIEW II
MAINTAIN GRAIN DIRECTION CENT.
DIMENSIONS SHOWN COMPENSATE FOR GROWTH OF MATERIAL DURING FORMING / AGING OPERATION TO OBTAIN PART TO CONFIGURATION OF MR&T-SK-714
RATES OF GROWTH AS FOLLOWS
NOTES
BLANK-CENTER PC.
LOWER HEAD
FUEL TANK
MR&T SK 714
FIG 5



KEY = T-37 COND. / T-87 COND.

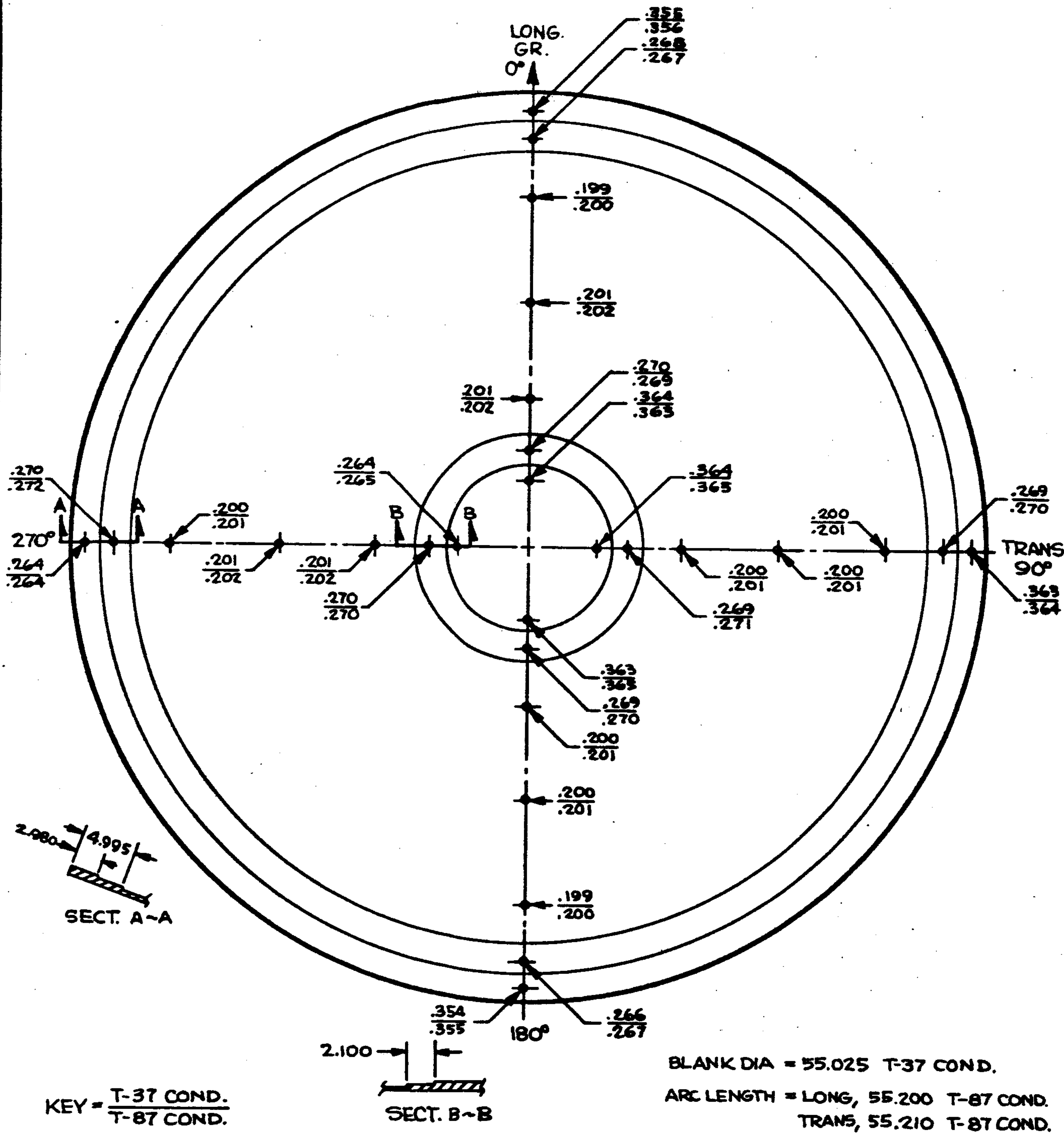
BLANK DIA = 55.000 T-37 COND.

ARC LENGTH = LONG, 55.190 T-87 COND.
TRANS, 55.206 T-87 COND.

CALC			REVISED	DATE	MR & T-SK-714 PART NO. 1 MATERIAL GROWTH	
CHECK						
APR						FIG. 6
APR			-		THE BOEING COMPANY AIRPLANE DIVISION - WICHITA BRANCH	
						PAGE

CONTRACT NO. NAS 8-11717

E-582 R4



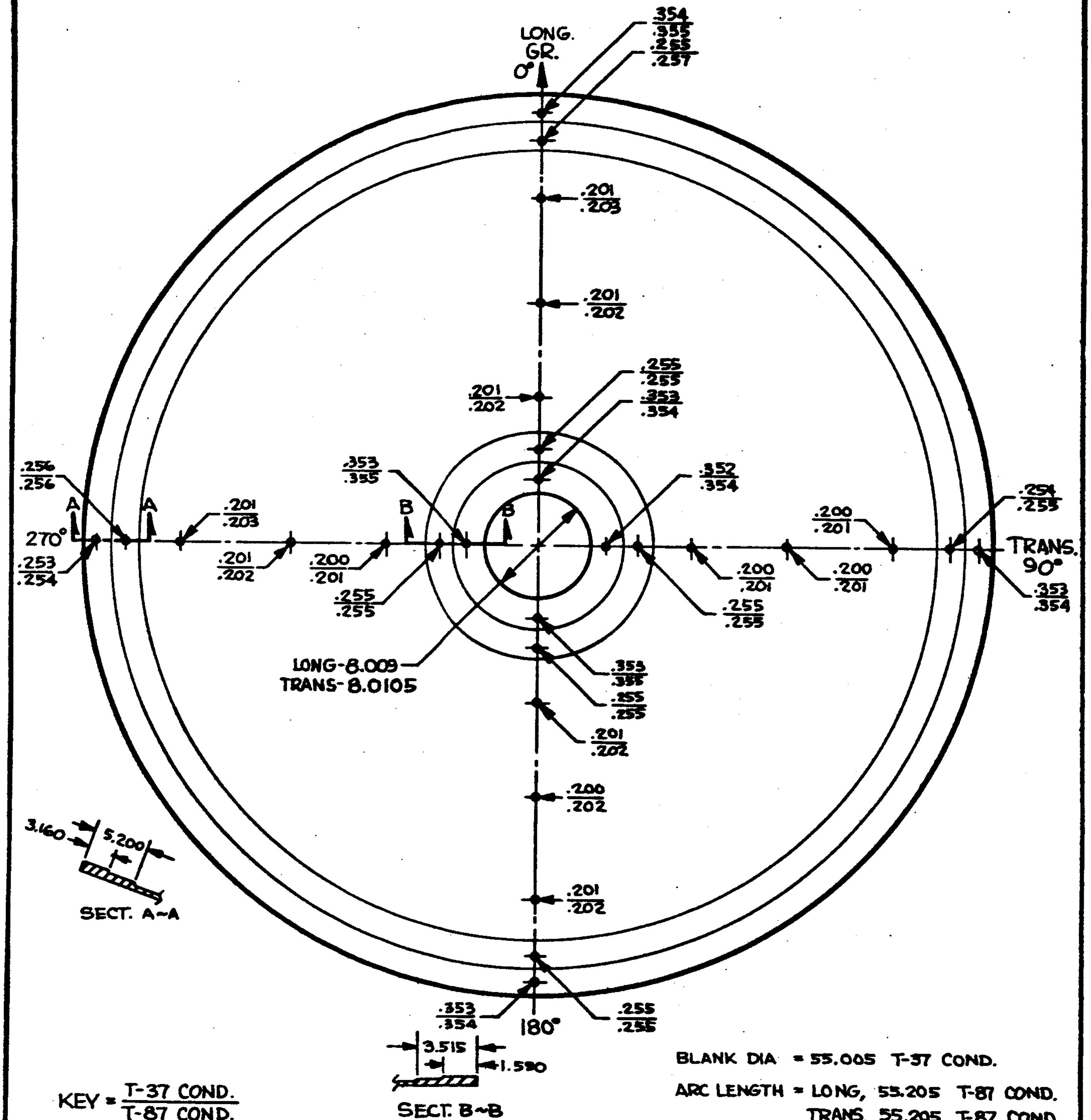
KEY = T-37 COND. / T-87 COND.

BLANK DIA = 55.025 T-37 COND.

ARC LENGTH = LONG, 55.200 T-87 COND.
TRANS, 55.210 T-87 COND.

			REVISED	DATE		
CALC					MR & T-SK-714 PART NO. 2 MATERIAL GROWTH	
CHECK						
APR						FIG. 7
APR					THE BOEING COMPANY AIRPLANE DIVISION - WICHITA BRANCH	
						PAGE
CONTRACT NO. NAS 8-11717						

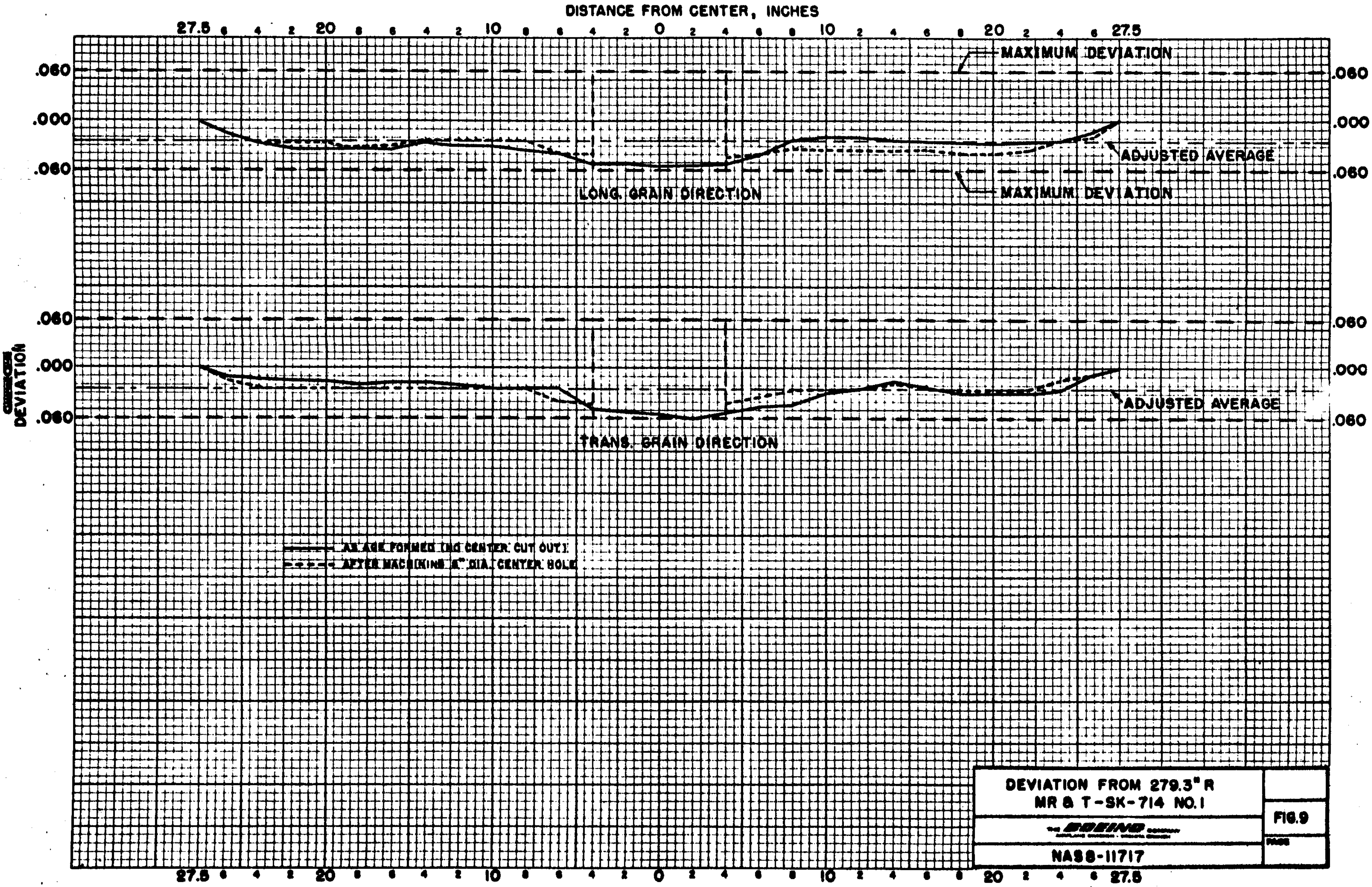
E-582 R4



CALC			REVISED	DATE	MR & T-SK-714 PART NO. 3 MATERIAL GROWTH	
CHECK						
APR						FIG. 8
APR					THE BOEING COMPANY AIRPLANE DIVISION - WICHITA BRANCH	
						PAGE

CONTRACT NO. NAS 8-11717

E-582 R4

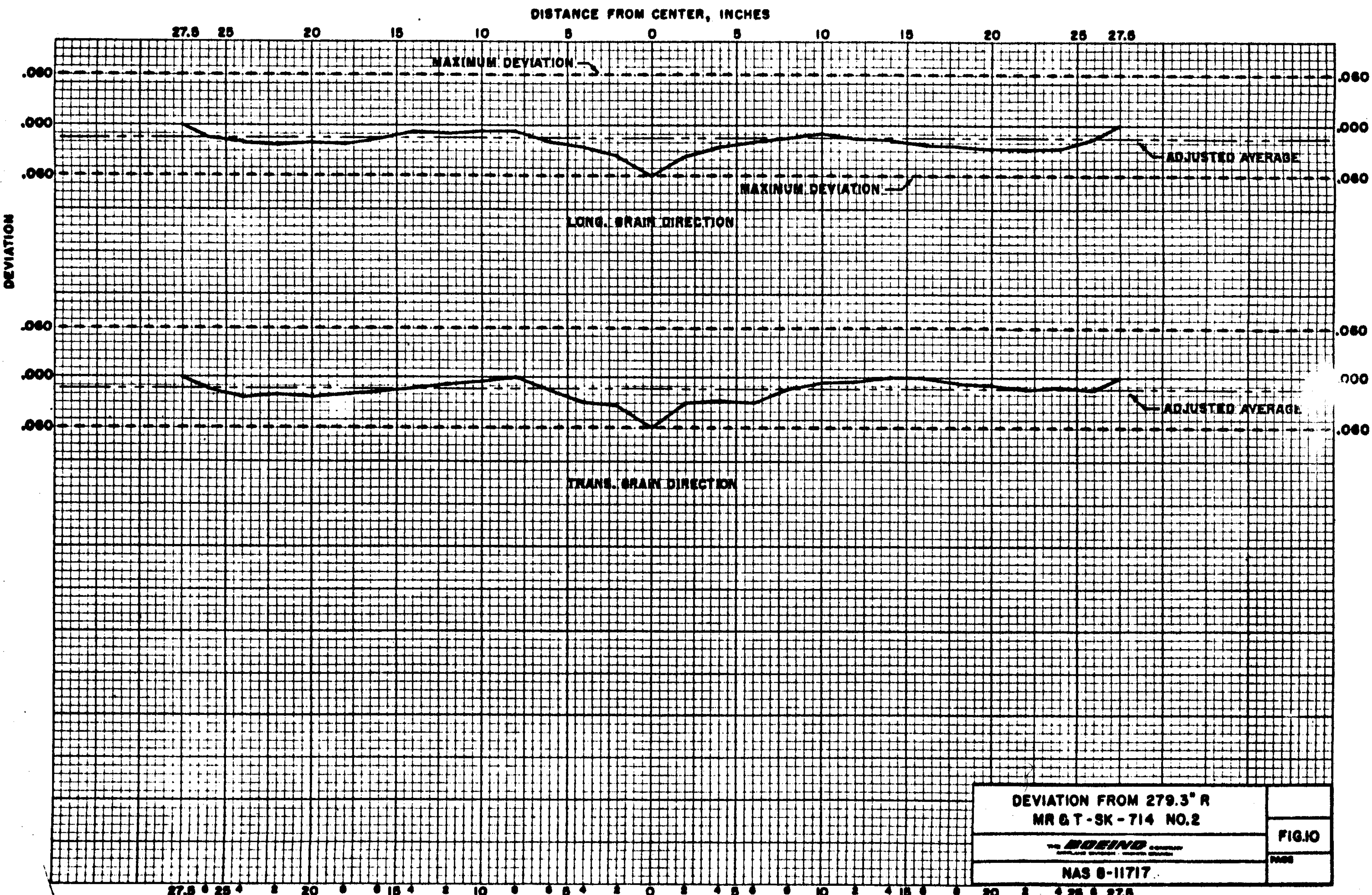


DEVIATION FROM 279.3" R
MR & T-SK-714 NO. 1

FIG. 9

THE BOEING COMPANY

NAS8-11717

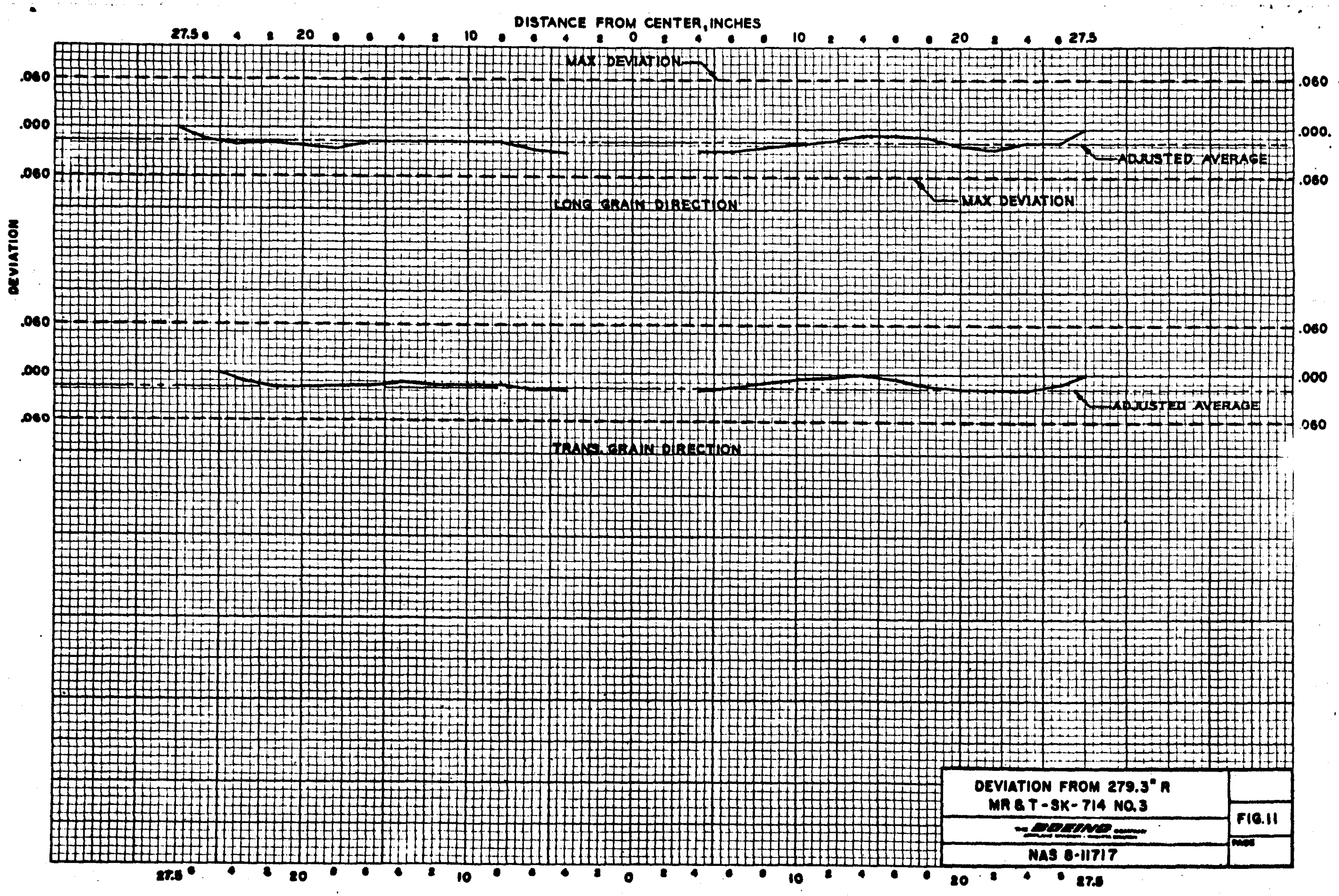


DEVIATION FROM 279.3" R
MR & T-SK-714 NO.2

THE BOEING COMPANY

NAS 8-11717

FIG.10



DEVIATION FROM 279.3" R
MR & T-SK-714 NO. 3

THE BOEING COMPANY

NAS 8-11717

FIG. 11

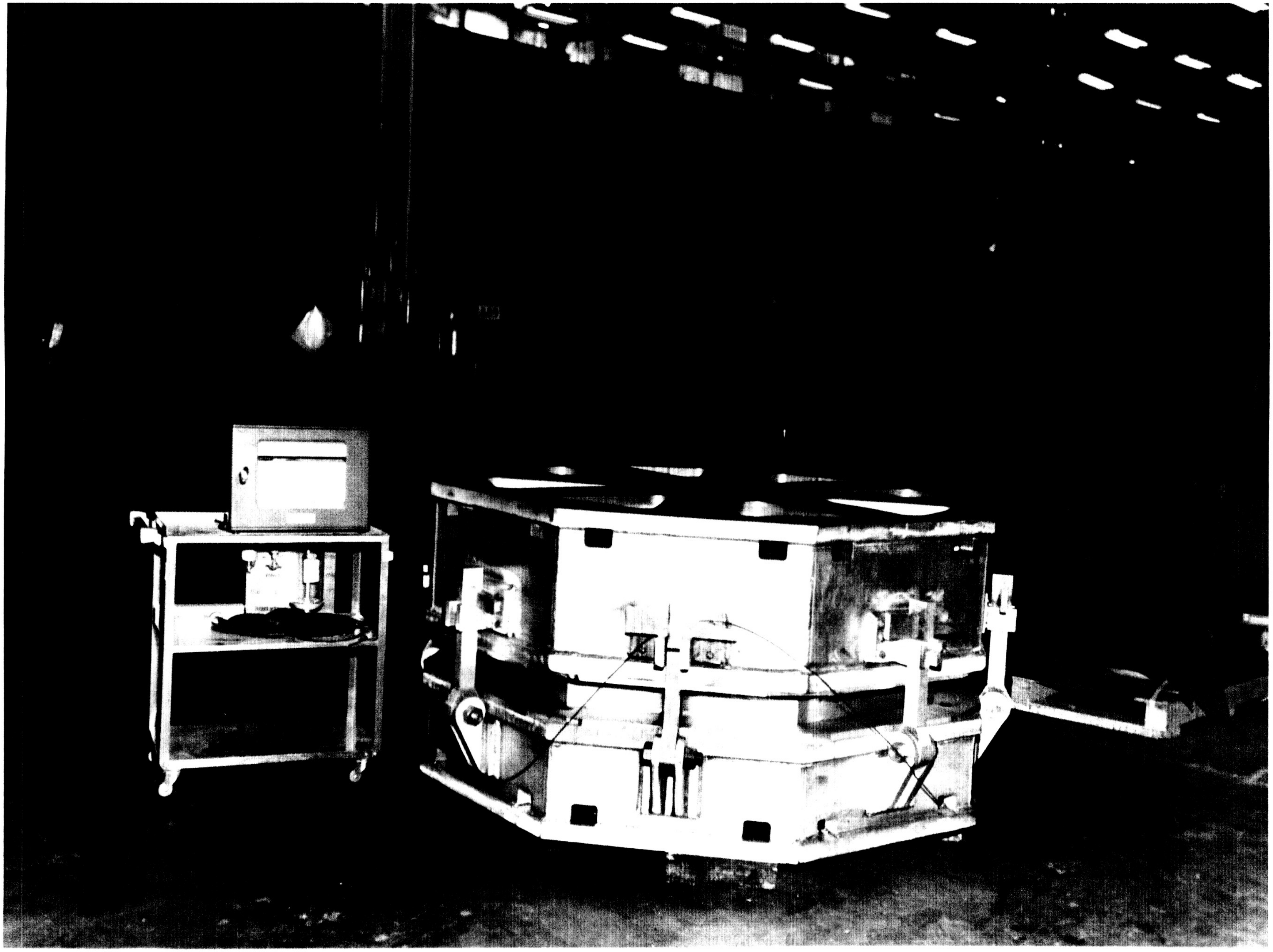


Fig. 12 MIT-RSC-MR&T-SK-714 Age Forming Fixture Proj.28.43

NAS8-11717 BWA-69712

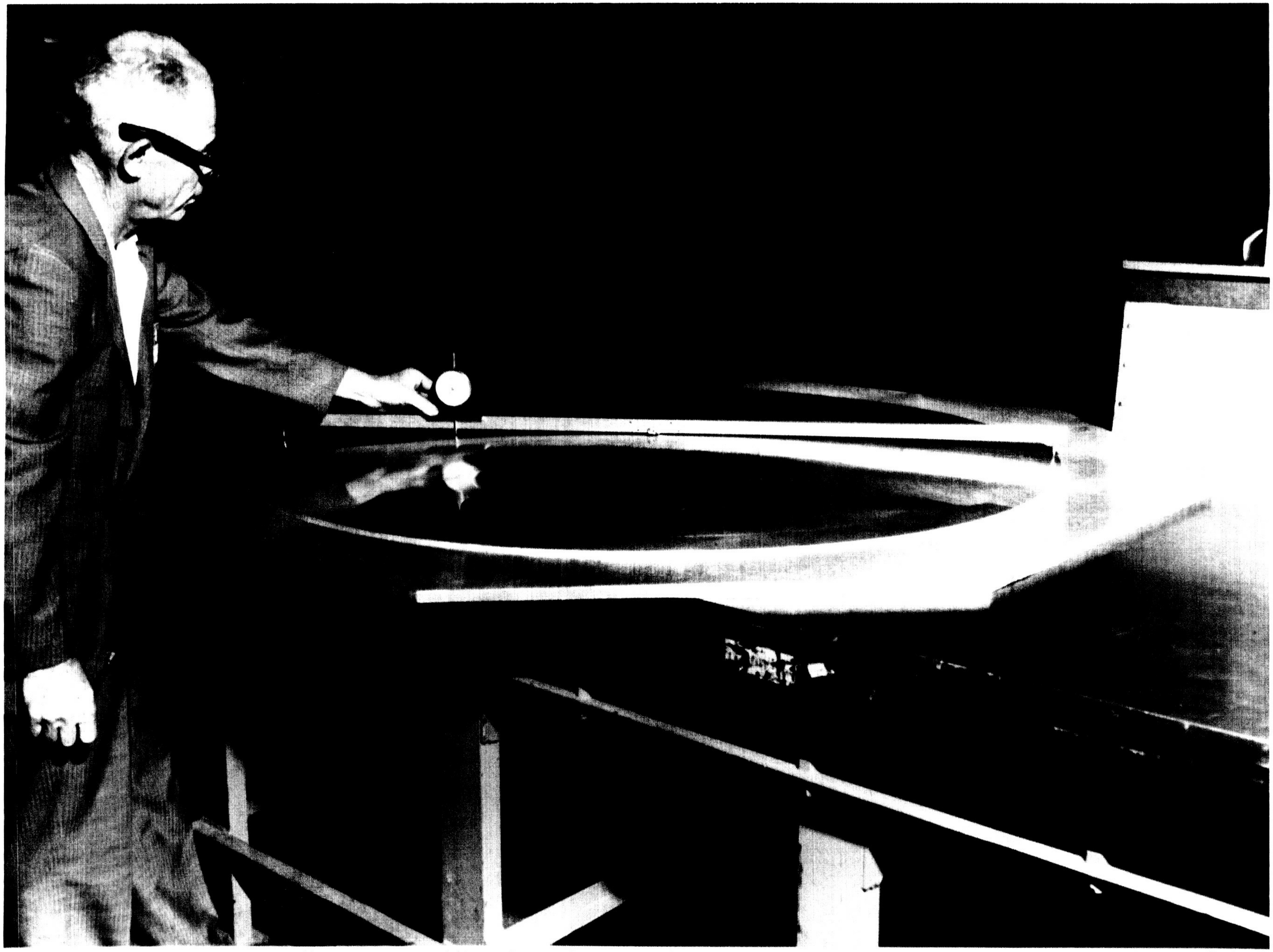


Fig. 13 Measurement With Part Supported on Flat Surface Proj.28.43

NAS8-11717 BWA-69713

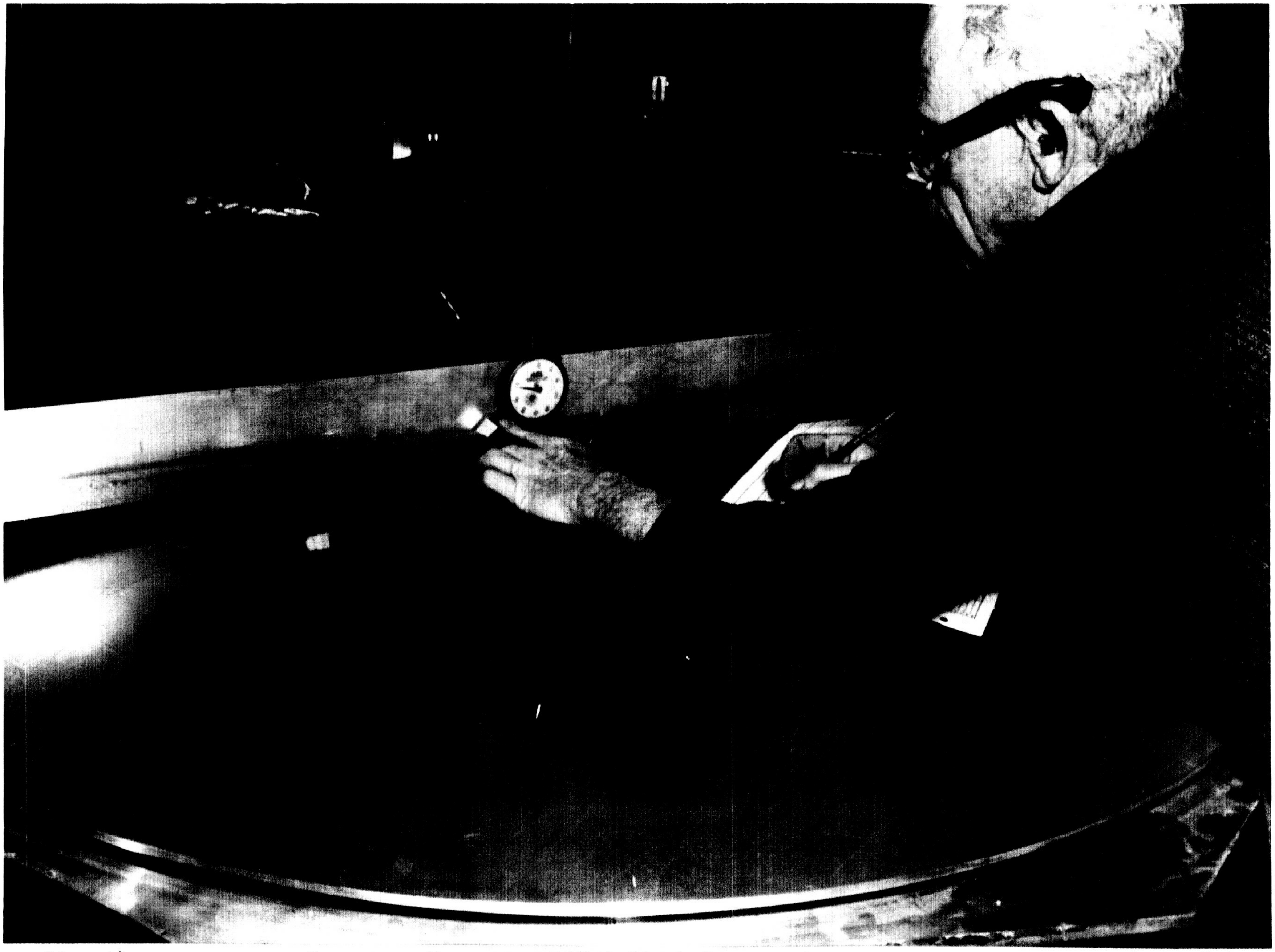


Fig. 14 Curvature Measurement With Blank Supported on Rubber Pad at Center of Concave Side

NAS8-11717

Proj.28.43
BWA-69714

Fig. 15 R&D Master In Open Fixture For Forming to 181" Radius Die Proj.28.43

NAS8-11717 BWA-69715

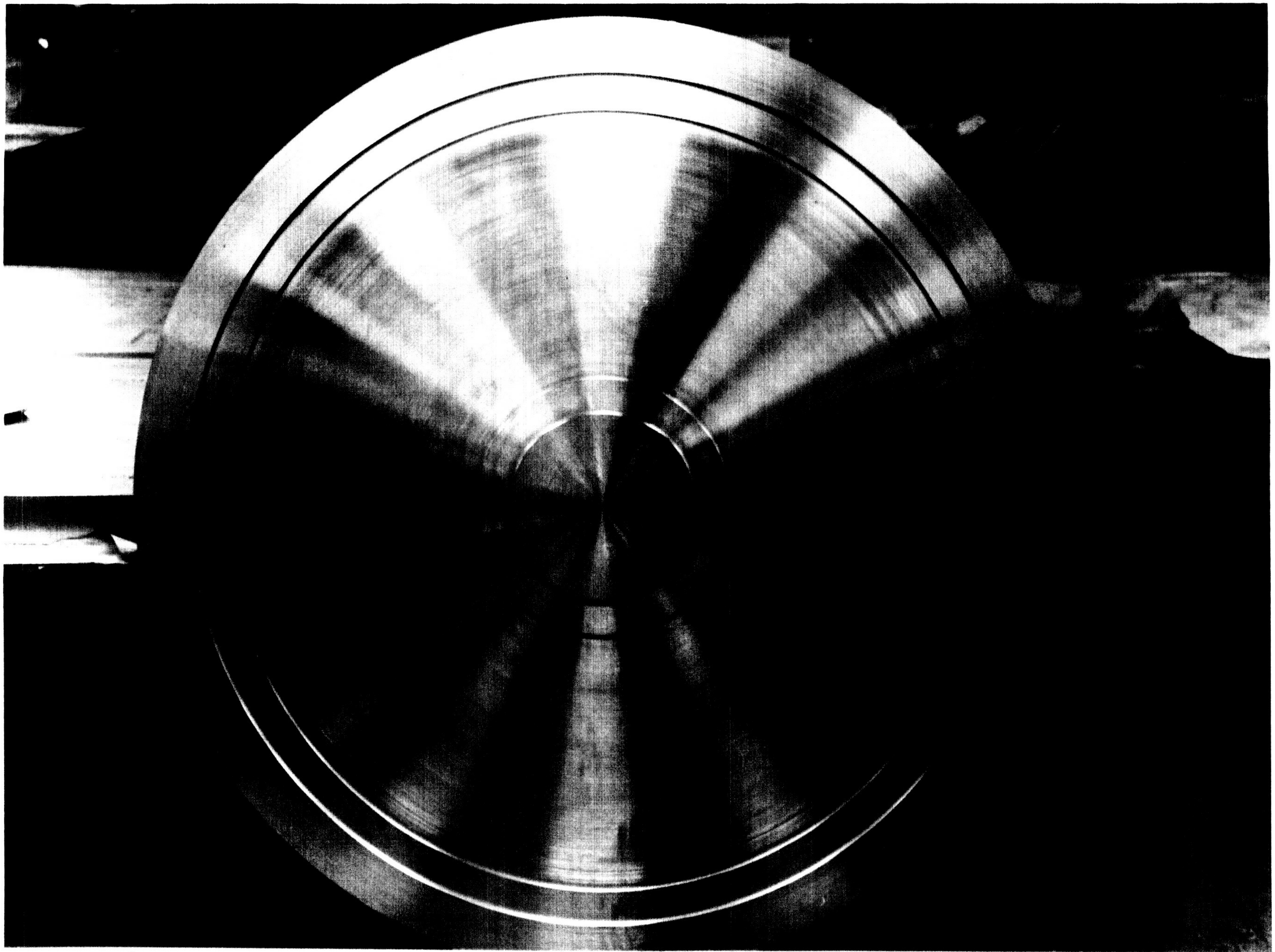


Fig. 16 Sculptured MR&T-SK-714 Center Piece Without 8" Diam. Center Hole - Prior to Age Forming

NAS8-11717

Proj.28.43
BWA-69716

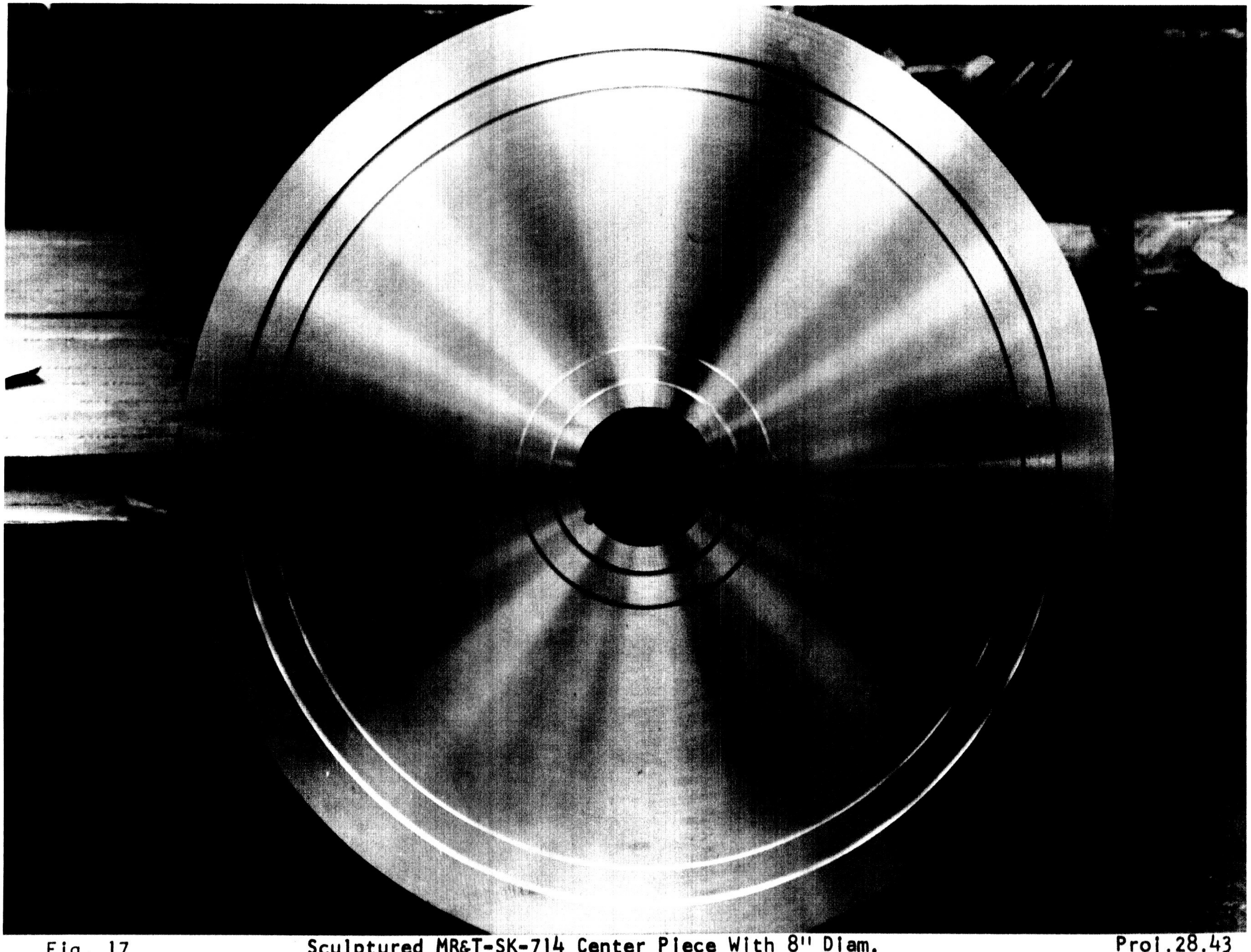


Fig. 17 NAS8-11717 | Sculptured MR&T-SK-714 Center Piece With 8" Diam. Cutout Prior to Age Forming | Proj.28.43 BWA-69717

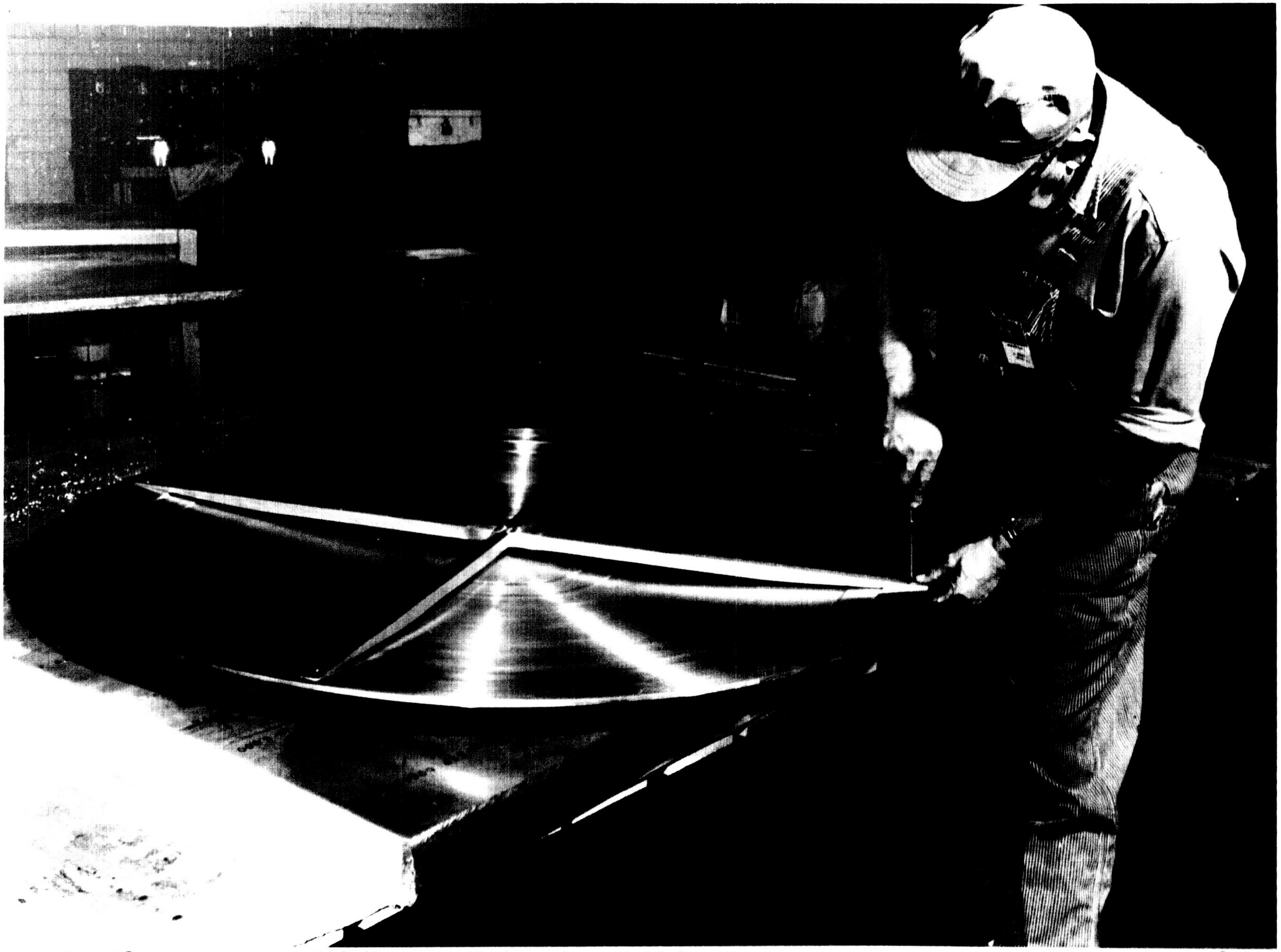


Fig. 18 R&D Master Reinforced to Hold Developed Configuration During Plaster Casting Proj.28.43

NAS8-11717 BWA-69718

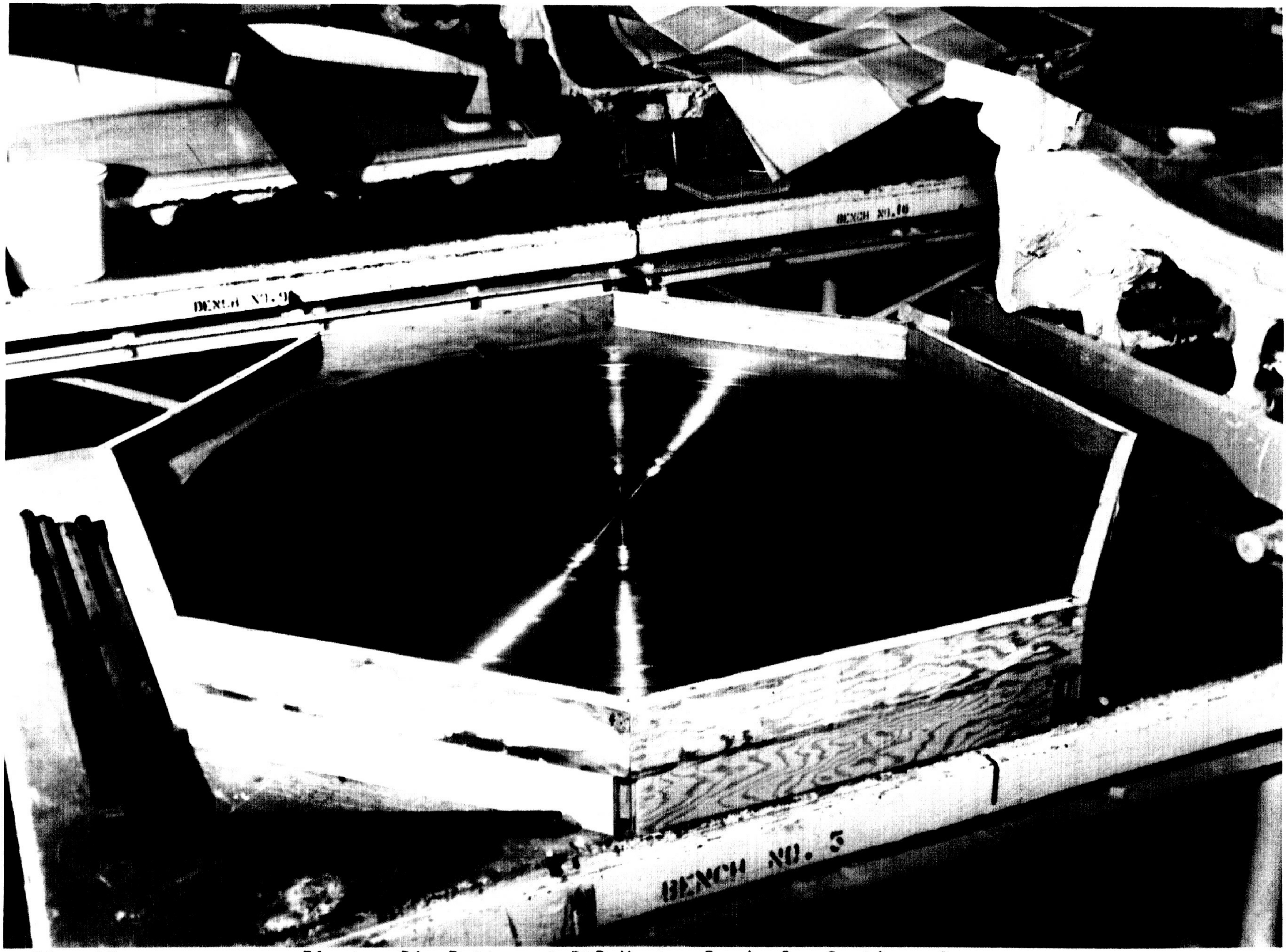


Fig. 19 Plaster Die Pattern & R&D Master Ready for Casting of Plaster Punch Pattern Proj.28.43

NAS8-11717 BWA-69719

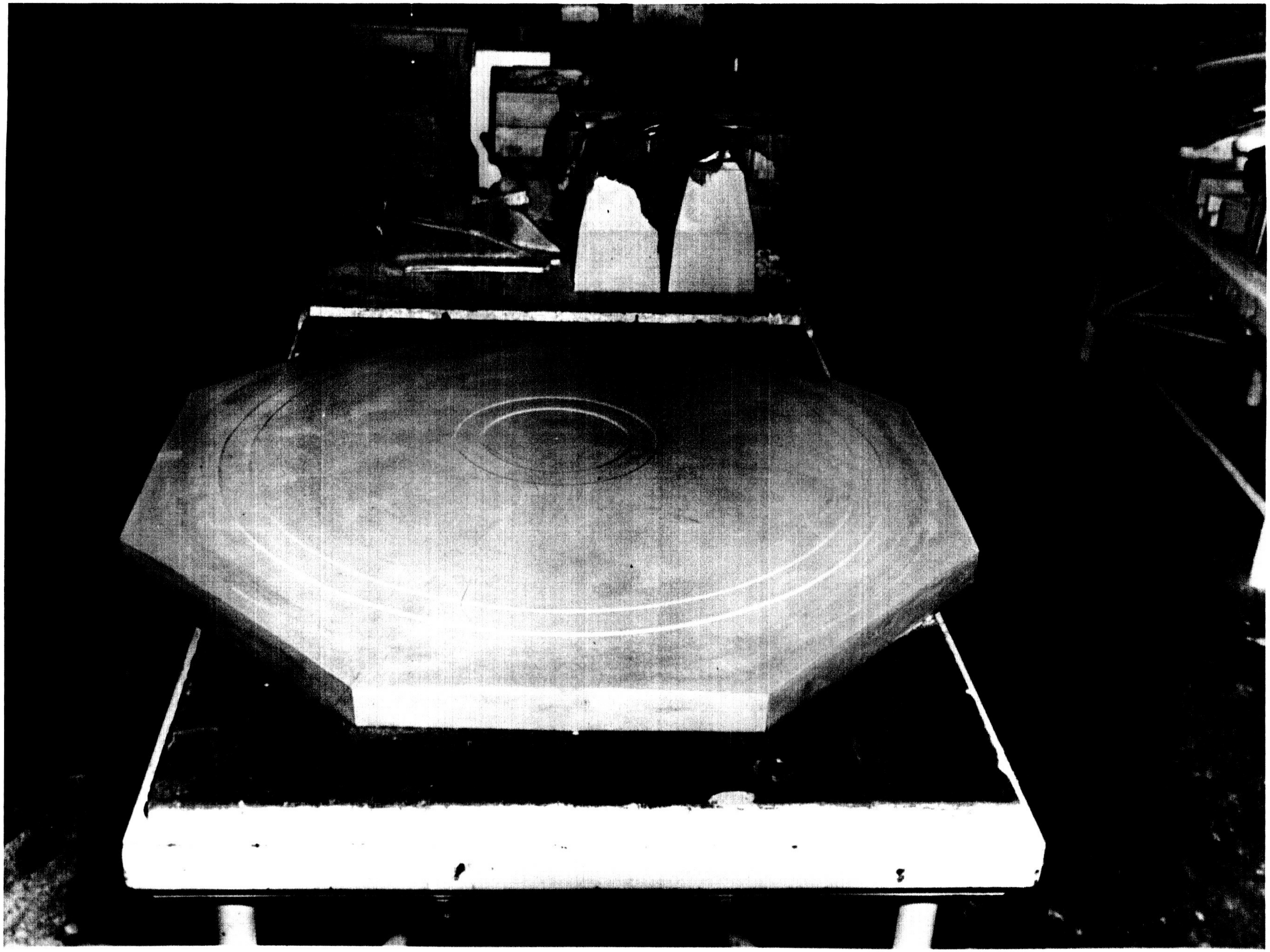


Fig. 20 Plaster Punch Pattern Proj.28.43
NAS8-11717 BWA-69720

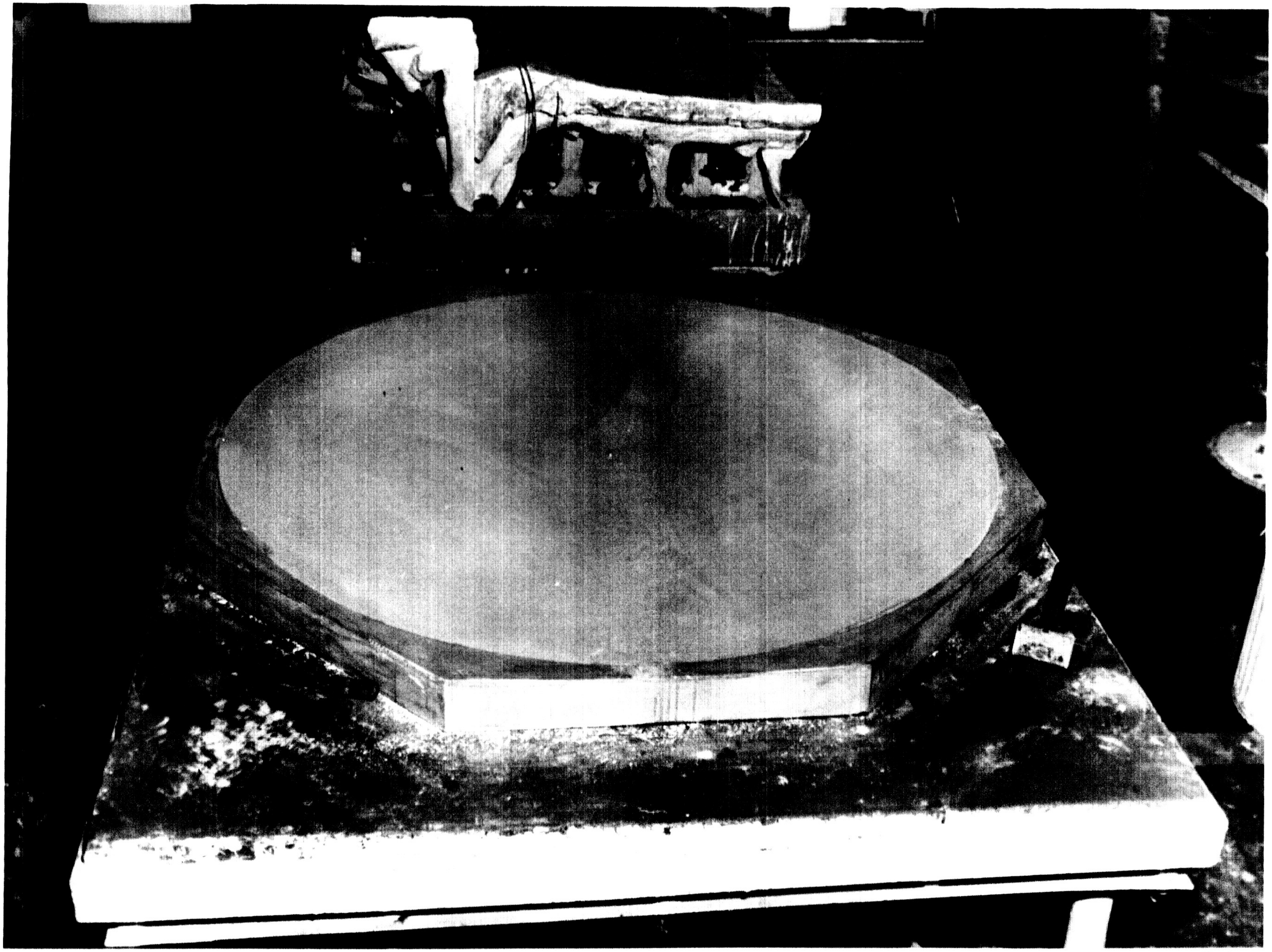


Fig. 21 Plaster Die Pattern Proj.28.43

NAS8-11717 BWA-69721

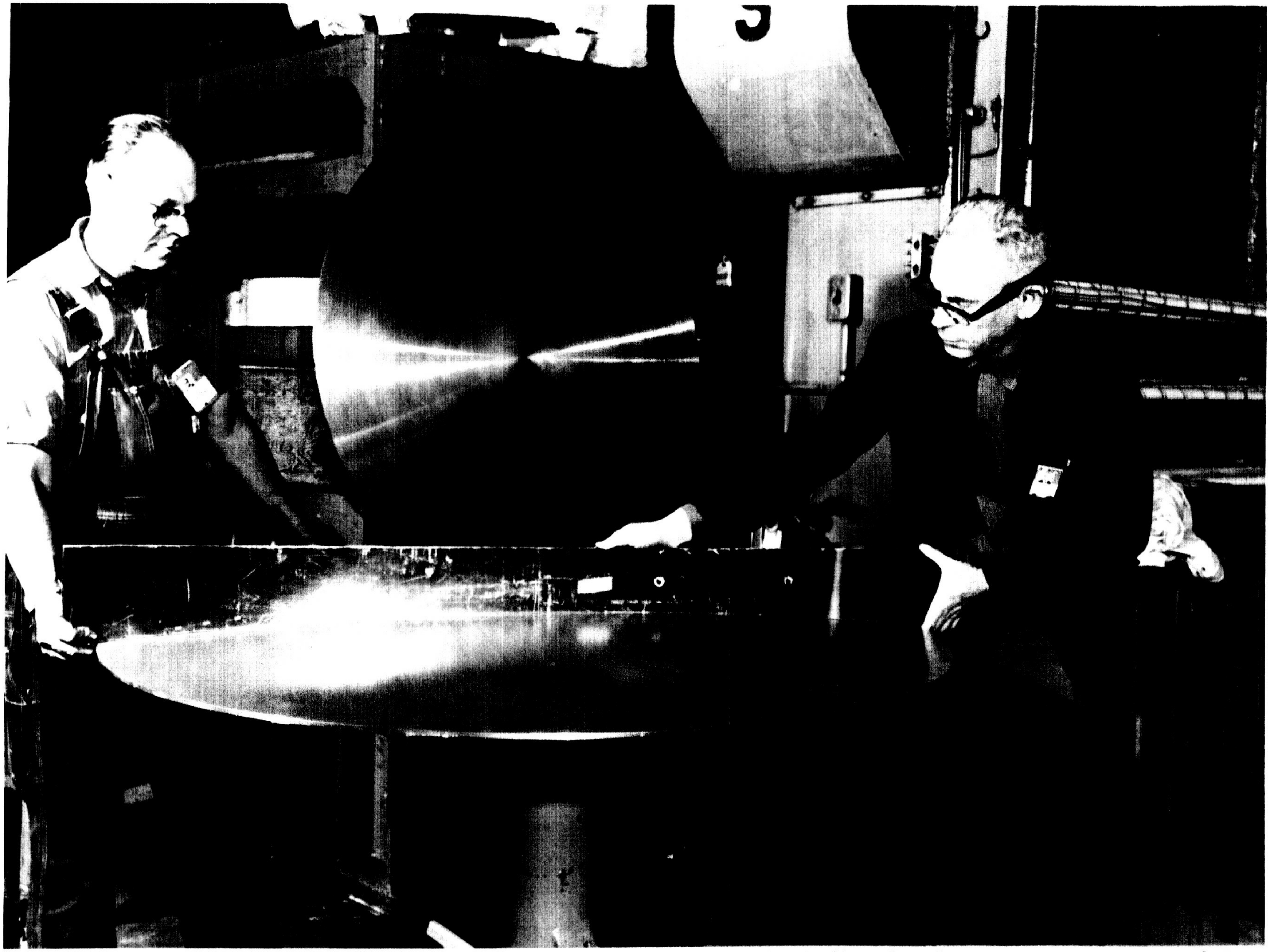


Fig. 22 NAS8-11717

Completed Part Contour Compared to 279.3" Radius Template

Proj.28.43 BWA-69722

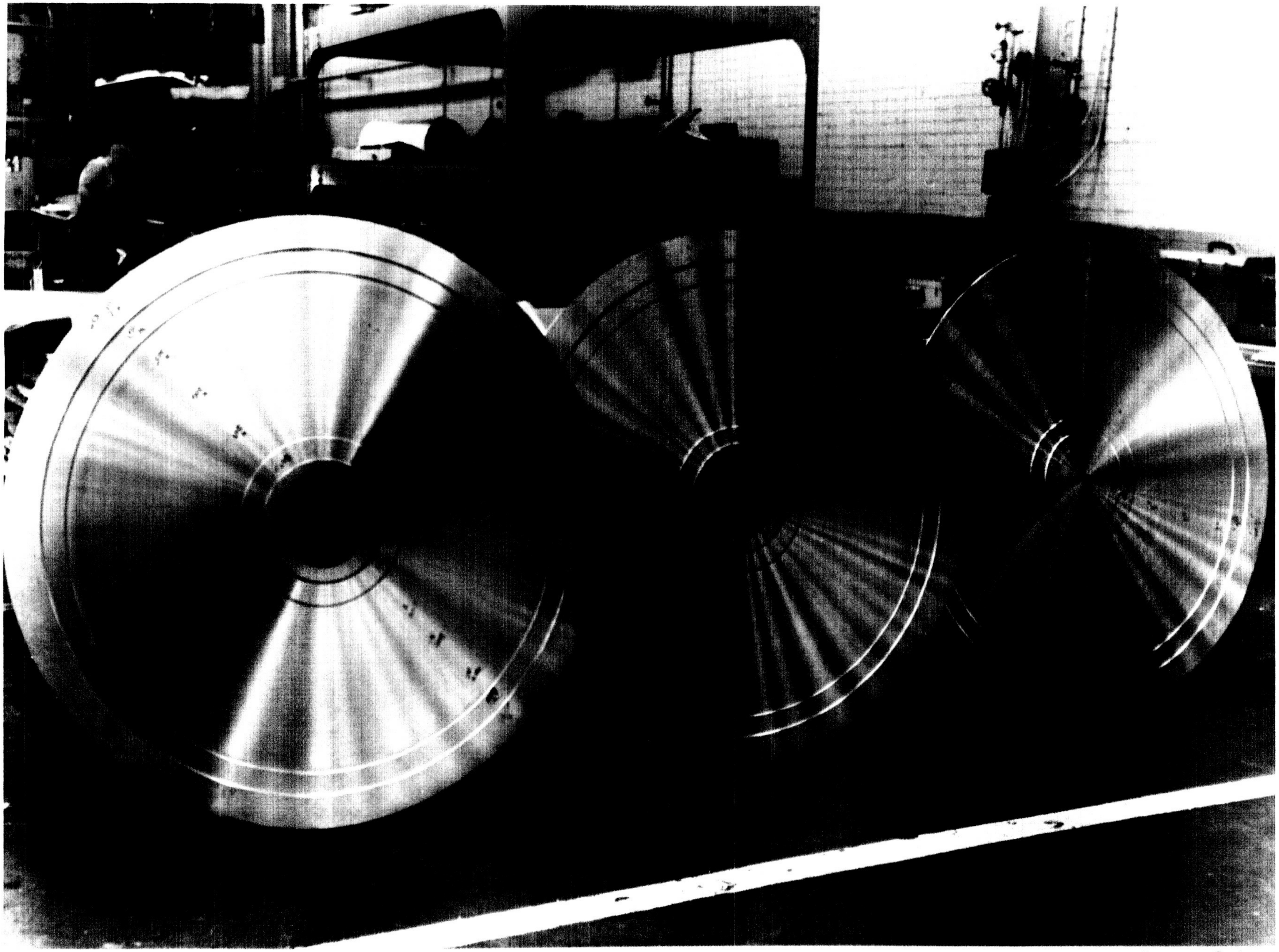


Fig. 23 Age Formed MR&T-SK-714 Part Nos. 1, 2, 3 Proj.28.43
NAS8-11717 BWA-69723