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PROPELLANT WEB VARIATIONS OF BLACK BRANT III ROCKET ENGINES

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ABSTRACT

The reported studies are directly associated with CARDE Technical Memorandum 699/62 "Performance Data From Static Firings of 9KS11000 Rocket Engines" (1). They attempt to describe some of the factors responsible for the uncertain ballistic performance of the Black Brant III rocket motor. The present results illustrate that the ballistic potential of the motor is considerably more uniform than previously reported, for many of the inconsistencies are now attributable to the relatively poor dimensional quality of the hardware and casting tools.

TABLE OF CONTENTS

INTRODUCTION

CARDE Technical Memorandum 699/62 (1) recommends an investigation into the factors which might reflect the uncertain performance of the Black Brant III motors. The burning time, action time and pressure integral under tail-off are emphasized because of their direct bearing upon the propellant burning rate and its web thickness. This report presents an analysis of the hardware dimensional qualities and of the restrictor application as they are relevant to the subject.

The Black Brant III motors were processed according to the techniques described in References 2 and 3. These techniques, like systems of this sort, possess the significant characteristic of employing the lined motor casing as the female member of a casting mold and the mandrel, or core, as the male component. It may be observed at the outset that, since the casings and other hardware cannot be expected to be identically perfect, the minimum over-all weight of the motor cannot be realized without some sacrifice relative to performance regularity.

1. THE CASTING MANDRELS

The ability of a casting mandrel to reproduce identical conduits through a series of propellant grains is dependent upon its straightness and other dimensional qualities as well as upon the tolerances of its locating fixtures. Certain imperfections may be acceptable since their effect will be faithfully reproduced but, when more than one mandrel is employed, a high degree of uniformity is essential. Three mandrels were fabricated for this project and they were employed with random cycling. Their effective length is 125 inches and the modified taper design affects the outer and root diameters to the extent of 0.006 inch per foot. The cross section of one mandrel appears in Figure 1. The mandrels are tapered for mold release purposes. To further assist they are teflon-coated to a thickness of 0.002 to 0.004 inch on all surfaces. When in the casting position, the small diameters are located at the igniter end of the motors.

The mean root and outer diameters of the mandrels are specified to be 3.069 and 5.719 inches nominal. The extremes are therefore 3.10/5.760 and 3.069/5.698 inches respectively, and the propellant web has a resulting pre-determined web differential of 0.031 inch over the length of the motor. Continuous cast, 65-S aluminum was selected for the mandrel fabrication because of its known resistance to warping during the teflon-baking cycle. It is nonetheless vulnerable to permanent sagging. When supported at each 60 inches of its length, the permanent deformation is negligible. The fabrication straightness tolerance was placed at not greater than 0.015 inch deviation from the centerline at any point, and inspection prior to teflon-coating proved the mandrels to be within the limits but significantly, they were not inspected following the teflon-coating. No untoward effect was observed during the processing of the first 25 heavy-wall motors and it was not until the current investigation was initiated that an appreciable lack of straightness was discovered.

The outer diameters of the three mandrels appear in Tables I, II and III and their deviations from the nominal in Tables IV, V and VI. An over-all comparison is presented in Table VII. Profiles of the average variations with length are shown in Figure 2 and the summation is that mandrels 28, 29 and 30, exhibit the low deviations of 1.0, 1.4 and 3.5 x 10^{-3} inches respectively.

Straightness, by contrast, was found to be excessive, particularly with mandrel 29 as exhibited by the measurements listed in Table VIII and plotted in Figure 3. The remaining two are not similarly detailed but the three are compared in Table IX and Figure 4. The deformation curves are strikingly similar to those exhibited by a single beam of the metal suspended at either end at 700°F, which is the temperature used for teflon-baking. The following formulae apply:

A - $\Delta_{75°F} = \frac{5}{384} \cdot \frac{WL}{EI}$, where:

$\Delta_{75°F}$	=	Max. deflection at 75°F	(in.)
W	=	Total Weight	(lb) = 198
L	=	Length	(in.) = 125
E	=	Modulus of Elasticity	(lb/in^2) = 10 x 10^6
I	=	Moment of Inertia	(in^4) = 15.9

B - $\Delta_{700°F} = \Delta_{75°F} \times \frac{E25}{E700}$

The deformation at 75°F is 0.031 inch and elastic, whereas the deformation at 700°F is 0.060 inch and plastic. Obviously the center support had been omitted during baking, else the deformation would have been 0.004 inch only.

The net propellant web differential is 0.12 inch at midsection with mandrels 28 and 30 and it is 0.182 inch with mandrel 29.

2. MANDREL LOCATION

A male threaded casing closure at the igniter end incorporates the "O" ringed locating plug and the spider for the core location at the nozzle end are illustrated in Figures 5 and 6. The spider arms are designed deliberately short to avoid hazardous binding and are shimmed to trueness as desired. Appendices A and B and Figure 5 show the results relative to the light-wall casings. Similarly, Appendices C and D and Figure 6 describe the heavy-wall motor casings. The latter casings are more complicated than the former because of their 3-piece construction. The cumulative tolerance effects on the light-wall casings are 0.0146 and 0.027 inch at the igniter and the nozzle end respectively.

3. MOTOR CASINGS

The maximum combined tolerances on bow, ovality and outer diameter of the unlined lightweight casings is ±0.100 inch from the nominal 5.058-inch radius. The mean outer diameter lies between 10.12 and 10.11 inches. The total combined tolerances result in radii of 4.895 to 5.105 inches which is the equivalent of propellant web deviations as high as 0.210 inch.

Figure 7 illustrates the method of measuring bow and ovality. The cylinder is divided into six rows of fourteen stations each so that eighty-four measurements are taken commencing at the index position, located two inches clockwise from the longitudinal weld when the casing is viewed from the igniter end. Of the fifteen casings thus examined, number L.W. 02 was the best. Its detailed measurements are shown in Table X. The oversized and undersized totals from stations three to twelve are 0.625 and 0.540 inch respectively for averages of 0.025 and 0.014 inch.

Table XI compares the bow and ovality of all fifteen light-wall casings. The over-all mean deviation is 0.0289 inch with a specific figure of 0.0194 inch for L.W. 02. The worst casings L.W. 25 and 26 gave deviations of 0.0548 and 0.0422 inch. The latter two were unique in presenting multiple readings in excess of 0.100 inch.

The heavy-wall casings were made from standard commercial tubing, nominal dimensions 10 inches I.D. and a 0.375-inch wall. The tolerances applied were ±0.04 inch I.D. and a maximum curvature of 0.020 inch per lineal foot. Full use of the latter tolerance could result in a total displacement of 0.209 inch over the 125-inch length. The total combined cumulative tolerances could result in extreme radii of 5.229 to 4.771 inches from the centerline which is the equivalent of up to 0.458 inch differential over the propellant web. All the casings, heavy and light, fell within the specified tolerances.

4. THE MOTOR LINING

The centrifugal spinning technique was adopted for the project because of its versatility relative to the common spray, strip or bag adhesion. It was decided in advance that the nozzle end would be lined with a thickness of restrictor consistent with its resistance to the propellant flame over the total burning period. The liner was designed to taper from that determined thickness to the minimum permissible thickness at the igniter end.

A total of four exploratory linings was required to establish the taper in the heavy-wall motors while five were required for the light-wall. Typical variations in liner thickness are shown in Figure 8 but because of the number of designs they cannot be logically assessed. Figure 9 illustrates the spinning assembly and Figure 10, the wide liner variation resulting from the casing bow and ovalities. Figures 11 and 12 compare the liner thickness mean deviation (ΔS) with the bow and ovality. The influence of the latter is clearly illustrated by casing L.W. 02 which exhibits only a small under-nominal radius at 0 degree and a compensating over-nominal at 180 degrees. Other casings are more marked in this respect, as shown in Figures 11 and 12. Figure 13 is a plot of sixty readings from various points of the circle. Casing No. L.W. 25 would have required ten more pounds of restrictor than casing L.W. 02 to realize the equivalent degree of trueness, as is further illustrated by Table XI.

It is of fundamental reasoning, therefore, that if the hollows exhibited by L.W. 25 had not been filled with restrictor (specific gravity 1.27 g/cc) they must ultimately have been filled with propellant, (specific gravity 1.63 g/cc) which represents 13 lb, all of which would burn under tail-off in an unpredictable manner. The graded effect over the range of casings used is shown in the following:

Bow and Ovality	Additional Restrictor required (17.2 lb basic)
0.000 inch	0.0 pound
0.020 inch	4.0 pounds
0.040 inch	8.0 pounds
0.060 inch	12.0 pounds

Compensating propellant weight under tail-off	Percent of the charge
0.0 pound	0.0
5.1 pounds	1.2
10.2 pounds	2.4
15.4 pounds	3.6

5. THE CHARGE DESIGN

The ideally conceived propellant grain will confine the burning under tail-off to the anticipated slivers remaining after web burn-out, and according to the concept the maximum in performance regularity may be expected. In practice, however, factors such as casing bow and ovality, mandrel taper, erosive burning, etc. are so influential with respect to all-up weight versus propellant weight that it is seldom indeed that a fully developed motor retains its originally designed grain. The Black Brant III grain evolved with the emphasis upon propulsive performance and not upon grain dimension uniformity. In order to achieve the latter it would first have been necessary to true the casings with the lining material using the worst one as the criterion. Following this, additional lining would have been required to taper the casing consistent with the mandrel and erosive burning effects.

The finally accepted charge design, in consideration of the restrictor and mandrel tapers alone, prescribes that the motor shall be endowed with a nominal 14 percent of the propellant weight burning under tail-off. The extremes in the total of the hardware dimensions show additional potentials of 0 to 6 percent and 0 to 11 percent with the light and heavy motors respectively; accordingly, the working ranges were 14 to 20 percent and 14 to 25 percent. It is of interest to note that whereas data are lacking with respect to the heavy-wall casings the determined values with the light-wall motors are in agreement with the calculated potential.

DISCUSSIONS

Burning under tail-off, though presumed identical with each motor, is known to adversely affect the performance regularity; thus, the 14-percent basic provision by the charge design probably exerted an influence. The additional factors which might more positively affect the performance are summarized in the following:

	Light-Wall (%)	Heavy-Wall (%)
Charge design	14	14
Bow and Ovality	0 - 3.6	0 - 8.6
All others	0 - 2.4	0 - 2.4
Total range	0 - 20.	0 - 25.

Contributions, in excess of the basic 14 percent, affect the web in a random manner and may consequently be expected to cause highly unpredictable motor performances.

Although not discussed in the text, the propellant grain conduits are slightly smaller at the mid-section than the true mirror image of the mandrel predicts. The web thickness at the igniter end, however, remains appreciably greater yet there is evidence that the web burns through first as predicted at the nozzle end, then by the igniter end and finally by the mid-section. It is suggested that this phenomenon might well have an undesirable effect upon the performance and it is highly recommended that the matter be investigated.

CONCLUSIONS

The experimental firing data presented in Reference 1 are in complete agreement with the measured and calculated values presented herein. The latter predict and show that 14 to 20 percent of the propellant may burn under tail-off. The authors therefore conclude that:

(1) The performance of the Black Brant III Motor, as regularity is related to burning under tail-off, is entirely consistent with its charge design and the dimensional quality of its specified hardware.

(2) From the measured and calculated values, it is concluded that the range minimum of 14 percent is entirely due to the charge design, that 3.6 percent is attributed to casing bow and ovality, and that all remaining factors combine to account for the discrepant 2.4 percent.

REFERENCES

1. Jackson F. and Roberts A.K. "Performance Data from Static Firings of 9KS11000 Rocket Engines"., CARDE Technical Memorandum 699/62, July 1962. Unclassified

2. Holsgrove B.J., Duchesne G.L. and Peacock W.B. "CARDE Processing Facilities for Black Brant III Static Rocket Engine". CARDE Technical Memorandum 676/62. August 1962. Unclassified

3. Holsgrove B.J., Flinn J.W. and Peacock W.B. "The Mixing of Pourable Composite Propellant Composition". CARDE Technical Memorandum 180/58, January 1959. Unclassified

APPENDIX A

MANDREL LOCATING DEVICES

IGNITER END OF LIGHT WEIGHT CASING

BLACK BRANT III PROGRAMME

Description	Drawing No. CARDE	Dimensions (in.)	
A) Machining Tolerances			
1) Mandrel locator socket	60112819	1.750 - 1.7516	max.
Mandrel locator plug	60112818	1.748 - 1.7464	min.
		.0052	on dia.
2) Shoulder on casing	(BAIL 600 - 13032)	4.000 - 4.004	max.
Shoulder on plug	60112818	3.998 - 3.996	min.
		.008	on dia.

3) Total $= \frac{.0052 + .008}{2} =$ .0066 in. on radius

Description		Dimensions (in.)
B) Concentricity Tolerances		
1) Mandrel locator socket to mandrel		.002
2) Mandrel locator plug		.001
3) Igniter end location shoulder		.005
	Total	.008

C) Total Machining and Concentricity Tolerances

Machining --	.0066	in.
Concentricity --	.008	in.
	.0146	in.

APPENDIX B

MANDREL LOCATING DEVICES

NOZZLE END OF LIGHT WEIGHT CASING

BLACK BRANT III PROGRAMME

Description	Drawing No. CARDE	Dimensions (in.)
A) Machining Tolerances		
1) Mandrel	60112810	2.500 - 2.504 max.
Mandrel socket	60112813	2.496 - 2.492 min.
		.012 on dia.
2) Mandrel locator	60112827	2.500 - 2.505 max.
Mandrel socket	60112813	2.496 - 2.498 min.*
		.007 on dia.
3) Nozzle end opening	(BAIL 600 - 13032)	6.500 - 6.505 max.
Mandrel locator	60112827	6.495 - 6.490 min.
		.015 on dia.**

4) Total = $\frac{.012 + .007 + .015}{2}$ = .017 in. on radius

B) Concentricity Tolerances

1) Mandrel	.004
2) Mandrel socket	.002
3) Mandrel locator	.005
4) Nozzle end opening	.005
Total	.016

C) Total Machining and Concentricity Tolerances

Machining -- .017 in.
Concentricity -- .016 in.
.033 in.

* The dimension 2.498 includes .006 inch teflon coating.
** The .015 inch is usually reduced to .003 inch with spacers when the mandrel locator is in place.

APPENDIX C

MANDREL LOCATING DEVICES

IGNITER END OF HEAVY WEIGHT CASING

BLACK BRANT III PROGRAMME

	Description	Drawing No. CARDE	Dimensions (in.)	
A)	Machining Tolerances			
1)	Mandrel locator socket	60112819	1.750 - 1.7516	max.
	Mandrel locator plug	60112818	1.748 - 1.7464	min.
			.0052	on dia.
2)	Shoulder on casing		4.000 - 4.004	max.
	Shoulder on plug	60112818	3.998 - 3.996	min.
			.008	on dia.
3)	Thread tapping		.010	
4)	Hole drill and bolt		.019	

$$\text{Total} = \frac{.0052 + .008 + .010 + .019}{2} = .0211 \text{ in. on radius}$$

	Description		Dimensions (in.)
B)	Concentricity Tolerances		
1)	Mandrel locator socket to mandrel		.002
2)	Mandrel locator plug		.001
3)	Igniter end location shoulder		.005
4)	Threads		.005
5)	Holes on dished end		.005
		Total	.018

C) Total Machining and Concentricity Tolerances

Machining	--	.0211 in.
Concentricity	--	.018 in.
		.039 in.

APPENDIX D

MANDREL LOCATING DEVICES

NOZZLE END OF HEAVY WEIGHT CASING

BLACK BRANT III PROGRAMME

Description	Drawing No. CARDE	Dimensions (in.)
A) Machining Tolerances		
1) Mandrel	60112810	2.500 - 2.504 max.
Mandrel socket	60112813	2.496 - 2.492 min.
		.012 on dia.
2) Mandrel locator	60112827	2.500 - 2.505 max.
Mandrel socket	60112813	2.496 - 2.498 min.*
		.007 on dia.
3) Nozzle end opening	(BAIL 600 - 13032)	6.500 - 6.505 max.
Mandrel locator	60112827	6.495 - 6.490 min.
		.015 on dia.**
4) Thread tapping .385 - .375		.010
5) Hole drill and bolt .381 - .372		.019

$$\text{Total} = \frac{.012 + .007 + .015 + .010 + .019}{2} = .0315 \text{ in. on radius}$$

B) Concentricity Tolerances	
1) Mandrel	.004
2) Mandrel socket	.002
3) Mandrel locator	.005
4) Nozzle end opening	.005
5) Threads	.005
6) Holes on dished end	.005
Total	.026

C) Total Machining and Concentricity Tolerances

Machining	--	.0315 in.
Concentricity	--	.026 in.
Total		.0575 in.

* The dimension 2.498 includes .006 inch teflon coating.

** The .015 inch is usually reduced to .003 inch with spacers when the mandrel locator is in place.

TABLE I

OUTSIDE DIAMETERS* OF MANDREL NO. 28

CROSS SECTION NO. 12

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)	Rows 2 and 5 (in.)	Rows 3 and 6 (in.)	Average Diameter (in.)	Nominal Diameter (in.)
0	5.7715	5.7707	5.7713	5.7712	5.776
1	5.7629	5.7608	5.7637	5.7625	5.760
2	5.7575	5.7577	5.7575	5.7576	5.754
3	5.7511	5.7508	5.7511	5.7510	5.748
4	5.7445	5.7445	5.7443	5.7444	5.742
5	5.7363	5.7348	5.7362	5.7358	5.736
6	5.7330	5.7333	5.7336	5.7333	5.730
7	5.7290	5.7289	5.7292	5.7290	5.724
8	5.7235	5.7232	5.7226	5.7231	5.718
9	5.7165	5.7168	5.7169	5.7167	5.712
10	5.7085	5.7095	5.7098	5.7093	5.706
10.5	5.7058	5.7078	5.7068	5.7068	5.703

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE II

OUTSIDE DIAMETERS* OF MANDREL NO. 29

CROSS SECTION NO. 12

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)	Rows 2 and 5 (in.)	Rows 3 and 6 (in.)	Average Diameter (in.)	Nominal Diameter (in.)
0	5.7682	5.7682	5.7672	5.7679	5.766
1	5.7630	5.7631	5.7623	5.7628	5.760
2	5.7549	5.7549	5.7539	5.7546	5.754
3	5.7492	5.7471	5.7468	5.7477	5.748
4	5.7428	5.7408	5.7416	5.7417	5.742
5	5.7349	5.7332	5.7350	5.7344	5.736
6	5.7308	5.7298	5.7298	5.7301	5.730
7	5.7241	5.7240	5.7246	5.7242	5.724
8	5.7193	5.7182	5.7183	5.7186	5.718
9	5.7130	5.7128	5.7130	5.7129	5.712
10	5.7062	5.7068	5.7065	5.7065	5.706
10.5	5.7034	5.7019	5.7020	5.7024	5.703

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE III

OUTSIDE DIAMETERS* OF MANDREL NO. 30

CROSS SECTION NO. 12

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)	Rows 2 and 5 (in.)	Rows 3 and 6 (in.)	Average Diameter (in.)	Nominal Diameter (in.)
0	5.7662	5.7639	5.7625	5.7642	5.766
1	5.7583	5.7570	5.7565	5.7573	5.760
2	5.7535	5.7528	5.7519	5.7527	5.754
3	5.7466	5.7464	5.7456	5.7462	5.748
4	5.7422	5.7419	5.7398	5.7413	5.742
5	5.7351	5.7348	5.7357	5.7352	5.736
6	5.7310	5.7310	5.7298	5.7306	5.730
7	5.7257	5.7253	5.7238	5.7249	5.724
8	5.7209	5.7210	5.7192	5.7204	5.718
9	5.7158	5.7131	5.7120	5.7136	5.712
10	5.7064	5.7068	5.7070	5.7069	5.706
10.5	5.7037	5.7042	5.7025	5.7035	5.703

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE IV

VARIATIONS OF OUTSIDE DIAMETERS*

MANDREL NO. 28

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)x 10^{-4}	Rows 2 and 5 (in.)x 10^{-4}	Rows 3 and 6 (in.)x 10^{-4}	Total Oversize (in.)x 10^{-4}	Average Oversize (in.)x 10^{-4}	Total Undersize (in.)x 10^{-4}	Average Undersize (in.)x 10^{-4}
0	+ 55	+ 47	+ 53	155	52	-	-
1	+ 29	+ 08	+ 37	74	25	-	-
2	+ 35	+ 37	+ 35	107	36	-	-
3	+ 31	+ 28	+ 31	90	30	-	-
4	+ 25	+ 25	+ 23	73	24	-	-
5	+ 3	- 12	+ 2	5	2	12	12
6	+ 30	+ 33	+ 36	99	33	-	-
7	+ 50	+ 49	+ 52	151	50	-	-
8	+ 55	+ 52	+ 46	153	51	-	-
9	+ 45	+ 48	+ 49	142	47	-	-
10	+ 25	+ 35	+ 38	98	33	-	-
10.5	+ 28	+ 48	+ 38	114	38	-	-
Total	411	422	440	1261	-	12	-
No. of readings	12	12	12	35	-	1	-
Average	34	35	37	36	-	12	-

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE V

VARIATIONS OF OUTSIDE DIAMETERS*

MANDREL NO. 29

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)x 10^{-4}	Rows 2 and 5 (in.)x 10^{-4}	Rows 3 and 6 (in.)x 10^{-4}	Total Oversize (in.)x 10^{-4}	Average Oversize (in.)x 10^{-4}	Total Undersize (in.)x 10^{-4}	Average Undersize (in.)x 10^{-4}
0	+ 22	+ 22	+ 12	56	19	-	-
1	+ 30	+ 31	+ 23	84	28	-	-
2	+ 9	+ 9	- 1	18	9	1	1
3	+ 12	- 9	- 12	12	12	21	10
4	+ 8	- 12	- 4	8	8	16	8
5	- 11	- 28	- 10	-	-	49	16
6	+ 8	- 2	- 2	8	8	4	2
7	+ 1	0	+ 6	7	2	-	-
8	+ 13	+ 2	+ 3	18	6	-	-
9	+ 10	+ 8	+ 10	28	9	-	-
10	+ 2	+ 8	+ 5	15	5	-	-
10.5	+ 4	- 11	- 10	4	4	21	10
Total	130	142	98	258	-	112	-
No. of readings	12	12	12	24	-	12	-
Average	11	12	8	11	-	9	-

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE VI

VARIATIONS OF OUTSIDE DIAMETERS*

MANDREL NO. 30

BLACK BRANT III PROGRAMME

Longitudinal Position** (ft.)	Rows 1 and 4 (in.)x 10^{-4}	Rows 2 and 5 (in.)x 10^{-4}	Rows 3 and 6 (in.)x 10^{-4}	Total Oversize (in.)x 10^{-4}	Average Oversize (in.)x 10^{-4}	Total Undersize (in.)x 10^{-4}	Average Undersize (in.)x 10^{-4}
0	+ 2	- 21	- 35	2	2	56	28
1	- 17	- 30	- 35	-	-	82	27
2	- 5	- 12	- 21	-	-	38	13
3	- 14	- 16	- 24	-	-	54	18
4	+ 2	- 1	- 22	2	2	23	12
5	- 9	- 12	- 3	-	-	24	8
6	+ 10	+ 10	- 2	20	10	2	2
7	+ 17	+ 13	- 2	30	15	2	2
8	+ 29	+ 30	+ 12	71	24	-	-
9	+ 38	+ 11	0	49	16	-	-
10	+ 4	+ 8	+ 10	22	7	-	-
10.5	+ 7	+ 12	- 5	19	10	5	5
Total	154	176	171	215	-	286	-
No. of readings	12	12	12	17	-	19	-
Average	13	15	14	13	-	15	-

* The readings include the teflon coating.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE VII

VARIATIONS OF OUTSIDE DIAMETERS

COMPARISON BETWEEN MANDRELS NO. 28- 29 and 30

BLACK BRANT III PROGRAMME

MANDREL NO.	28	29	30
Oversize Readings			
Total (in.)x 10^{-3}	126.1	25.8	21.5
No. of readings	35	24	17
Average (in.)x 10^{-3}	3.6	1.1	1.3
Max. (in.)x 10^{-3}	5.5	3.1	3.8
Undersize Readings			
Total (in.)x 10^{-3}	1.2	11.2	28.6
No. of readings	1	12	19
Average (in.)x 10^{-3}	1.2	0.9	1.5
Max. (in.)x 10^{-3}	1.2	2.8	3.5
Overall			
Total (in.)x 10^{-3}	127.3	37.0	50.1
No. of readings	36	36	36
Average (in.)x 10^{-3}	3.5	1.0	1.4

TABLE VIII

OUT-OF-STRAIGHTNESS MEASUREMENT*

MANDREL NO. 29

BLACK BRANT III PROGRAMME

Longitudinal Position (ft)**	Radial Readings (in.)x10^{-3}					
	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6
0	0	+ 2	- 3	0	0	1
1	+26	+ 7	-17	-24	- 1	+23
2	+47	+13	-33	-44	- 3	+41
3	+72	+23	-48	-68	- 4	+62
4	+89	+26	-60	-84	- 4	+78
5	+96	+28	-65	-86	- 4	+83
6	+90	+25	-58	-84	- 4	+80
7	+76	+23	-49	-71	- 2	+67
8	+63	+23	-35	-59	- 2	+54
9	+34	+ 9	-27	-32	- 1	+29
10	+12	+ 4	- 7	-11	- 0	+11
10.5	+ 1	+ 1	- 1	- 2	0	0
Total	+606	+184	-443	-565	-25	+533
Readings	12	12	12	12	12	12
Average	+50.5	+15.3	-37.0	-47.1	- 2.1	+44.4

Average Sag	32.7
Maximum Oversize	+96
Maximum Undersize	-86

* Taken from theoretical center line of the engine.

** Position 0 is at the nozzle end while position 10.5 is at the igniter end.

TABLE IX

OUT-OF-STRAIGHTNESS MEASUREMENTS*

COMPARISON BETWEEN MANDRELS NO. 28- 29 and 30

BLACK BRANT III PROGRAMME

	MANDREL NO.	28	29	30
**	Row 1 (in.)x 10^{-3}	-57	+96	+44
**	" 2 "	- 2	+27	+53
**	" 3 "	+49	-65	- 6
**	" 4 "	+61	-86	-38
**	" 5 "	+19	- 4	-58
**	" 6 "	-41	+83	+14
***	Average "	20.8	32.7	19.3

* Taken from theoretical centre line of the engine.

** Maximum reading at the centre of the mandrel.

*** The average includes 72 readings as listed in Table VIII.

TABLE X

BOW AND OVALITY DATA

OF LIGHT WEIGHT CASING NO LW-02

BLACK BRANT III PROGRAMME

Longitudinal Readings	Radial Readings (in.) x 10^{-3} 0°	60°	120°	180°	240°	300°	Total Oversized	Total Undersized
1	- 2	0	- 1	0	+ 1	- 2		
2	- 4	+13	+ 5	+ 8	- 6	+ 1		
3	-14	+ 7	-17	+55	-29	+31	93	60
4	-18	+15	- 2	+45	-30	+20	80	50
5	-10	+ 9	+ 2	+40	- 1	- 9	51	20
6	- 8	+13	- 7	+19	+36	-20	68	35
7	- 7	+11	-28	- 4	-31	- 9	11	79
8	-12	+16	-25	- 5	-31	-11	16	84
9	-28	+30	-13	+21	+36	- 6	87	47
10	-34	+35	- 6	+35	+ 9	-11	79	51
11	-40	+40	-15	+29	- 7	+ 4	73	62
12	-22	+44	-24	+23	- 2	- 4	67	52
13	- 6	+17	- 9	+13	- 7	- 8		
14	- 5	- 6	- 4	- 2	- 7	- 8		

		Oversized	Undersized
Total	--	625	540
Readings	--	25	35
Average	--	25.0	15.4
Overall Average	--	19.4	

TABLE XI

COMPARISON OF BOW AND OVALITY DATA

FOR FIFTEEN LIGHT WEIGHT CASINGS

BLACK BRANT III PROGRAMME

CASING NO. (LW)	02	11	16	17	19	24	25	26	27	04	05	09	12	13	14	Mean
A) Oversized Readings																
Total $\times 10^{-3}$(in.)	625	625	598	1064	988	878	1638	1371	1002	600	990	625	630	720	1055	
No.	25	26	36	38	22	33	35	24	33	27	32	31	31	27	31	451
Average $\times 10^{-3}$(in.)	25.0	24.0	16.6	28.0	44.9	26.6	46.8	57.1	33.4	22.2	30.9	20.2	20.3	26.7	34.0	30.4
B) Undersized Readings																
Total $\times 10^{-3}$(in.)	540	640	515	823	1406	466	1653	1160	614	855	739	720	670	820	960	
No.	35	34	24	22	38	27	25	36	27	33	28	29	29	33	29	449
Average $\times 10^{-3}$(in.)	15.4	18.8	21.5	37.4	37.0	17.3	66.1	32.2	22.7	25.9	26.4	24.8	23.1	24.8	33.1	28.4
C) Overall (A & B)																
Total $\times 10^{-3}$(in.)	1165	1265	1113	1887	2394	1344	3291	2531	1616	1455	1729	1345	1300	1540	2015	
No.	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	900
Average $\times 10^{-3}$(in.)	19.4	21.1	18.6	31.4	39.9	22.4	54.8	42.2	26.9	24.3	28.8	22.4	21.7	25.7	33.6	28.9
D) Distribution of Readings																
.040 - .059 in.	6	7	4	10	14	6	19	18	9	7	17	10	11	14	8	
.060 - .079 in.	0	2	1	8	7	2	18	8	3	3	3	3	0	1	4	
.080 - .099 in.	0	0	0	2	6	0	3	1	3	1	0	0	0	0	6	
.100 and greater in.	0	0	0	0	1	0	6	5	1	0	0	0	0	0	0	

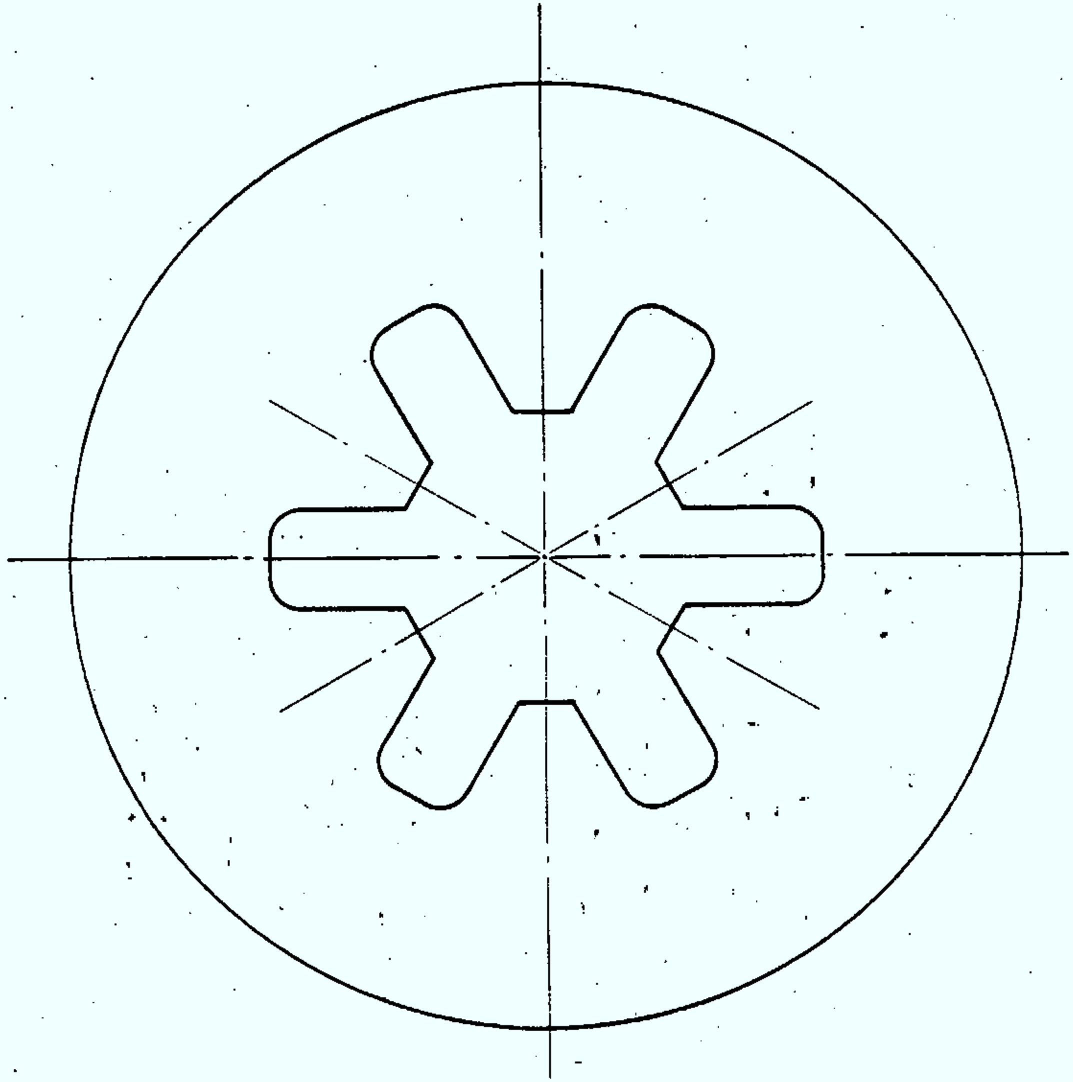


FIGURE 1 – Grain 10" Cross Section No. 12 – Black Brant III Programme

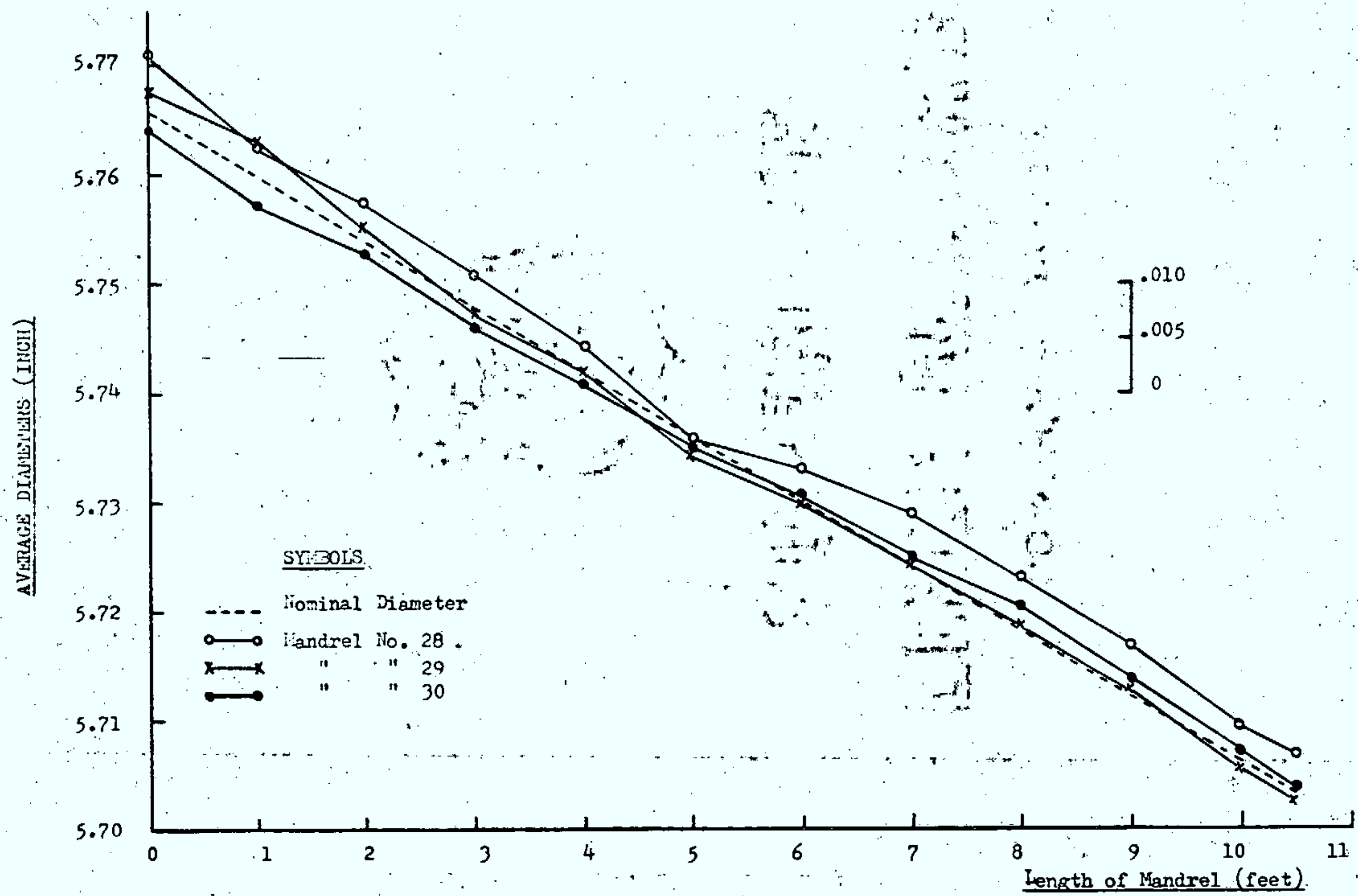


FIGURE 2 – Profiles of Outside Diameters – Mandrels No. 28, 29, 30

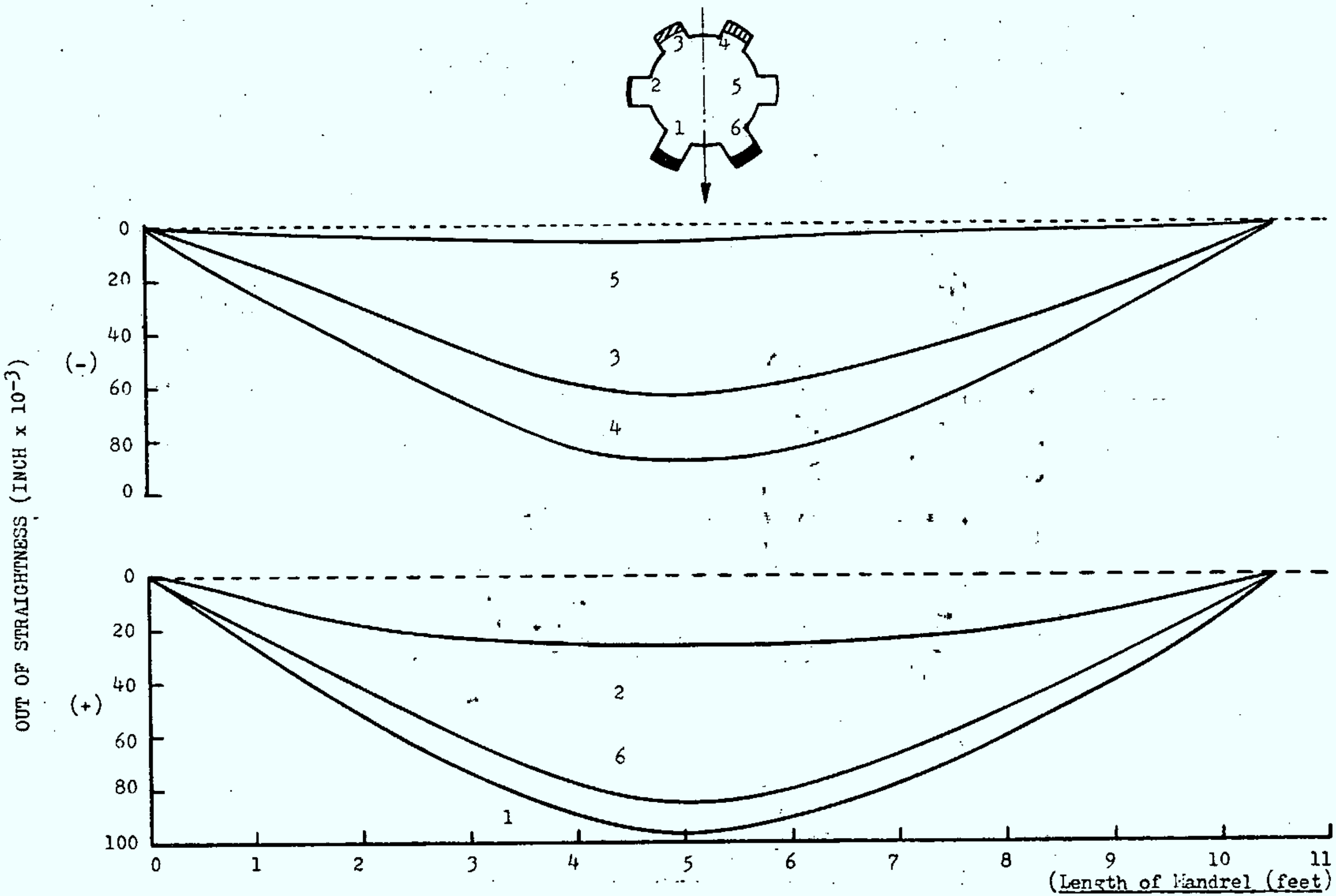


FIGURE 3 – Out of Straightness Measurements – Mandrel No. 29

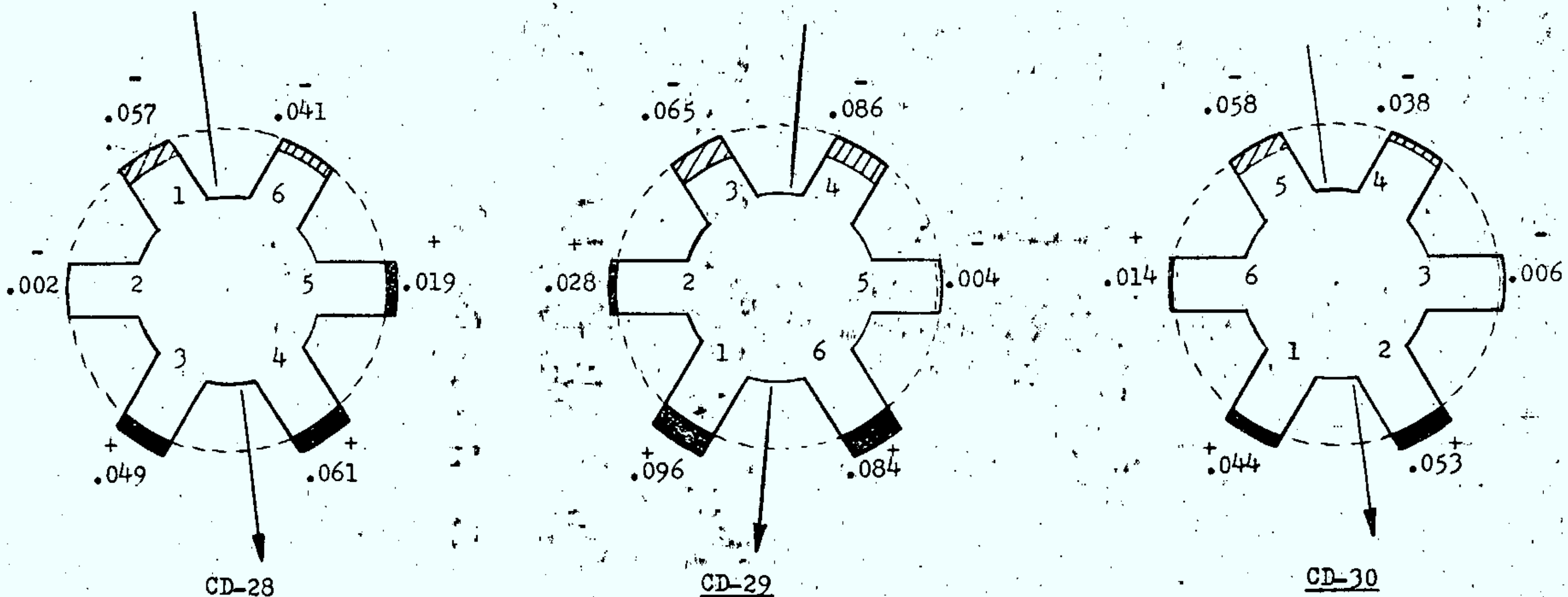


FIGURE 4 – Maximum Deflection – Mandrels No. 28, 29, 30

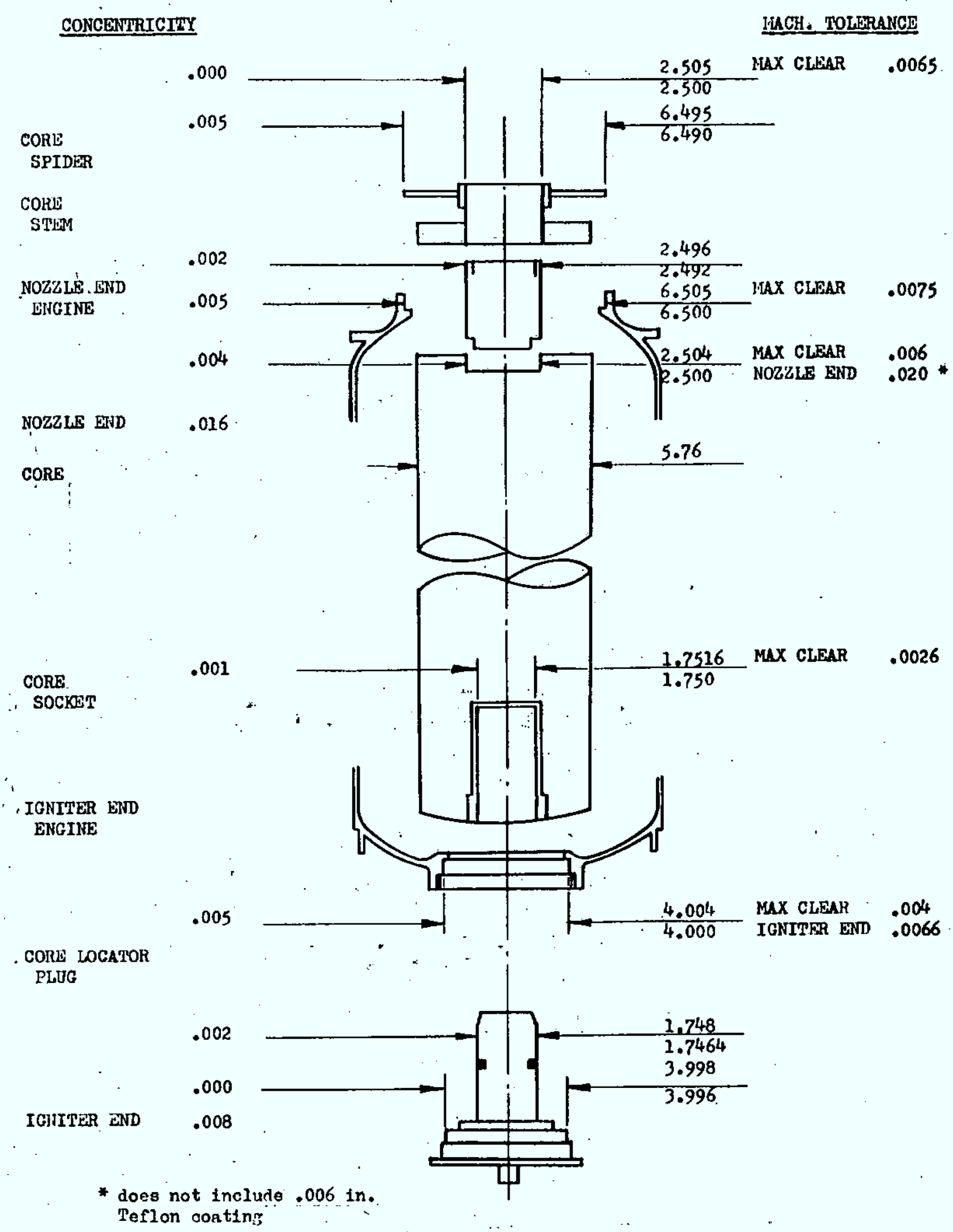


FIGURE 5 – Mandrel Locating Devices – Light-Weight Casing Black Brant III Programme

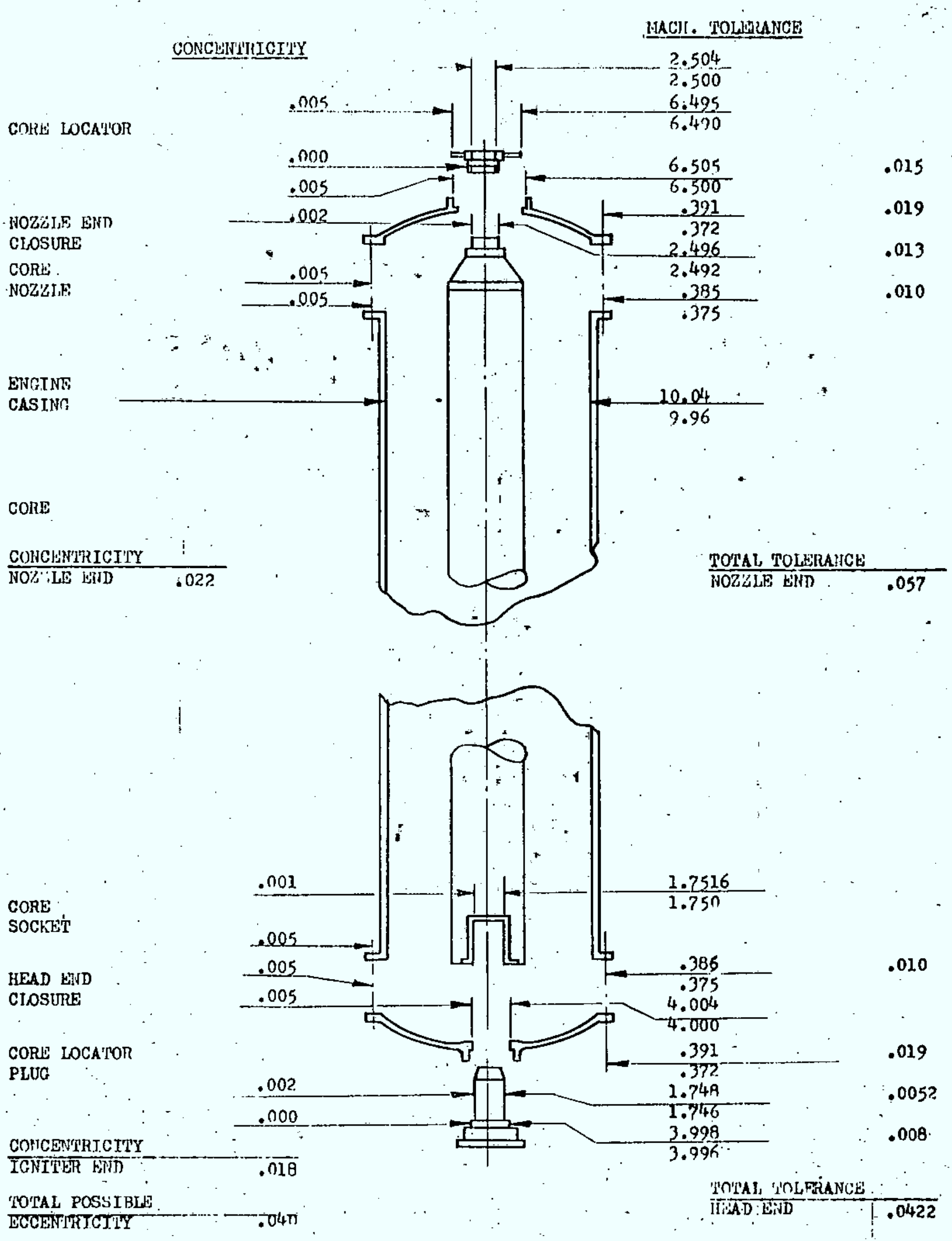
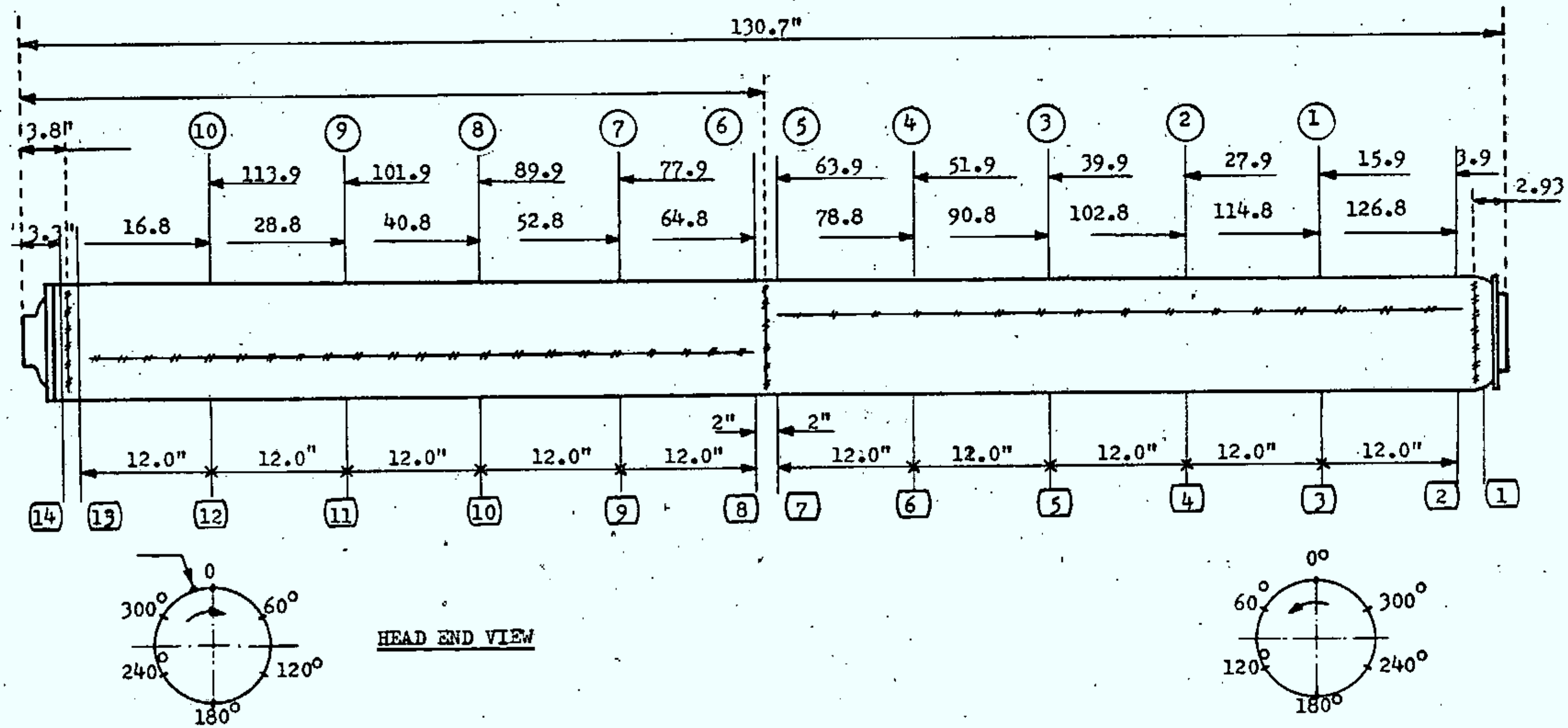


FIGURE 6 – Mandrel Locating Devices – Heavy-Wall Casing Black Brant III Programme



NOTES:

1. The 0° position is to be taken 2" clockwise of the longitudinal weld closest to the igniter end when looking at the igniter end.
2. Transpose the 0° position to the nozzle end and measure 0°, 60°, 120°, 180°, 240° and 300° positions counter clockwise.
3. Longitudinal readings for restrictor thickness are marked 1 to 10 inclusively.
4. Longitudinal readings for ovality are marked 1 to 14 inclusively.

SYMBOLS

Welds

Restrictor readings

Bow and ovality readings

FIGURE 7 – Bow and Ovality Measurement – Light-Wall Casing Black Brant III Programme

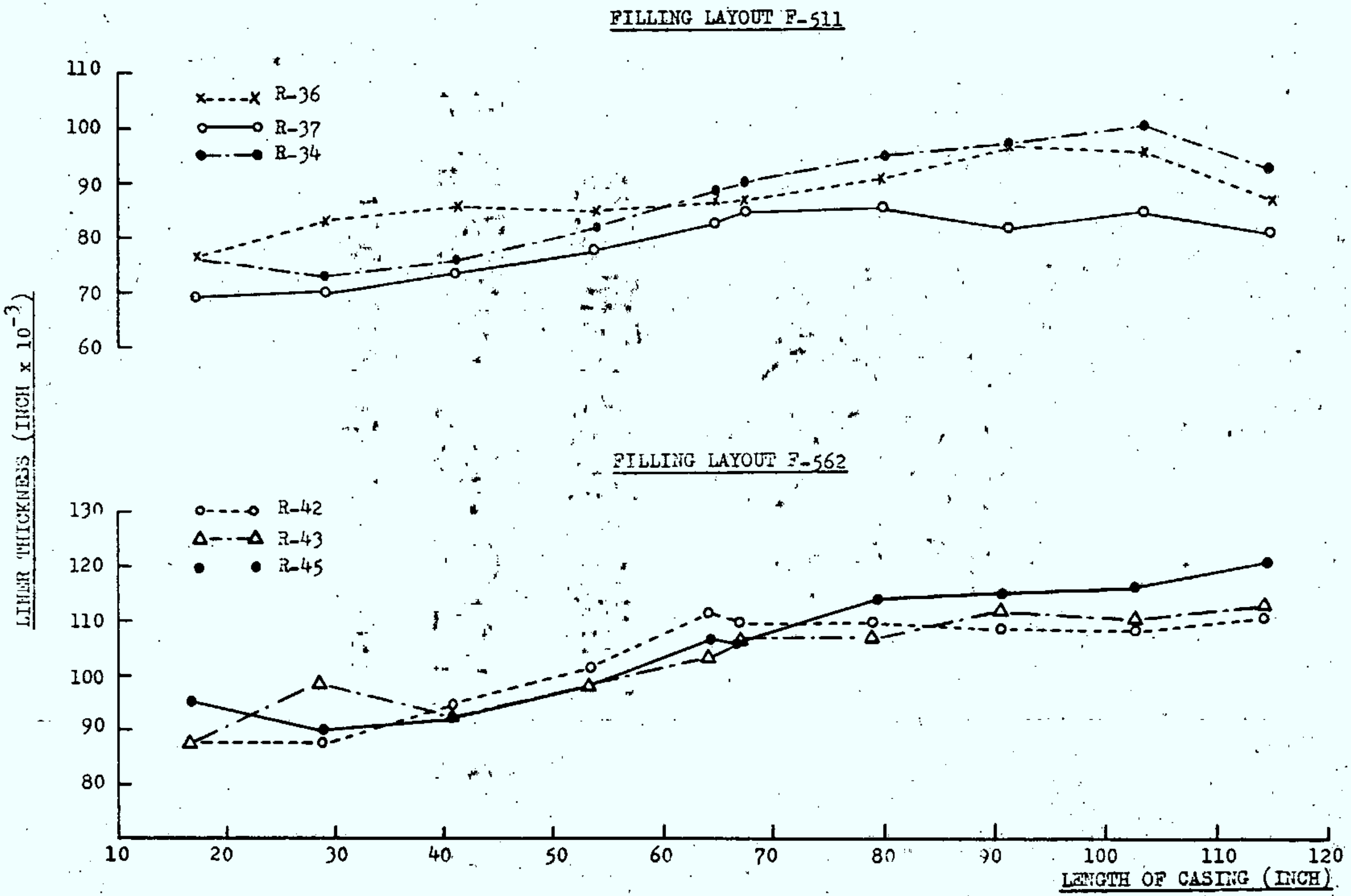


FIGURE 8 – Liner Thickness Profiles, Filling Layouts F-511 and F-562

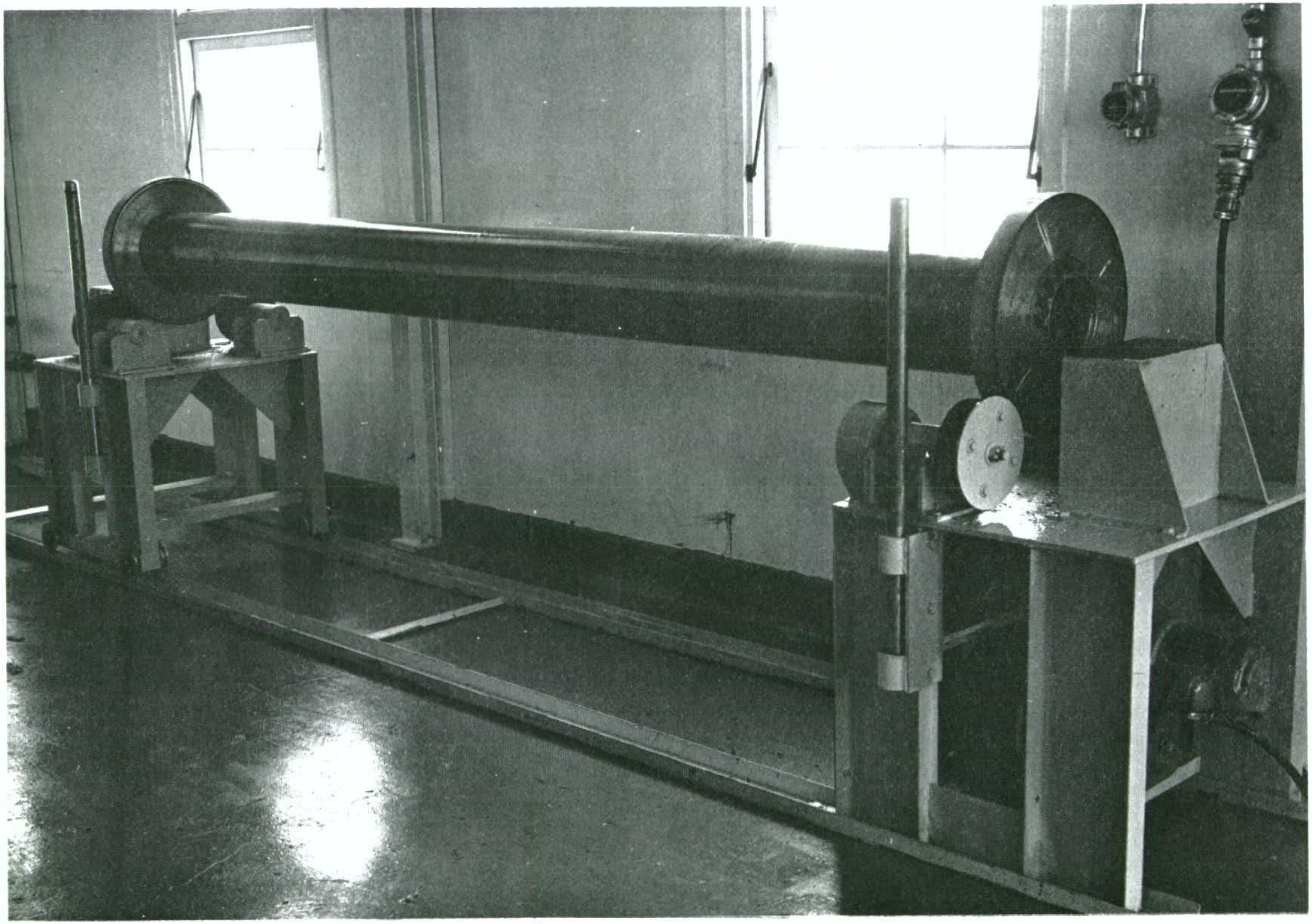


FIGURE 9

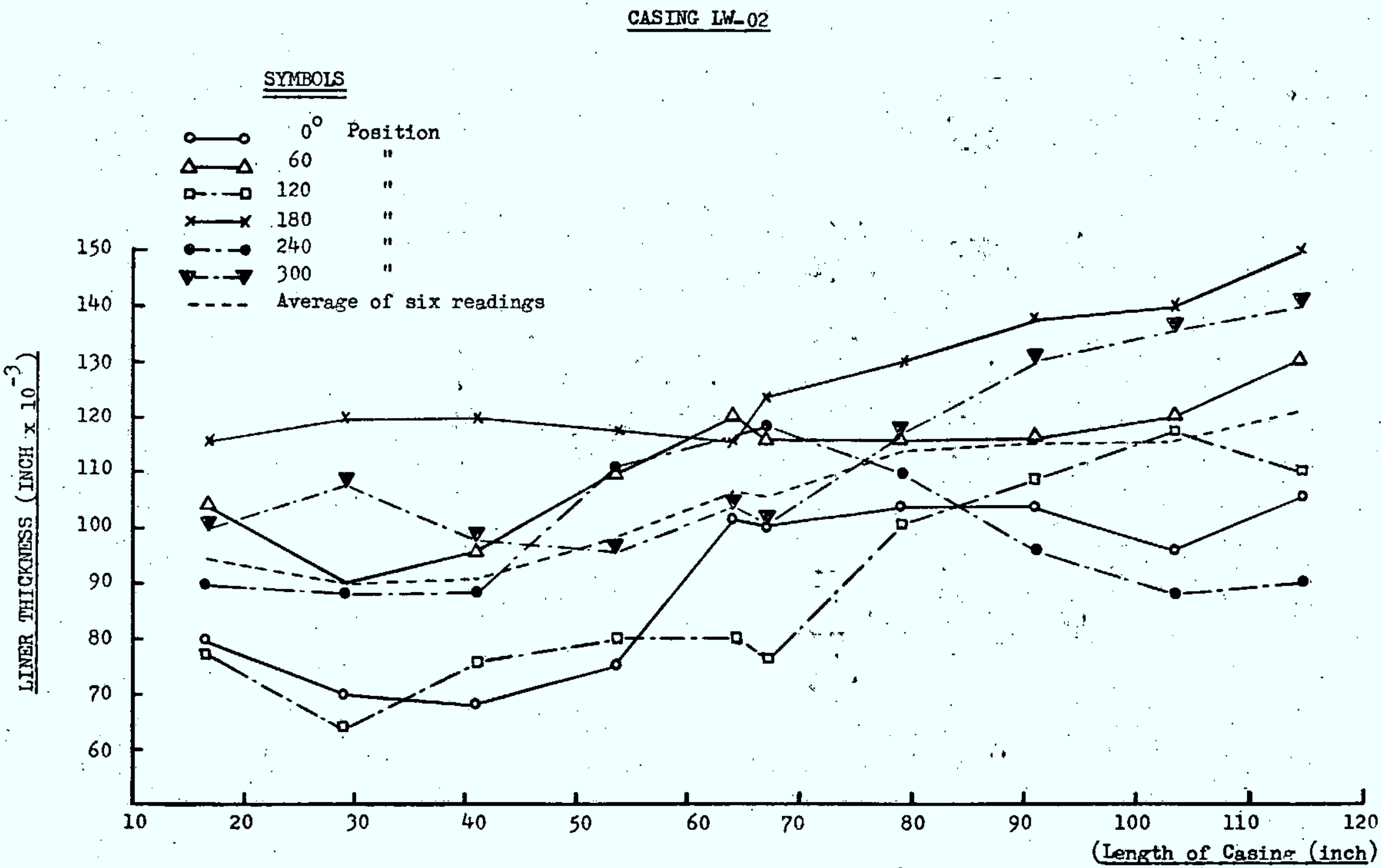


FIGURE 10 – Liner Thickness Profiles, Black Brant III Programme

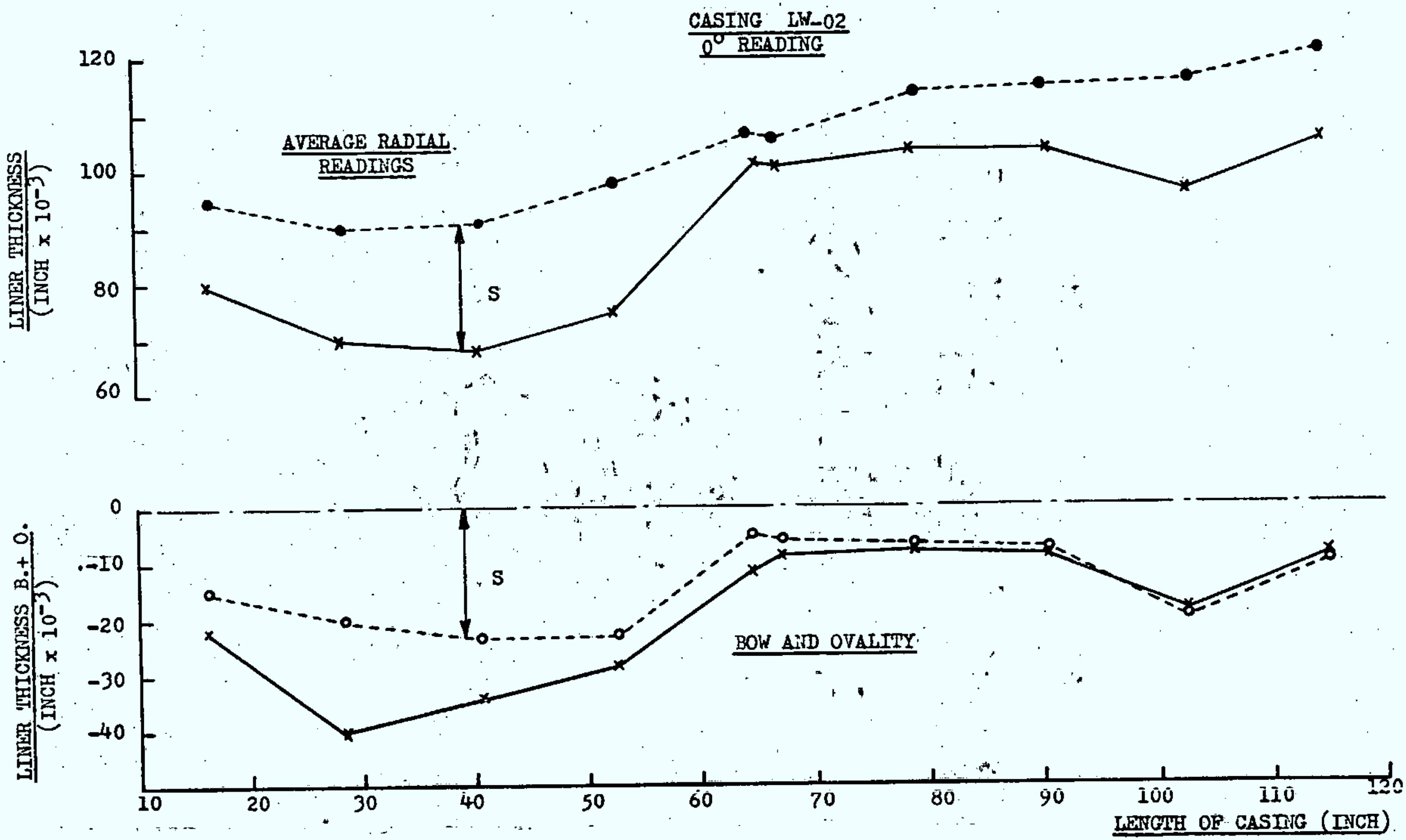


FIGURE 11 – Comparison Between Liner Thickness and Bow and Ovality

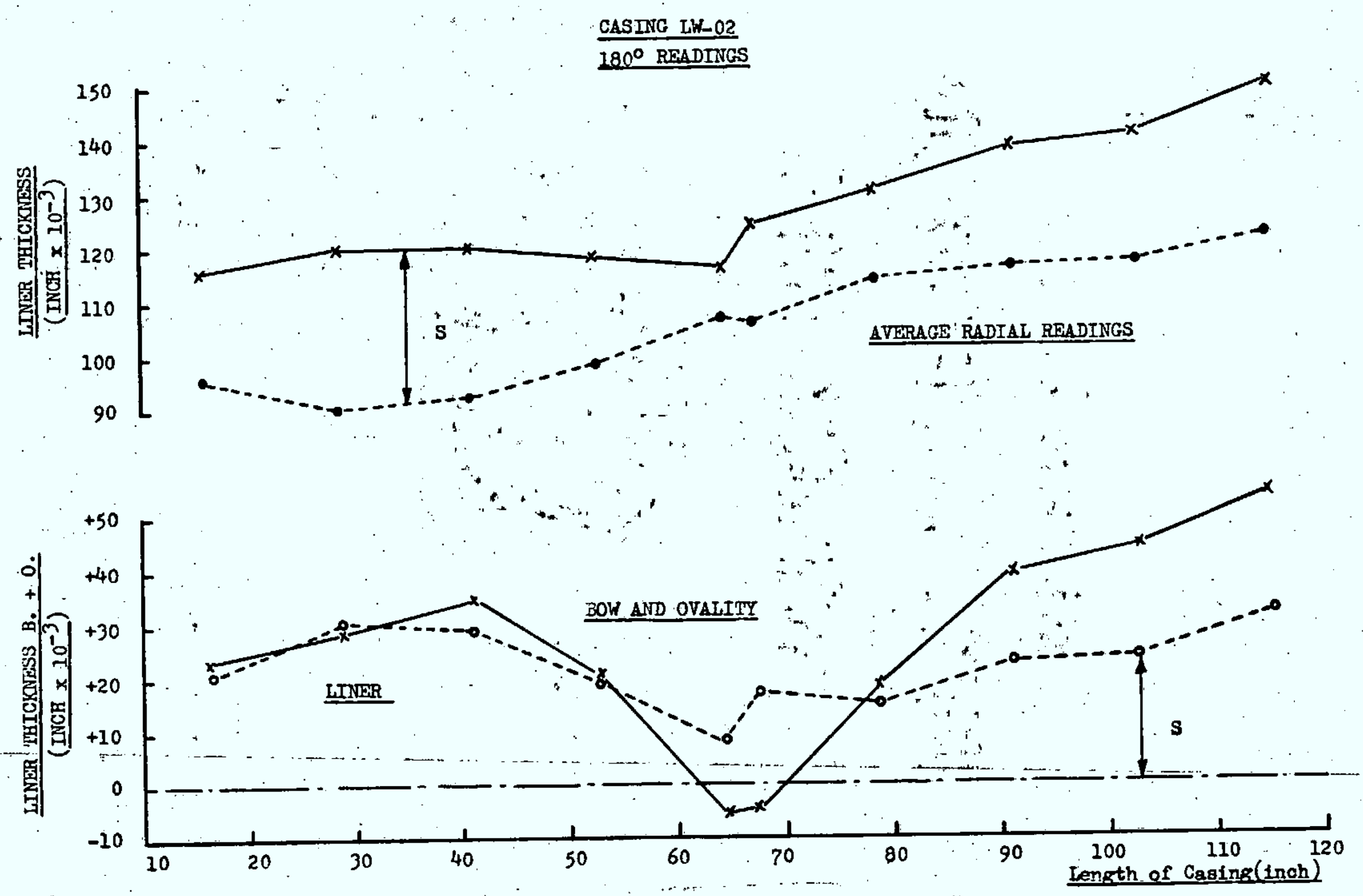


FIGURE 12 – Comparison Between Liner Thickness and Bow and Ovality

UNCLASSIFIED

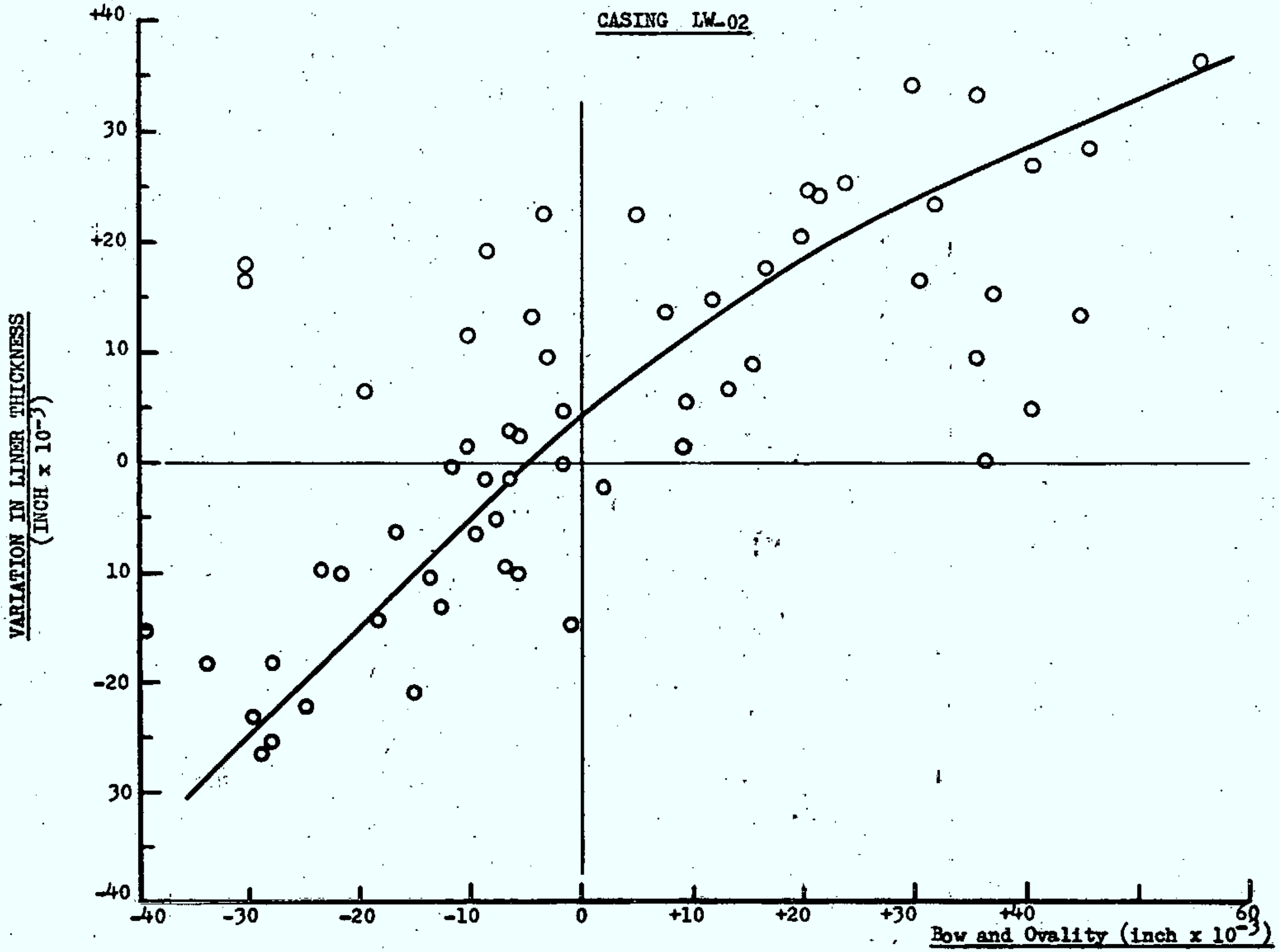


FIGURE 13 – Correlation Between Liner Thickness and Bow and Ovality

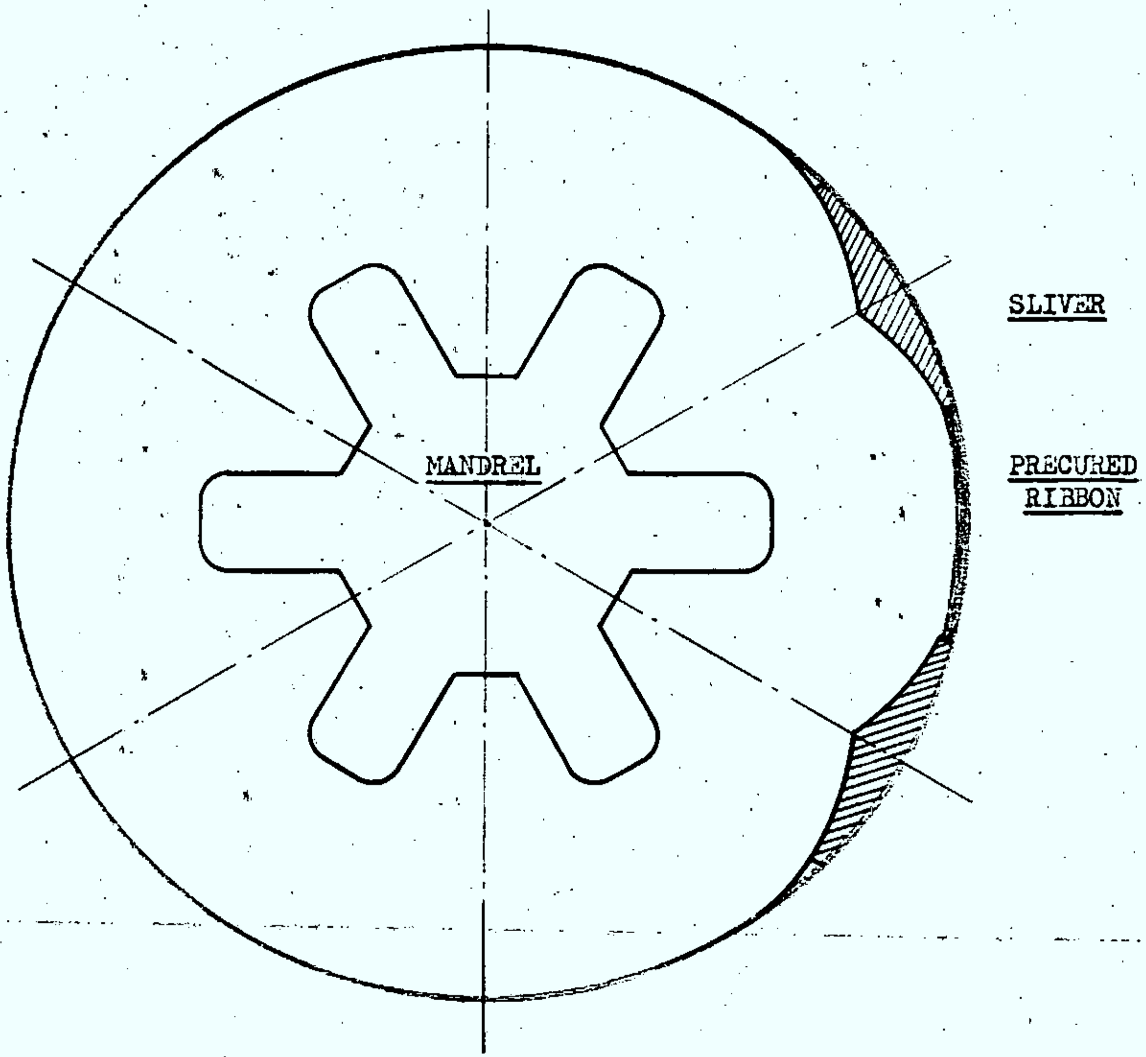


FIGURE 14 – Location of Precured Ribbons

CANADA

DRB

3 – DSIS Circ: UKLO

Plus Distribution

1 – Reference File
1 – NRE
1 – DWER
1 – DRCL
2 - DRTE
1 – SES
1 – DRNL

8 – Advisory Committee on Explosives and Propellants Research

2 – DRM London
1 – Canadian Armed Forces Ordnance Board Rep.

3 – Miss White, NRC/CB Library

1 – DSS/N

2 – DGFE

2 – DEE/TL (1 – AEEE)

1 - Sec. CSAC

1 – D. Arm. Eng. Library

1 – CFHQ/TL

1 – AMTS

OTHER CANADIAN

3 - Canadian Arsenals
(1 - D/Chem. & Explosives Production)

3 - Controller General, Inspection Services

~~2 - DDP, Armament Branch~~

3 - NRC
1 - D/R and E, Engineering Div.
1 - Cosmic Ray Sec. (Dr. D.C.Rose)

2 – Bristol Aero Industries Ltd., Winnipeg

2 – Canadair, Montreal

2 – Churchill Research Range

BRITISH

MINISTRY OF AVIATION

25 – Ministry of Defence (Army)
for Serial 7.
(3 – RAE/GWD/Mr. J. F Hazell)

MINISTRY OF DEFENCE (ROYAL NAVY)

2 - ESTIC Repts. Sec./R.D.S.D.(N)

1 – Admiralty Director of Physical Research

1 – Chief Inspector of Naval Ordnance

1 – NOIL (Caerwent) Attn: Dr. J. W. Wight

UNITED STATES

3 – NAVAL ATTACHÉ, US EMBASSY

Plus Suggested Distribution

1 – Naval Ordnance Lab., Tech. Library
1 – U.S. Naval Ordnance Test Station, Inyokern, Calif.

1 – U. S. Naval Powder Factory, Technical Library, Indian Head, Md.

2 – Bureau of Ordnance
1 – Tech. Library
1 – Re2c

26 – SENIOR STANDARDIZATION REP. US ARMY (625)

Plus Suggested Distribution

4 – Commanding General, US Army Material Command, Director of R&D (52)

2 – Ballistics Research Labs. APG (64)

1 – Picatinny Arsenal, Tech. Library Dover, N.J. (155)

15 - Chemical Propellant Inf. Agency (551)
1 - Frankford Arsenal (151)
1 - Redstone Arsenal (125)

1 – Jet Propulsion Lab., CIT (6)

4 – AIR ATTACHÉ, US EMBASSY

Plus Suggested Distribution

10 – DDC

1 - Air Research & Development Command
1 – Air University, Maxwell, AFB

1 – Eglin Air Force Base, Air Proving Ground Armament Center

1 – Aeronautical Systems Division

Direct

10 – NASA

2 - Solid Propellants Rocket Div.
2 - Wallops Station
2 - Langley Field
2 - Goddard Flight Centre

1 – UK Tech Rep. for British Defence Staff (Munitions/XP)

2 – Mr. Rolfe Kingsley, U.S. Embassy