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T. L. Wall
Safety in Mines Research Establishment, Buxton

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Spatial Distribution of Fragments, III

by

T.L. Wall, B.Eng.

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SUMMARY

The fragment speed and dispersion from scaled cylindrical casings has been examined for two diameters of case and a range of L/D ratios for each diameter. Four fragmentation zones were observed with long casings. A method of obtaining the dispersion angle for fragments from the various parts of the casing is suggested. The application of this method to the cases used leads to a maximum divergence of only 1° between observed and expected angles. The results have all been obtained with cylindrical casings: no work has yet been done with other shapes.

1. INTRODUCTION

In the first stage of the investigation on the spatial distribution of fragments (Ref. 1) a formula was derived which indicated that a fragment is deflected from the normal to the inner surface of the casing by an amount $\frac{\theta}{2}$ where

$$\sin\frac{\theta}{2} = \frac{V}{2U}\cos\left(\frac{\pi}{2} + \alpha - \phi\right) \qquad (1)$$

where α is the angle between the normal to the detonation wave and the axis, ϕ is the angle between the normal to the casing and the axis, V is the speed of projection of the fragment, and U the velocity of detonation of the explosive filling. The formula was tested by application to data from cylindrical and barrel shaped model casings, to data from two full scale G.W. warheads and to additional data from model cylindrical casings with various types of end confinement. It was found that expected distributions deduced from the formula agreed very well with the observed distributions except at two sections along the casing. These sections consisted of a length equal to twice the internal diameter at the detonator end of the casing, and a much shorter length at the opposite end of the casing, the length of both sections being independent of the type of end restraint (Ref. 2).

Over the first of these two sections, i.e. at the detonator end, there is a progressive increase in speed of projection of the fragments; at the end remote from the detonator there is a progressive reduction towards the end. That some other factor or factors must be taken into account is indicated by the fact that there is disagreement between observed and expected angles of throw even when the lower measured fragment speeds are used in the calculation.

The present series of experiments was designed to study the effect of scaling the dimensions of the casings and has also yielded information on the dispersion of the fragments from the end near the detonator.

2. EXPERIMENTAL METHOD

The lay-out consisted, exactly as previously, of a surround of strawboard packs arranged tangentially along two semi-circular arcs at distances of 3, 5 or 10 ft. from the casing. The casing was suspended in the centre of the lay-out with its axis vertical, detonation of the charge being from the top. Horizontal zones, each representing a 5 degree arc from the centre of the casing were marked on the strawboard packs. Multi-velocity screens connected to an argon lamp chronograph were attached to the front of the packs and were arranged in the various zones.

In order to assist correlation of both speed and direction of flight with the origin of the fragments on the case, the cases were very lightly stamped. Examination of the collected fragments showed that the stamping did not affect the break-up of the casing when the fragmentation was controlled, and it is thought that due to the lightness of the stamping (under 0.005 in.) that it did not have any effect when the casings were naturally fragmented. After detonation the position, mass and depth of penetration of each fragment were recorded together with an associated speed and an estimate of its original position in the casing whenever possible.

The experiments were carried out with scaled casings having inside diameters of $1\frac{1}{4}$ in. and $2\frac{1}{2}$ in. and lengths giving L/D ratios of 0.6, 1.0, 2.0 and 4.0 at each diameter. The wall thickness, thickness of screwed end pieces and fragment length (for controlled fragmentation) were in the ratio of the diameters. The charge weight ratio for all the casings was approximately 0.45, a small difference occurring between the controlled and naturally fragmented casings due to the weight of explosive lost in forming the grooves. Scaled casings having an inside diameter of 5 in. were also prepared, but these charges were too heavy to be fired at Buxton and facilities were not immediately available elsewhere. These charges, therefore, have not yet been fired.

All casings were of mild steel normalized at 850°C and were filled with cast CE/TNT 30/70 with an inset axial CE booster 0.55 in. diameter and 0.45 in. long at one end. At each diameter and each length two casings were naturally fragmented and two others were fragmented with the grooved-charge method of control of the fragmentation. The grooved charges were produced by casting the charges in fluted rubber liners in a mould, peeling off the rubber when the explosive had set and then inserting the charges into the particular casings (Ref. 3).

A summary of all the experiments, with a full list of dimensions of the casings is given in Table 6 (Appendix).

3. RESULTS

The data relating to spatial distribution are shown in Tables 6 to 67 (Appendix). The data can be represented by weight histograms showing percentage weight of fragments collected against angular zone measured from the centre of the casing (Figs. 1 and 2). From the histograms a comparison can easily be made between the results for controlled and naturally fragmented casings.

It would seem that for all series except Nos. 1 and 2 the peak of the histogram is more sharply defined and greater in magnitude with natural fragmentation. It is impossible, however, to establish the point of projection of the majority of the individual fragments in the series with natural fragmentation, and this is essential for a precise study of dispersion. To compare the dispersion angles of the fragments from casings with controlled and natural fragmentation a method has already been evolved (Ref. 1) to obtain estimated values of the dispersion angles from all parts of the casing for natural fragmentation. Cumulative curves showing the percentage weight of fragmented casing collected forward of angle $\underline{\theta}$ are shown in Figs. 3 and 4 for natural fragmentation. To compare with controlled fragmentation each casing may be regarded as comprising the same number of sections marked A, B .... from the detonator end as the corresponding controlled casings, and from the curves estimates of the dispersion angles relative to the centre of the case corresponding with each row can be deduced. From the geometry of the casing and the collecting arc, a correction must then be applied to each row to obtain the true dispersion angle with respect to the point of projection. This was unnecessary in Series 1 as most of the fragments were the whole length of the casing and the remainder were easily identified. With controlled fragmentation the dispersion angle with respect to the point of projection was measured directly as the fragments were easily identified.

Similarly the speed of fragments with respect to the originating row (A,B, ...) for the series with controlled fragmentation was measured directly, but the speeds so obtained were corrected to give the fragment speed on leaving the casing. The corrected speeds were then plotted and a smooth curve drawn through the points; these smooth curves are shown in Fig. 5 and the speeds are given in Table 1.

TABLE 1

Comparison of fragment speeds, controlled fragmentation. Smoothed speeds of fragments corrected to give instantaneous speed at the casing, ft/sec.

Section	Series 2	Series 4	Series 6	Series 8	Series 10	Series 12	Series 14	Series 16
A	3270	3480	3630	3580	3250	3580	3640	3500
B	3380	3740	3830	3900	3420	3870	3900	3770
C	3400	3880	4000	4080	3240	4010	4060	3980
D		3910	4140	4220		4070	4180	4140
E		3890	4260	4320		4030	4290	4270
F			4350	4410			4370	4390
G			4400	4480			4430	4480
H			4420	4560			4460	4540
I			4420	4620			4470	4570
J			4380	4670			4440	4580
K				4690				4580
L				4710				4580
M				4710				4580
N				4710				4580
O				4700				4580
P				4690				4580
Q				4670				4580
R				4650				4580
S				4600				
T				4530				

With the naturally fragmented casings the speeds relative to the centre of the casing were measured for the various dispersion zones and the probable source of the fragments (sections A, B, etc.) on the casing was deduced by the method previously discussed: the speeds from the different sections could then be deduced. Corrected speeds could not be obtained for this series since very few fragments could be associated with a particular speed measurement.

Estimates of speeds associated with the sections, taken from the smoothed curves shown in Fig. 6, are given in Table 2.

TABLE 2

Comparison of fragment speeds, natural fragmentation. Deduced average speeds over a distance of 3-5 ft. from the casing, ft/sec.

Section	Series 1	Series 3	Series 5	Series 7	Series 9	Series 11	Series 13
A	3160	4040	4350	4280	3650	4100	4090
B	3540	4080	4500	4390	3650	4200	4300
C	3390	4080	4560	4460	3640	4200	4430
D		4090	4570	4510		4180	4510
E		4070	4580	4550		4170	4570
F			4590	4580			4610
G			4600	4630			4640
H			4600	4660			4640
I			4610	4680			4620
J			4600	4710			4590
K				4720			
L				4730			
M				4750			
N				4760			
O				4770			
P				4770			
Q				4770			
R				4760			
S				4760			
T				4740			

Expected dispersion angles for each row of fragments along the casings were calculated by substituting the smoothed speeds in formula 1 and these are compared in Table 3 with the observed angles for the controlled series and in Table 4 with the extrapolated angles for the natural series: they are shown graphically in Figs. 7, 8, and 9, 10 respectively.

Difficulty was experienced in the series with controlled fragmentation in obtaining the individual speeds of fragments from the last few rows remote from the detonator. The fragments from the rows approaching the remote end are thrown forward at progressively smaller angles and strike the velocity screens almost at the same level. Too much reliance cannot therefore be placed upon the speeds of fragments associated with each of the last three rows or upon the expected angle of projection of these fragments for the longest casings.

TABLE 3

Comparison of observed and expected angles, Series 2, 4, 6, 8, 10, 12, 14, 16
Controlled fragmentation

Section	Series 2		Series 4		Series 6		Series 8		Series 10		Series 12		Series 14		Series 16	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
A	91.0	90.7	91.1	89.0	91.1	88.4	91.1	88.1	90.9	90.1	91.0	88.1	91.0	87.3	90.9	87.0
B	92.5	90.5	92.8	89.7	92.9	89.1	92.9	88.4	92.3	91.0	92.7	90.0	92.7	89.0	92.6	89.1
C	93.3	90.0	93.8	92.0	93.9	91.6	94.0	90.6	93.0	89.9	93.7	91.9	93.8	91.1	93.7	90.5
D			94.2	93.2	94.5	92.9	94.6	91.7			94.3	93.2	94.4	92.3	94.3	92.1
E			94.4	92.4	94.8	93.9	94.9	92.8			94.5	92.1	94.8	93.6	94.8	93.1
F					95.1	94.5	95.2	93.8					95.0	94.2	95.1	94.0
G					95.2	94.8	95.3	94.3					95.2	94.9	95.3	94.9
H					95.3	94.4	95.5	94.9					95.3	94.9	95.4	95.4
I					95.4	94.8	95.6	95.3					95.4	94.6	95.5	95.6
J					95.3	93.3	95.7	95.5					95.4	92.8	95.5	95.7
K							95.7	95.9							95.6	96.1
L							95.8	95.7							95.6	96.0
M							95.8	95.7							95.6	95.9
N							95.8	95.7							95.6	95.8
O							95.8	95.7							95.6	95.9
P							95.8	95.9							95.6	96.0
Q							95.8	95.8							95.6	96.1
R							95.8	95.6							95.6	95.8
S							95.7	95.5							95.6	95.9
T							95.6	94.1							95.6	93.8

TABLE 4

Comparison of observed and expected angles, Series 1, 3, 5, 7, 9, 11, 13
Natural fragmentation

Section	Series 1		Series 3		Series 5		Series 7		Series 9		Series 11		Series 13	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
A	91.0	91.0	91.2	90.3	91.3	91.0	91.3	91.2	90.6	90.1	91.1	89.8	91.1	88.7
B	92.6	90.5	93.1	91.1	93.4	92.8	93.3	91.2	92.5	90.1	92.9	91.9	93.0	90.8
C	93.3	89.5	94.0	91.1	94.4	93.4	94.3	92.8	93.4	90.1	93.9	92.5	94.1	91.9
D			94.4	91.3	95.0	93.4	94.9	93.4			94.4	92.5	94.7	92.5
E			94.6	91.6	95.2	93.3	95.1	93.9			94.6	92.4	95.1	92.9
F					95.4	93.1	95.4	94.2					95.3	93.2
G					95.5	93.1	95.5	94.6					95.5	93.4
H					95.5	92.9	95.6	95.0					95.5	93.6
I					95.6	92.9	95.7	95.1					95.6	93.6
J					95.6	93.7	95.7	95.4					95.6	94.0
K							95.8	95.4						
L							95.8	95.4						
M							95.8	95.5						
N							95.9	95.5						
O							95.9	95.4						
P							95.9	95.5						
Q							95.9	95.3						
R							95.9	95.3						
S							95.9	95.7						
T							95.9	95.9						

4. DISCUSSION

In the following discussion $\underline{L}$ represents the total fragmented length of the casing, $\underline{l}$ the distance from the detonator end to some position along the casing and $\underline{D}$ the internal diameter of the case.

Taylor (Ref. 6) has shown that the angle of projection of a fragment from a point some distance along an infinitely long cylindrical casing is given by:-

$$\sin \frac{\theta}{2} = \frac{V}{2U} \qquad (2)$$

where $\underline{V}$ is the fragment velocity, $\underline{U}$ is the detonation velocity and $\underline{\theta}$ is the angle of coning. This formula was modified during the first stage of this work (Ref. 1) to take into account the shape of the casing and the angle at which it is struck by the detonation wave (equation 1).

Even when these factors and the observed variation in fragment speed from the different parts of the casing have been taken into account, there is still a divergence between the observed angles of throw and those calculated from equation 1 over the length of the case represented by values of l/D between 0 and 2 and also at the end remote from the detonator. For the remainder of the casing, provided L/D exceeds 2, the observed and expected angles agree to within $\frac{1}{2}^{o}$: if L/D is less than 2 there is no agreement between the observed and expected angles.

The speed of projection of fragments from casings has been discussed by Gurney (Ref. 4). He assumes for simplicity that the initial speed of fragments from all parts of the case is the same and hence the speed obtained from his formula is a mean. The formula contains an empirical constant E which is different for each explosive and must be determined by experiment. In the report quoted, only the value for cast TNT is given: it is stated that other values were to be found.

Analysis of the early results (Refs. 1 and 2) and the present results shows that there is a progressive increase in the speed of projection of the fragments at the detonator end of the casing, over a region extending from the end up to a distance equal to twice the internal diameter of the case (l/D equal to 2). At the end remote from the detonator there is a progressive reduction in speed over a much shorter length of the case. The lower speed of projection at the detonator end has been found to be more than 20% below the average maximum speed of projection of the fragments from the centre of the case. Over the length of the case between l/D equal to 2 and the last two rows of fragments the speed of projection has been found to be constant.

Fig. 7(d) shows the angles at which fragments are thrown from a casing with an L/D ratio greater than 2. When the observed angles are plotted against log l/D, shown in Fig. 12(d), three discontinuities are seen in the line.

The variation in fragment dispersion from different portions of the case is to be expected from a consideration of the geometry of the expanding detonation wave and the manner in which it impinges on the wall of the case. With initiation from a point at the centre of one end of a long case the wave becomes approximately hemispherical before reaching the wall: it then impinges normally. During this period detonation in the charge is building up and may not be fully established: the end of the casing is also beginning to move and is absorbing and releasing some energy. Thus the fragments from the first portion of the wall are not only subjected to a weaker blow but are also restrained differently at the two ends and they tend to be projected backwards: their motion is affected considerably by the end restraint.

After the first few rows of fragments have been formed the end restraint can no longer have any effect, but the wave is still not stable in shape. If unit time is taken to be the time required for the (spherical) detonation wave to expand a distance equal to the radius of the tube, it is found that after first impact on the walls the lengths of tube affected by the wave in successive unit intervals of time are 0.866D, 0.548D, 0.523D, 0.512D, and when the wave becomes essentially plane, 0.5D. Thus initially the rate of fracture of the case is continually decreasing and the weight of charge exploded relative to length of case fractured is increasing: the angle at which the wave approaches the wall is also varying.

It can be seen from the figures given above that conditions should become approximately stable when the wave has travelled a distance along the casing of approximately two diameters. Thereafter, fragmentation should remain constant indefinitely almost up to the remote end. Here, there will again be differential restraint at the ends of the incipient fragments and there will be some release of energy from the end.

Starting from the detonator end, the dispersion of the fragments from the first short length of case, examined previously, (Ref. 2) is affected by the end restraint. The effect of end restraint found to extend for a distance of approximately 0.4 = l/D for all casings used in the present series but the angle of throw of fragments from this part of the case varies with the L/D ratio. This variation with the L/D ratio for the particular diameters used is shown in Fig. 14. It is not possible to establish with certainty from the results that the angle of throw of fragments from the first row tends to become constant when the L/D ratio exceeds 4 for a particular diameter, but from the shape of the curve it would appear that any further variation in angle with increasing length of case would be small.

The second fragmentation zone extends from l/D = 0.4 to 2. The observed angle of projection of fragments is plotted against log l/D for all casings in this series in Fig. 13 and a mean of the results for the previous series (Ref. 2) is also included. In Figs. 11 to 13 the curves for the individual series are plotted, together with the expected angles from formula 1 and those which would be obtained by using the Gurney calculated fragment speed.

The two main points of interest are as follows:

1. The slope of the line is constant within experimental error for all casings in the present series and for all casings used in the previous series. The charge/weight ratio was the same in both series but the explosive was different. The mean slope of the lines for the previous series with RDX/TNT 55/45 filling is 8.64 and the mean slope for the present series with CE/TNT 30/70 filling is 8.94. This only affects the angle of throw by 12 minutes.

2. The position of the line is determined by the L/D ratio of the case and is independent of the actual diameter. For a given diameter the angle of throw of a particular fragment at a specified distance from the detonator tends to decrease as the L/D ratio of the case is increased. It is not certain from these results whether the position of the line representing L/D = 7 for the previous work indicates a continued reduction of the angle of throw as the L/D ratio increases or whether it is due to the different explosive used.

Equations have been deduced for all lines by means of the method of least squares: they are given in Table 5. For the column headed "mean", an average slope has been calculated using all the lines and the value of the constant in the equation is the average value of the constant for each pair having the same L/D ratio but different diameters.

TABLE 5

Relationship between dispersion angle and point of origin of fragment on the case for values of l/D up to 2

L/D	1¼ in. dia. casings	2½ in. dia. casings	Explosive	Mean
1	$Y = 9.50 \log_{10} X + 94.70$ $84.0^\circ = \tan^{-1} 9.5$	$Y = 8.90 \log_{10} X + 94.60$ $83.6^\circ = \tan^{-1} 8.90$	CE/TNT 30/70	$Y = 8.89 \log_{10} X + 94.65$
2	$Y = 8.66 \log_{10} X + 94.06$ $83.4^\circ = \tan^{-1} 8.66$	$Y = 8.77 \log_{10} X + 93.77$ $83.5^\circ = \tan^{-1} 8.77$	CE/TNT 30/70	$Y = 8.89 \log_{10} X + 93.92$
4	$Y = 8.90 \log_{10} X + 93.18$ $83.6^\circ = \tan^{-1} 8.90$	$Y = 8.88 \log_{10} X + 93.56$ $83.5^\circ = \tan^{-1} 8.77$	CE/TNT 30/70	$Y = 8.89 \log_{10} X + 93.37$
7	$Y = 8.64 \log_{10} X + 92.46$ $83.4^\circ = \tan^{-1} 8.64$ (Mean of experiments reported in Ref. 2)		RDX/TNT 55/45	

where Y = angle of throw of fragment
X = value of l/D at the particular part of the case

When the L/D ratio of the casing exceeds 2 the angle of projection of the fragments reaches a constant value at the point l/D = 2 and this marks the beginning of the third fragmentation zone present in long casings. It extends almost up to the end remote from the detonator, however long the casing may be. In this zone both the shape of the detonation wave and the mechanism of fracture of the case have become stable.

At the end remote from the detonator there is a short fourth fragmentation zone arising as a result of the end effect. The stable speed of projection in the third zone is progressively reduced towards the end. The results do not permit a precise estimate of the length of this zone but it appears to be not greater than one half the diameter of the case.

Thus, for cases with a L/D ratio not greater than 0.6 the fragmentation is entirely governed by the combined end effects, and the fragments are projected approximately normal to the case with little more than 1° scatter.

When the L/D ratio lies between 0.6 and 2.0 the fragment dispersion is according to the first, second and fourth zones. The stable conditions of the third zone are not attained and the length of case within the second zone will depend on the L/D ratio.

For long casings, the first and fourth zones are negligible and the fragment pattern may be obtained by consideration of the second and third zones. The fragment speed calculated from the Gurney formula is substituted in equation 2 and this immediately gives the angle of projection throughout the third zone. This angle is then plotted, and from a point in the case where l/D = 2 a line is drawn with the mean slope indicated in the empirical equation given in Table 5. The fragment dispersion along the second zone is then defined.

The fragment dispersion predicted by this method for the casings used in this series are shown in Figs. 11 to 13, together with the dispersion predicted by the Gurney formula alone and by using equation 1. It can be seen that, using the method described above, the difference between observed and calculated angles of throw is little more than 1 degree at any point.

It must be remembered, however, that these equations have been derived solely from experiments with cylindrical casings having a constant E/C ratio. The effects of shape of casing and E/C ratio have yet to be examined. Some American results (Ref. 5) with cylindrical casings of different metals containing different explosives at different loading densities indicate that similar curves were obtained for the relationship between fragment speed and distance from point of initial expansion. The values of l/D at the point of change-over from unstable to stable conditions appeared to vary from $1\frac{1}{2}$ to $2\frac{1}{2}$, with an average value nearer the lower figure.

5. CONCLUSIONS

1. The fragmentation of scaled cylindrical casings of two different diameters having a constant charge/weight ratio but different L/D ratios has been examined. The fragment speeds and dispersion angles from different parts of the cases were found to scale with the linear dimensions.

2. In the fragmentation of long cylindrical casings four zones have been observed.

(i) Up to a distance 0.4D from the detonator end the fragmentation is affected by the end confinement of the case and also by the L/D ratio for values less than 4.

(ii) From this zone and up to a distance of 2D the dispersion may be described by an empirical equation.

(iii) The third zone begins at a distance of 2D from the detonator end and extends up to a point approximately 0.5D from the remote end, however long the case may be. In this zone stable conditions of detonation wave and fracture of case are attained. All fragments are projected at the angle deduced from the simple Taylor formula using a fragment speed calculated according to Gurney.

(iv) In the final zone up to the remote end the dispersion is again affected by end confinement.

3. If the L/D ratio of the case is less than 2 the third (stable) fragmentation zone does not occur and the second zone may be shortened. If the ratio is less than 0.6 all fragments are projected approximately normal to the case, with only about 1° scatter.

4. Similar results are obtained with both controlled and natural fragmentation. With natural fragmentation there appears to be more scatter about the mean dispersion angle from a particular part of the case than with controlled fragmentation. Owing to ease and certainty of identification of fragments, however, the data with controlled fragmentation are more reliable than those with natural fragmentation.

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APPENDIX

The Appendix contains the full experimental data from Series 1 to 16. Tables 6 and 7 give collected results and summaries and descriptions of experiments. Corresponding with each series there are four Tables; the first gives raw data classified into shots, collecting arcs and dispersion zones. Numbers and weights of fragments are shown; in the number column, the first number represents the total number of fragments collected and the second bracketed number represents the number of holes made in the strawboard packs. The second Table in each series gives numbers and weights of fragments corrected to 360 degrees from that part of the casing which lies between the end plugs. The third and fourth Tables show averages over collecting arcs and experiments.

TABLE 6

Summary of Experiments

Series	Number of experiments	Details of casings: Total length, in.	Fragmented length, in.	Thickness of wall in.	Shape	Internal diameter, in.	Fragment length	Fragmentation	Collecting medium	Number of rows of fragments	Total number of fragments	L/D
1	3	1.25	0.75	0.125	Cylinder	1.25		Natural	Strawboard			0.60
2	2	"	"	"	"	"	0.25	Controlled	"	3	60	0.60
3	2	1.75	1.25	"	"	"		Natural	"			1.00
4	2	"	"	"	"	"	0.25	Controlled	"	5	100	1.00
5	2	3.00	2.50	"	"	"		Natural	"			2.00
6	2	"	"	"	"	"	0.25	Controlled	"	10	200	2.00
7	2	5.50	5.00	"	"	"		Natural	"			4.00
8	2	"	"	"	"	"	0.25	Controlled	"	20	400	4.00
9	2	2.50	1.50	0.25	"	2.50		Natural	"			0.60
10	2	"	"	"	"	"	0.50	Controlled	"	3	60	0.60
11	2	3.50	2.50	"	"	"		Natural	"			1.00
12	2	"	"	"	"	"	0.50	Controlled	"	5	100	1.00
13	2	6.00	5.00	"	"	"		Natural	"			2.00
14	2	"	"	"	"	"	0.50	Controlled	"	10	200	2.00
15	Not used	11.00	10.00	"	"	"		Natural	"			4.00
16	2	"	"	"	"	"	0.50	Controlled	"	20	400	4.00

TABLE I

Summary of Results

Series	Expt.	Weight of casing, g.		Weight of explosive, g.	Fragments recovered							
		Total	Fragmented part		Total		5 ft. Packs		3 ft. Packs		10 ft. Packs	
					Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
1	A	68	52	24.5	77	45.58	34	22.34	43	23.24		
	B	67	52	24.0	69	46.27	38	23.59	31	22.68		
2	A	68	52	22.0	54	43.29	29	23.13	25	20.16		
	B	68	52	21.5	58	46.48	25	21.34	33	25.14		
3	A	114.5	86.0	40.0	97	74.73	49.0	38.68	48	36.05		
	B	102.0	86.0	40.0	96	54.40	48	27.92	48	26.48		
	C	100.0	86.0	39.0	95	70.36	51	37.60	44	32.76		
4	A	101.0	86	36.0	99	74.46	52	39.74	47	34.72		
	B	101.0	86	37.0	95	75.95	49	38.81	46	37.14		
5	A	187.5	173	77.0	193	108.18	96	60.73	97	47.45		
	B	188.5	173	79.0	200	123.73	104	69.06	96	54.67		
6	A	188.0	173	72.5	194	150.40	103	79.54	91	70.86		
	B	187.5	173	73.0	180	131.78	78	60.43	102	71.35		
7	A	360	346	155.5	483	233.77	251	127.65	232	106.12		
	B	360.5	346	156.0	430	242.91	242	134.48	188	108.43		
8	A	359.0	346	149.0	332	260.67	183	146.96	149	113.71		
	B	359.0	346	152.0	374	279.10	197	146.69	177	132.41		
9	A	523	415	183	155	356.01	92	199.04	63	156.97		
	B	542	415	192	156	386.18	73	202.06	83	184.12		
10	A	520	415	175	80	324.83	47	162.67	33	162.16		
	B	533	415	178	72	324.99	44	170.02	28	154.97		
11	A	809	691	322	220	456.51	122	241.03	98	215.48		
	B	807	691	324	254	441.82	138	238.50	116	203.32		
12	A	804	691	305	92	352.08	52	175.46	40	176.62		
	B	804	691	303	97	367.76	56	238.12	41	129.64		
13	A	1478	1382	634	437	866.42	301	633.32			136	233.10
	B	1498	1382	635	478	860.79	343	635.83			135	224.96
14	A	1495	1382	581	171	907.50	108	678.84			63	228.66
	B	1497	1382	582	165	1035.93	117	739.89			48	296.04
16	A	2934	2764	1176	206	1285.26	147	910.76			59	374.50
	B	2906	2764	1169	214	1361.44	155	978.42			59	383.02

TABLE 8

Dispersion of fragments, Series 1 - Numbers and weights of fragments

Experiment	1A				1B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
- 60								
60- 65								
65- 70								
70- 75								
75- 80	1 (1)	1.15						
80- 85							1 (1)	1.05
85- 90	27 (17)	16.61	9 (5)	5.24	7 (5)	5.97	31 (22)	20.99
90- 95	15 (8)	6.33	25 (17)	17.10	27 (22)	16.60	5 (3)	1.55
95-100	1 (1)	0.30						
100-105							1 (1)	0.15
105-110								
110-115	1 (1)	1.10						
115-120					1 (1)	0.11		
120								
Sum	43 (26)	23.24	34 (22)	22.34	30 (27)	22.57	37 (26)	23.59
Dust		0.39		0.38		0.79		0.82
Total		23.63		22.72		23.36		24.41
Estimated weight of fragmented part, g.	52.0				52.0			

TABLE 9

Dispersion of fragments, Series 1 - Numbers and weights corrected to 360°

Experiment	1A				1B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85							2 (2)	4.45
85- 90	59 (37)	71.47	21 (11)	23.46	16 (11)	26.45	66 (47)	88.98
90- 95	33 (18)	27.24	57 (39)	76.54	60 (49)	73.55	11 (64)	6.57
95-100	2 (2)	1.29						

TABLE 10

Dispersion of fragments, Series 1 - Averages over collecting arcs

Experiment	1A		1B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85			1 (1)	2.23
85- 90	40 (24)	47.46	41 (29)	57.71
90- 95	45 (29)	51.89	36 (56)	40.06
95-100	1 (1)	0.65		

TABLE 11

Dispersion of fragments, Series 1 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85			1 (1)	2.23
85- 90	38 (24)	48.96	44 (29)	56.22
90- 95	47 (34)	50.39	34 (52)	41.55
95-100	1 (1)	0.65		

TABLE 12

Dispersion of fragments, Series 2 - Numbers and weights of fragments

Experiment	2A								2B							
Collecting Arc	3-ft.			5-ft.					3-ft.				5-ft.			
Zone of dispersion, degrees	Number		Wgt., g.	Number		Wgt., g.			Number		Wgt., g.		Number		Wgt., g.	
- 60																
60- 65																
65- 70																
70- 75																
75- 80																
80- 85																
85- 90	5	(5)	3.64	19	(19)	15.09			17	(17)	13.54		3	(3)	2.21	
90- 95	20	(20)	16.52	10	(10)	8.04			16	(15)	11.60		22	(21)	19.13	
95-100																
100-105																
105-110																
110-115																
115-120																
120																
Sum	25	(25)	20.16	29	(29)	23.13			33	(31)	25.14		25	(24)	21.34	
Dust			0.14			0.16					0.11				0.09	
Total			20.30			23.29					25.25				21.43	
Estimated weight of fragmented part, g.	52								52							

TABLE 13

Dispersion of fragments, Series 2 - Numbers and weights corrected to 360°

Experiment	2A						2B					
Collecting Arc	3-ft.			5-ft.			3-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %
85-90	13	(13)	18.06	42	(42)	65.24	35	(35)	53.86	7	(7)	10.36
90-95	51	(51)	81.94	22	(22)	34.76	33	(31)	46.14	53	(51)	89.64

TABLE 14

Dispersion of fragments, Series 2 - Averages over collecting arcs

Experiment	2A			2B		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
85-90	28	(28)	41.65	21	(21)	32.11
90-95	37	(37)	58.35	43	(41)	67.89

TABLE 15

Dispersion of fragments, Series 2 - Averages over experiments

Collecting Arc	3-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
85-90	24	(24)	35.96	25	(25)	37.80
90-95	42	(41)	64.04	38	(37)	62.20

TABLE 16

Dispersion of fragments, Series 3 - Numbers and weights of fragments

Experiment	3A				3B				3C			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60												
60- 65												
65- 70												
70- 75												
75- 80												
80- 85												
85- 90	15 (15)	8.74	21 (19)	13.14	4 (2)	1.57	10 (8)	4.94	2 (2)	0.60	3 (2)	1.72
90- 95	33 (20)	27.31	28 (24)	25.54	43 (32)	24.77	38 (22)	22.98	42 (27)	32.16	47 (32)	35.56
95-100					1 (1)	0.14					1 (1)	0.32
100-105											1 (1)	0.11
105-110			1 (1)	0.10								
110-115	1 (1)	0.10										
115-120									1 (1)	0.14		
120												
Sum	48 (35)	36.05	49 (43)	38.68	48 (35)	26.48	48 (30)	27.92	44 (29)	32.76	51 (35)	37.60
Dust		2.52		2.72		2.28		2.47		1.87		2.16
Total		38.57		41.40		28.76		30.39		34.63		39.76
Estimated weight of fragmented part, g.	86.0				86.0				86.0			

TABLE 17

Dispersion of fragments, Series 3 - Numbers and weights corrected to 360°

Experiment	3A				3B				3C			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
85-90	33 (33)	24.24	44 (39)	33.97	12 (6)	5.93	28 (22)	17.69	5 (5)	1.83	6 (4)	4.57
90-95	74 (45)	75.76	58 (50)	66.03	129 (96)	93.54	108 (62)	82.31	104 (67)	98.17	102 (69)	94.57
95-100					3 (3)	0.53					2 (2)	0.86

TABLE 18

Dispersion of fragments, Series 3
Averages over collecting arcs

Experiment	3A		3B		3C	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
85- 90	39 (36)	29.10	20 (14)	11.81	6 (5)	3.20
90- 95	66 (48)	70.90	118 (79)	87.93	103 (68)	96.37
95-100				0.26	1 (1)	0.43

TABLE 19

Dispersion of fragments, Series 3
Averages over experiments

Collecting arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
85- 90	17 (15)	10.67	26 (22)	18.74
90- 95	102 (69)	89.16	89 (60)	80.97
95-100	1 (1)	0.17	1 (1)	0.29

TABLE 20

Dispersion of fragments, Series 4 - Numbers and weights of fragments

Experiment	4A						4B					
Collecting Arc	3-ft.			5-ft.			3-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., g.	Number		Wgt., g.	Number		Wgt., g.	Number		Wgt., g.
60												
60- 65												
65- 70												
70- 75												
75- 80												
80- 85												
85- 90	19	(19)	15.85	20	(20)	15.92	15	(15)	13.10	14	(14)	11.45
90- 95	28	(28)	18.87	31	(31)	23.07	31	(31)	24.04	34	(33)	26.79
95-100				1	(1)	0.75				1	(1)	0.57
100-105							1	(1)	0.24			
105-110												
110-115												
115-120												
120												
Sum	47	(47)	34.72	52	(52)	39.74	46	(46)	37.14	49	(48)	38.81
Dust			0.49			0.56			0.43			0.44
Total			35.21			40.30			37.81			39.25
Estimated weight of fragmented part, g.	86.0						86.0					

TABLE 21

Dispersion of fragments, Series 4 - Numbers and weights corrected to 360°

Experiment	4A						4B					
Collecting Arc	3-ft.			5-ft.			3-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %
85- 90	46	(46)	45.65	43	(43)	40.06	34	(34)	35.27	31	(31)	29.50
90- 95	68	(68)	54.35	66	(66)	58.05	71	(71)	64.73	75	(72)	69.03
95-100				2	(2)	1.89				2	(2)	1.47

TABLE 22

Dispersion of fragments, Series 4 - Averages over collecting arcs

Experiment	4A			4B		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
85- 90	45	(45)	42.86	33	(33)	32.39
90- 95	67	(67)	56.20	73	(72)	66.88
95-100	1	(1)	0.94	1	(1)	0.73

TABLE 23

Dispersion of fragments, Series 4 - Averages over experiments

Collecting Arc	3-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
85- 90	40	(40)	40.46	37	(37)	34.78
90- 95	70	(70)	59.54	72	(69)	63.34
95-100				2	(2)	1.68

TABLE 24

Dispersion of fragments, Series 5 - Numbers and weights of fragments

Experiment	5A				5B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85			1 (1)	0.48				
85- 90	7 (7)	3.57	10 (10)	3.60	6 (6)	1.67	4 (3)	2.15
90- 95	84 (46)	41.79	82 (52)	56.33	81 (43)	47.25	93 (51)	62.83
95-100	6 (5)	2.09	3 (3)	0.32	9 (7)	5.75	7 (5)	4.08
110-105								
105-110								
110-115								
115-120								
-120								
Sum	97 (58)	47.45	96 (66)	60.73	96 (56)	54.67	104 (59)	69.06
Dust		2.94		3.76		3.97		5.03
Total		50.39		64.49		58.64		74.09
Estimated weight of fragmented part, g.	173				173			

TABLE 25

Dispersion of fragments, Series 5 - Numbers and weights corrected to 360°

Experiment	5A				5B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85			3 (3)	0.79				
85- 90	24 (24)	7.52	27 (27)	5.93	18 (18)	3.05	9 (7)	3.11
90- 95	288 (158)	88.07	220 (139)	92.75	239 (127)	86.42	217 (119)	90.98
95-100	21 (17)	4.41	8 (8)	0.53	27 (21)	10.53	16 (12)	5.91
100-105								

TABLE 26

Dispersion of fragments, Series 5 - Averages over collecting arcs

Experiment	5A		5B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	2 (2)	0.40		
85- 90	26 (26)	6.72	14 (13)	3.08
90- 95	254 (149)	90.41	228 (123)	88.70
95-100	15 (13)	2.47	22 (17)	8.22
100-105				

TABLE 27

Dispersion of fragments, Series 5 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85			2 (2)	0.40
85- 90	21 (21)	5.28	18 (17)	4.52
90- 95	264 (143)	87.25	209 (129)	91.86
95-100	24 (19)	7.47	12 (10)	3.22
100-105				

TABLE 28

Dispersion of fragments, Series 6 - Numbers and weights of fragments

Experiment	6A				6B			
Collecting Arc	3-ft		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85	2 (2)	1.78	1 (1)	0.20				
85- 90	22 (22)	18.20	22 (22)	18.84	20 (20)	16.05	17 (17)	14.40
90- 95	46 (46)	35.46	46 (46)	36.55	57 (57)	38.56	38 (38)	28.94
95-100	21 (21)	15.42	34 (34)	23.95	25 (24)	16.74	23 (23)	17.09
100-105								
105-110								
110-115								
115-120								
120								
Sum	91 (91)	70.86	103 (103)	79.54	102 (101)	71.35	78 (78)	60.43
Dust		0.57		0.63		1.06		0.89
Total		71.43		80.17		72.41		61.32
Estimated weight of fragmented part, g.	173				173			

TABLE 29

Dispersion of fragments, Series 6 - Numbers and weights corrected to 360°

Experiment	6A				6B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85	5 (5)	2.51	2 (2)	0.25				
85- 90	53 (53)	25.68	47 (47)	23.69	48 (48)	22.49	50 (50)	23.83
90- 95	111 (111)	50.04	99 (99)	45.95	136 (136)	54.04	107 (107)	47.89
95-100	51 (51)	21.77	73 (73)	30.11	60 (57)	23.47	65 (65)	28.28

TABLE 30

Dispersion of fragments, Series 6 - Averages over collecting arcs

Experiment	6A		6B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	4 (4)	1.38		
85- 90	50 (50)	24.68	49 (49)	23.16
90- 95	105 (105)	48.00	122 (122)	50.96
95-100	62 (62)	25.94	63 (61)	25.88

TABLE 31

Dispersion of fragments, Series 6 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	3 (3)	1.25	1 (1)	0.13
85- 90	51 (51)	24.09	49 (49)	23.76
90- 95	124 (124)	52.04	103 (103)	46.92
95-100	56 (54)	22.62	69 (69)	29.19

TABLE 32

Dispersion of fragments, Series 7 - Numbers and weights of fragments

Experiment	7A				7B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85								
85- 90	27 (17)	10.33	24 (19)	9.36	29 (19)	15.04	21 (14)	12.66
90- 95	94 (33)	42.00	103 (50)	54.77	62 (25)	30.14	76 (52)	43.56
95-100	111 (43)	53.79	124 (58)	63.52	96 (34)	63.15	146 (65)	78.26
100-105					1 (1)	0.10		
105-110								
110-115								
115-120								
120								
Sum	232 (93)	106.12	251 (127)	127.65	188 (79)	108.43	243 (131)	134.48
Dust		8.64		10.36		9.82		12.18
Total		114.76		138.01		118.25		146.66
Estimated weight of fragmented part, g.	346				346			

TABLE 33

Dispersion of fragments, Series 7 - Numbers and weights corrected to 360°

Experiment	7A				7B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
85- 90	81 (51)	9.73	60 (48)	7.33	85 (56)	13.87	50 (33)	9.41
90- 95	283 (99)	39.58	259 (126)	42.91	181 (73)	27.80	179 (123)	32.39
95-100	335 (130)	50.69	312 (146)	49.76	281 (99)	58.24	342 (153)	58.20
100-105					3 (3)	0.09		

TABLE 34

Dispersion of fragments, Series 7 - Averages over collecting arcs

Experiment	7A		7B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
85- 90	71 (50)	8.53	68 (45)	11.64
90- 95	271 (113)	41.24	180 (98)	30.09
95-100	324 (138)	50.23	303 (126)	58.22
100-105			2 (2)	0.05

TABLE 35

Dispersion of fragments, Series 7 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
85- 90	83 (54)	11.80	55 (41)	8.37
90- 95	232 (86)	33.69	219 (125)	37.65
95-100	308 (115)	54.47	327 (150)	53.98
100-105	2 (2)	0.04		

TABLE 36

Dispersion of fragments, Series 8 - Numbers and weights of fragments

Experiment	8A				8B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85	6 (6)	5.17	2 (2)	1.63	11 (11)	9.98	3 (3)	2.53
85- 90	28 (28)	22.57	32 (32)	26.06	24 (24)	19.11	33 (33)	26.39
90- 95	42 (41)	35.07	58 (58)	42.25	51 (51)	38.40	64 (64)	48.18
95-100	73 (71)	50.90	91 (89)	77.02	90 (90)	64.19	97 (94)	69.59
100-105					1 (1)	0.73		
105-110								
110-115								
115-120								
120								
Sum	149 (146)	113.71	183 (181)	146.96	177 (177)	132.41	197 (194)	146.69
Dust		1.06		1.37		1.31		1.46
Total		114.77		148.33		133.72		148.15
Estimated weight of fragmented part, g.	346				346			

TABLE 37

Dispersion of fragments, Series 8 - Numbers and weights corrected to 360°

Experiment	8A				8B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85	18 (18)	4.55	5 (5)	1.11	28 (28)	7.54	7 (7)	1.72
85- 90	84 (84)	19.85	75 (75)	17.73	62 (62)	14.43	77 (77)	17.99
90- 95	127 (124)	30.84	135 (135)	28.75	132 (132)	29.00	149 (149)	32.84
95-100	220 (214)	44.76	212 (208)	52.41	233 (233)	48.48	227 (220)	47.45
100-105					3 (3)	0.55		

TABLE 38

Dispersion of fragments, Series 8 - Averages over collecting arcs

Experiment	8A		8B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	12 (12)	2.83	18 (18)	4.63
85- 90	80 (80)	18.79	70 (70)	16.21
90- 95	131 (130)	29.79	141 (141)	30.92
95-100	166 (211)	48.59	230 (227)	47.96
100-105			2 (2)	0.28

TABLE 39

Dispersion of fragments, Series 8 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	23 (23)	6.04	6 (6)	1.42
85- 90	73 (73)	17.14	76 (76)	17.86
90- 95	130 (130)	29.92	142 (142)	30.79
95-100	227 (224)	46.62	220 (214)	49.93
100-105	2 (2)	0.28		

TABLE 40

Dispersion of fragments, Series 9 - Numbers and weights of fragments

Experiment	9A				9B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85								
85- 90	56 (28)	142.97	29 (21)	41.90	36 (16)	60.37	37 (20)	106.57
90- 95	7 (3)	14.00	63 (36)	157.14	47 (26)	123.75	36 (22)	95.49
95-100								
100-105								
105-110								
110-115								
115-120								
120								
Sum	63 (31)	156.97	92 (57)	199.04	83 (42)	184.12	73 (42)	202.06
Dust		2.60		2.30		2.98		2.02
Total		159.57		201.34		187.10		204.08
Estimated weight of fragmented part, g.	415				415			

TABLE 41

Dispersion of fragments, Séries 9 - Numbers and weights corrected to 360°

Experiment	9A				9B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
85- 90	146 (73)	91.08	60 (43)	21.05	80 (35)	32.79	75 (41)	52.74
90- 95	18 (8)	8.92	130 (74)	78.95	104 (58)	67.21	73 (45)	47.26

TABLE 42

Dispersion of fragments, Series 9 - Averages over collecting arcs

Experiment	9A		9B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
85-90	103 (58)	56.07	78 (38)	42.77
90-95	74 (41)	43.93	89 (52)	57.23

TABLE 43

Dispersion of fragments, Series 9 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
85-90	113 (54)	61.93	68 (42)	36.89
90-95	61 (33)	38.07	101 (60)	63.11

TABLE 44

Dispersion of fragments, Series 10 - Numbers and weights of fragments

Experiment	10A				10B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85			2 (2)	0.29			1 (1)	7.75
85- 90	12 (12)	54.52	18 (18)	57.17	14 (14)	84.79	18 (18)	55.61
90- 95	20 (20)	107.49	26 (24)	104.96	13 (13)	70.05	24 (24)	106.49
95-100	1 (1)	0.15	1 (1)	0.25	1 (1)	0.13	1 (1)	0.17
100-105								
105-110								
110-115								
115-120	4 (4)	0.47						
125	1 (1)	0.15			1 (1)	0.10		
Sum	33 (33)	162.16	47 (45)	162.67	28 (28)	154.97	44 (44)	170.02
Dust		1.67		1.68		2.29		2.51
Total		163.83		164.35		157.26		172.53
Estimated weight of fragmented part, g.	415				415			

TABLE 45

Dispersion of fragments, Series 10 - Numbers and weights corrected to 360°

Experiment	10A				10B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85			5 (5)	0.18			2 (2)	4.56
85- 90	30 (30)	33.62	47 (47)	35.14	37 (37)	54.71	43 (43)	32.71
90- 95	50 (50)	66.29	66 (61)	64.52	35 (35)	45.20	58 (58)	62.63
95-100	2 (2)	0.09	2 (2)	0.16	2 (2)	0.09	2 (2)	0.10
100-105								

TABLE 46

Dispersion of fragments, Series 10 - Averages over collecting arcs

Experiment	10A		10B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	3 (3)	0.09	1 (1)	2.28
85- 90	39 (39)	34.38	40 (40)	43.71
90- 95	58 (56)	65.41	47 (47)	53.92
95-100	2 (2)	0.12	2 (2)	0.09

TABLE 47

Dispersion of fragments, Series 10 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85			3 (3)	2.37
85- 90	33 (33)	44.17	45 (45)	33.92
90- 95	43 (43)	55.74	62 (60)	63.58
95-100	2 (2)	0.09	2 (2)	0.13

TABLE 48

Dispersion of fragments, Series 11 - Numbers and weights of fragments

Experiment	11A				11B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85	1 (1)	0.15			3 (3)	0.55	1 (1)	0.10
85- 90	21 (21)	36.46	36 (28)	56.35	31 (21)	44.93	18 (16)	22.37
90- 95	74 (38)	178.44	83 (56)	183.37	82 (42)	157.84	119 (72)	216.03
95-100	2 (1)	0.43	2 (2)	1.21				
100-105			1 (1)	0.10				
105-110	1 (1)	0.25			3 (3)	0.34	2 (2)	0.48
110-115	1 (2)	0.40			1 (1)	0.16		
115-120	7 (7)	2.65			1 (1)	0.21		
120	14 (14)	7.31			9 (9)	2.25		
Sum	98 (61)	215.48	122 (87)	241.03	116 (66)	203.32	138 (89)	238.50
Dust		2.35		2.63		2.58		3.15
Total		217.83		243.66		205.80		251.73
Estimated weight of fragmented part, g.	691				691			

TABLE 49

Dispersion of fragments, Series 11 - Numbers and weights corrected to 360°

Experiment	11A				11B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85	3 (3)	.07			10 (10)	.27	3 (3)	0.04
85- 90	67 (67)	16.92	102 (79)	23.38	104 (71)	22.10	49 (44)	9.38
90- 95	235 (121)	82.81	235 (159)	76.08	275 (141)	77.63	327 (198)	90.58
95-100	6 (3)	.20	6 (6)	0.50				
100-105			3 (3)	0.04				

TABLE 50

Dispersion of fragments, Series 11 - Averages over collecting arcs

Experiment	11A		11B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	2 (2)	0.03	7 (7)	0.16
85- 90	85 (73)	20.15	127 (75)	15.74
90- 95	235 (140)	79.45	255 (150)	84.10
95-100	6 (5)	0.35	3 (3)	
100-105	2 (2)	0.02	2 (2)	

TABLE 51

Dispersion of fragments, Series 11 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	7 (7)	0.17	2 (2)	0.02
85- 90	86 (69)	19.51	76 (62)	16.38
90- 95	255 (131)	80.22	281 (179)	83.33
95-100	3 (2)	0.10	3 (3)	0.25
100-105			2 (2)	0.02

TABLE 52

Dispersion of fragments, Series 12 - Numbers and weights of fragments

Experiment	12A				12B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80	1 (1)	0.14	1 (1)	0.16				
80- 85	2 (2)	0.22	6 (5)	1.08	1 (1)	0.18	1 (1)	0.20
85- 90	11 (11)	47.12	14 (14)	61.61	9 (9)	14.52	24 (22)	115.93
90- 95	19 (18)	98.00	27 (27)	112.07	25 (25)	96.78	30 (30)	121.74
95-100	8 (8)	31.28	2 (2)	0.25	5 (5)	12.00	1 (1)	0.25
100-105			3 (3)	0.45	1 (1)	6.16		
105-110	1 (1)	0.25	1 (1)	0.10	2 (2)	0.29		
110-115	1 (1)	0.37						
115-120	2 (2)	0.45			4 (4)	0.82		
120	2 (2)	0.55	3 (3)	0.38	3 (3)	0.65		
Sum	40 (39)	176.62	52 (51)	175.46	41 (41)	129.64	56 (54)	238.12
Dust		4.35		4.32		3.10		5.70
Total		180.97		179.78		132.74		243.82
Estimated weight of fragmented part, g.	691				691			

TABLE 53

Dispersion of fragments, Series 12 - Numbers and weights corrected to 360°

Experiment	12A				12B			
Collecting Arc	3-ft.		5-ft.		3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85	8 (8)	0.12	23 (19)	0.62	5 (5)	0.14	3 (3)	0.09
85- 90	42 (42)	26.68	54 (54)	35.11	47 (47)	11.20	68 (62)	48.68
90- 95	73 (69)	55.49	104 (104)	63.87	130 (130)	74.65	85 (85)	51.12
95-100	31 (31)	17.71	8 (8)	0.14	26 (26)	9.26	3 (3)	0.11
100-105			12 (12)	0.26	5 (5)	4.75		

TABLE 54

Dispersion of fragments, Series 12 - Averages over collecting arcs

Experiment	12A		12B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	16 (14)	0.37	4 (4)	0.12
85_ 90	48 (48)	30.90	58 (55)	29.94
90- 95	89 (87)	59.68	108 (108)	62.88
95-100	20 (20)	8.92	15 (15)	4.68
100-105	6 (6)	0.13	3 (3)	2.38

TABLE 55

Dispersion of fragments, Series 12 - Averages over experiments

Collecting Arc	3-ft.		5-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	7 (7)	0.13	13 (11)	0.36
85- 90	45 (45)	18.94	61 (58)	41.89
90- 95	102 (100)	65.07	95 (95)	57.50
95-100	29 (29)	13.48	6 (6)	0.12
100-105	3 (3)	2.38	6 (6)	0.13

TABLE 56

Dispersion of fragments, Series 13 - Numbers and weights of fragments

Experiment	13A				13B			
Collecting Arc	10 ft.		5 ft.		10 ft.		5 ft.	
Zone of dispersion, degrees	Number	Wgt., g	Number	Wgt., g	Number	Wgt., g	Number	Wgt., g
60								
60- 65								
65- 70								
70- 75								
75- 80			1 (1)	0.14				
80- 85	2 (2)	0.41	9 (8)	1.55	1 (1)	0.12	3 (3)	0.99
85- 90	35 (23)	58.12	63 (54)	99.14	18 (14)	36.55	59 (48)	103.36
90- 95	96 (57)	173.87	128 (80)	313.91	102 (56)	177.08	161 (105)	329.08
95-100	1 (1)	0.39	100 (56)	218.62	14 (11)	11.21	119 (71)	202.20
100-105	2 (2)	0.31	1 (1)	0.10			1 (1)	0.20
105-110	1 (1)	0.17	6 (6)	0.87				
110-115			2 (2)	0.28				
115-120			2 (2)	0.29				
120	2 (2)	0.26	10 (10)	1.58				
Sum	136 (85)	233.10	199 (301)	633.32	135 (82)	224.96	343 (228)	635.83
Dust		1.88		5.12		1.11		3.14
Total		234.98		638.44		226.07		638.97
Estimated weight of fragmented part, g	1382				1382			

TABLE 57

Dispersion of fragments, Series 13 - Numbers and weights corrected to 360°

Experiment	13A				13B			
Collecting Arc	10 ft.		5 ft.		10 ft.		5 ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
80- 85	12 (12)	0.18	19 (17)	0.24	6 (6)	0.05	6 (6)	0.16
85- 90	206 (135)	24.93	136 (117)	15.65	110 (86)	16.26	128 (104)	16.26
90- 95	565 (335)	74.59	277 (173)	49.56	624 (342)	78.72	348 (227)	51.75
95-100	(6) (6)	0.17	216 (121)	34.52	86 (67)	4.98	257 (154)	31.80
100-105	12 (12)	0.13	2 (2)	0.03			2 (2)	0.03

TABLE 58

Dispersion of fragments, Series 13 - Averages over collecting arcs

Experiment	13A		13B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	16 (15)	0.21	6 (6)	0.11
85- 90	171 (126)	20.29	119 (95)	16.25
90- 95	421 (254)	62.07	486 (285)	65.24
95-100	111 (64)	17.35	172 (111)	18.39
100-105	7 (7)	0.08	1 (1)	0.01

TABLE 59

Dispersion of fragments, Series 13 - Averages over experiments

Collecting Arc	10 ft.		5 ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
80- 85	9 (9)	0.11	13 (12)	0.20
85- 90	158 (111)	20.59	132 (111)	15.96
90- 95	595 (339)	76.66	313 (200)	50.65
95-100	46 (37)	2.57	237 (138)	33.16
100-105	6 (6)	0.07	1 (1)	0.03

TABLE 60

Dispersion of fragments, Series 14 - Numbers and weights of fragments

Experiment	14A								14B							
Collecting Arc	10-ft.			5-ft.					10-ft.				5-ft.			
Zone of dispersion, degrees	Number		Wgt., g.	Number		Wgt., g.			Number		Wgt., g.		Number		Wgt., g.	
60																
60- 65																
65- 70																
70- 75																
75- 80	1	(1)	0.10													
80- 85	1	(1)	0.31						2	(2)	13.67		7	(7)	48.84	
85- 90	10	(10)	41.60	24	(24)	167.18			11	(11)	77.15		27	(27)	180.45	
90- 95	35	(34)	146.48	50	(48)	305.41			31	(30)	179.83		54	(54)	330.80	
95-100	17	(16)	40.27	34	(34)	206.25			4	(4)	25.39		29	(29)	179.80	
100-105																
105-110	1	(1)	0.13													
110-115																
115-120																
120	1	(1)	0.10													
Sum	63	(61)	228.66	108	(106)	678.84			48	(47)	296.04		117	(117)	739.89	
Dust			1.73			5.13					1.71				4.27	
Total			230.39			683.97					297.75				744.16	
Estimated weight of fragmented part, g.	1382								1382							

TABLE 61

Dispersion of fragments, Series 14 - Numbers and weights corrected to 360°

Experiment	14A						14B					
Collecting Arc	10-ft.			5-ft.			10-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %	Number		Wgt., %
80- 85	6	(6)	0.14				9	(9)	4.62	13	(13)	6.60
85- 90	60	(60)	18.19	48	(48)	24.63	51	(51)	26.06	50	(50)	24.39
90- 95	210	(204)	64.06	101	(97)	44.99	144	(139)	60.74	100	(100)	44.71
95-100	102	(96)	17.61	69	(69)	30.38	19	(19)	8.58	54	(54)	24.30
100-105												

TABLE 62

Dispersion of fragments, Series 14 - Averages over collecting arcs

Experiment	14A			14B		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
80- 85	3	(3)	0.07	11	(11)	5.61
85- 90	54	(54)	21.41	51	(51)	25.22
90- 95	156	(151)	54.53	122	(120)	52.73
95-100	86	(83)	23.99	37	(37)	16.44
100-105						

TABLE 63

Dispersion of fragments, Series 14 - Averages over experiments

Collecting Arc	10-ft.			5-ft.		
Zone of dispersion, degrees	Number		Wgt., %	Number		Wgt., %
80- 85	8	(8)	2.38	7	(7)	3.30
85- 90	56	(56)	22.13	49	(49)	24.51
90- 95	177	(172)	62.40	101	(99)	44.85
95-100	61	(58)	13.09	62	(62)	27.34
100-105						

TABLE 64

Dispersion of fragments, Series 16 - Numbers and weights of fragments

Experiment	16A				16B			
Collecting Arc	5-ft.		10-ft.		5-ft.		10-ft.	
Zone of dispersion, degrees	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.	Number	Wgt., g.
60								
60- 65								
65- 70								
70- 75								
75- 80								
80- 85	9 (9)	64.27	3 (3)	21.83	12 (12)	77.18	3 (3)	20.04
85- 90	21 (21)	141.82	5 (5)	32.83	19 (19)	128.29	7 (7)	47.49
90- 95	35 (34)	223.53	18 (18)	115.90	36 (36)	237.30	17 (17)	111.71
95-100	69 (67)	424.32	33 (33)	203.92	73 (73)	443.66	32 (31)	203.78
100-105	13 (13)	56.82			15 (15)	91.99		
105-110								
110-115								
115-120								
120								
Sum	147 (144)	910.76	59 (59)	374.50	155 (155)	978.42	59 (58)	383.02
Dust								
Total		910.76		374.50		978.42		383.02
Estimated weight of fragmented part, g.	2764				2764			

TABLE 65

Dispersion of fragments, Series 16 - Numbers and weights of fragments

Experiment	16A				16B			
Collecting Arc	5-ft.		10-ft.		5-ft.		10-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %	Number	Wgt., %
60- 65								
65- 70								
70- 75								
75- 80								
80- 85	27 (27)	7.06	22 (22)	5.83	34 (34)	7.89	22 (22)	5.23
85- 90	64 (64)	15.57	37 (37)	8.77	54 (54)	13.11	51 (51)	12.40
90- 95	106 (103)	24.54	133 (133)	30.95	102 (102)	24.25	123 (123)	29.17
95-100	209 (203)	46.59	244 (244)	54.45	206 (206)	45.34	231 (224)	53.20
100-105	39 (39)	6.24			42 (42)	9.41		
105-110								
110-115								
115-120								
120								

TABLE 66

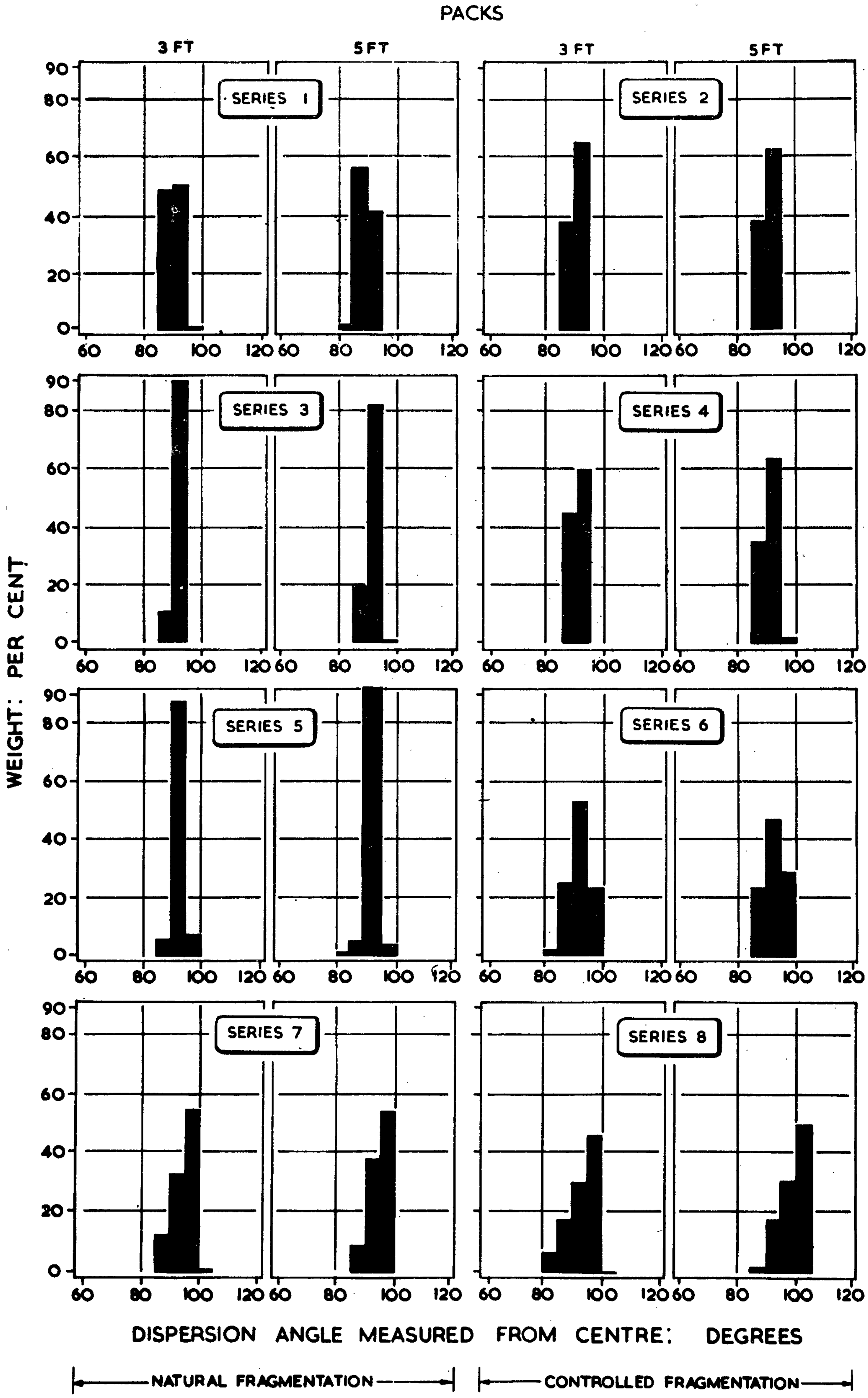
Dispersion of fragments, Series 16 - Averages over collecting arcs

Experiment	16A		16B	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
60				
60- 65				
65- 70				
70- 75				
75- 80				
80- 85	25 (25)	6.45	28 (28)	6.56
85- 90	52 (52)	12.17	53 (53)	12.76
90- 95	120 (118)	27.75	113 (113)	26.70
95-100	227 (224)	50.51	219 (215)	49.27
100-105	20 (20)	3.12	21 (21)	4.71
105-110				
110-115				
115-120				
120				

TABLE 67

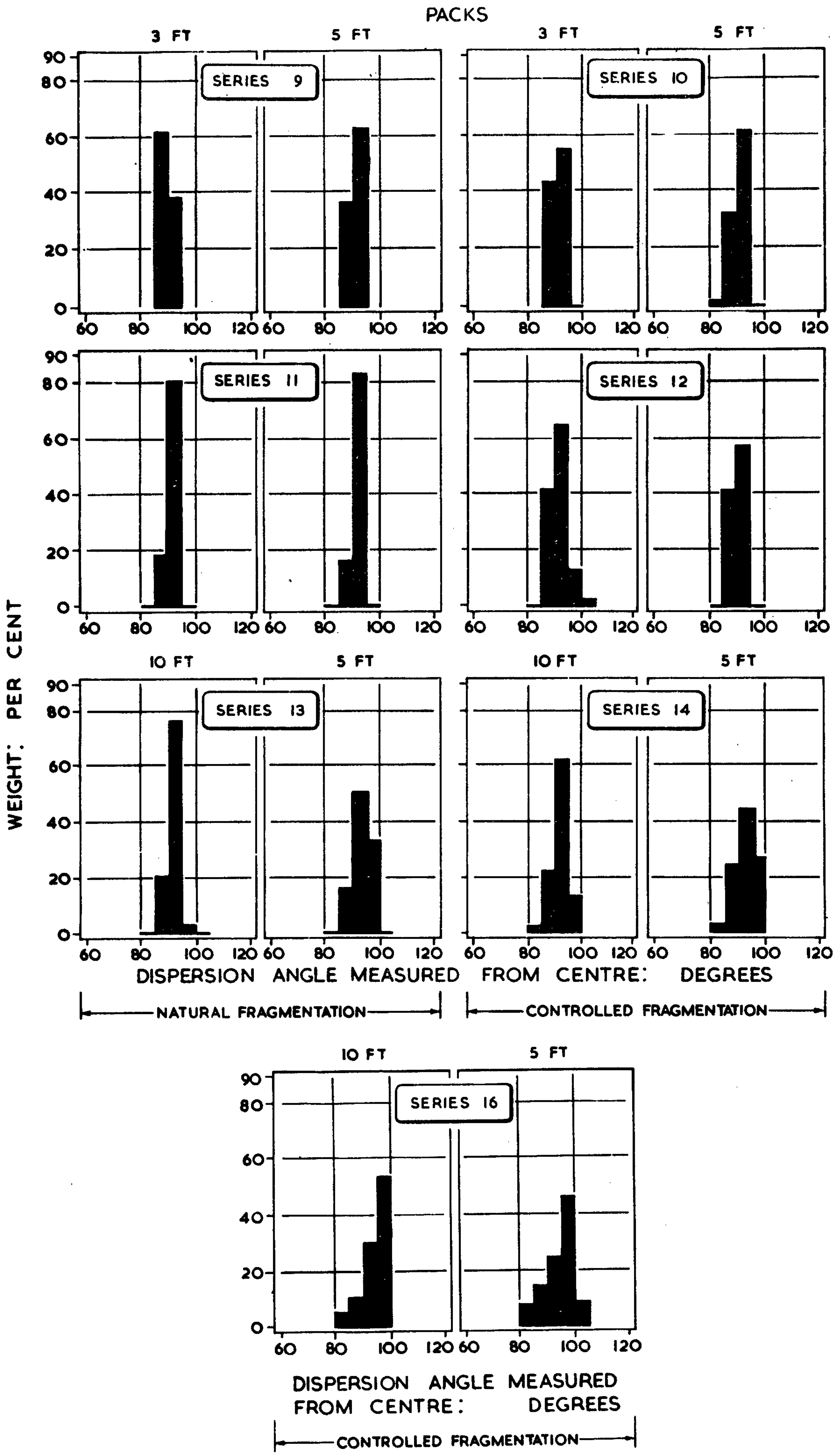
Dispersion of fragments, Series 16 - Averages over experiments

Collecting Arc	5-ft.		10-ft.	
Zone of dispersion, degrees	Number	Wgt., %	Number	Wgt., %
60				
60- 65				
65- 70				
70- 75				
75- 80				
80- 85	31 (31)	7.47	22 (22)	5.53
85- 90	59 (59)	14.34	44 (44)	10.59
90- 95	104 (103)	24.40	128 (128)	30.04
95-100	208 (205)	45.96	238 (238)	53.84
100-105	41 (41)	7.83		
105-110				
110-115				
115-120				
120				



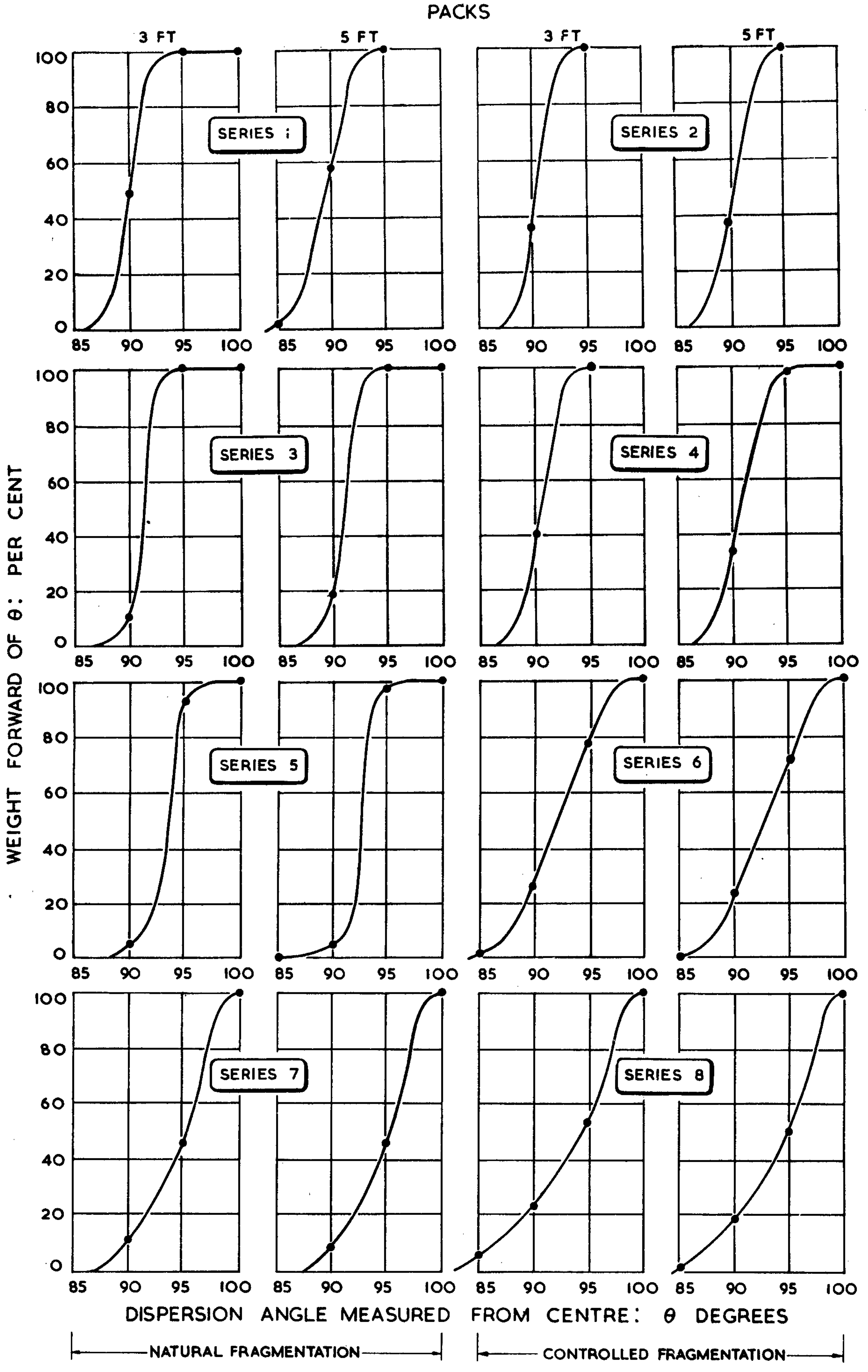
PERCENTAGE WEIGHT OF CASING
FRAGMENTED INTO ANGULAR ZONES

FIG. 1



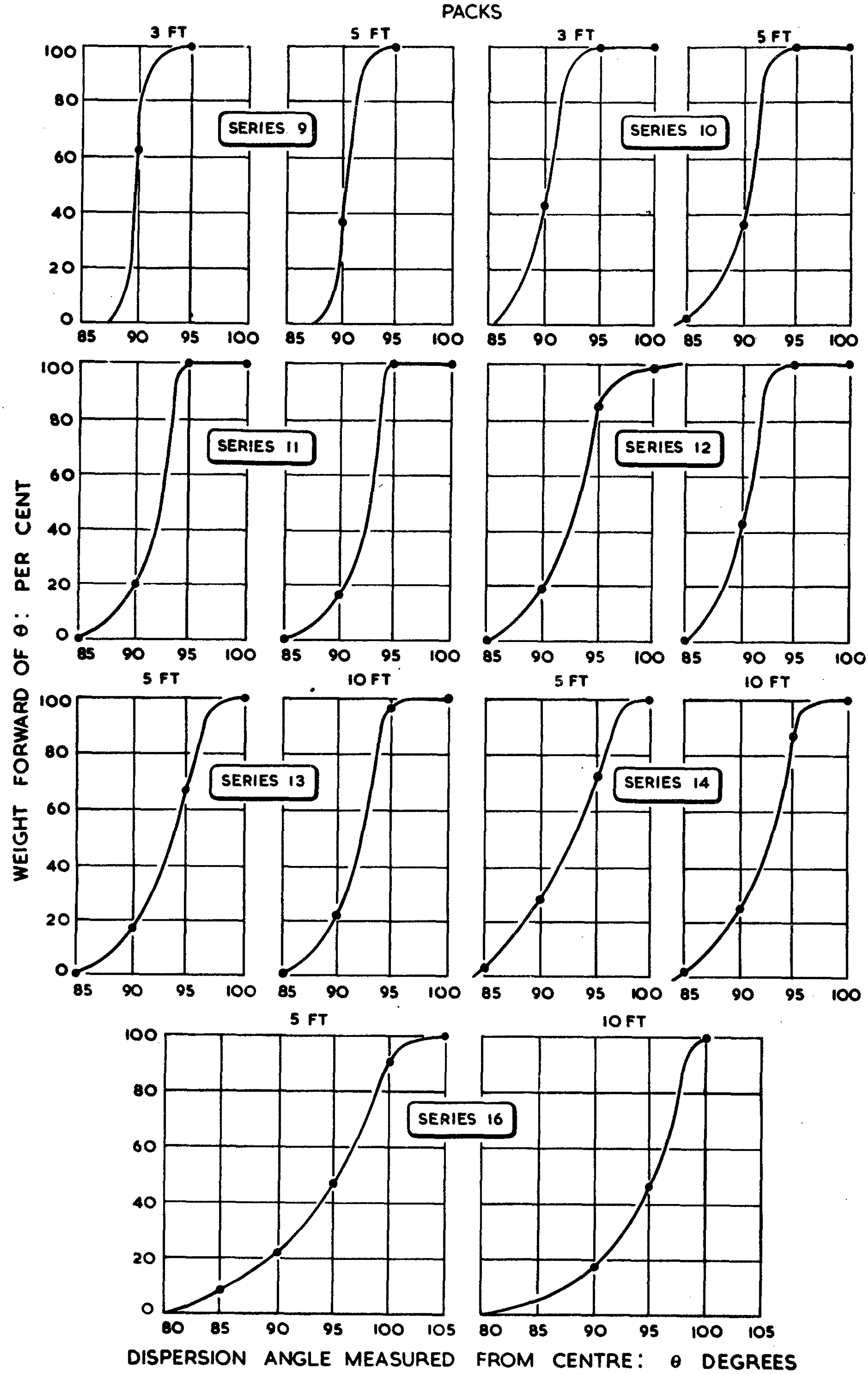
PERCENTAGE WEIGHT OF CASING FRAGMENTED INTO ANGULAR ZONES

FIG. 2



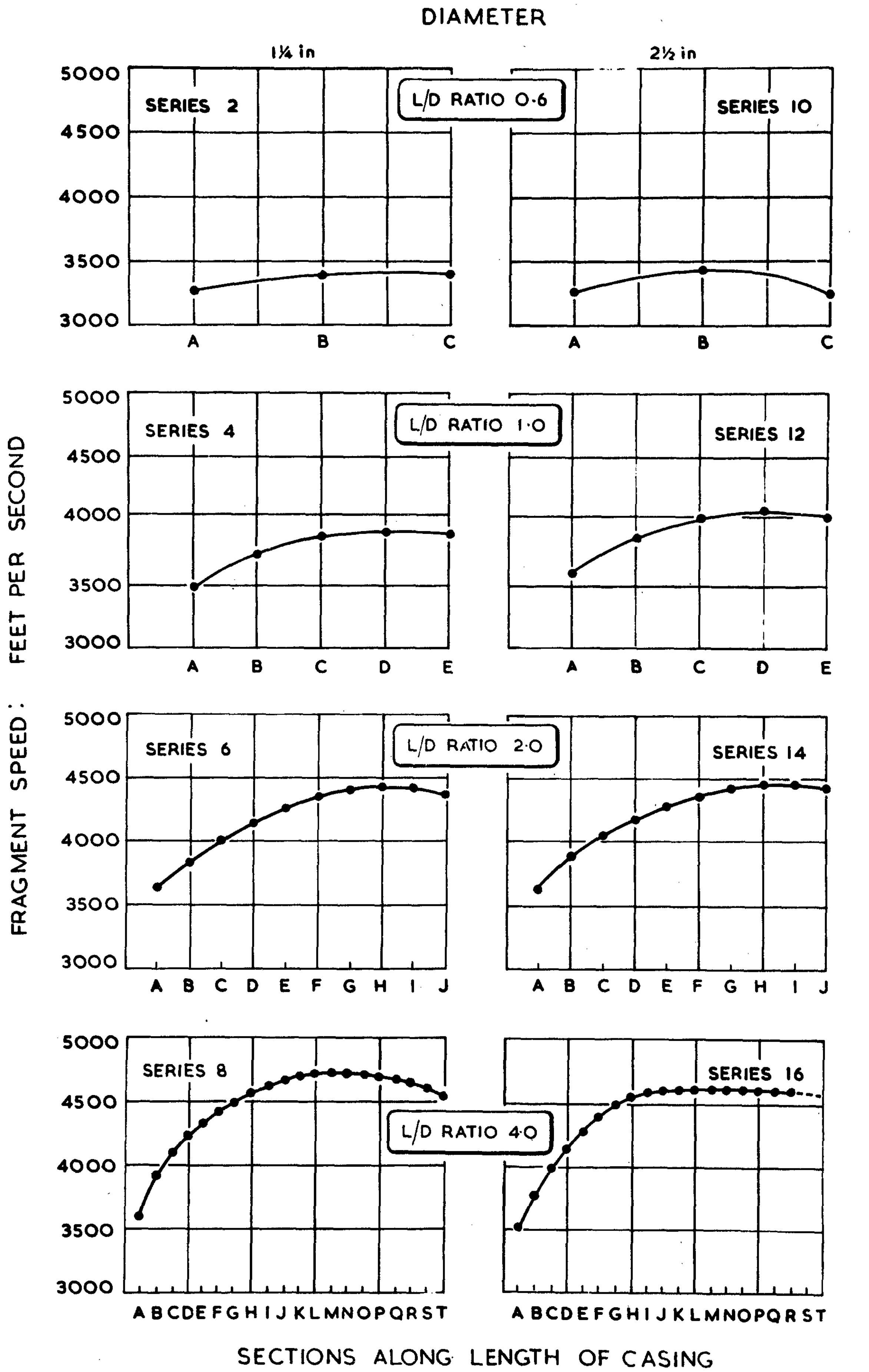
PERCENTAGE WEIGHT OF CASING FORWARD OF θ

FIG. 3



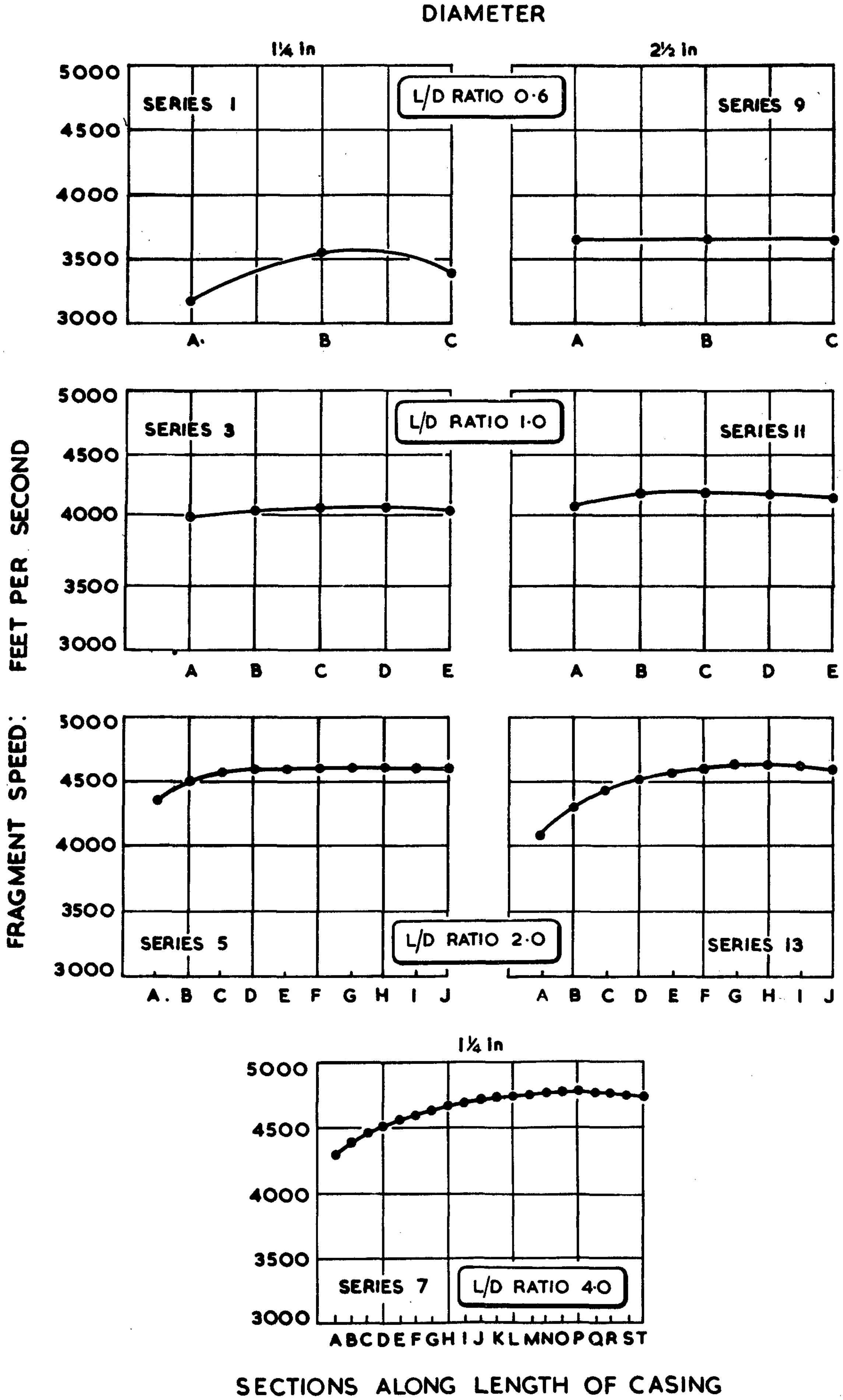
PERCENTAGE WEIGHT OF CASING FORWARD OF θ

FIG.4



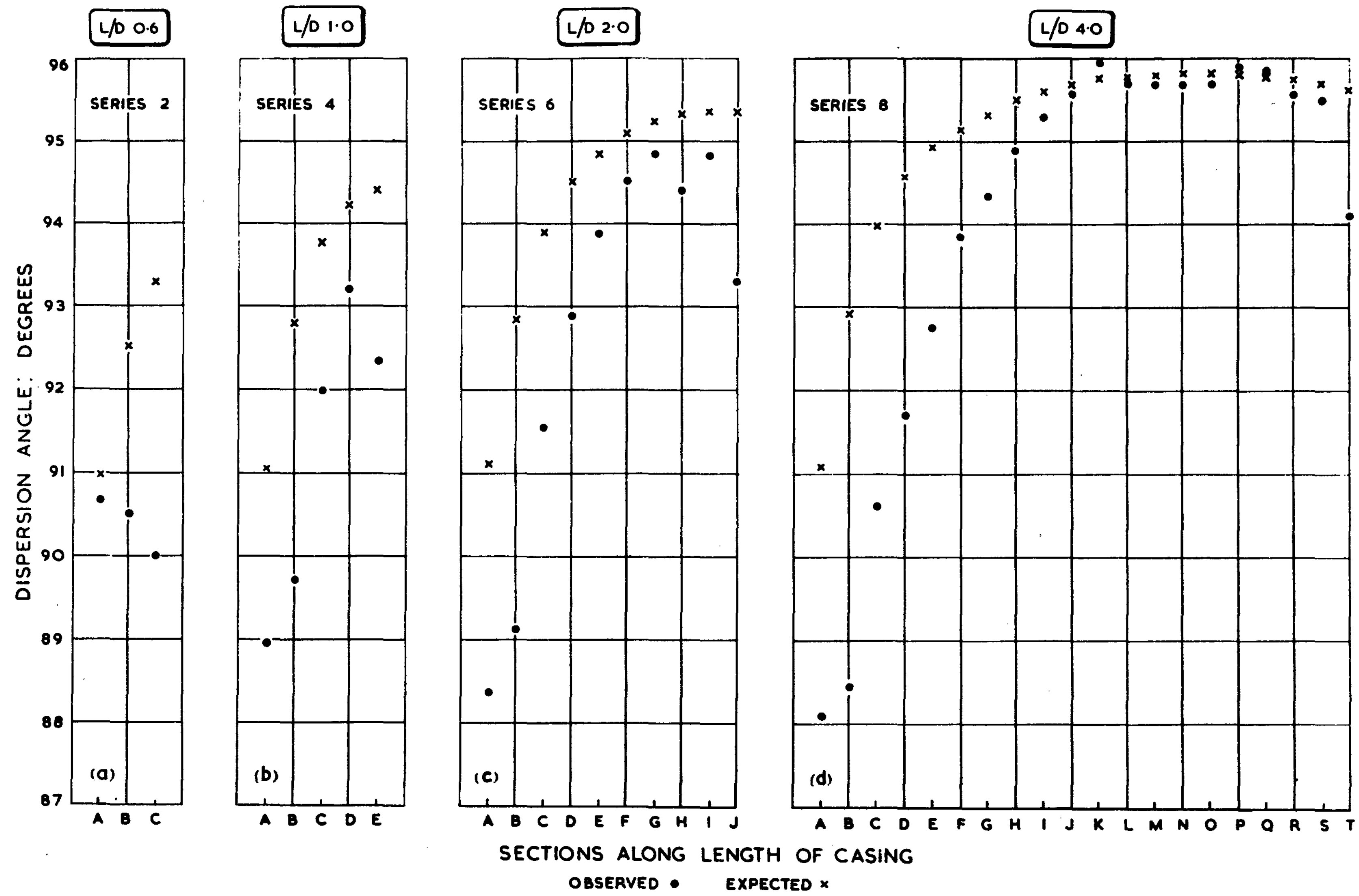
VARIATION OF SPEED ALONG LENGTH OF CASING

FIG. 5



VARIATION OF SPEED ALONG LENGTH OF CASING

FIG. 6



COMPARISON OF EXPECTED ANGLES WITH OBSERVED ANGLES

FIG.7

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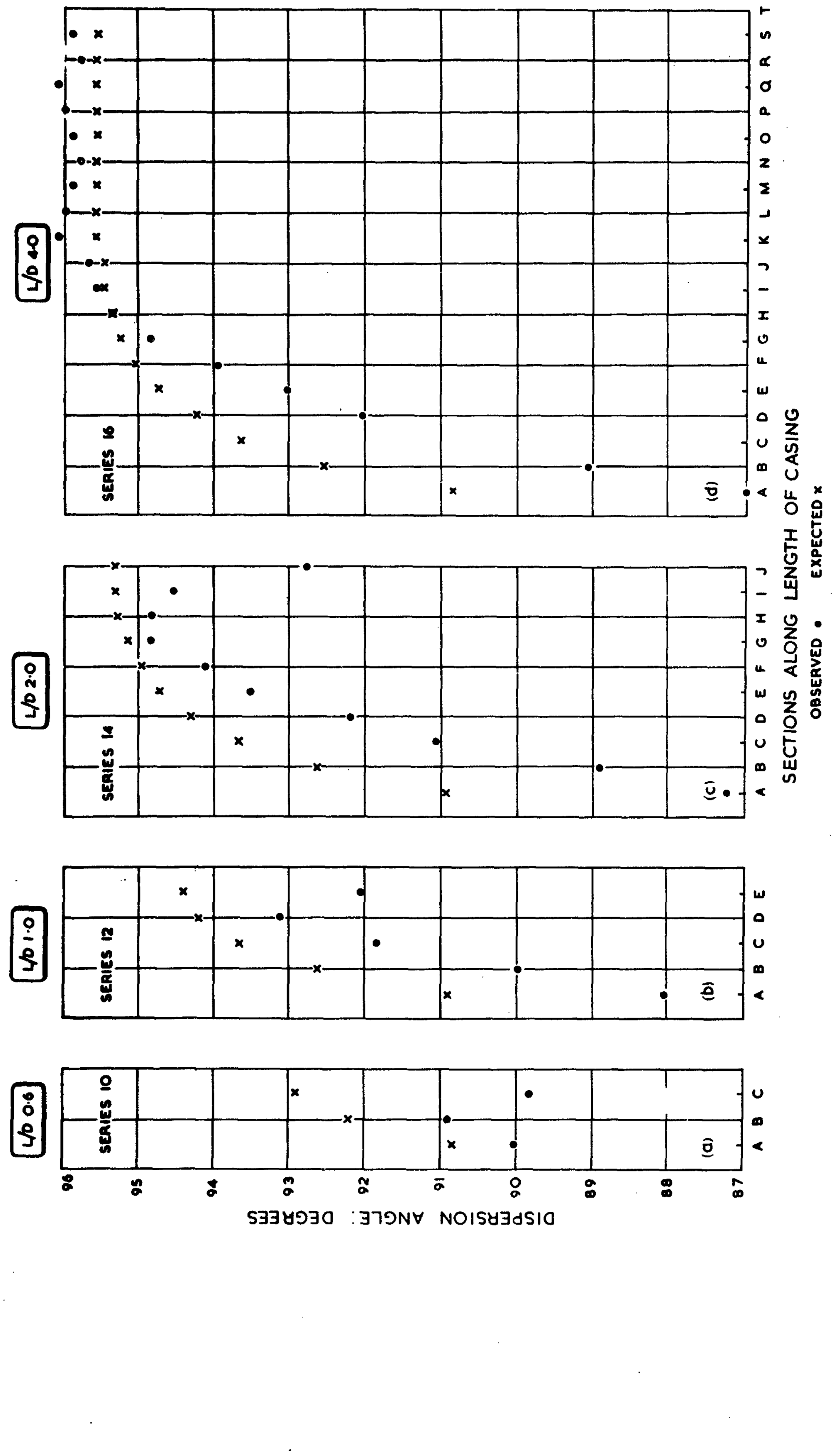
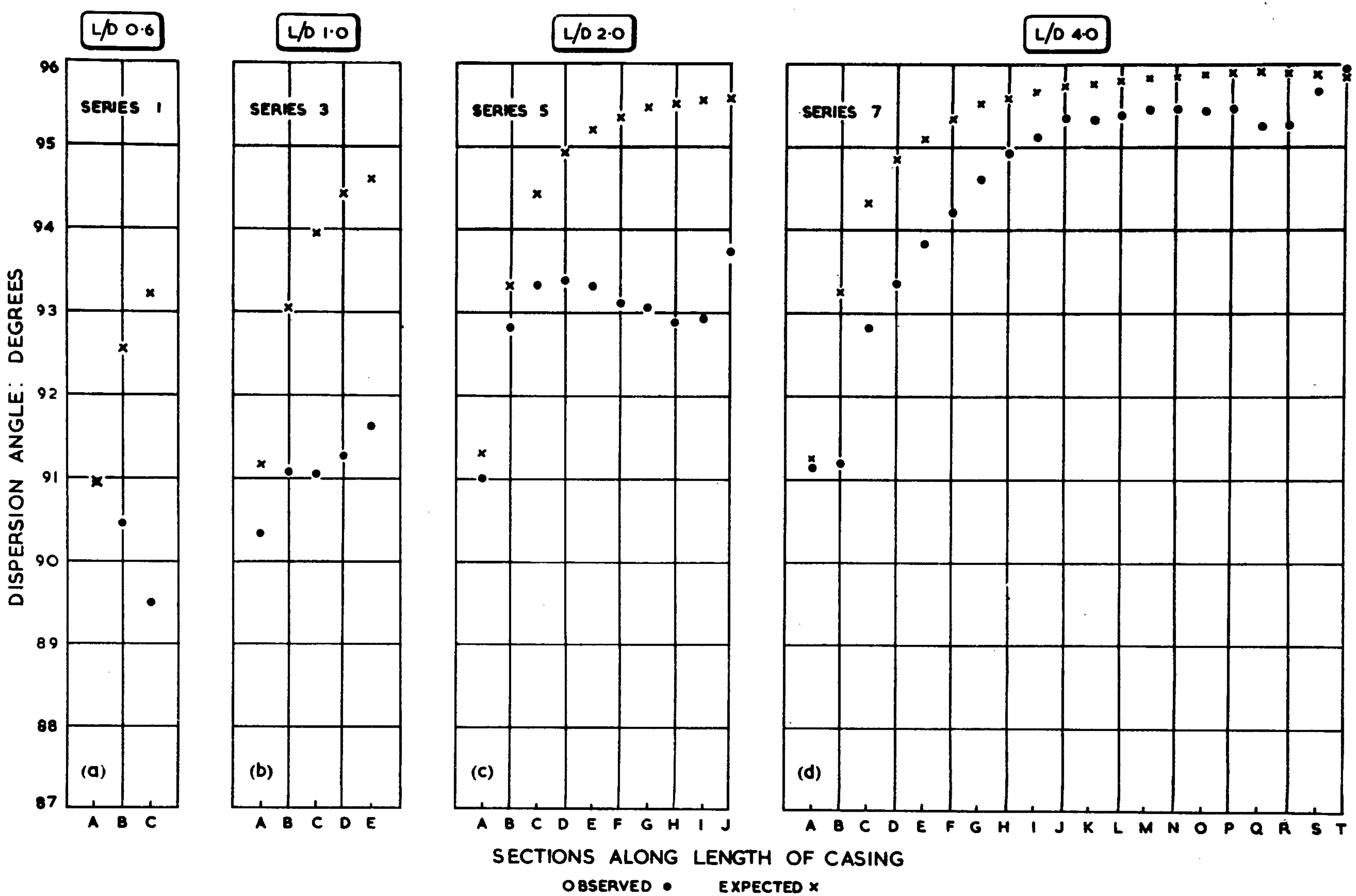


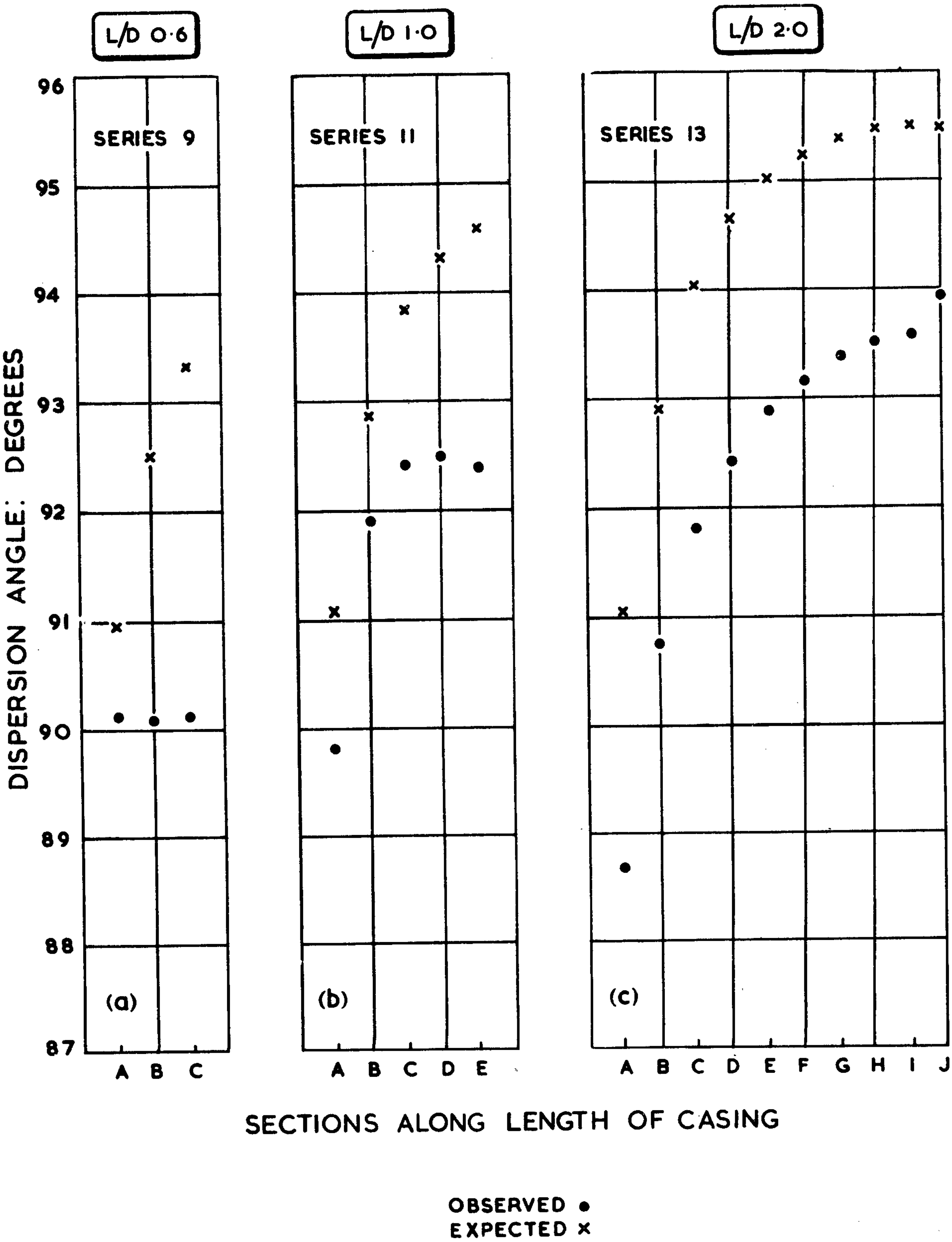
COMPARISON OF EXPECTED ANGLES WITH OBSERVED ANGLES

FIG.8



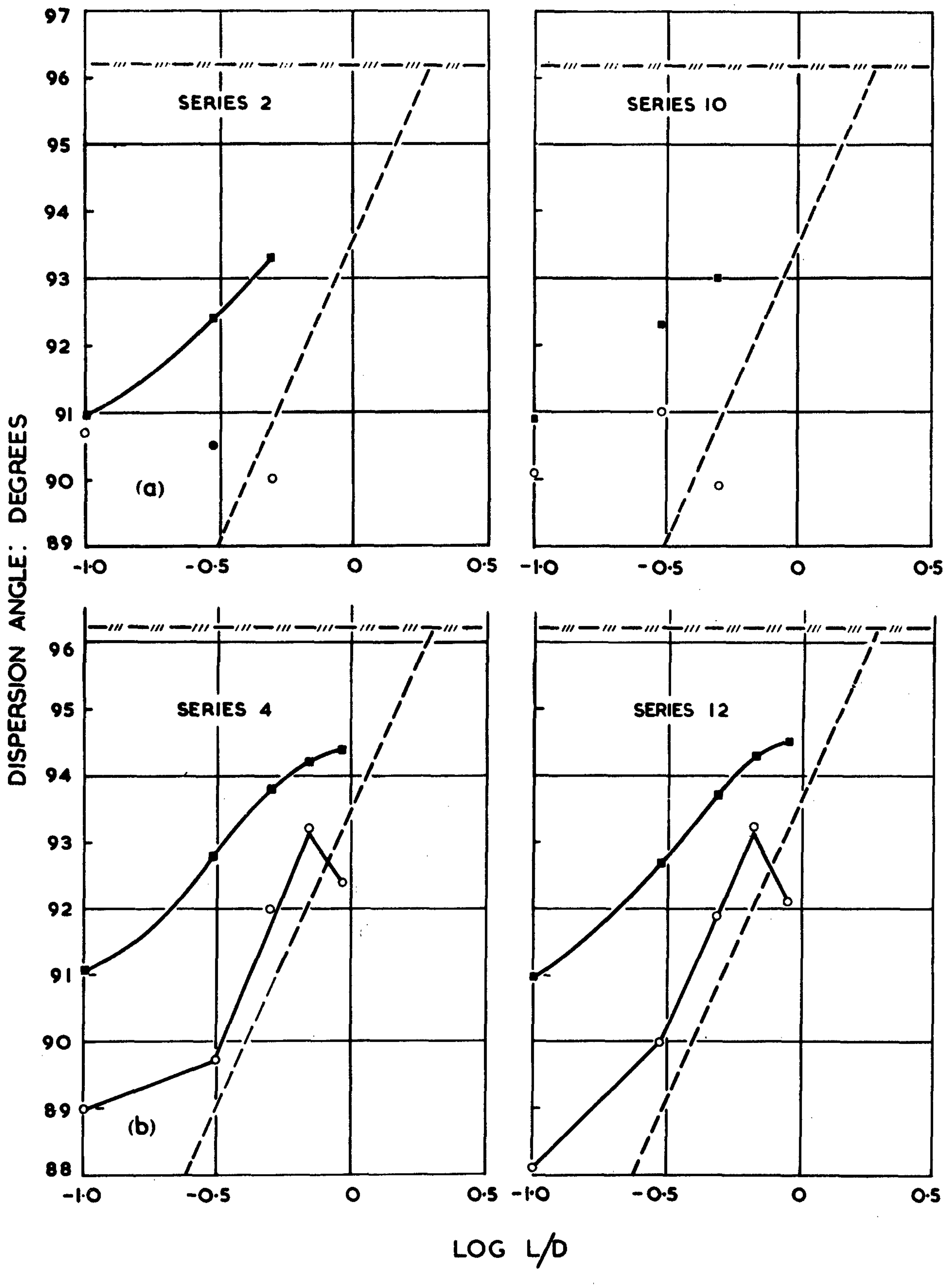
COMPARISON OF EXPECTED ANGLES WITH OBSERVED ANGLES

FIG.9



COMPARISON OF EXPECTED ANGLES WITH OBSERVED ANGLES

FIG. 10



DISPERSION VELOCITY USING GURNEY FORMULA ... ... —///—///—

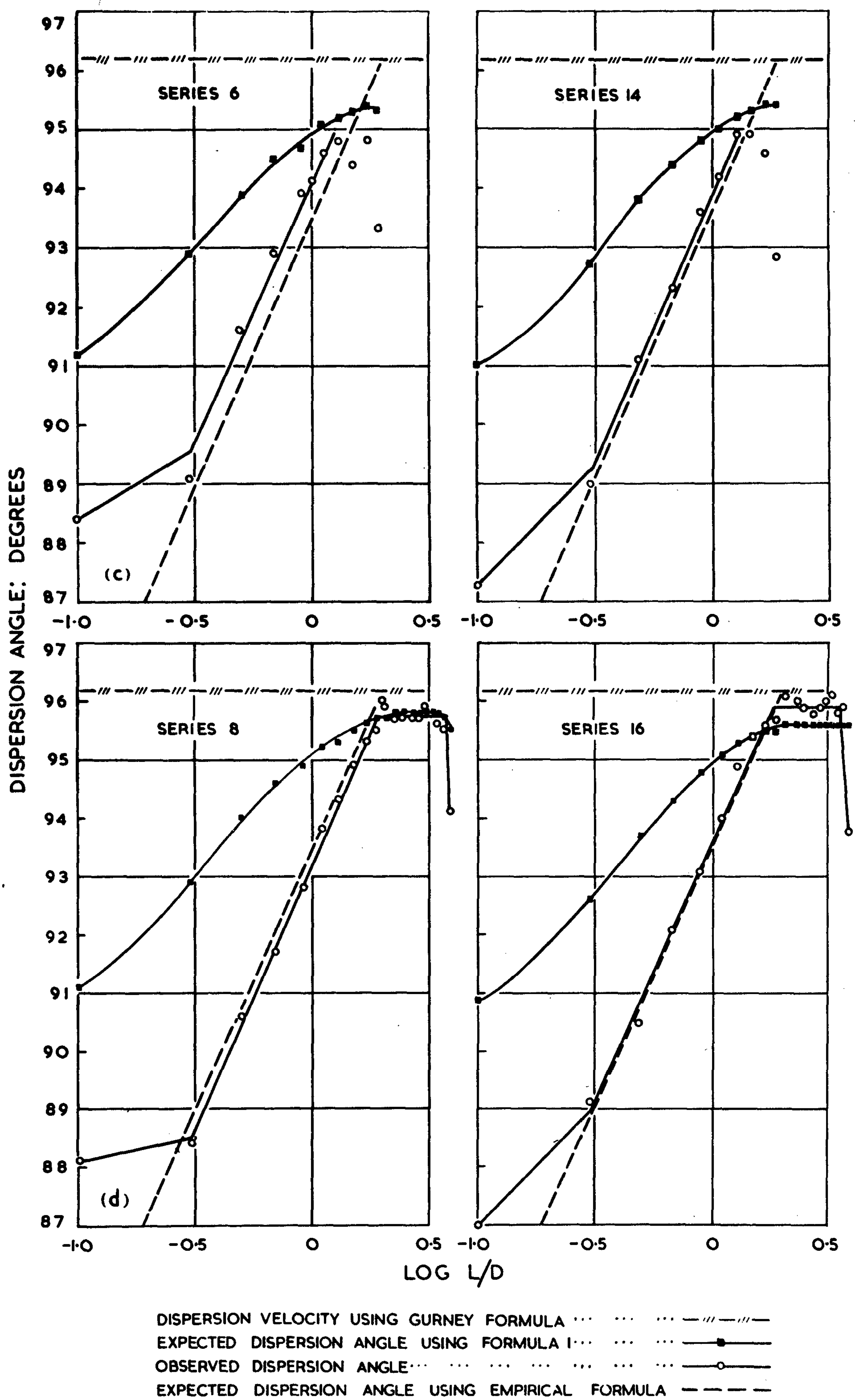
EXPECTED DISPERSION ANGLE USING FORMULA I ... ... ——■——

OBSERVED DISPERSION ANGLE ... ... ——○——

EXPECTED DISPERSION ANGLE USING EMPIRICAL FORMULA — — — —

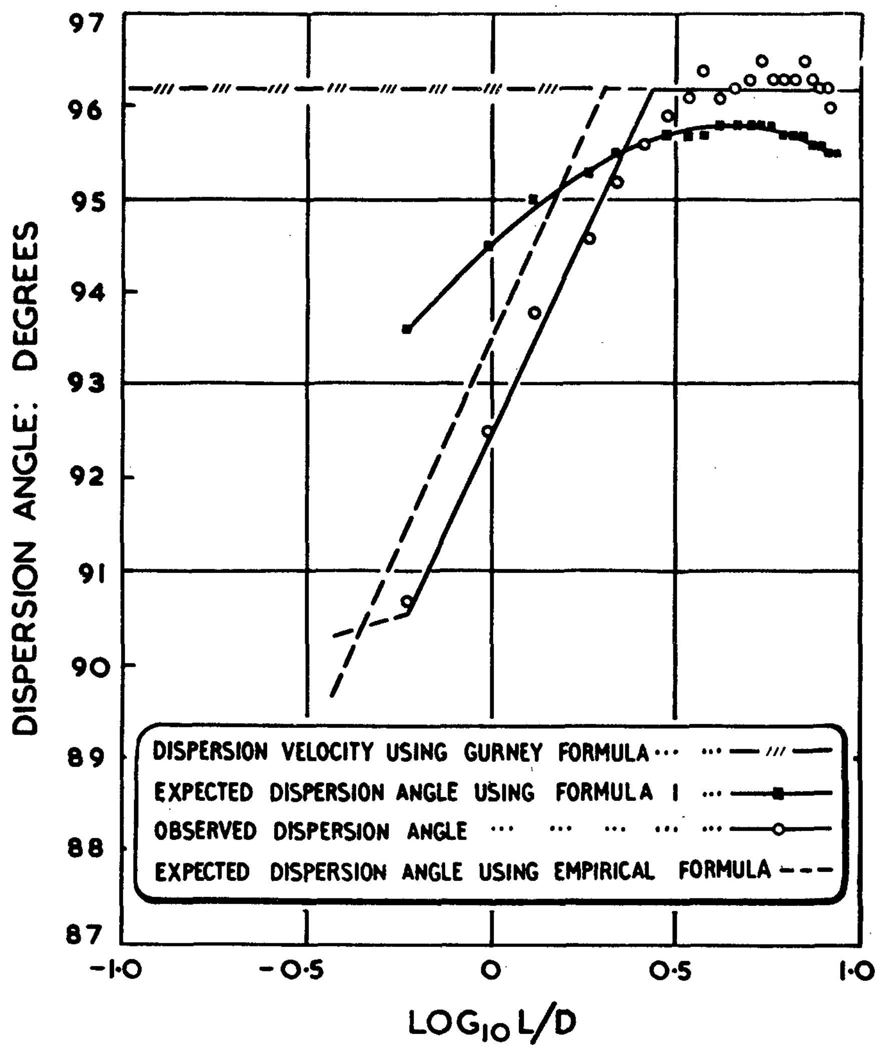
COMPARISON OF OBSERVED ANGLE AND ANGLE PREDICTED BY DIFFERENT FORMULAE

FIG. 11

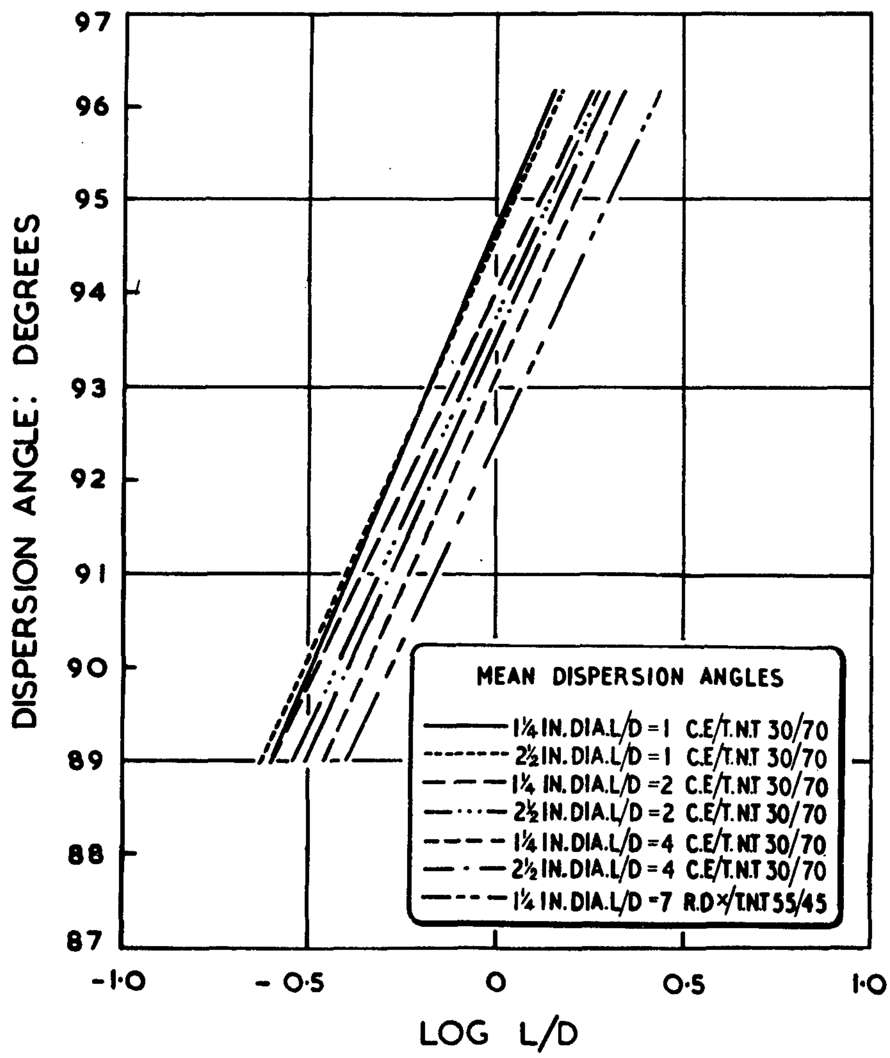


COMPARISON OF OBSERVED ANGLE AND ANGLE PREDICTED BY DIFFERENT FORMULAE

FIG. 12

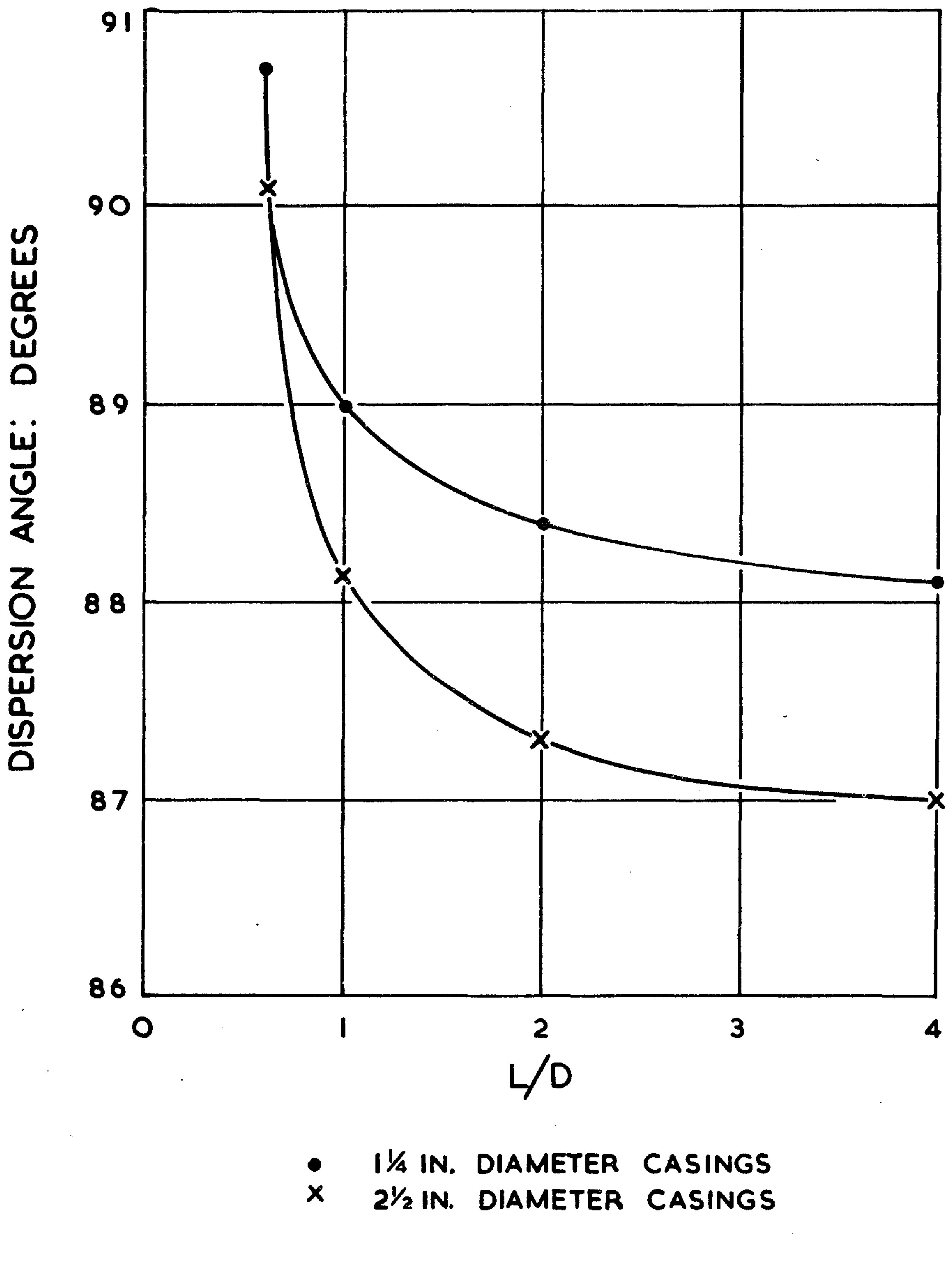


DISPERSION ANGLE: DEGREES
97
96
95
94
93
92
91
90
89
88
87
-1·0
-0·5
0
0·5
1·0
LOG10 L/D
DISPERSION VELOCITY USING GURNEY FORMULA
EXPECTED DISPERSION ANGLE USING FORMULA 1
OBSERVED DISPERSION ANGLE
EXPECTED DISPERSION ANGLE USING EMPIRICAL FORMULA



DISPERSION ANGLE: DEGREES
97
96
95
94
93
92
91
90
89
88
87
-1·0
-0·5
0
0·5
1·0
LOG L/D
MEAN DISPERSION ANGLES
1¼ IN. DIA. L/D = 1 C.E/T.N.T 30/70
2½ IN. DIA. L/D = 1 C.E/T.N.T 30/70
1¼ IN. DIA. L/D = 2 C.E/T.N.T 30/70
2½ IN. DIA. L/D = 2 C.E/T.N.T 30/70
1¼ IN. DIA. L/D = 4 C.E/T.N.T 30/70
2½ IN. DIA. L/D = 4 C.E/T.N.T 30/70
1¼ IN. DIA. L/D = 7 R.D.X/T.N.T 55/45

FIG.13



VARIATION OF DISPERSION ANGLE OF FIRST FRAGMENT ROW WITH L/D RATIO

FIG. 14

For Indexing

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62-493:
623.565.32

Spatial Distribution of Fragments, III.

A.R.E. Report 58/54 T.L.Wall. December 1954

The fragment speed and dispersion from scaled cylindrical casings has been examined for two diameters of case and a range of L/D ratios for each diameter. Four fragmentation zones were observed with long casings. A method of obtaining the dispersion angle for fragments from the various parts of the casing is suggested. The application of this method to the cases used leads to a maximum divergence of only 1° between observed and expected angles. The results have all been obtained with cylindrical casings; no work has yet been done with other shapes.

31 pp. 14 figs. 67 tabs. 6 refs.

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