LA-214

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February 2, 1945

This document contains 35 pages

EFFECT OF VOIDS ON DETONATION WAVES

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ABSTRACT

The problem of the effect of voids in cast high explosive upon the configuration of the shock-wave front was investigated by photographing the detonation of slab castings with a void at one end, initiated at both ends. The exposure was stopped with a smoke shutter just after the two shock waves met. The distorting effect of the void on one shock wave appeared in the luminous interaction line.

Voids of various shapes, sizes, orientation, and number were tested in Comp. B. The character and extent of the void effect was influenced by all those variables, but certain tendencies were generally displayed. Most voids produced a leading bulge in the wave front, with a maximum aberration of about one-third the average dimension; the bulge continued to be evident in the wave front until it had gone a distance of three to four times the average dimension past the void.

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EFFECT OF VOIDS ON DETONATION WAVES

I. OBJECTIVE

To determine the effect of various types of voids in cast explosives upon the configuration of the shock wave front passing through and beyond the void.

II. PREVIOUS WORK ON SAME PROBLEM

The only known previous work on the problem was done by Bradner between August 3 and 26, 1944. This work was confined to a small group of shots similar to the one-inch-hole series described below (page 6). The work was insufficient to provide more than a proof of the photographic equipment and method, and a qualitative indication of probable results. Both the photographic method described below (pages 3 -5 , Figs. 1 and 2) and the well-known technique of shock-wave interaction traces on a soft metal plate in contact with the charge were used. The latter method was discarded because it was insufficiently sensitive to reveal the small effects of small voids.

III. METHOD

The method employed is the technique of recording photographically the explosive flash of two shock waves created by initiating a high-explosive slab at its two ends. A third luminous zone is created when the two shock waves meet. By stopping the exposure of the film a very short time after this meeting occurs, a thin luminous line of interaction is left in between the two individual wave flashes. Any departure of this line from a normal circular-arc or straight-line form is interpreted as a dis-

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tortion of one of the wave fronts due to a void through which it is passing or has passed at the time of interaction.

Fig. 1 is a schematic diagram showing all essential features of the method. The charge is a 1" x 4" x 10" cast high-explosive slab standing upright on a 1" x 10" side and directly facing the surface-silvered mirror. The camera is focussed upon the mirror image of the slab as seen through the slot on the smoke-shutter plate. The two 1" by 4" ends of the slab are provided with tetryl boosters which are initiated by two primacords of carefully fixed length. A third long primacord leads to the smoke-shutter plate. These three cords are initiated by a special junction (Figs. 5 and 6) in which a single short primacord from the detonator initiates a composite tetryl booster which in turn initiates the three long primacords, all at the same time within an error range of $\pm$ 0.1 microsecond.

The smoke shutter utilizes the dense black smoke resulting from the explosion of primacord. As the explosive shock wave proceeds along the primacord, a trailing V pattern of smoke follows. Each side of the V makes an angle of approximately 22° with the cord. The primacord is held by wood blocks at the same angle with the slot (see Fig. 2) such that as the shock wave passes the far end of the slot a straight-fronted curtain of smoke crosses the slot along its shortest dimension. This crossing takes place in approximately one-third microsecond. The effective length of this shutter primacord relative to the length of the two primacords to the slab determines the smoke-shutter timing.

The simple electrical firing circuit is shown in Fig. 1A. When the safety and firing switches are closed, the solenoid trips the mechanical shutter. As the latter opens, its cocking lever swings back to the uncocked position, closing the detonator microswitch as it passes and firing the explosive chain. Thus first the mechanical shutter opens, then the explosives fire, the smoke shutter closes, and before the smoke disperses the mechanical shutter closes.

A setup picture is taken to provide a check of details of the charge and its placement and a dimensional reference for measurements on the shot picture. Figs. 3 and 4 are setup and shot pictures respectively for Shot No. HH-16 for which the following are figures pertinent to the timing:

Length of left primacord	S_1	= 155 cm
" " right "	S_2	= 145 cm
" " shutter "	S_3	= 170 cm
" " " overlap	K	= 7.5 cm
Effective length of shutter primacord	$S_3 - K$	= 162.5 cm

Fig. 7 shows how shot photographs are interpreted. The entire picture is considered in two dimensions only. The geometric center of the circular wave front from either initiating point is taken to be in the booster on the axis 9 mm from the surface of the cast explosive. This was determined from careful examination of, and constructions upon, shots in the preliminary shot series, run to prove the setup and decide upon type, placement, and method of fixation of boosters. Circular arcs drawn from these centers in the two boosters through two selected points, A and B, on the wave interaction trace represent the two shock waves at a certain time, undisturbed by voids. If one wave is undisturbed the other may be found as the locus of points at the same distance from the interaction trace as the other wave front but on the opposite side of the interaction from the other wave front. Of course this method falls down when the interaction trace passes through the void, because then both wave fronts are affected by the void, and in the same section.

IV. PROCEDURE

Using the methods of preparation, firing, and interpretation described in Part III, the following schedule (not chronological) was followed to obtain the specific information listed at the head of each section (A, B, C, etc.) of the schedule. It should be kept in mind that in this and all subsequent parts of the report, the test explosive is cast Comp. B unless otherwise specified.

SCHEDULE OF INVESTIGATION

	Number of Shots: Fired	Interpretable
A. Preliminary: To determine best type and placement of boosters, and timing constants	16	16
B. Single Circular Hole: To study in two dimensions effect of hole on shock wave front, and especially persistence of effect		
1. One-inch hole	10	7
2. One-half-inch hole	19	12
3. One-quarter-inch hole	9	6
4. One-eighth-inch hole	9	6
C. Single Shaped Hole: Object as in B, and to check reconvergence effect.		
1. Square hole, shock wave crossing along diagonal	12	8
2. Square hole, shock wave crossing parallel to side	8	5
3. Triangular hole, shock wave crossing along least height	11	7

[redacted]

	Number of Shots Fired	Number of Shots Interpretable
D. Multiple Circular Holes: (3 - one-eighth inch diam.) To determine if effect of hole is additive or individual		
1. Quarter-inch vertical spacing	5	3
2. Half-inch vertical spacing	5	2
3. Quarter-inch horizontal spacing	6	5
4. Half-inch horizontal spacing	6	4
E. Natural Casting Imperfections: To determine if they alter wave front at slab surface, and in the same way as artificial voids		
1. "Stress cracks"	6	2
F. Artificial Enclosed Spherical Voids: To serve as a substitute for large cooling voids, not obtainable for Section E.	4	4
G. Wide Slots: Two-dimensional simulation of cooling voids.		
1. Horizontal slots, long dimension parallel to wave motion	10	5
2. Vertical slots, long dimension perpendicular to wave motion	8	6
H. Thin Slots: To check effect of open cracks between blocks of explosive in build-up charge.		
1. Diagonal Slot, sixteenth inch, air filled	4	3
2. Diagonal Slot, eighth inch, air filled	4	1
3. Diagonal Slot, eighth inch, felt filled	4	3
4. Horizontal Slot, sixteenth inch, air filled	4	3
5. Horizontal Slot, eighth inch, air filled	4	3
6. Horizontal Slot, eighth inch, felt filled	4	3
I. Other Explosives (with one-inch circ. hole): To compare void effect with same in Comp. B		
1. T.N.T.	5	0
2. Pentolite	6	4
3. Torpex	6	4
4. Baronal	5	4

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The group of shots which were not interpretable were so for a number of reasons of which the following are most frequently occurring:

1. Timing irregularities giving either no interaction line or too broad an interaction line.

2. Mechanical failure in camera.

3. Failure of boosters to detonate slab.

4. Badly placed interaction line.

The first listed difficulty accounts for the majority of the losses.

V. RESULTS

The length of the timing primacords are so calculated as to give, for a certain void case, a series of interaction traces at varying distances from the void. These, after interpretation, may be transferred to a single plot to represent the character of the shock-wave front from the time it first displays conclusively the distorting effect of the void until it is restored to normal circular arc configuration. Fig. 8 is an example of such a plot, and Figs. 9 through 14 are the shot pictures from which the plot was made. Any interpreted wave front on the plot can be matched with the corresponding shot picture by means of the shot number. The information yielded by any series of shots is deduced primarily from the shock wave plot, and to some extent from the shot pictures themselves. Results, by sections (see Part IV, Schedule of Investigation), are as follows:

B. Single Circular Hole Fig. 8 shows that a one-inch round-hole void produces a leading bulge in the wave front. This bulge is practically a circular arc and persists through a space of between three to four inches

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past the void. The result is proportionally much the same in the half-inch-hole case, Fig. 15, and also the quarter-inch-hole case, Fig. 16. In the eighth-inch hole example, also shown in Fig. 16, the void effect is almost the same in absolute extent as with a quarter-inch hole, and this apparently disproportionate behavior occurs again in the multiple hole cases, Figs. 20 and 21, in which three one-eighth-inch holes were used. It was desired to further investigate this change in relation of magnitude and persistence of distortion to hole size, but the information was considered not immediately essential and the work was transferred to more vital questions.

C. Single Shaped Hole. In the oblique square-hole case, Fig. 17, the leading bulge is still essentially circular, especially in the brighter traces close to the void. Persistence here is somewhat less than in the one-inch-hole case, although a greater section of the wave front is distorted. When the sides of the square are parallel to the shock-wave motion, a quite different form of distortion results, as shown in Fig. 18. This plot, along with Figs. 19, 22, and 23 demonstrate that the shock-wave distortion is not simply a matter of discontinuity in medium. The shape of the air space definitely affects the distortion, suggesting that the orientation of the boundaries at which the wave front enters the air and then re-enters the explosive determines the nature of the wave front aberration. The persistence in the parallel square-hole case is similar to that of the oblique square hole. The triangular hole demonstrates two cases, both shown in Fig. 19, one of which could not be carried to completion for the same time-limiting reason stated before. Two

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decidedly different aberrations are displayed. Persistence in the one completed case is similar to that of the square holes.

D. Multiple Circular Holes. The two cases of multiple holes in line perpendicular to the wave motion are shown in Fig. 20. The hole effect is apparently not truly additive; that is, no increase of extent or persistence of aberration is displayed; although with quarter-inch spacing there is a sort of interference effect yielding more numerous bulges. With multiple holes in line with the shock wave motion and quarter-inch spacing, Fig. 21, some addition of effect is noted.

E. Natural Casting Imperfections. When slabs with so-called "stress cracks", revealed by x-ray examination to occur quite frequently, were fired, no evidence of any effect of the cracks could be noted either in the interaction trace or in the explosive flash. This was so regardless of the number, size, or location of the cracks.

It was hoped that slabs could be cast with natural cooling voids, that is, large air spaces occurring inside the charge due to uneven cooling, and fully enclosed. It was necessary that they be enclosed all around so that initiation would be normal at both ends of the slab. No such charges were made.

F. Artificial Enclosed Spherical Voids. These voids were in the form of a thin-walled, air-filled glass spheres one-half inch in diameter, held in place by a glass capillary. No effect whatever could be observed.

G. Wide Slots. The case of the wide slot with its long dimension parallel to the wave motion, Fig. 22, shows considerably greater effect than the half-inch hole, and along with the perpendicular slot of the same size,

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Fig. 23, it lends support to the idea of average dimension or cross section area of void as a criterion of proportionality of extent of distortion. Here again not enough traces were obtained to complete the picture; it was necessary to turn to more pressing problems.

H. Thin Slots. Thin diagonal slots (of one-sixteenth and one-eighth inch thickness) at a mean angle of 63° with the shock-wave motion have the effect of turning the entire wave front through an angle of from 1-1/2 to 3 degrees. As the wave progresses beyond the slot this effect tends to disappear. No other distortion is evident. When the same slots are in line with the wave motion, a much greater effect is noted. The disturbance is not a clear-cut distortion of a continuous wave front, but rather a large zone of apparent turbulence, showing in the shot picture, Fig. 24, as a broad area of luminosity rather than a thin line. The extent of this disturbance is practically the same for the two cases (a) one-sixteenth-inch air-filled, and (b) one-eighth-inch air-filled. The effect is about half as intense in the one-eighth-inch felt-filled case, Fig. 25.

I. Other Explosives. Of the other explosives tested to compare their void effect with that of Comp. B, Pentolite and Torpex show similar behavior to that of Comp. B. In TNT and Baronal, however, the shock waves have a quite different character. The TNT shock wave, Fig. 26, is very irregular, and two of them colliding will not produce a geometric trace as in Comp. B. In Baronal, comparatively slow burning of the aluminum results in a broad, somewhat indistinct interaction zone, Fig. 27, with an almost complete gap resulting from the void in the casting. Again in this case of other explosives, the work done was not sufficient to permit firmly grounded con-

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clusions.

Fig. 28 is a combined plot of extent of distortion in all Comp. B tests except the thin-slot and eighth-inch-hole cases. The plots for individual cases are erratic, no one of them closely follows the combined curve over all its length, and departures from the combined curve of as much as sixty per cent are noted. However, the plot was very carefully prepared, and it is believed that it will provide a reliable means of estimating the magnitude of the extent and persistence of effect of large voids in Comp. B.

VI. CONCLUSIONS

The results described in Part V lead to the following conclusions:

1. Single voids of average dimension greater than 3 mm produce a leading bulge, that is, a section ahead of the remainder, in the shock wave front.

2. Spherical voids produce spherical bulges, as do some non-spherically shaped voids. However, some oddly shaped voids result in more complicated forms of aberration in the wave front; and with odd void shapes the aberration is not independent of void orientation. Thus it is believed that the profile and orientation of the surfaces between air and high explosive are the primary determinants of void shape.

3. This leading bulge in the wave front will disappear when the wave front has traveled three to four times the void average dimension past the void. The average dimension is defined as the diameter of a circle of area equal to the cross section area of the void. (Thus the cross section area might be used as the criterion, but a one-dimensional concept is more

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convenient.)

4. The maximum distortion of the wave front (see Fig. 28) generally will be from 20 to 45 per cent of the void average dimension and will occur in the range of from three-fourths to two times the average dimension past the void.

5. Long thin slots have two decidedly different effects:

(a) If the wave strikes them obliquely, it will be turned as whole through a small angle of the order of two degrees.

(b) If it moves parallel to the slot, it will acquire a zone of turbulence in the wave front at and near the slot.

6. Pentolite and Torpex behave similarly to Comp. B with respect to void effect; but TNT and Baronal have different shock wave characteristics and no conclusions on the effect of voids in them has been reached.

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FIGURE 1
DIAGRAM OF SETUP

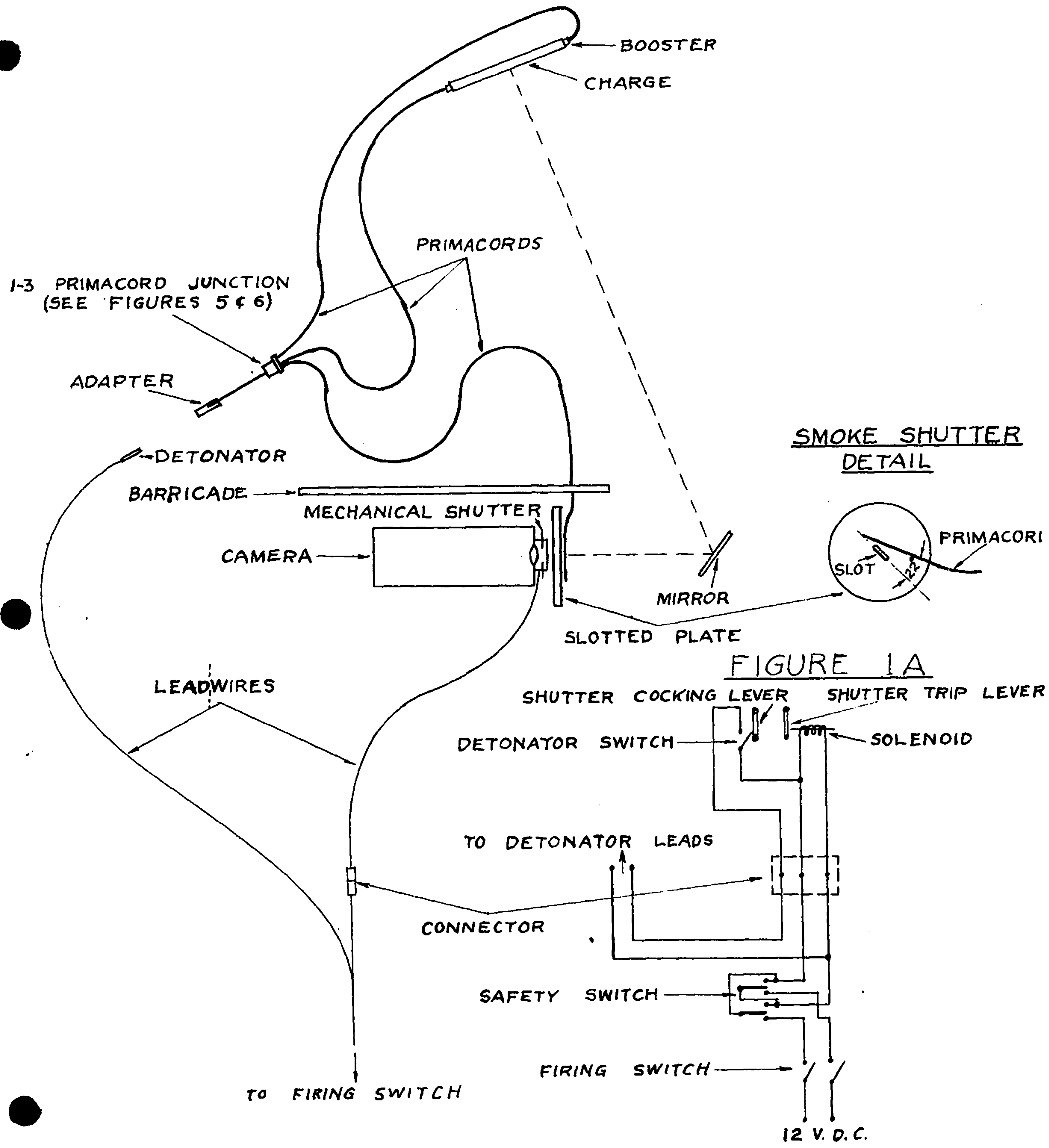

FIGURE 1A

C. B. C. 10-27-44

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FIG. 2

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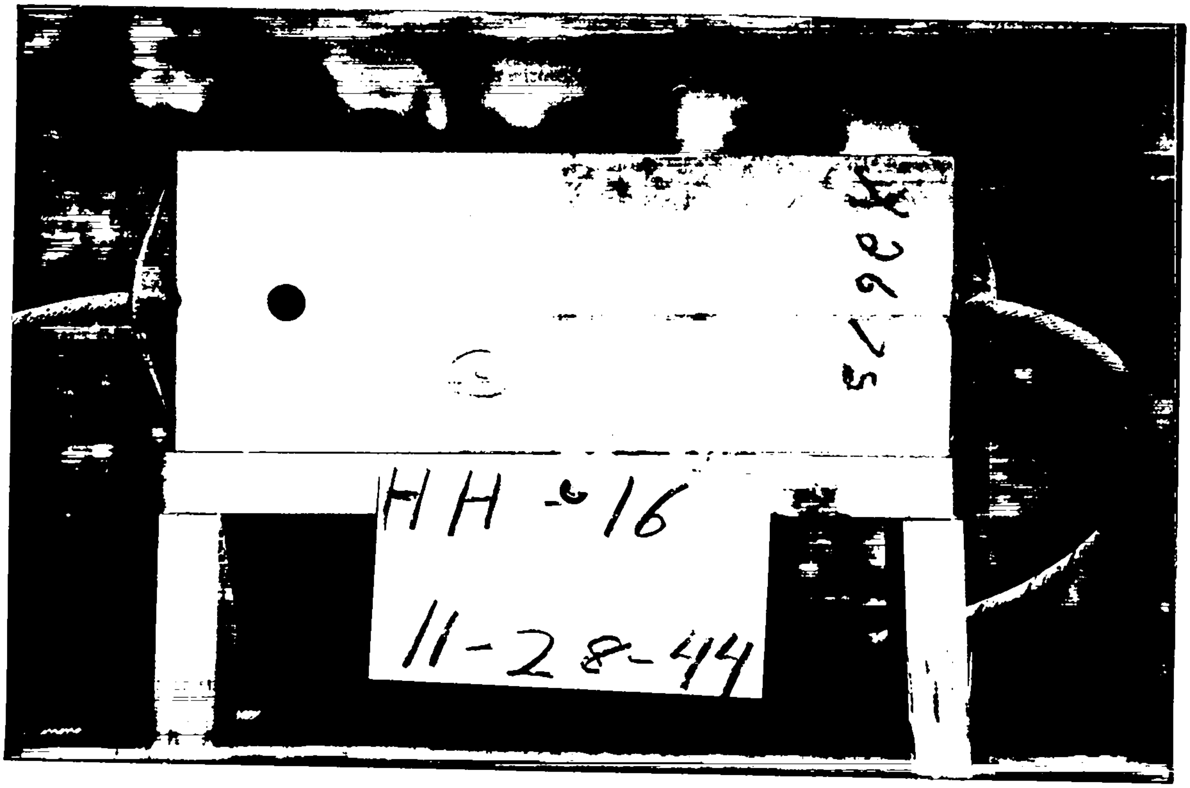

Fig. 3. HH-16

Fig. 4. HH-16

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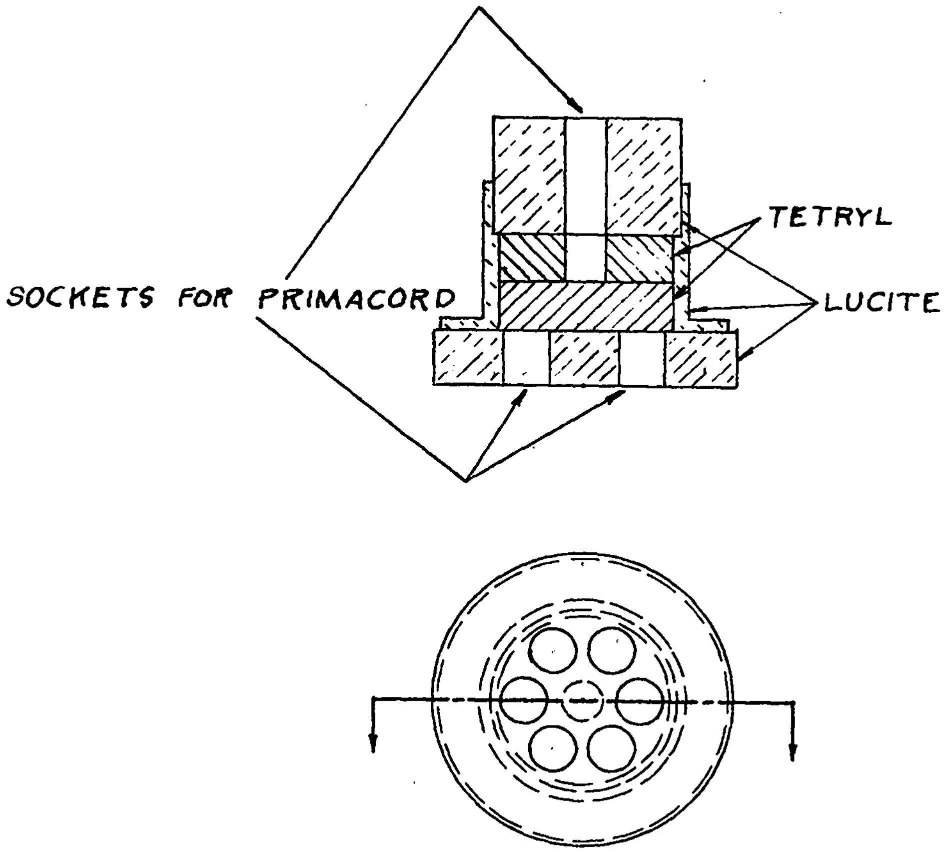
PRIMACORD JUNCTION



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C. B. C. 10-27-

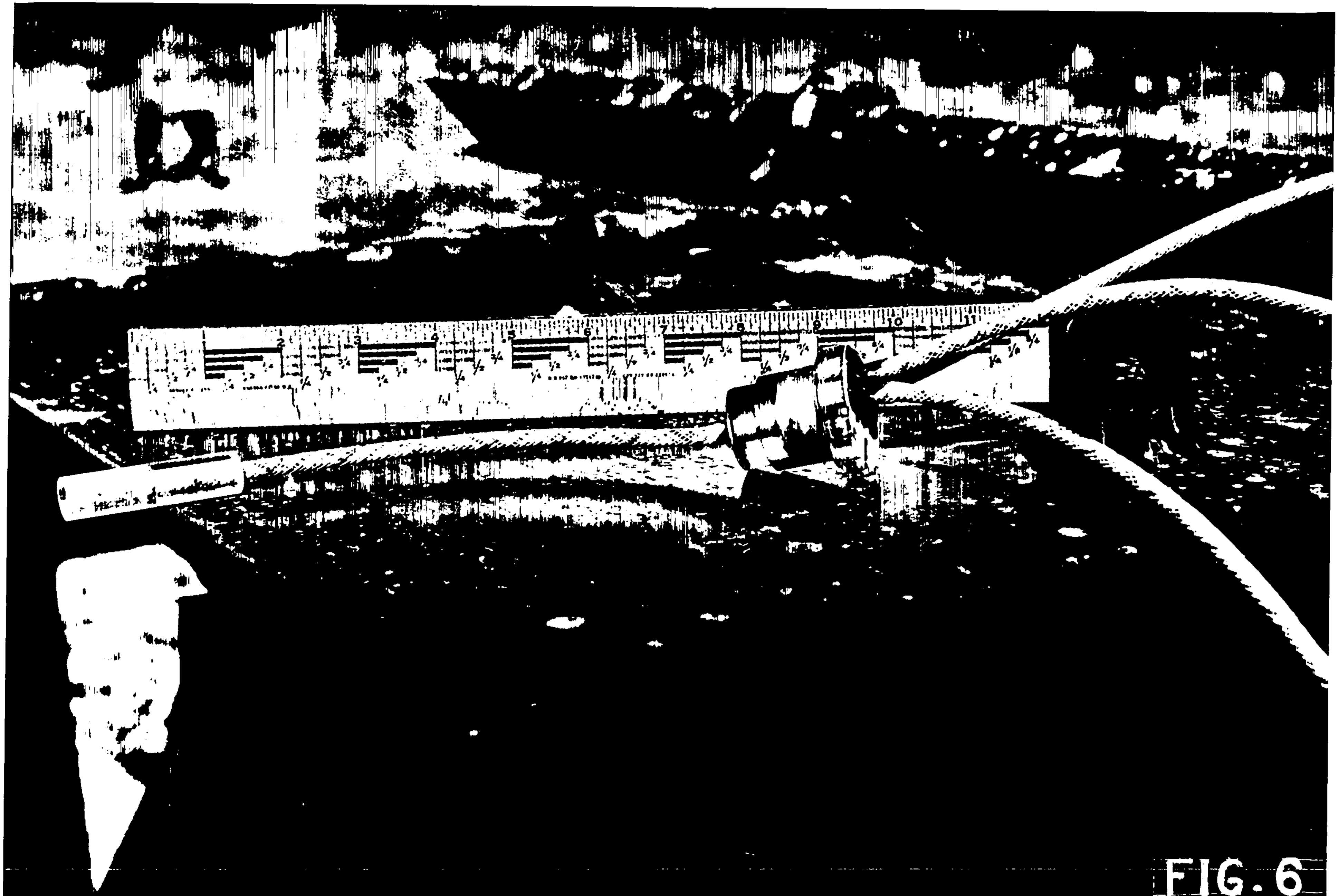

FIG. 6

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FIGURE 7

METHOD OF INTERPRETATION OF SHOT PICTURE

SAMPLE SHOT NO. HH-16 (SEE FIGURES 3 & 4)

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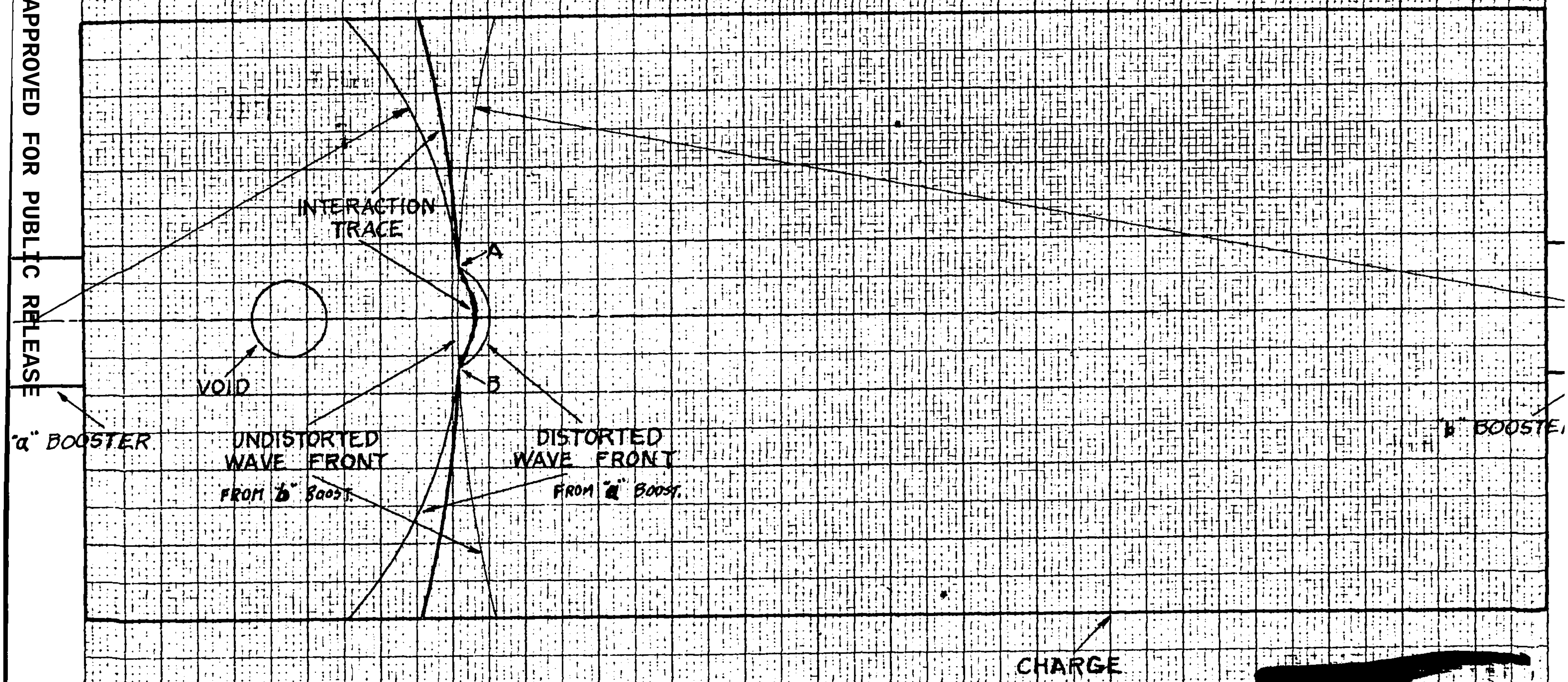

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C.B.C. 1-30-45

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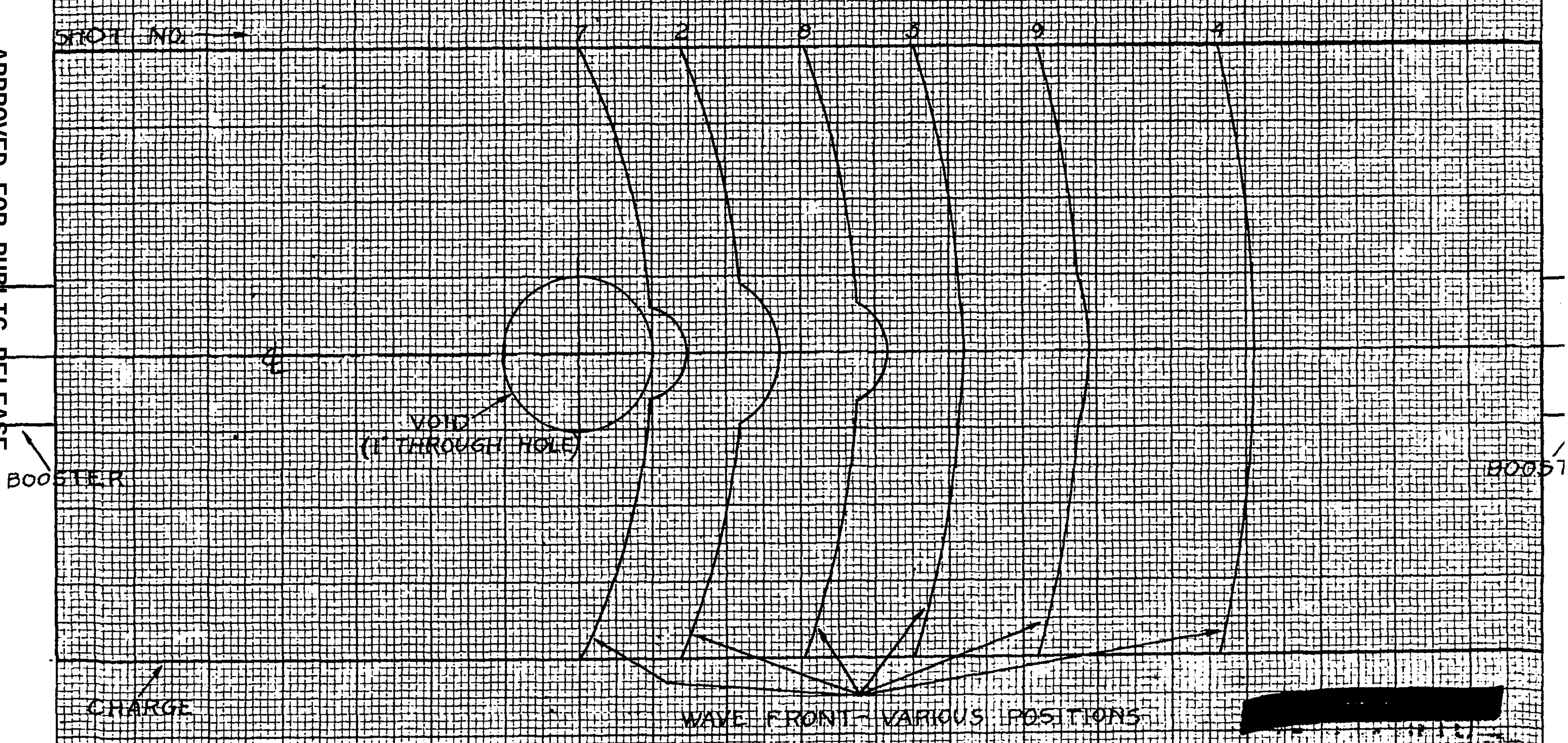
[redacted] FIGURE [redacted]8

PLOT OF SHOCK WAVE FRONT LEAVING VOID

[redacted]



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 [redacted]

Fig. 9. IH-7

Fig. 10. IH-2

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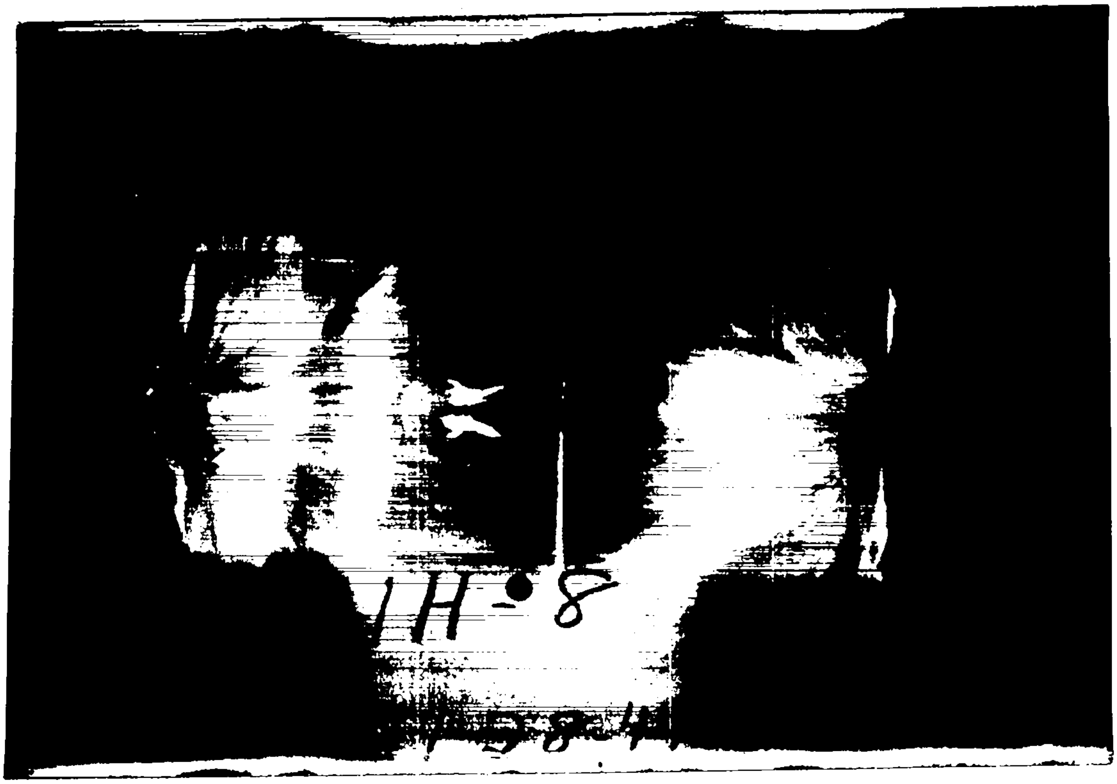

Fig. 11. IH-8

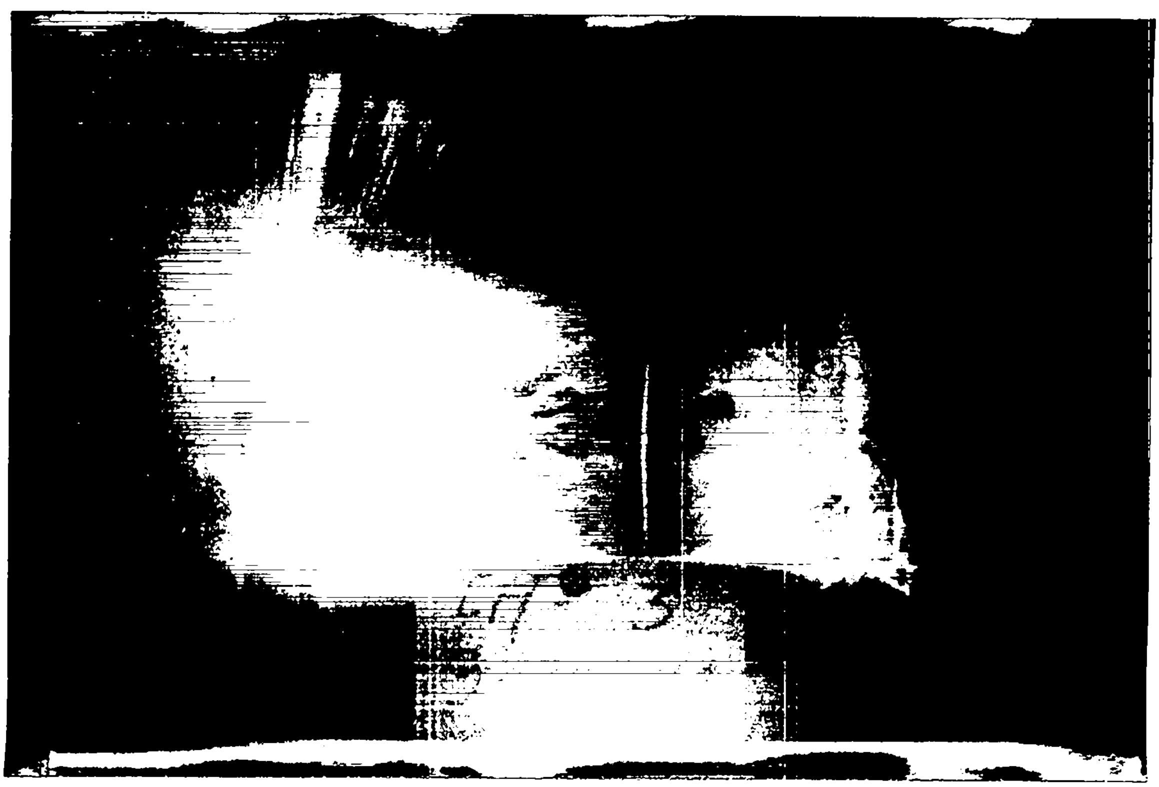

Fig. 12. IH-3

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Fig. 13. IH-9

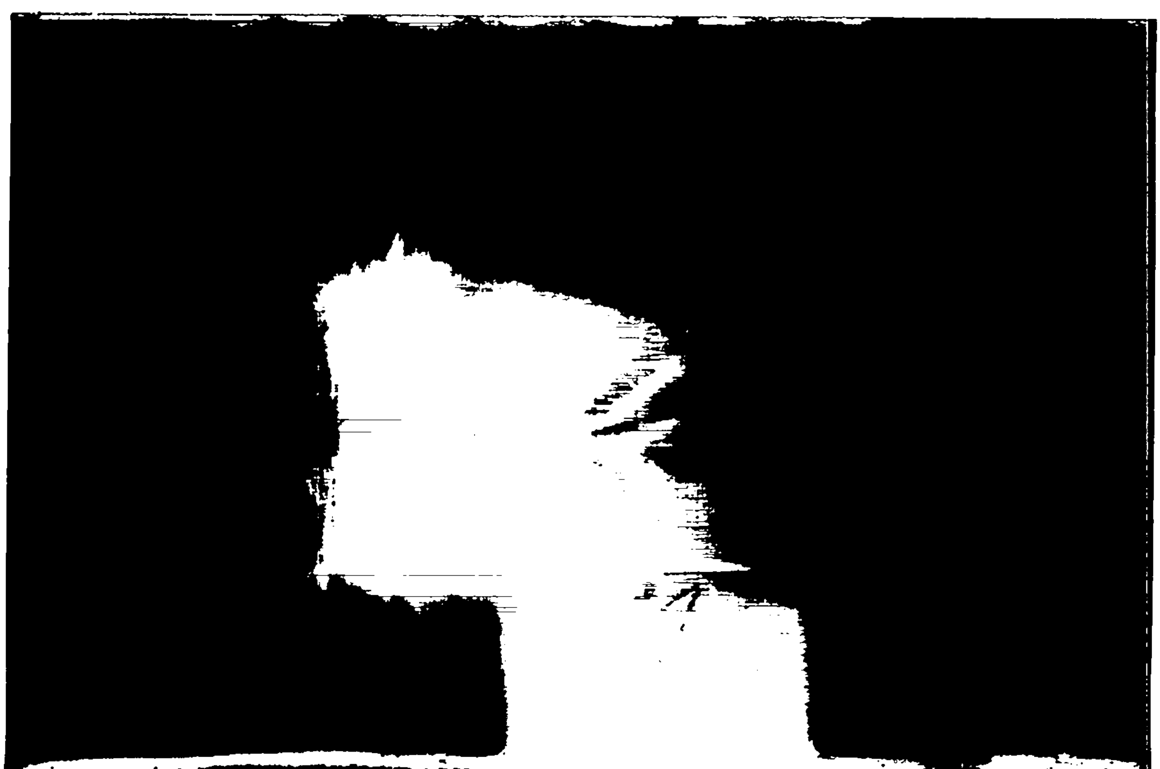

Fig. 14. IH-4

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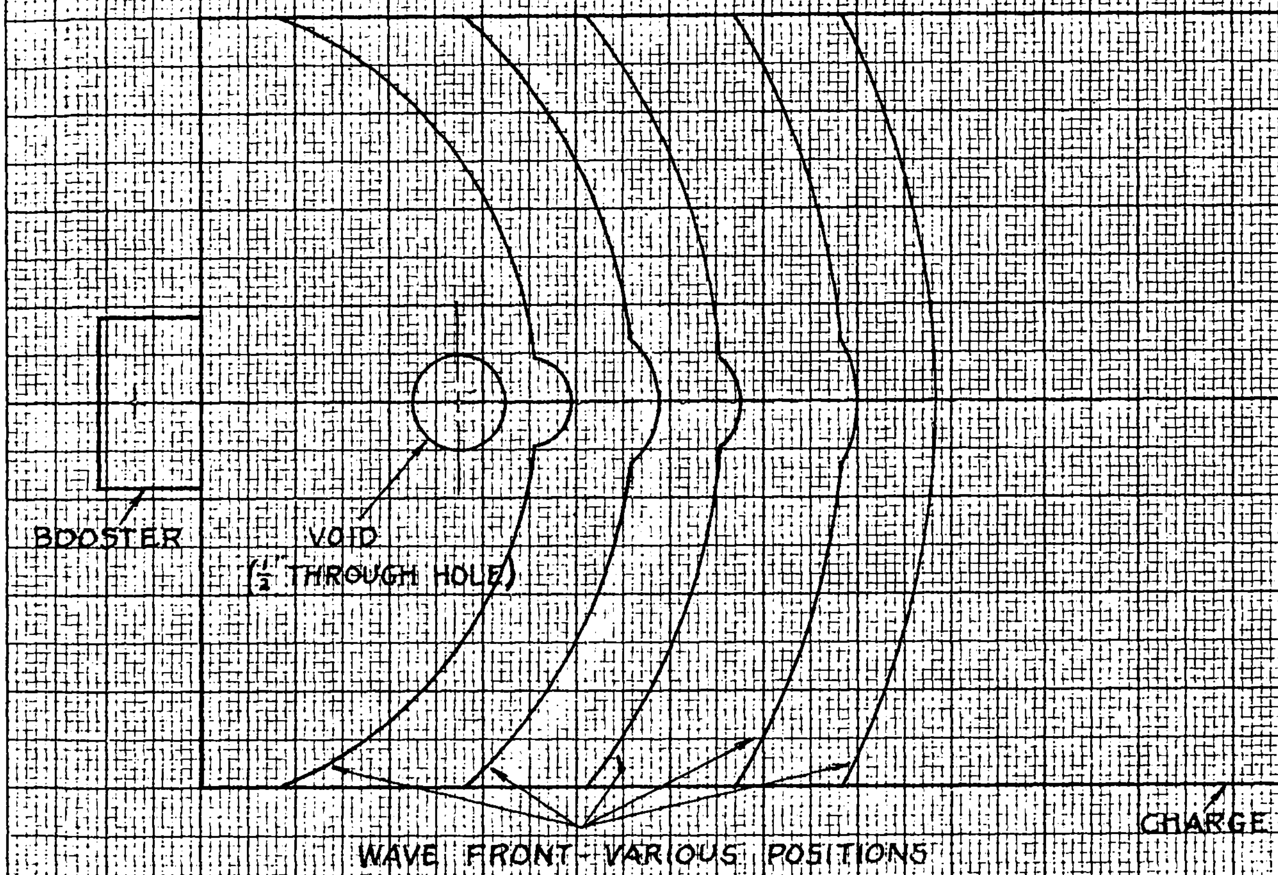
[redacted] FIGURE [redacted] 15

PLOT OF SHOCK WAVE FRONT LEAVING VOID

[redacted]



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C. B. C. 10-29-44

FIGURE 15

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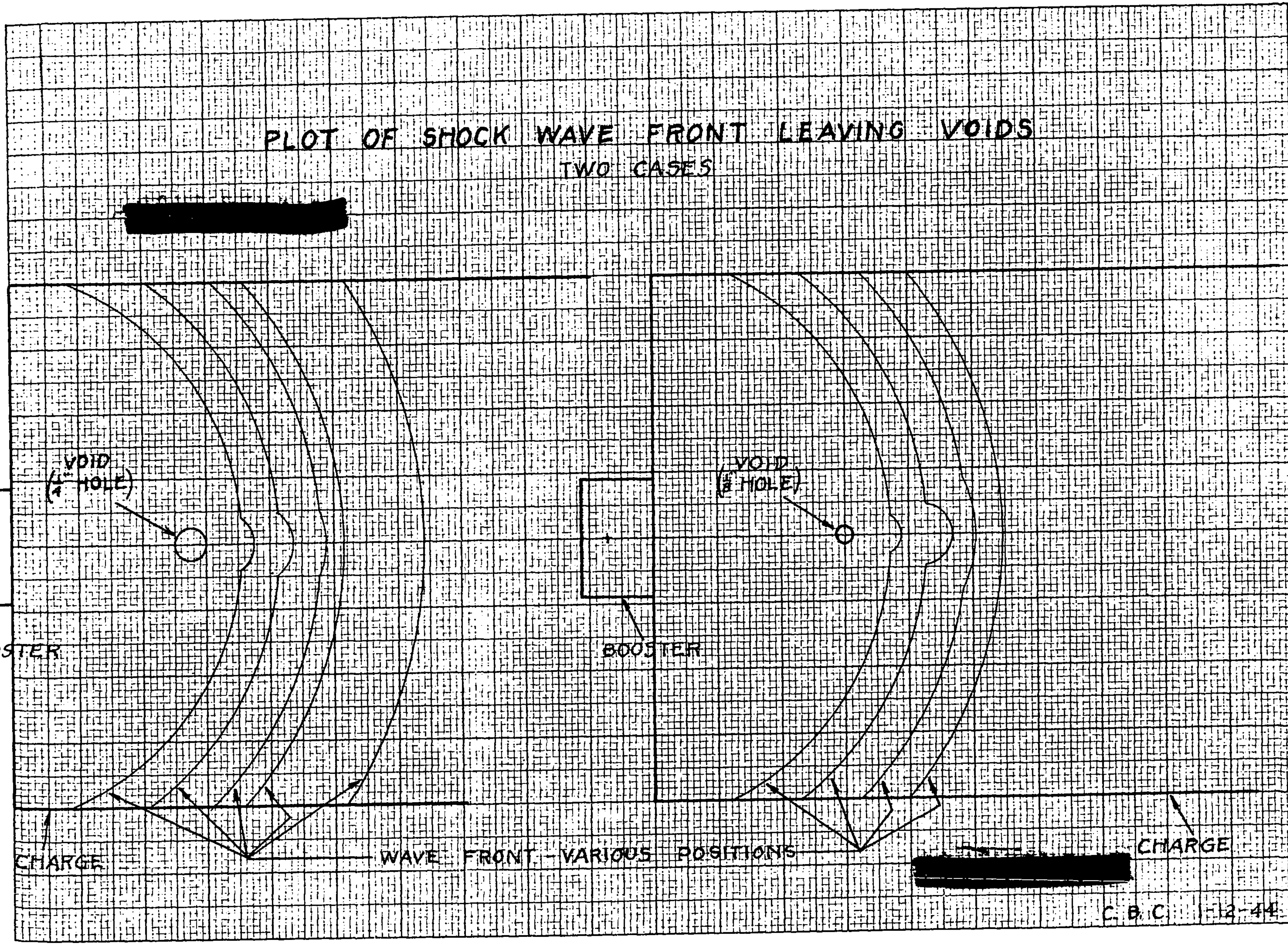
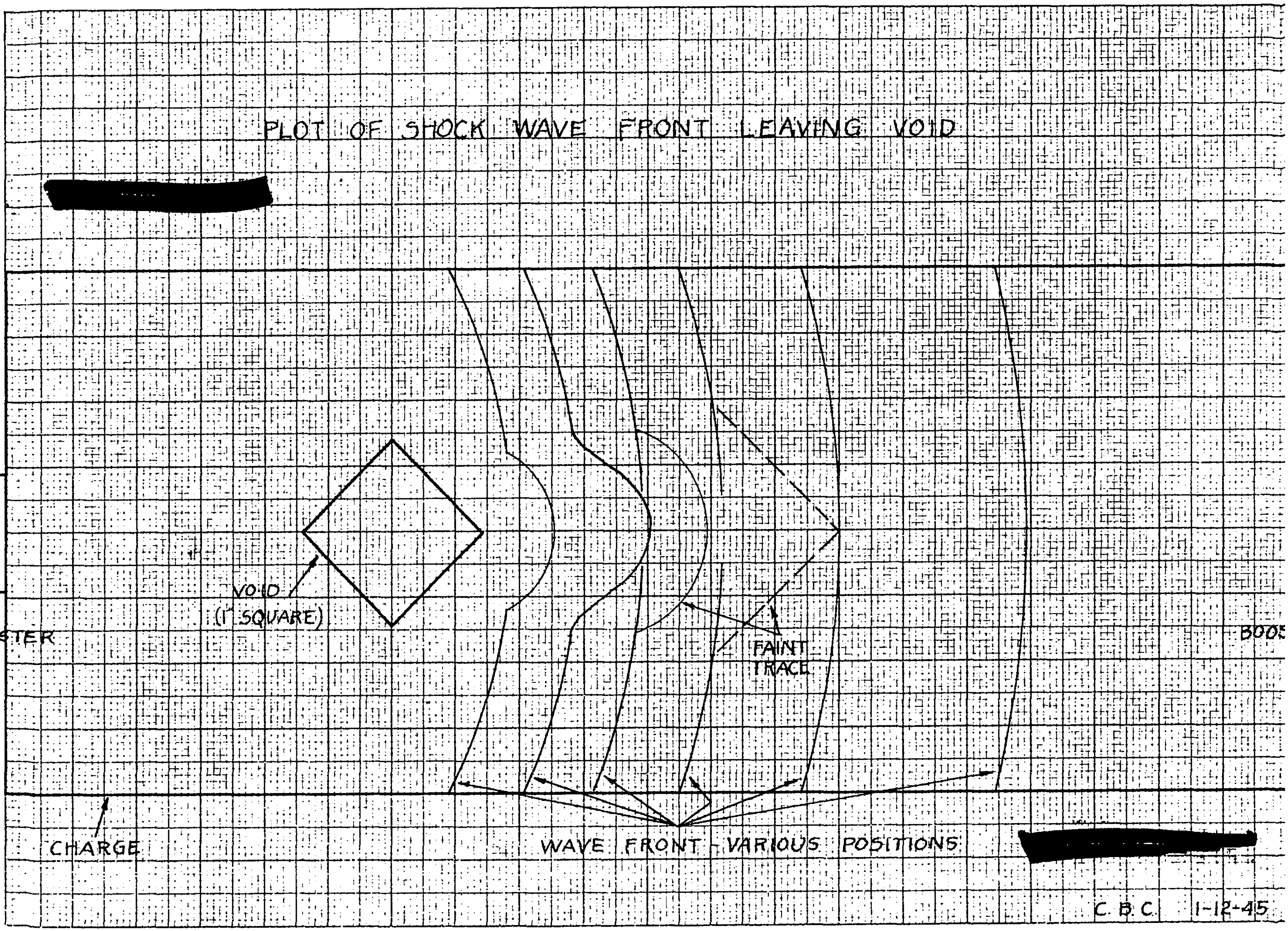

PLOT OF SHOCK WAVE FRONT LEAVING VOIDS
TWO CASES
[redacted]
VOID
HOLE
BOOSTER
CHARGE
WAVE FRONT - VARIOUS POSITIONS
VOID
HOLE
BOOSTER
CHARGE
[redacted]
C. B. C. -12-44

FIGURE 16



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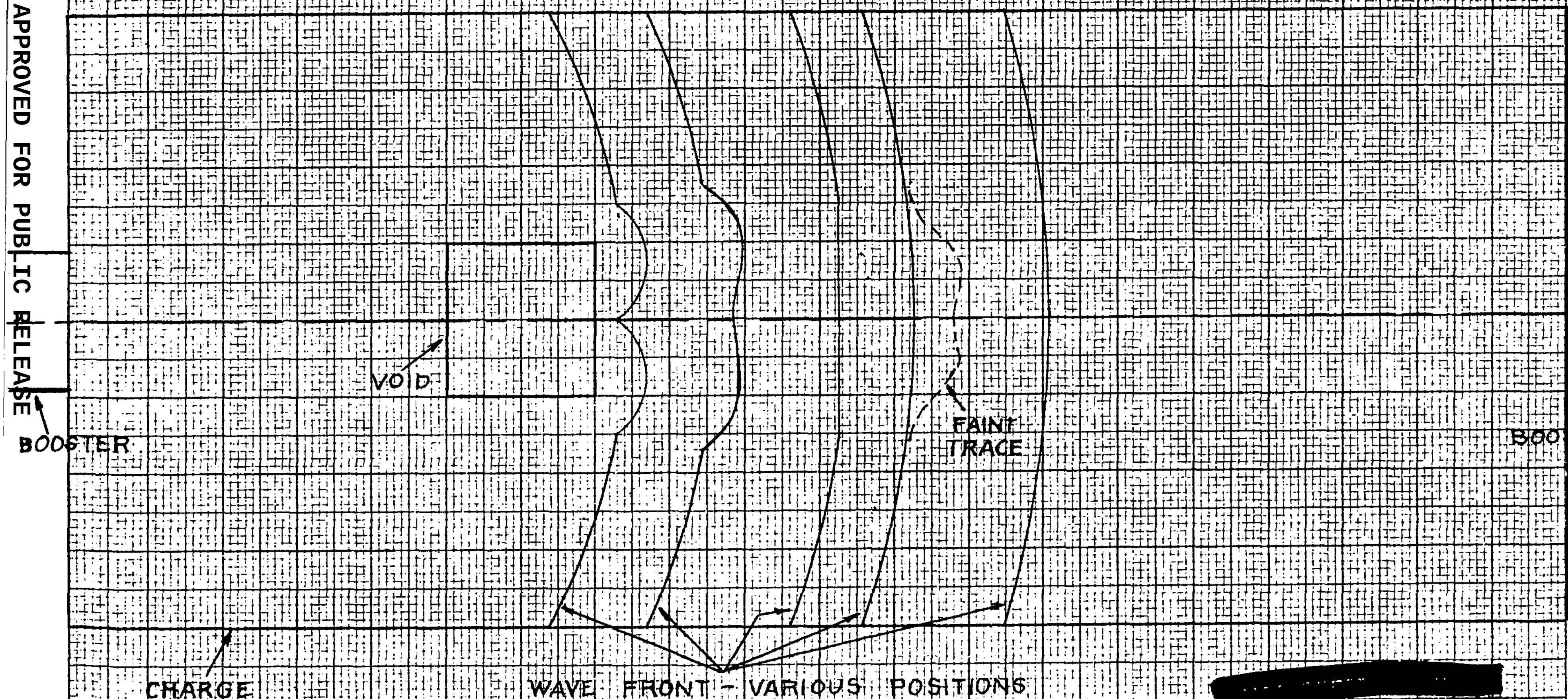
[redacted] FIGURE [redacted] 18

PLOT OF SHOCK WAVE FRONT LEAVING VOID

[redacted]



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C.B.C. 1-12-45

PLOT OF SHOCK WAVE FRONT LEAVING VOID.

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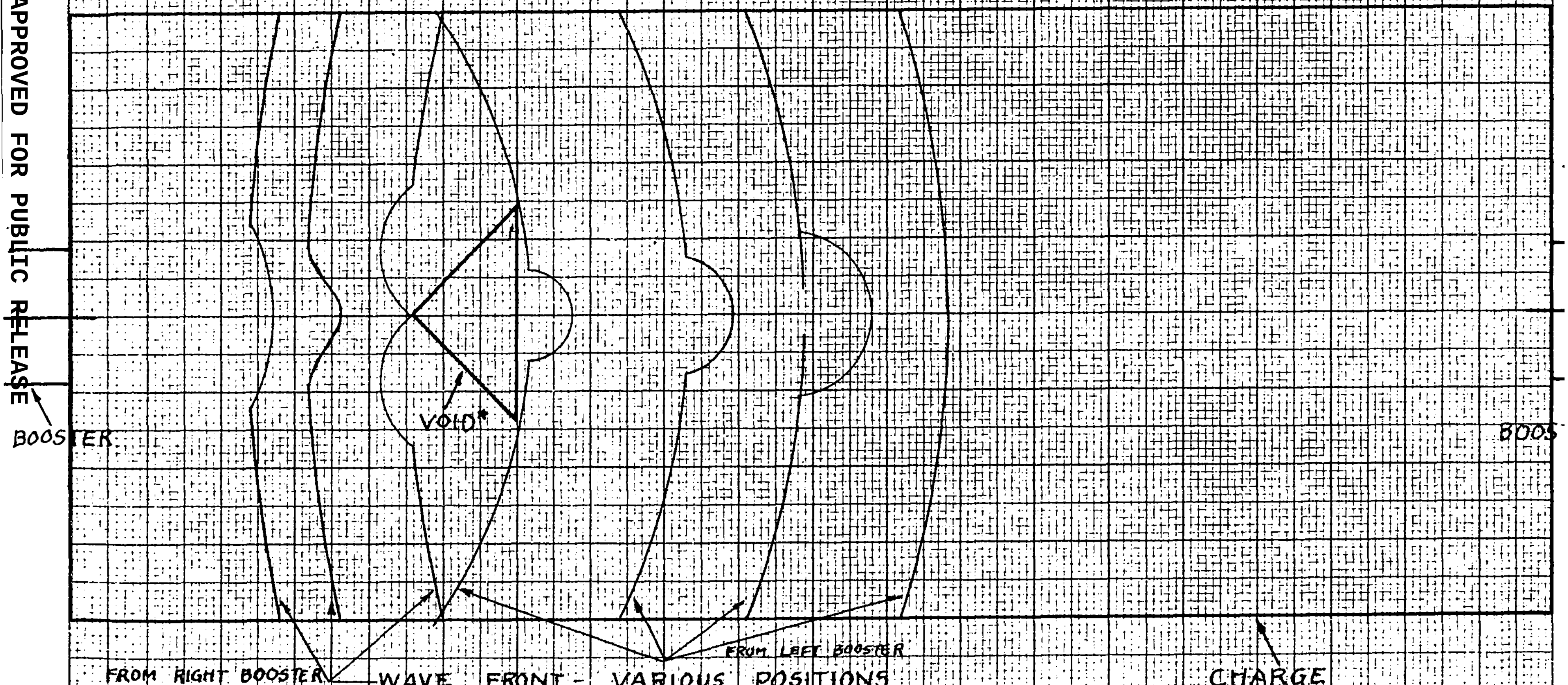

* RIGHT ISOSCELES TRIANGLE, 1" LEGS

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C.B.C. 1-13-45

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PLOT OF WAVE FRONT LEAVING VOIDS
TWO CASES

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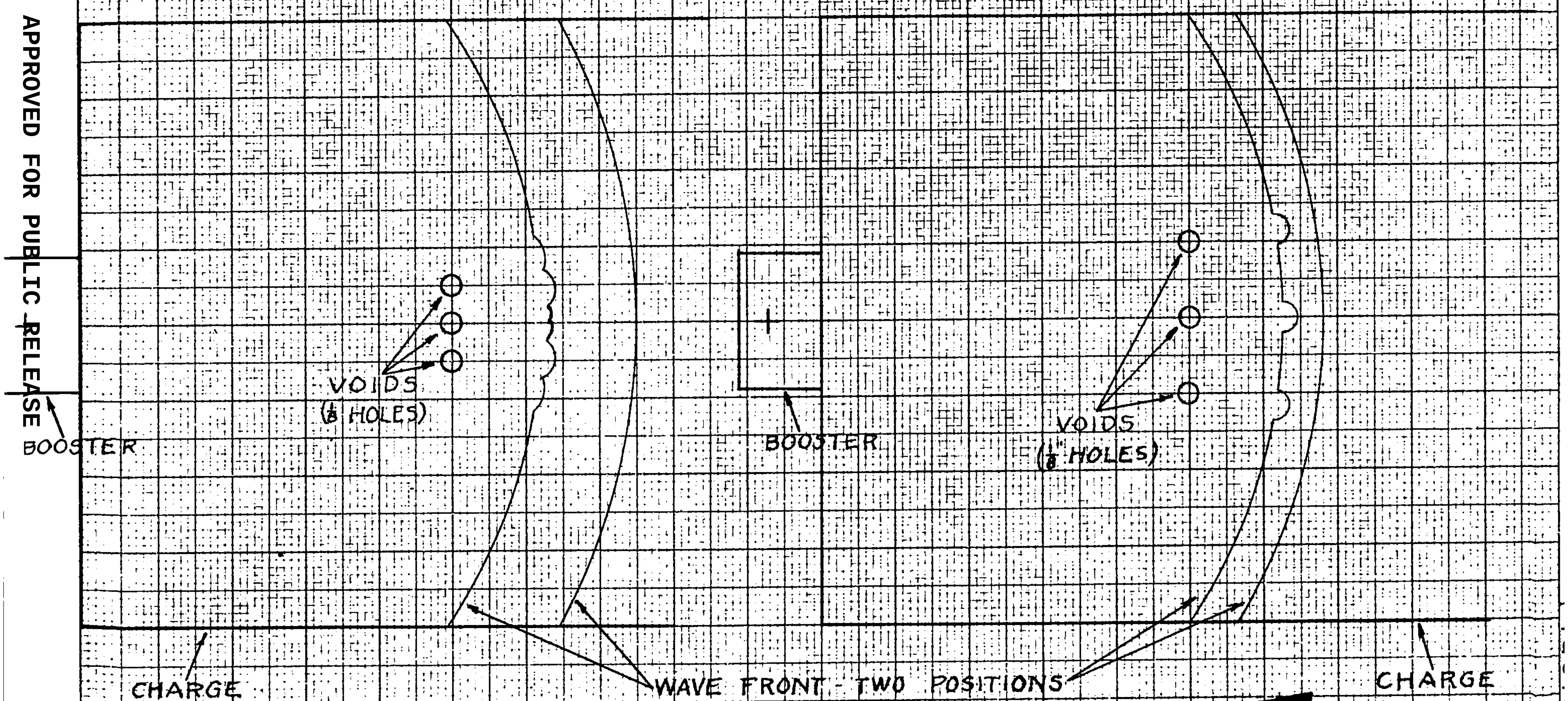

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C. B. C. 1-15-45

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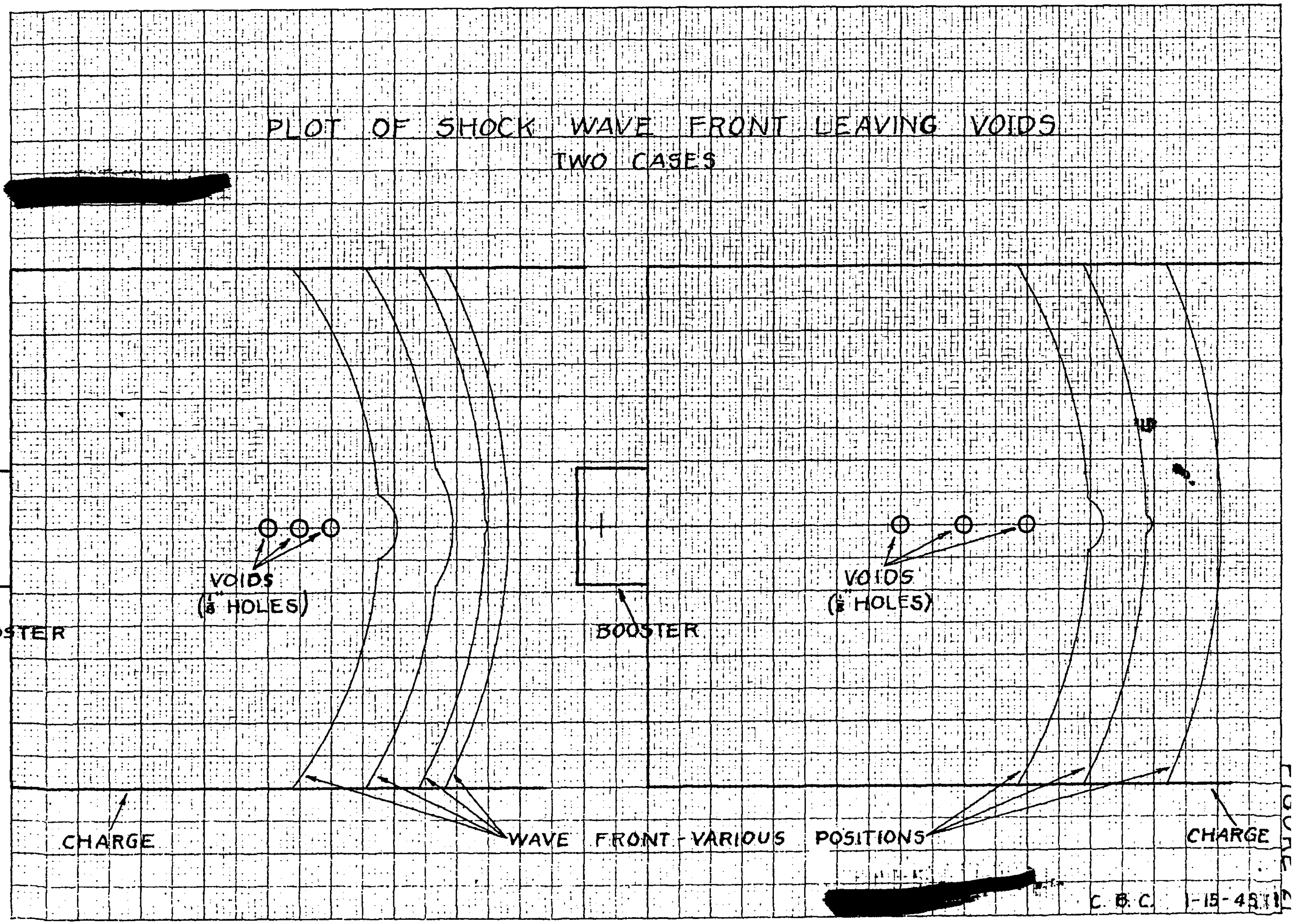

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PLOT OF SHOCK WAVE FRONT LEAVING VOID

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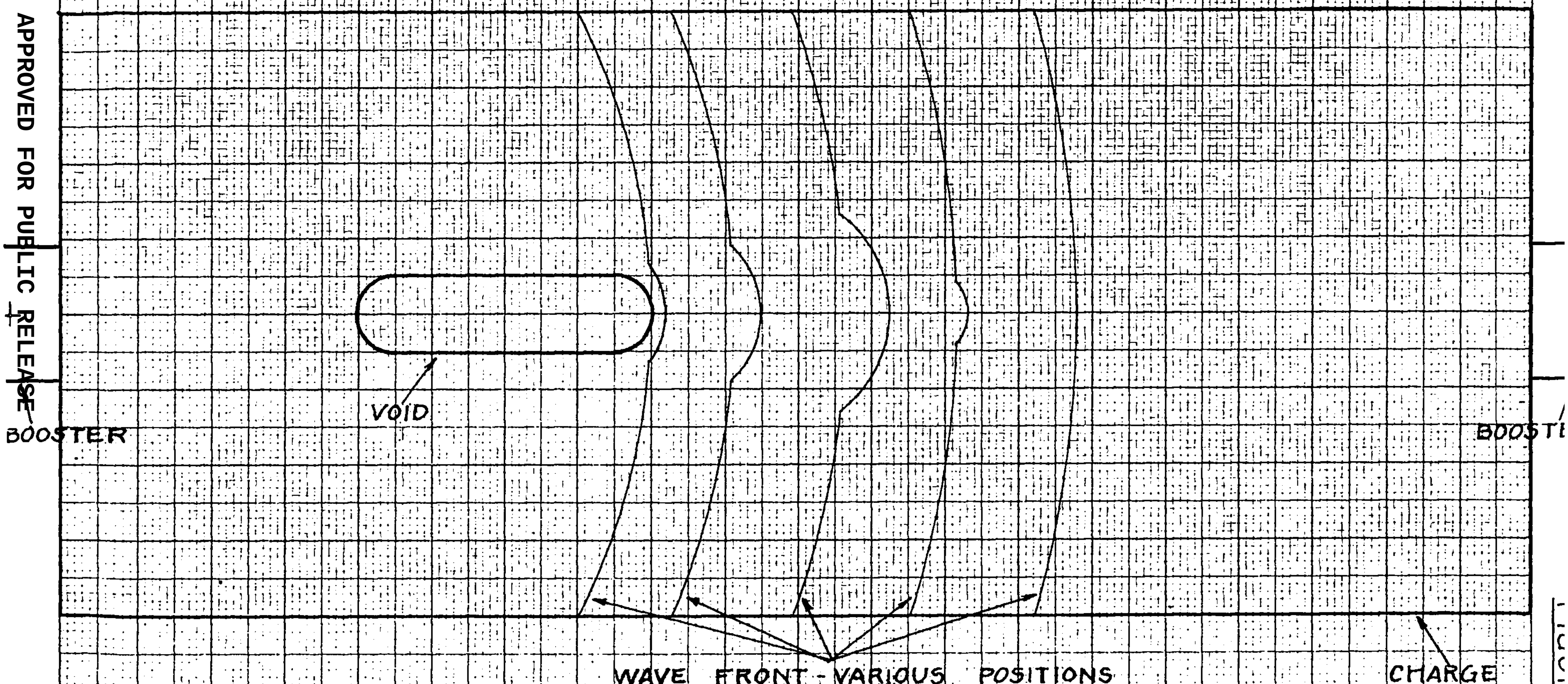

[redacted] C. B. C. 1-15-45

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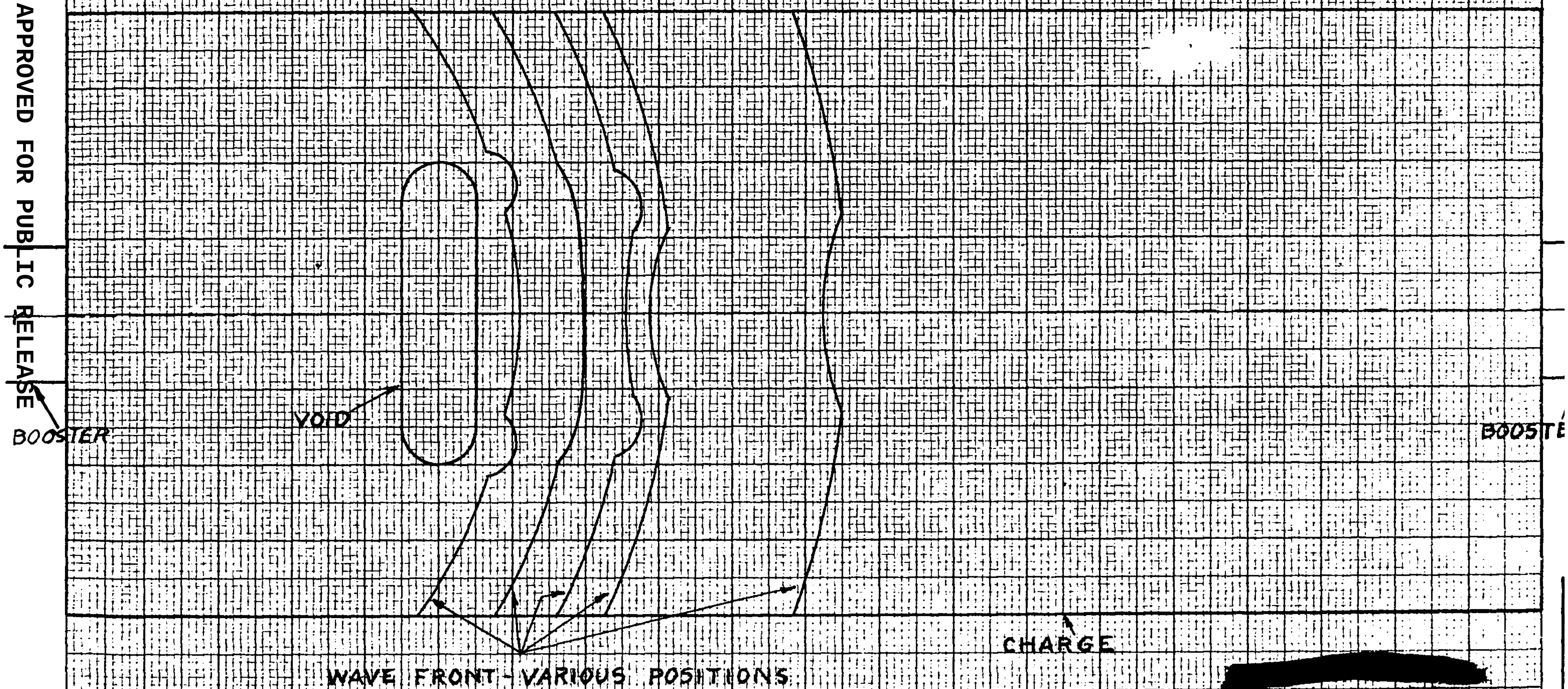
[redacted] FIGURE 23

PLOT OF SHOCK WAVE FRONT LEAVING VOID

[redacted]



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C. B. C. 1-12-45

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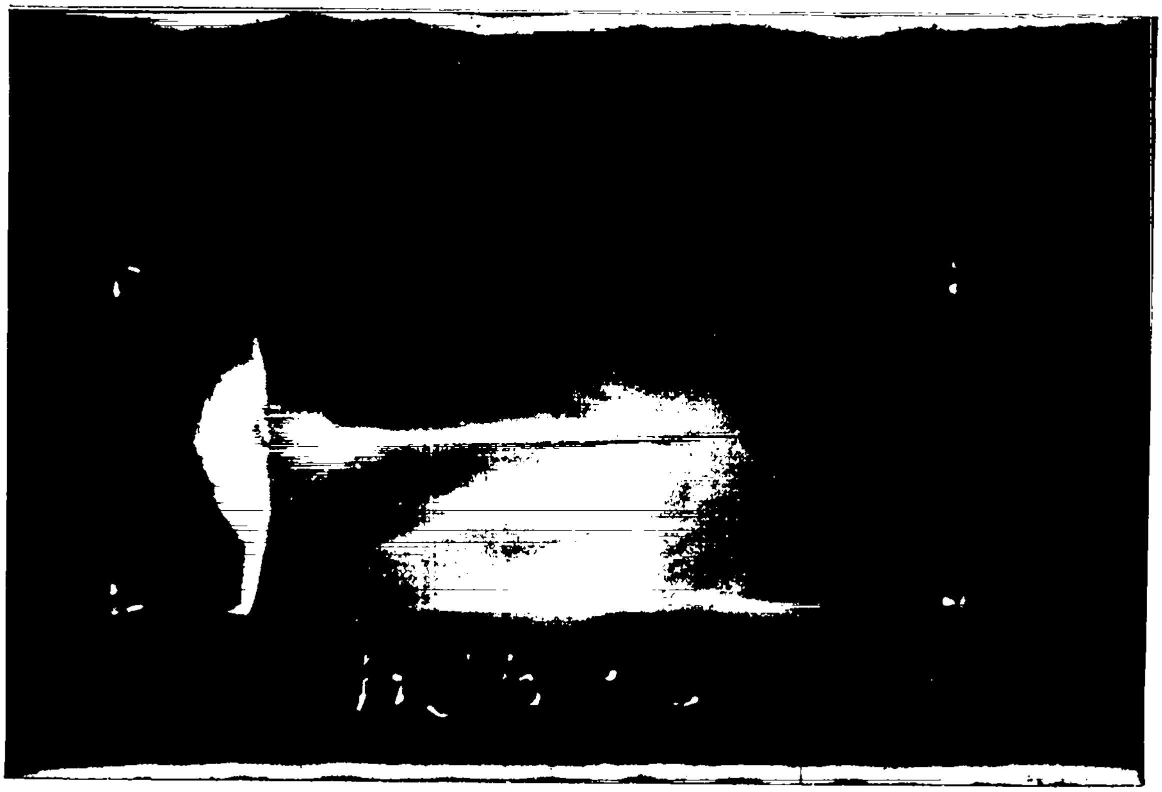

Fig. 24. HSE-2

Fig. 25. HSF-2

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Fig. 26. TT1-5

Fig. 27. BL1-5

[redacted]

EXTENT OF DISTORTION OF WAVE FRONT LEAVING VOID

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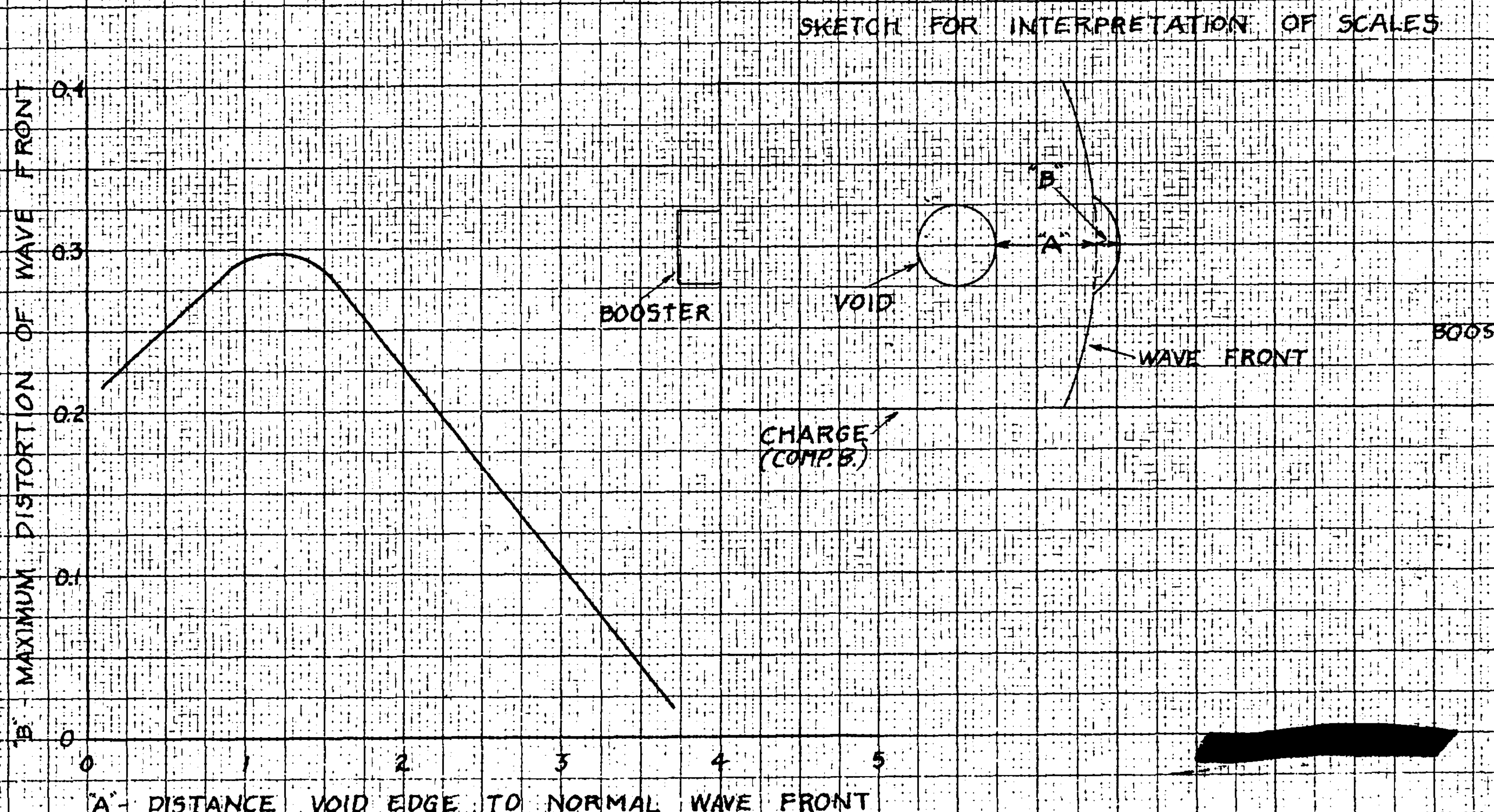

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THE UNIT FOR BOTH SCALES IS THE VOID AVERAGE DIMENSION.

C. B. C. 1-25-45

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