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Vulnerability of Aircraft to 75MM Air-Burst Shell, Project TB3-0238A

41431

Weiss, Herbert K.; Stein, Arthur

(None)

(Same) Aberdeen Proving Ground, Ballistic Research Lab., Aberdeen, Md
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Conditional probabilities are developed from the results of air-burst firings of the 75mm HE, M48 against the B-25 bomber. These are used to prepare contours of constant probabilities about the aircraft. From these contours the conditional probability that a 75mm shell burst causes a kill on the aircraft may be obtained. The pilots represent the most vulnerable component of the B-25 in regards to the air-burst 75mm shell. Average zonal vulnerable areas are obtained for the various major components as a result of field trials. These may then be combined to give the over-all vulnerability of any aircraft with similar components.

Copies of this report obtainable from Central Air Documents Office; Attn: MCIDXD
Ordnance and Armament (22) Shells, Fragmentation (85806);
Ballistics (12) Airplanes - Vulnerability (08494)

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Dated 3 November 1948
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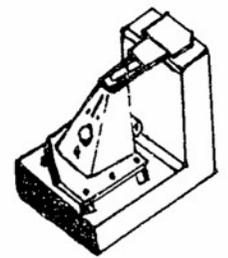


MEMORANDUM
REPORT No. 482



**Vulnerability of Aircraft to
75mm Air-Burst Shell**

Herbert K. Weiss
Arthur Stein



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**Vulnerability of Aircraft to
75mm Air-Burst Shell**

MEMORANDUM
REPORT No. 482

**Herbert K. Weiss
Arthur Stein**

PROJECT NO. TB3-0238A OF THE RESEARCH AND
DEVELOPMENT DIVISION, ORDNANCE DEPARTMENT

20 SEPTEMBER 1948

ORDNANCE DEPARTMENT
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MD.

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BALLISTIC RESEARCH LABORATORIES

MEMORANDUM REPORT NO. 482

Weiss/Stein/mjs
Aberdeen Proving Ground, Md.
8 April 1948

VULNERABILITY OF AIRCRAFT TO 75MM AIR-BURST SHELL

ABSTRACT

Conditional probabilities are developed from the results of air-burst firings of the 75mm HE, M48 against the B-25 bomber. These are used to prepare contours of constant probabilities about the aircraft.

From these contours the conditional probability that a 75mm shell burst causes a kill on the aircraft may be obtained. The pilots represent the most vulnerable component of the B-25 to the air-burst 75mm.

Average zonal vulnerable areas are obtained for the various major components as a result of field trials. These may then be combined to give the overall vulnerability of any aircraft with similar components. Here they were combined for the same type of aircraft as used in the field trials for illustrative purposes.

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INTRODUCTION

This report contains a preliminary description and analysis of firings to determine the vulnerability of aircraft targets to fragmenting 75mm shell, bursting outside the aircraft. The experimental firings were carried out at Aberdeen Proving Ground as a part of an extensive program to determine the vulnerability of aircraft and their components to attacks by missiles, HE charges, fragments, jets, and other weapons.

In these experiments only two types of standard fragmentation shell were employed. They are the 75mm HE, M48 and the 105mm, HE, M1. The present report deals with the 75mm shell only.

In planning the overall vulnerability program originally, it was realized that the variation in fragment mass distribution and velocity among the many types of service ammunition would limit the value of results obtained by firing any particular standard shell, such as the M48. It was apparent that it would be practically impossible to predict from the results obtained with one shell, the effectiveness of a shell of widely different characteristics. Since at least 20 aircraft are expended in firings of a single ammunition type, another and more basic method of determining aircraft vulnerability to fragmenting projectiles was sought.

A solution was found in the firing of special shell constructed to emit fragments all of closely the same mass and initial velocity. Development work on these controlled fragmentation shell was started in February 1946. Nine shell types representing three fragment masses and three velocities have been designed, produced and fired to date.¹ It is anticipated that a report on these controlled fragmentation firings will be prepared in the near future.

In spite of the firings of controlled fragmentation shell, it was considered desirable to fire standard shell in order to provide check points for the analysis involved in use of the controlled fragmentation results. Knowing, from results of the controlled fragmentation experiments, the probability that a single fragment of known mass and velocity will cause specified amounts of damage to aircraft components, and knowing, from pit tests of standard ammunition or design estimates the fragment density, mass range, and velocity range of artillery shell, rocket or guided missile warheads, it should be possible to predict the effectiveness of such weapons without the necessity for expending additional aircraft.

The feasibility of such a method may be determined by comparing its results with the vulnerability figures presented in the present report. It is expected that this comparison will be carried out when more results are available from the controlled fragmentation phase.

The present report is, however, concerned solely with the presentation of the program and analyses that have been carried out with the 75mm shell. B-25 bombers were used as a target aircraft and the results are interpreted in terms of vulnerability of the B-25. Since component vulnerabilities are obtained, however, the basic figures may be applied to the determination of the vulnerability to 75mm air-burst shell of any aircraft of similar structure, engine type, and fuel system.

Although sporadic attempts to determine the vulnerability of aircraft to weapons of various sorts have been made by the various services since World War I, most of these studies involved the expenditure of not more than one aircraft. This single aircraft was frequently fired upon by a half dozen different

¹BRL Report 637, "Development of Controlled Fragmentation Shell Using Grooved Rings", J. E. Shaw, 8 April 1947.

weapon types. The first thorough vulnerability program during World War II was carried out in the United States at the New Mexico Proving Ground by the Applied Physics Laboratory of Johns Hopkins University.¹ The present program at Aberdeen Proving Ground has been strongly influenced by the methods used, and the results obtained in that pioneering study, particularly with regard to the air burst shell phases, with which the New Mexico program was entirely concerned.

A continuing program is now being carried out at Albuquerque by the New Mexico School of Mines, under Navy contract. A comparison of some of the results of the present New Mexico program, which is also concerned primarily with fragment damage, with the Aberdeen results is contained in an appendix to the present report.

Mention must also be made of the extensive vulnerability experiments of the British references, which are contained in an attached bibliography.

PROGRAM

Description of Firings. The 75mm HE, M48 shell weighs 14.70 lbs. and has a TNT loading of 1.47 lbs. The shell was fired against a 3" thick wooden bursting screen with a muzzle velocity of approximately 1876 ft/sec, at a range of 170 ft. and elevation of about 7°. The striking velocity on the screen was about 1870 ft/sec. The projectile lost about 200 ft/sec in passing through the screen; hence, the velocity at the time of burst was about 1670 ft/sec. The striking velocity at the screen and the exit velocity were obtained by ultra-high speed motion pictures. Figure 1 shows such pictures for the 105mm HE, M1 shell. Similar pictures were also used in a few representative firings to determine the average distance behind the screen at which the shell would detonate.

The shell contained the Fuze, PD, M51A4, modified by removal of the black powder delay pellet. As a result, when the fuze was set for delay action the shell functioned 2' ± 8" behind the screen. The point of burst was always considered to be 2 feet behind the screen.

Firings were conducted from the front and rear of the target B-25 aircraft with the plane of the trajectory parallel to the longitudinal axis of the fuselage. Initial burst points were chosen to lie on the surface of a cylinder with radius of 40 ft. The axis of the cylinder was the axis of the fuselage. The positions of burst were later modified somewhat for further study of particular components.

Description of Target. The B-25 medium bomber (see Figure 2) is a mid-wing land monoplane powered by two radial air-cooled Wright engines (series R 2600-13 or -29) which drive the three-bladed, full-feathering, Hamilton Standard Hydromatic propellers. Each engine has 14 cylinders (attached to the crankcase in 2 rows of 7 cylinders each) and is supplied by individual fuel and oil systems. Two compensated Scintilla SF-14LN-3 magnetos are used for ignition and are attached to the supercharger rear housing cover. In each cylinder, the "right hand" magneto fires the front spark plug while the "left hand" magneto fires the rear.

¹Technical Monograph No. 113, Applied Physics Laboratories, Johns Hopkins University. Part I, Experiments on the Vulnerability of Military Aircraft to High Explosive Shell Fragments, etc., April 1945.

The primary fuel supply for each engine is composed of two large self-sealing tanks located within the wing between the fuselage and the engine nacelle. These are called the main tanks and are placed one behind the other interconnected by a booster line and pump. In addition, three interconnected auxiliary cells located outboard of the nacelle feed each engine. The B-25 S is sometimes equipped with a self-sealing fixed bomb bay tank, located in the upper portion of the bomb bay. A supplementary droppable aluminum tank can also be attached to the support of the fixed tank; however, it is assumed that the bomber considered throughout this report carried neither of these two tanks. The front main tanks each have a capacity of 189 gallons; the rear contain 151 gallons each; and the auxiliaries have a combined capacity of 152 gallons. The fuel system is illustrated in Figure 3. Figure 4 illustrates the armor for the B-25.

The target airplane was usually completely combat equipped. The fuel tanks were loaded with 100 octane gasoline. The engines were running at 2000 rpm and usually six 500 lb., M64, GP bombs as well as 4800 rounds of Cal. 0.50 ammunition were stowed aboard. In some firings twelve 100 lb. bombs replaced the 500 lb. bomb. Twelve caliber 0.50 machine guns were installed as were six low pressure oxygen bottles, each filled to 50 psi. Personnel were simulated by six wooden dummies equipped with flak suits and helmets. The dummies were three-dimensional and constructed of 7/8" pine.

Figures 5 - 7 illustrate the firing position and details of construction of the dummies.

Firings were conducted against the B-25 in both the upright and inverted positions. For fuel cell damage to the plane from bursts occurring below the wings, shells were statically detonated in positions such that the angle of spray would be essentially the same with respect to the target as for the shell which were fired from a gun.

In all, 24 aircraft were expended in the 75mm air-burst tests. This report, however, presents an analysis of only those burst positions occurring above the plane of the wings. In these positions 12 planes were expended.

A left-handed coordinate system was used to identify the points of burst and impact. This system is illustrated in Figure 8. The left-handed system was selected in order to avoid the negative sign for the Y-coordinate characterizing an impact on the plane. A right-handed system is simply obtained by reversing the sign of the Y-coordinate.

RESULTS

Definitions of Assessments. Damage is assessed in the following four categories:

"A" DAMAGE is the probability that the aircraft will start to fall or go out of control within a period of five minutes from the time it is hit. The letter "K" in this category has been used to denote an immediate crash without reasonable doubt; whereas, a notation of "KK" has indicated an immediate crash as well as defeat of the mission.

"B" DAMAGE is the probability that the plane fails to return to base as a result of assessed damage. This category includes the five minutes after the burst as well as the time to return to base; therefore, "B" damage is always larger than or equal to "A" damage but never exceeds 100%. The sum of "A" and "B" may exceed 100%, and an assessment of "100 A" implies an assessment of "100 B" as well.

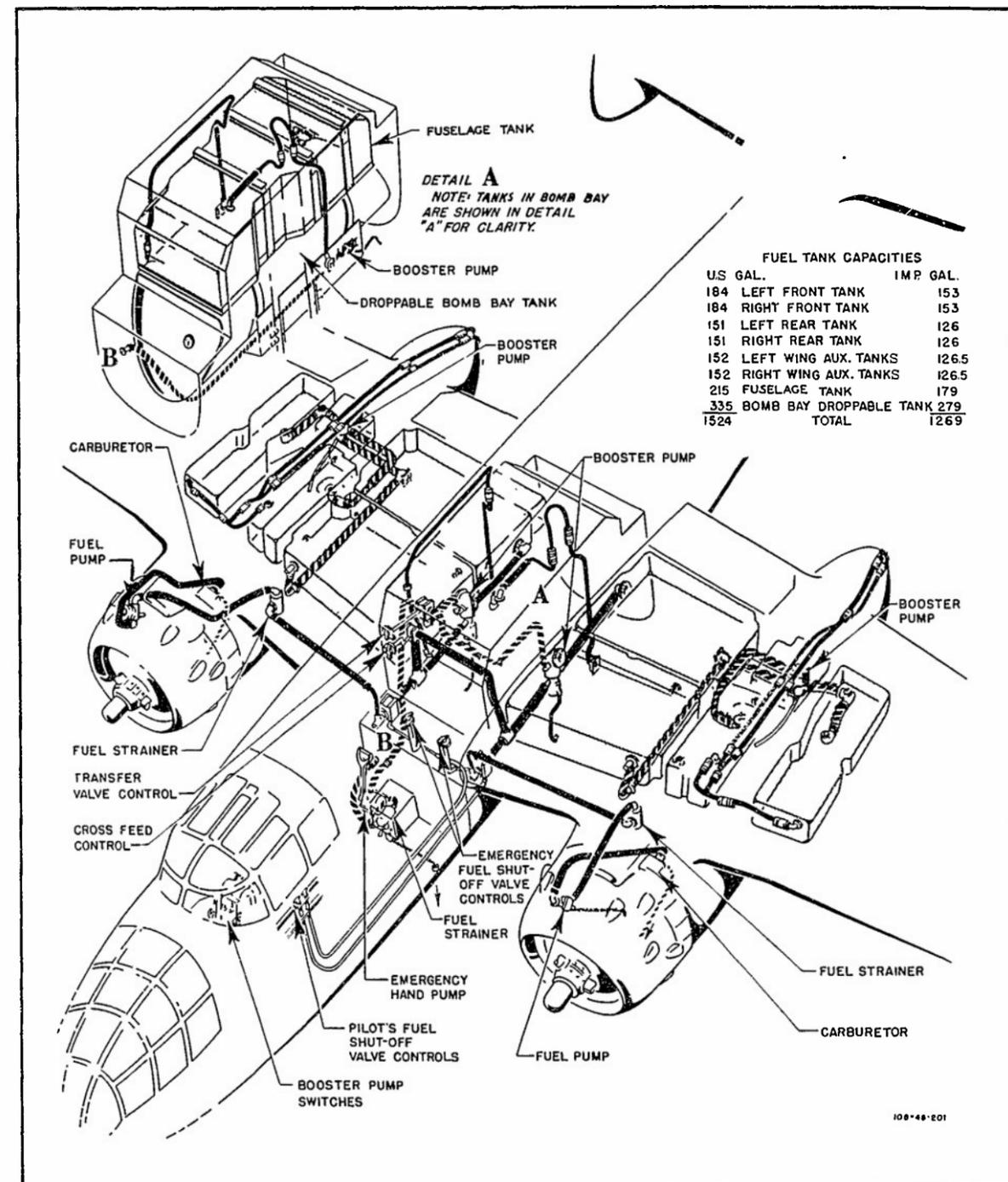


FIGURE 3

The primary fuel supply for each engine is composed of two large self-sealing tanks located within the wing between the fuselage and the engine nacelle. These are called the main tanks and are placed one behind the other interconnected by a booster line and pump. In addition, three interconnected auxiliary cells located outboard of the nacelle feed each engine. The B-25 S is sometimes equipped with a self-sealing fixed bomb bay tank, located in the upper portion of the bomb bay. A supplementary droppable aluminum tank can also be attached to the support of the fixed tank; however, it is assumed that the bomber considered throughout this report carried neither of these two tanks. The front main tanks each have a capacity of 189 gallons; the rear contain 151 gallons each; and the auxiliaries have a combined capacity of 152 gallons. The fuel system is illustrated in Figure 3. Figure 4 illustrates the armor for the B-25.

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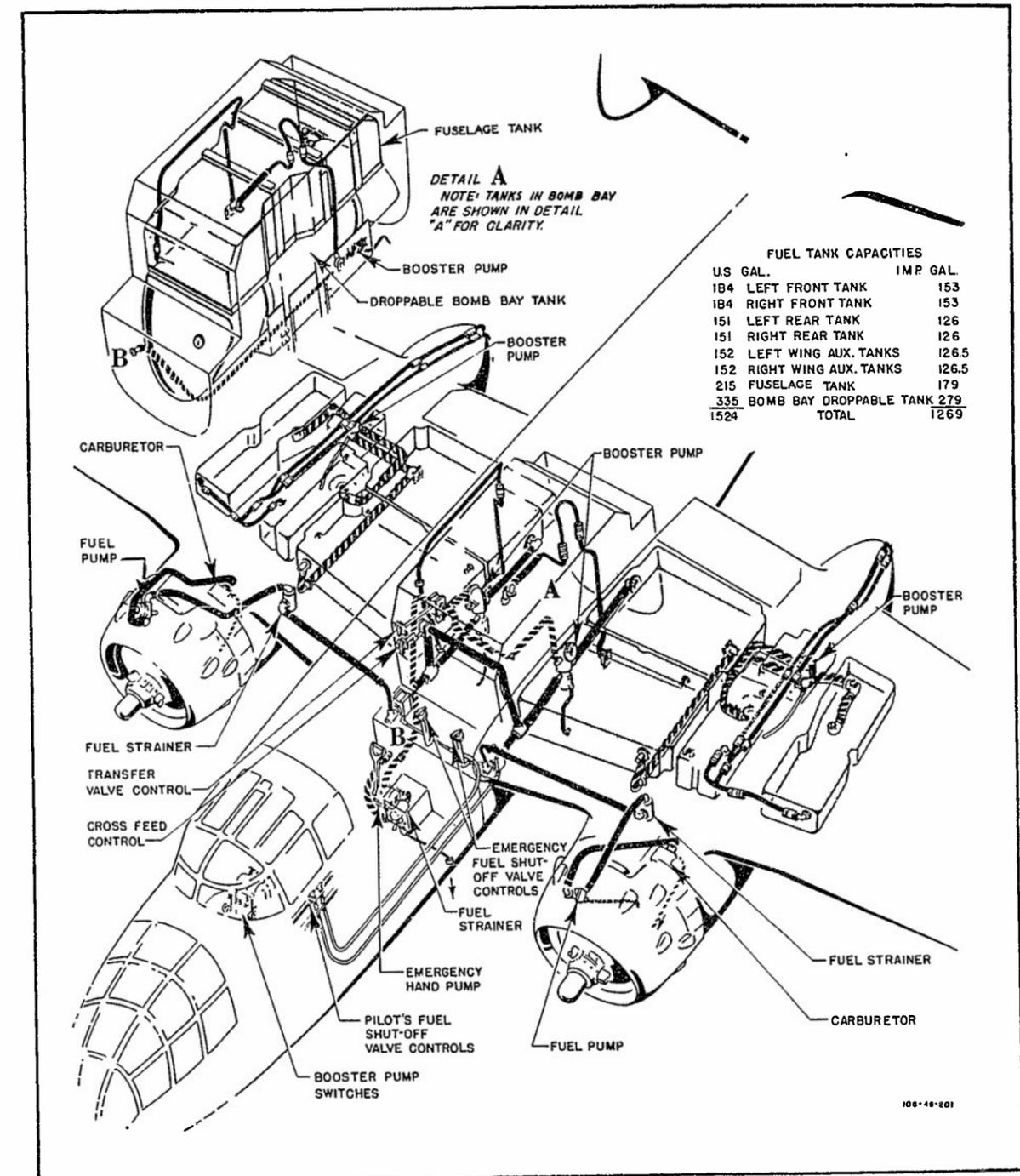


FIGURE 3

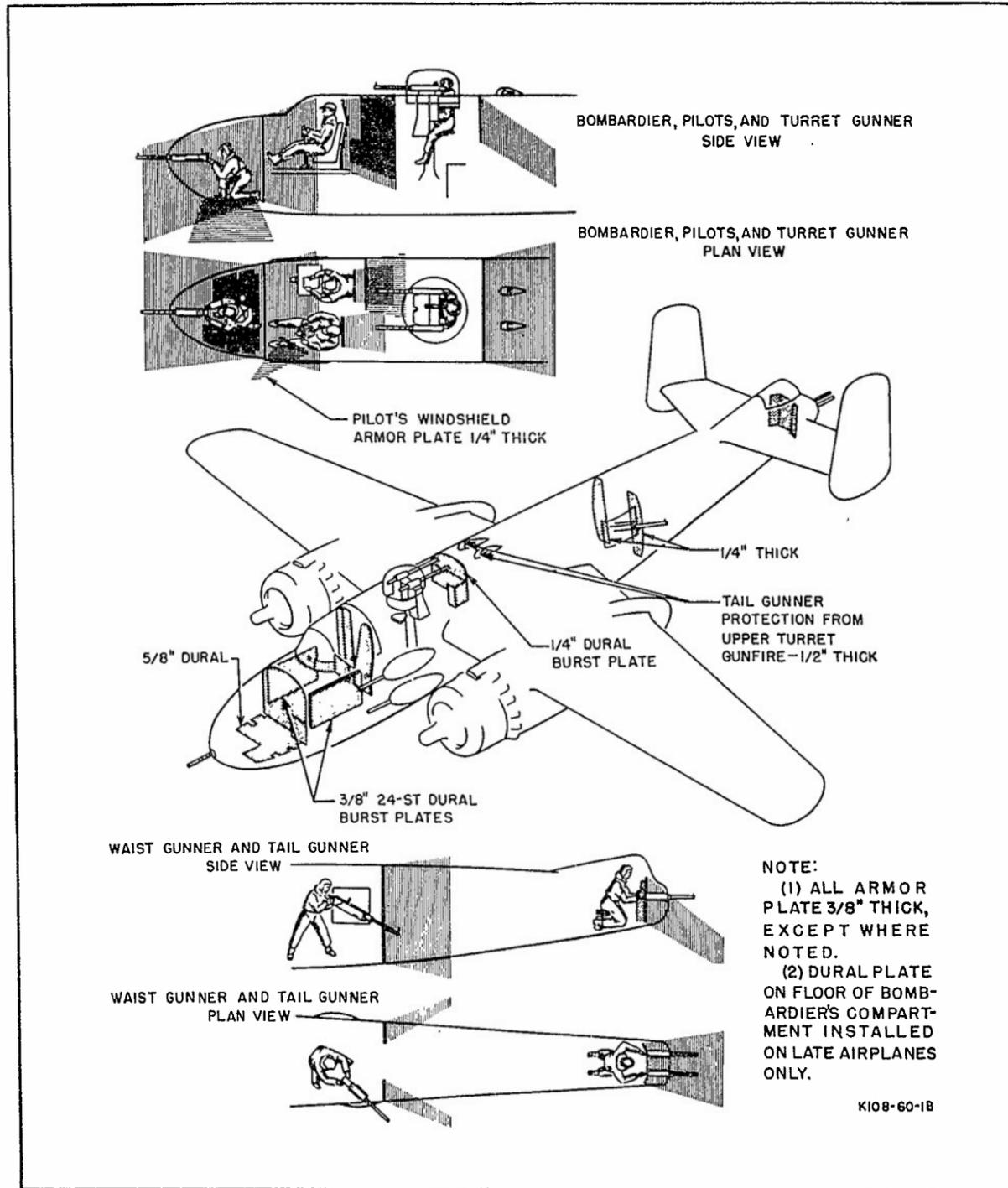


FIGURE 4

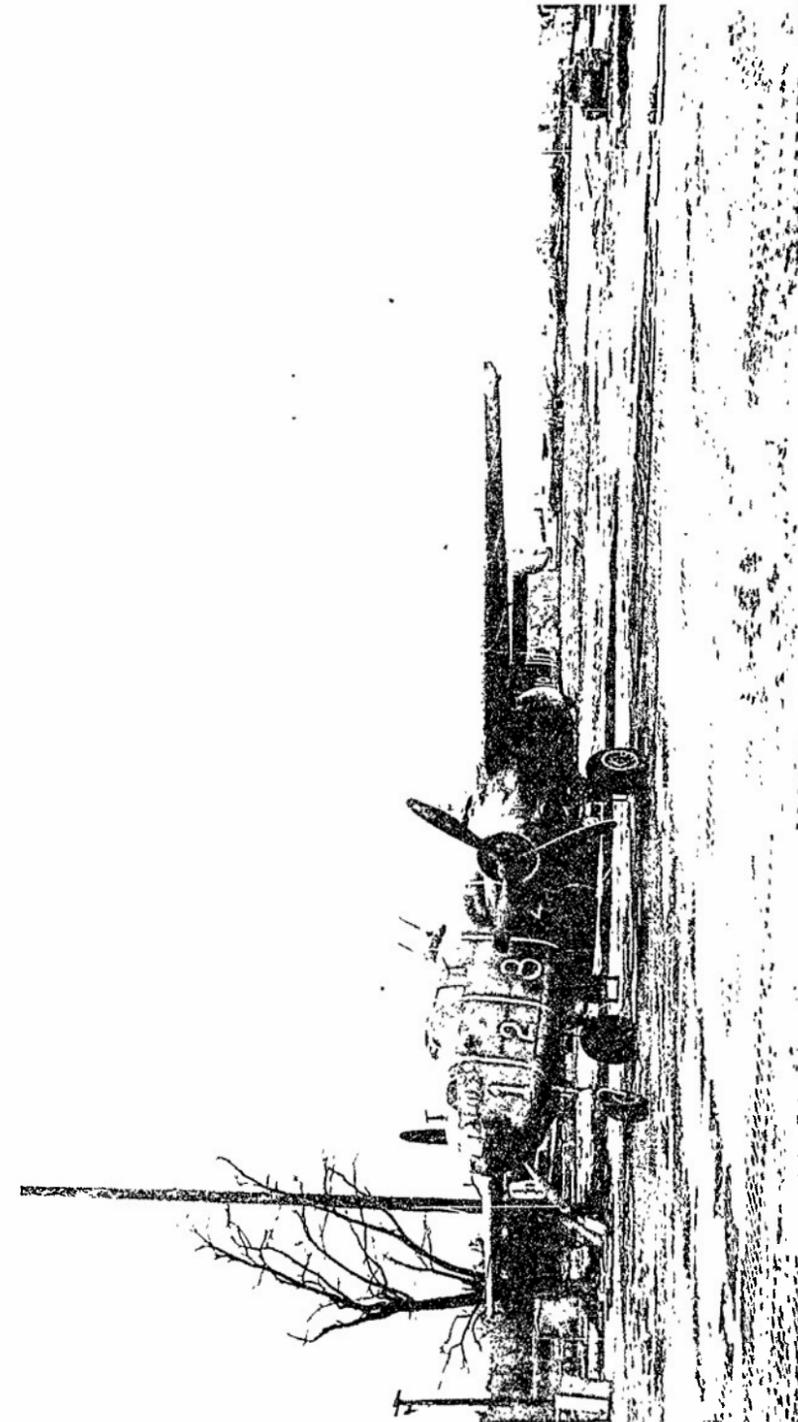


Figure 5. Effect of Shell Fragments upon B25 Airplane. Overall view of installation for dynamic fragmentation test of Shell, HE, M48, 75mm (TNT loaded) when fired from the 75mm Gun, M6.

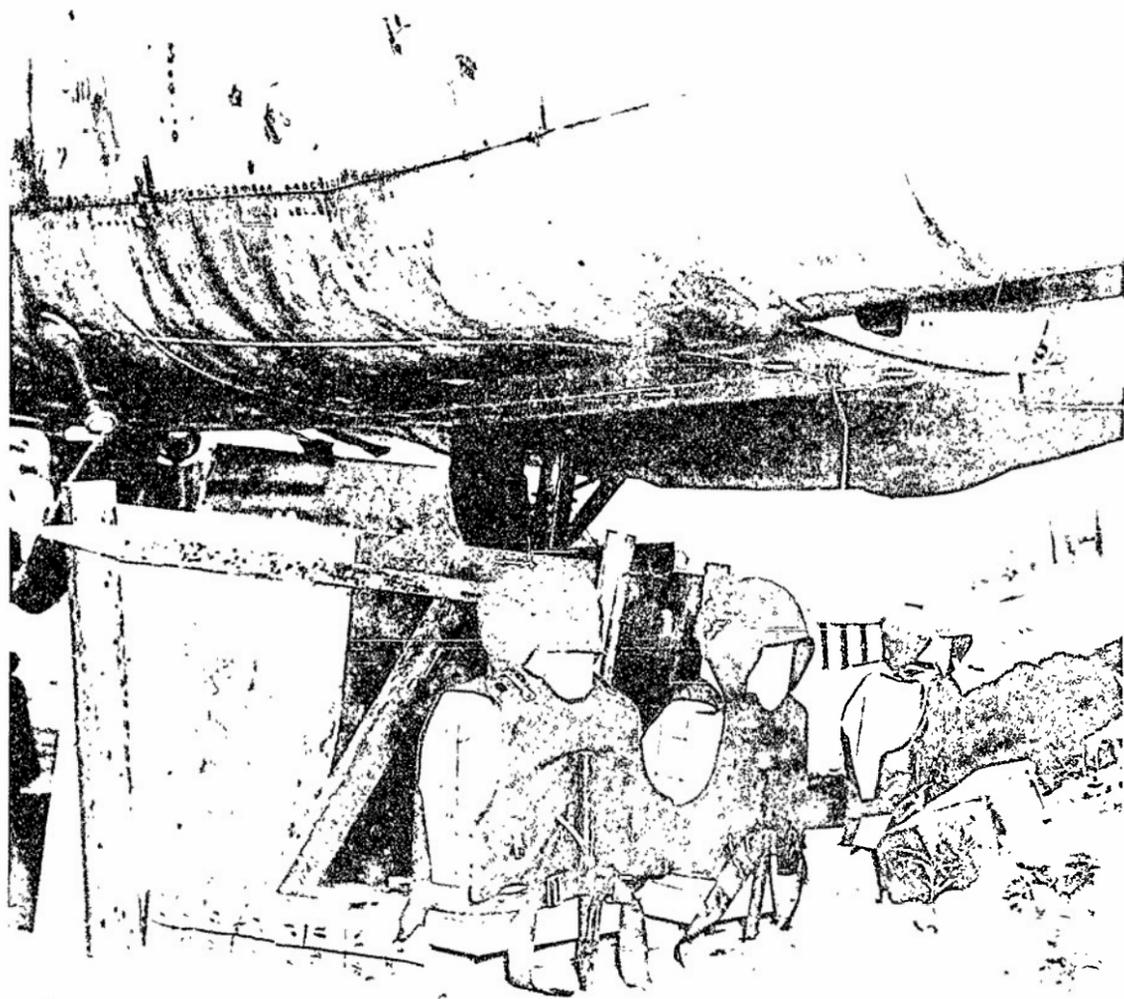
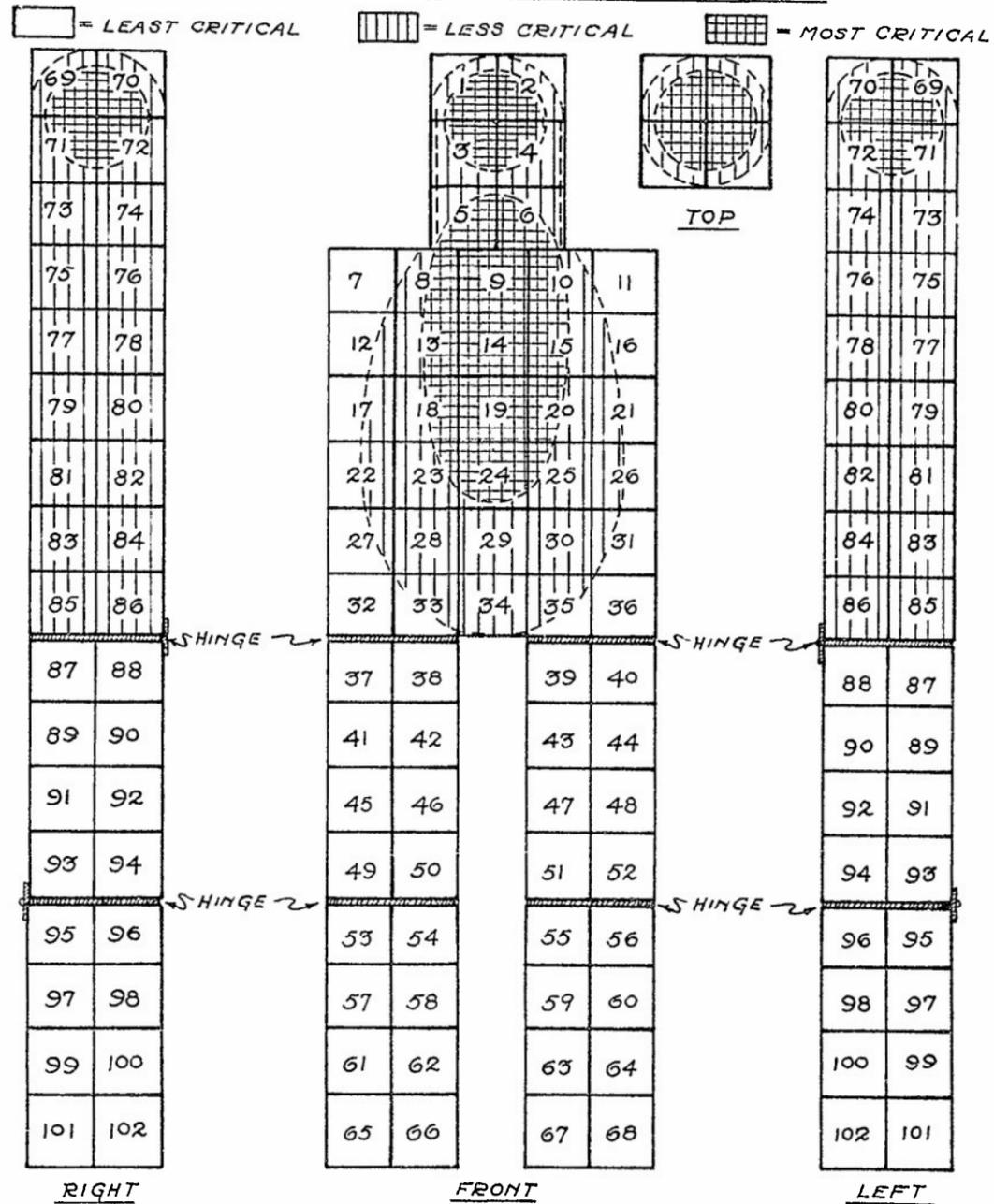


Figure 6. Controlled Fragmentation Test Against Aircraft. General view of dummies placed 2.2' to rear of .051 and .025 Aluminum Alloy plates after test of Type 2 Shell, No. 4, on aircraft No. 31151.

THREE DIMENSIONAL WOODEN DUMMY
USED IN CONTROLLED FRAGMENTATION FIRINGS



RIGHT & LEFT NUMBERS SHALL BE DESIGNATED R. & L. FOR OUTBOARD IMPACTS & R.I. & L.I. FOR IMPACTS ON INBOARD SIDE OF LEGS

FIGURE 7

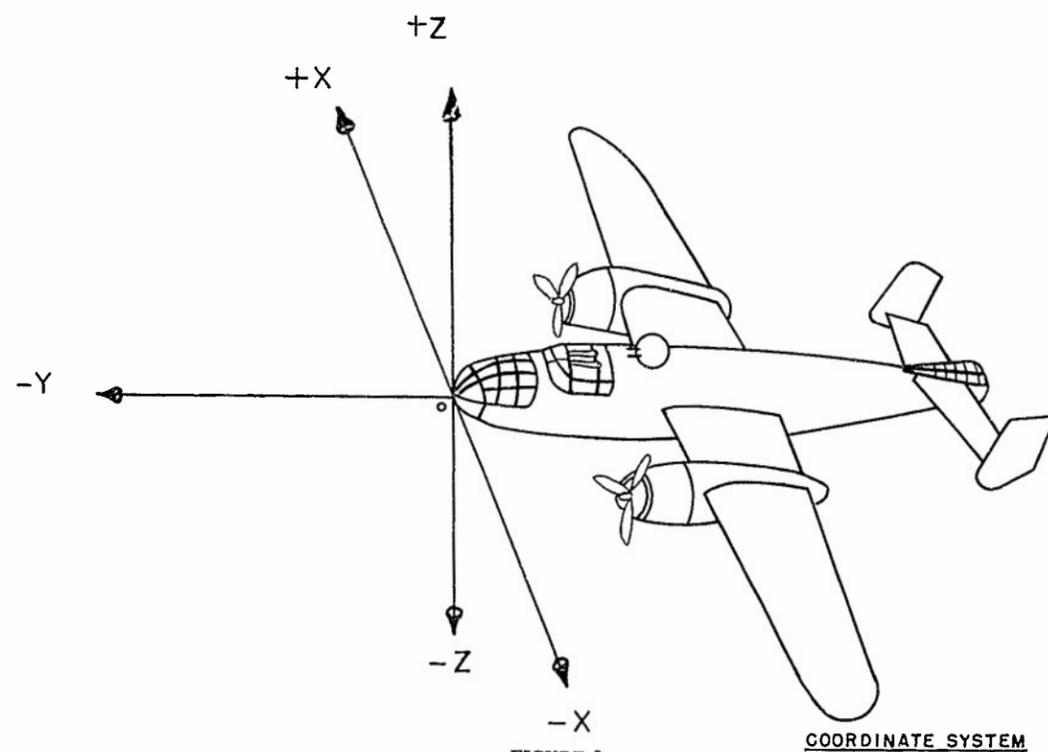


FIGURE 8

COORDINATE SYSTEM

"C" DAMAGE is the probability that the particular attack will not be completed. It is possible to have "C" damage although no "A" or "B" damage exists. Thus, damage to guns, bomb release mechanism, controls whose loss would interfere with the prosecution of the attack, and incapacitation of personnel involved in the attack, would be classed as "C" damage. An immediate kill, KK, implies 100 "C" damage. In assessing "C" damage, or in fact any category of damage, it is assumed that the pilot will remain with the plane and try to prosecute the attack, even though "bailing out" is feasible. The assumption that the attack is 2-1/2 minutes away is also an important one in evaluating "C" damage.

"E" DAMAGE is the probability that the plane will be structurally damaged while landing. ("D" damage, which pertained to manhours required for repair of damage, has been omitted and is not assessed.)

This report analyzes the "A" and "B" categories of damage caused by the 75mm HE, M48 to the B-25.

Compound Damage. Any fragment impacting on an undamaged area or component may be given a single fragment assessment. A fragment impacting on a previously damaged area or component will result in compound damage, and a "compound assessment" is given to the combination of hits in the area. The compound assessments are used to evaluate the conditional probability for obtaining such damage in actual combat. The same definition holds for the "single burst" assessment as compared to a "compound burst" assessment.

Cumulative Damage. Cumulative damage assessments are given for damage to the entire plane. Thus, whereas two hits on the same fuel cell may cause both compound and cumulative damage, two hits on tanks on opposite sides of the plane may be assessed singly and also cumulatively where the resulting damage to the plane is greater than would be expected from the single fragment assessments alone.

Some slight modifications of the definitions of numerical assessments must be made in some cases. Thus, if assessments of damage to a single engine of a multi-engined aircraft were made as defined above, one would not have a true measure of damage to the aircraft as a whole, since even an immediate kill on one engine would not necessarily result in an immediate kill on the aircraft. Hence, for twin-engine and multi-engine aircraft, "A" and "B" assessments for engine damage refer to that engine only, and not to the aircraft. The "C" and "E" assessments in these cases will still refer to the aircraft as a whole.

The "engine" in the B-25 is defined as that part of the power plant forward of the firewall, the engine controls and the oil system.

The "fuel system" includes all fuel tanks or cells, selector valves, transfer and booster pumps, strainers, and fuel hoses, lines and fittings.

"Structures" are defined as any part of the plane except the engine and engine controls and include the aircraft structure, surface controls, dummy personnel, armor, armament, landing gear, etc. The "Structures" assessment is also given exclusive of damage to personnel, and pilot damage is separately listed.

A code is used to describe the physical components and functional systems that are damaged or impaired during the firings, so for each part hit and identified by the code there is an estimate of the relative contribution of damage by that part. Also a non-function code is used to denote component parts that have been rendered ineffective. However, this report dealing with the fragment damage from the 75mm will not present a tabulation of damage to individual components, since such a tabulation is under preparation for controlled fragments. It is much more meaningful to have the component damage resulting from strikes by fragments whose mass and velocity are known.

Assumption of the Mission. Assessments of aircraft damage will vary according to tactical situations. For this reason some basic assumptions are made to which the assessments apply. The following assumptions are made with regard to the B-25.

- a. The aircraft is in level flight, on a solo mission, at an altitude of 10,000 feet.
- b. It is on its bomb run and is hit 2-1/2 minutes (at 200 IAS) from point of release of bombs. Bomb doors are opened two minutes before "bombs away."
- c. The bombsight is pre-set for 200 mph IAS, and the bombs are armed by the bomb-shackle arming hooks.
- d. No evasive action is necessary, and the target area is 500 feet square.
- e. The mission is to drop twelve 100 lb. or six 500 lb. bombs on the target.
- f. Each engine has a spring loaded throttle on the carburetor that will maintain 30" Hg manifold pressure in the event that the throttle cables are severed,
- g. The aircraft flies to the target on fuel in the auxiliary cells and has all four main cells full for the return to base.
 - (1) On twin-engine operation 100 gallons per hour are consumed.
 - (2) On single-engine operation 125 gallons per hour are consumed.
- h. The base landing area is a steel mat 100 feet wide and 6000 feet long.
- i. Both pilots are as competent as possible, know all emergency procedures, and each member of the crew has a working knowledge of every other man's assignment.

If now the vulnerable area of a component to a given type of fragment is defined as the presented area of the component times the probability that the fragment will kill the component if it hits the presented area, the assumption is made that the vulnerable area of a component is the same for all bursts within a zone.

The zones employed in this study are shown in Figures 9 and 10 for the engines and pilots respectively. The zones for fuel and structures are the hemispheres above and below the XY-plane.

The vulnerable areas of the individual major components which constitute the B-25 were determined for each of the zones associated with those components. The calculation of the vulnerable areas was based on the fact that the density of fragments, (fragments per square foot) multiplied by the vulnerable area in square feet, yields the expected number of kills. This may be written as $\rho (A_v) = K$ where K is expected number of kills, ρ is density and A_v is vulnerable area. Because not all of the rounds fired burst at the same distance from each vulnerable component, a correction must be applied for the variation in effectiveness of the fragments with distance from burst point to impact. The dependence of damage on fragment mass and velocity will be determined for aircraft components in the controlled fragmentation firings. Since the controlled fragmentation results are not yet available, a fall-off law for damage was used which was based on the number of perforations obtained per unit solid angle through 1" spruce panels placed at four different distances from the bursting shell.

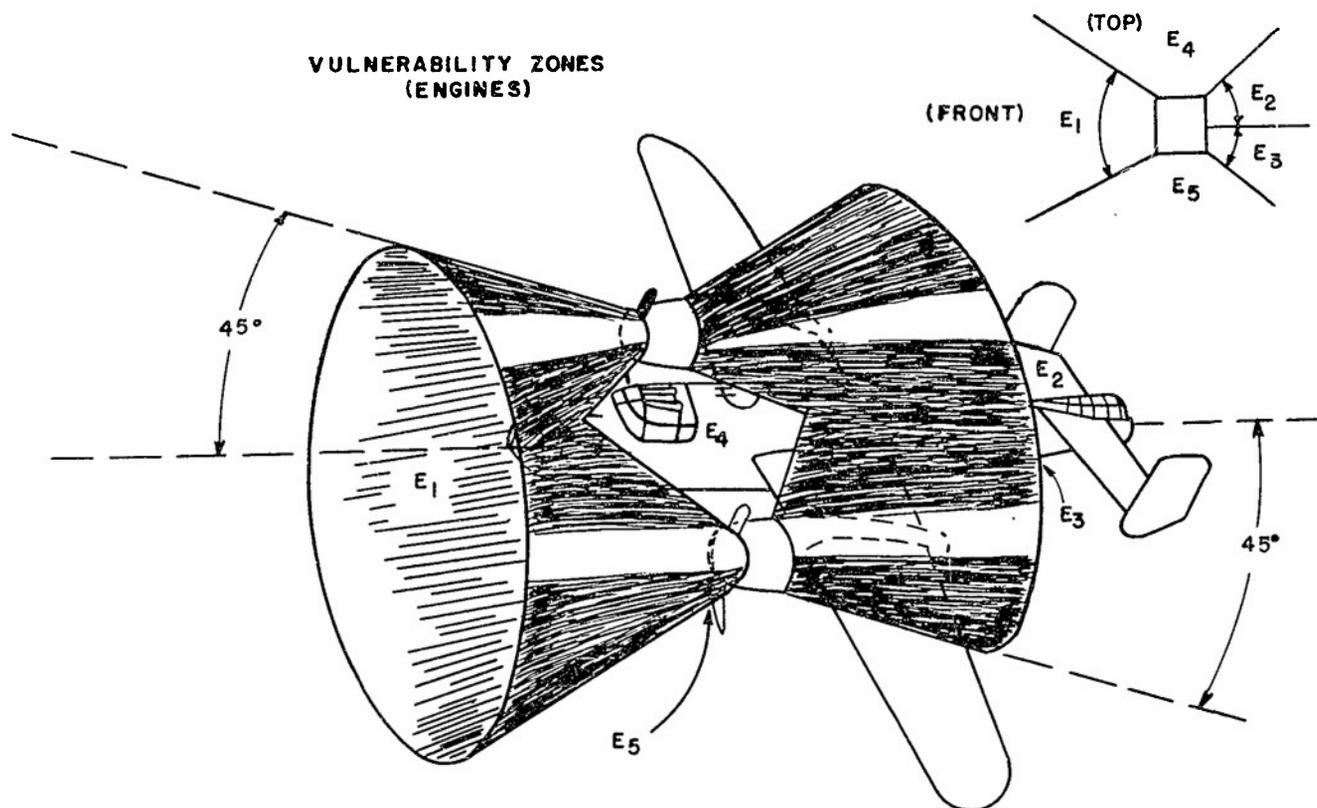


Figure 9.

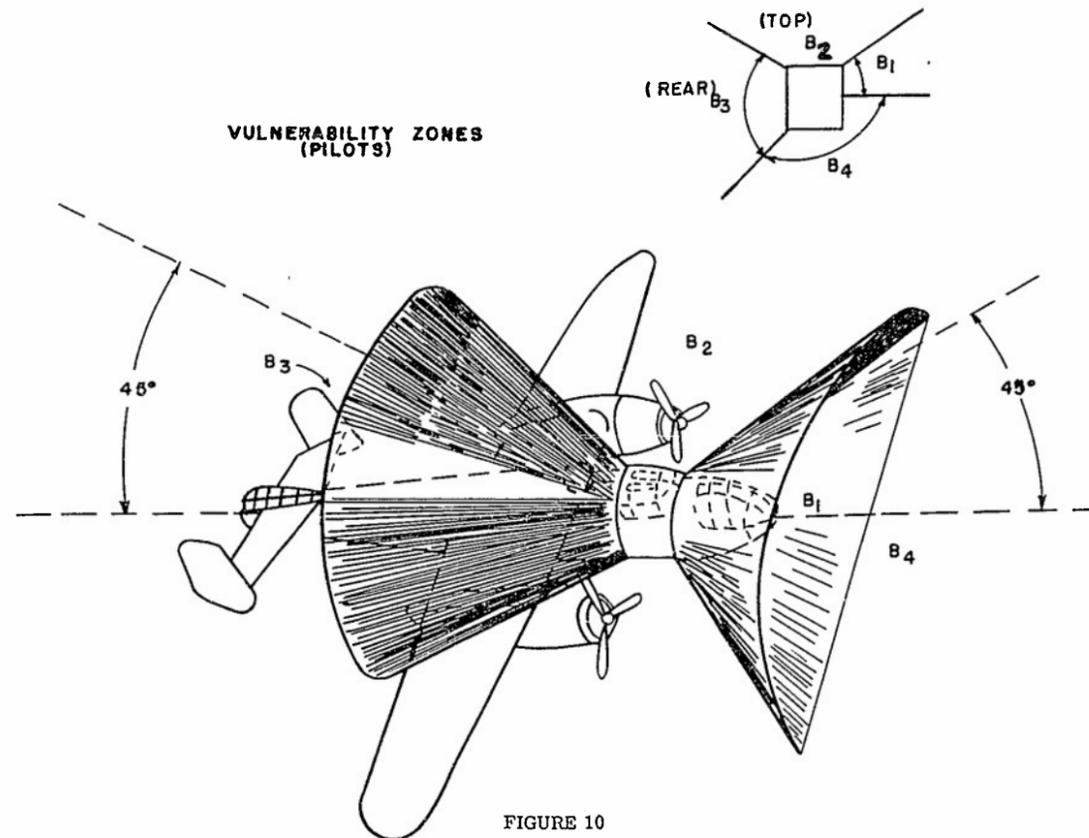


FIGURE 10

Figure 11 shows the fragments to be expected from one 75mm HE, M48 shell. In a series of panel tests conducted with this shell, the perforations of 1" spruce per unit solid angle were obtained as a function of the angle with the axis of the shell¹. The tests were conducted for shell fired statically and also for shell with remaining velocities of 700 and 1085 ft/sec. Perforations were obtained through spruce panels, with approximate thickness of 1", placed 15, 36, 75 and 120 feet from the bursting shell. Figure 12 reproduced from BRL Report No. 126, shows the distribution of perforating fragments for a shell with a remaining velocity of 1085 ft/sec. At this remaining velocity, the side spray is found to lie between angles of 56° to 91° from the nose of the shell. At a remaining velocity of 1670 ft/sec, such as obtained in the air-burst firings against the B-25 aircraft, the side spray moves forward so that it lies between 45° and 80° from the nose of the shell. For computational purposes, this 35° spray was broken up into a main side spray with 2 fringe sprays on either side, as in Figure 13.

¹BRL Report No. 126, "Fragmentation Effects of the 75mm HE Shell T3 (M48) as Determined by Panel and Pit Fragmentation Tests", by N. A. Tolch, contains a detailed description of the tests and analysis of the fragmentation patterns for this shell.

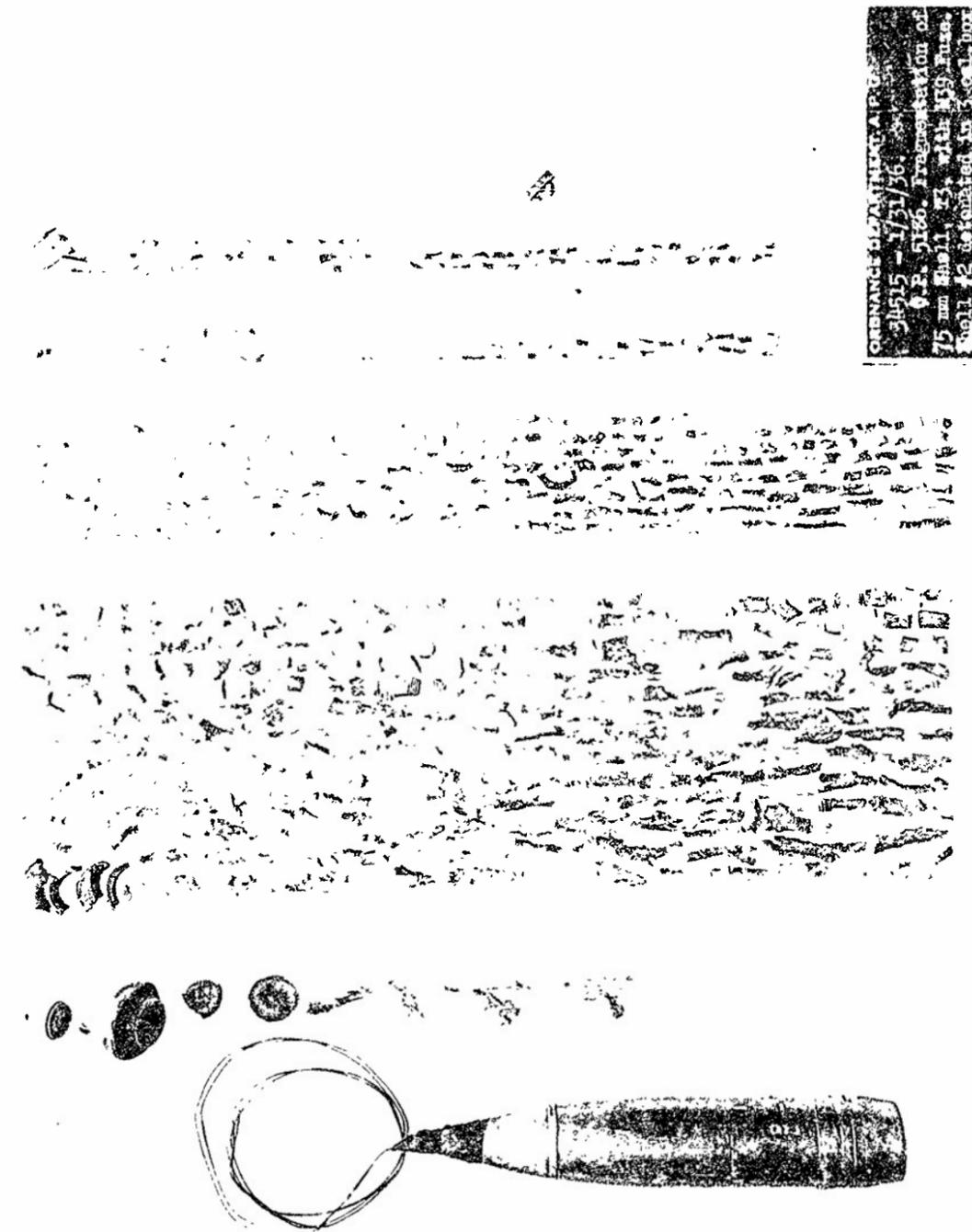


FIGURE 11

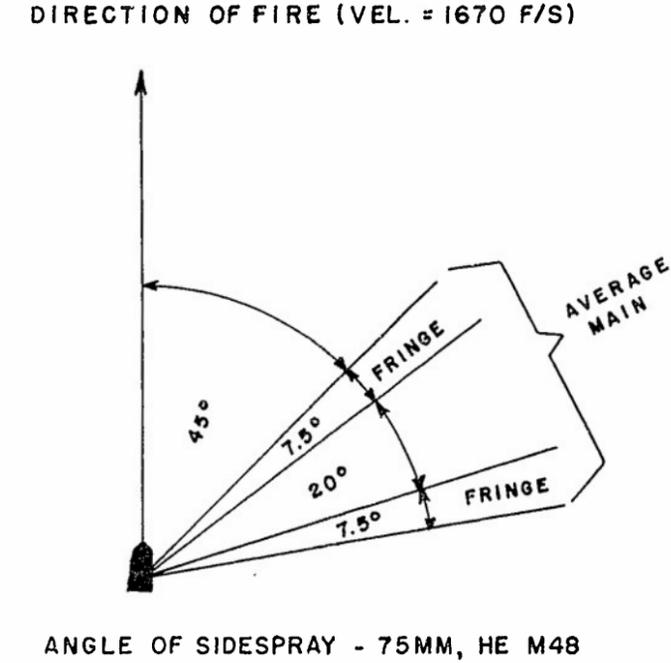
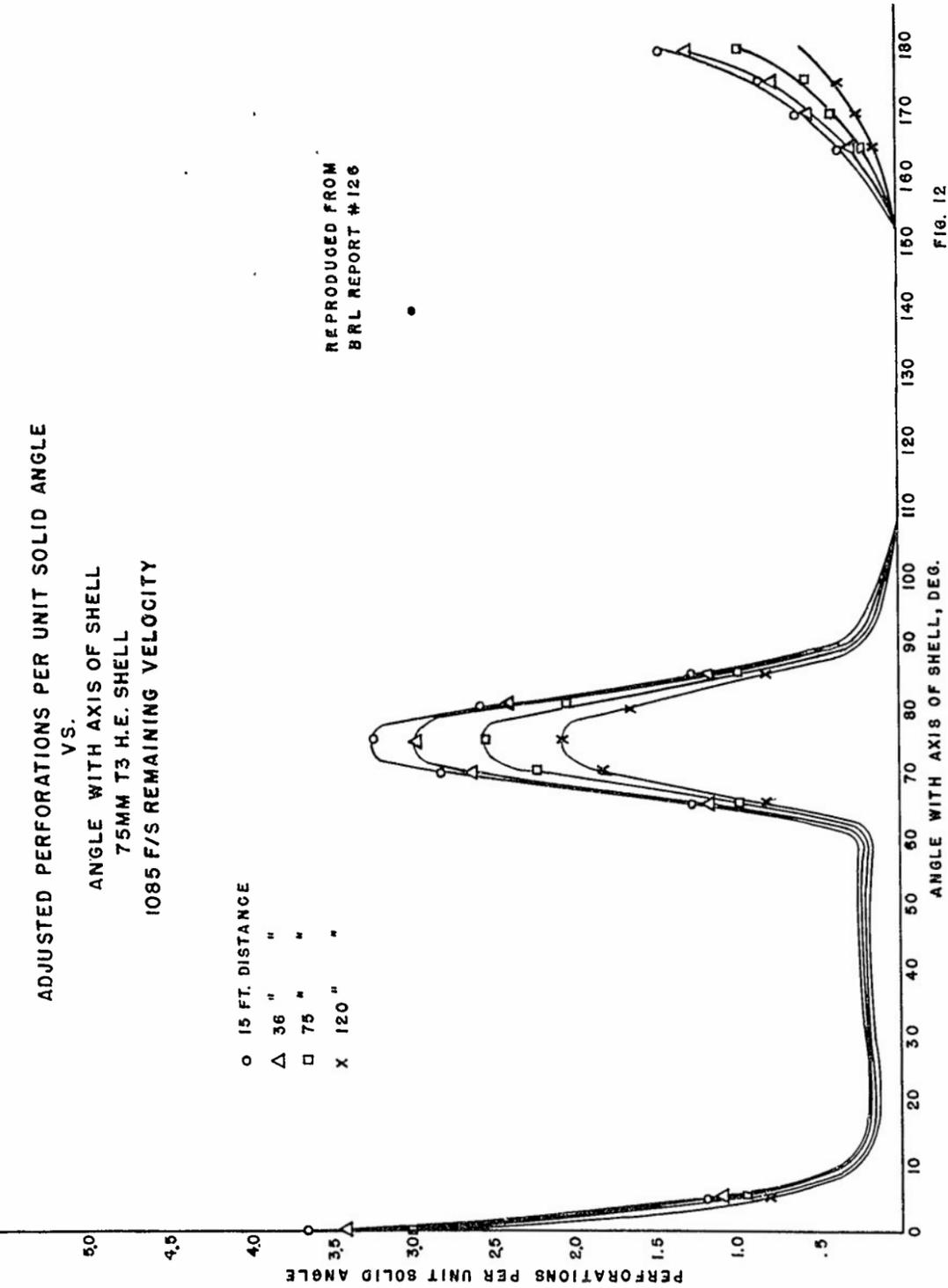


FIGURE 13

The fragment density was converted from perforations per unit solid angle to perforations per square foot (normal to the trajectories of the fragments) by the equation:

$$\rho(d) = \frac{\sigma(d)}{d^2}$$

where d is the distance in feet, $\rho(d)$ is the density of fragments per square foot at distance d and $\sigma(d)$ is the number of perforations per unit solid angle at distance d , as obtained from BRL Report No. 126. The graphs of this equation for the main and fringe side sprays as given in Figure 13 are shown in Figure 14. The $\sigma(d)$ used to obtain these graphs was the average ordinate in Figure 12 of the side spray. Whenever a component was hit by the fringe of the side spray the average density for that fringe was used. When the component was hit by the entire side spray the average density of the main spray was employed.

Reduction of Field Test Observations.

Zonal vulnerable areas. For each burst recorded in Table I a tabulation was made of the distance to any of 14 component areas which fall within the side spray. These included: the near engine, far engine, near pilot, far pilot, near fuel cells, far fuel cells, near outboard wing, far outboard wing, near inboard wing, far inboard wing, forward fuselage, mid-fuselage, aft fuselage and empennage. By means of Figure 14, the density per square foot of fragments capable of perforating 1" spruce was then tabulated for each component area as a function of the distance from the burst. The observed sum of "A" and "E" damage on the

FRAGMENT DENSITY V S. DISTANCE

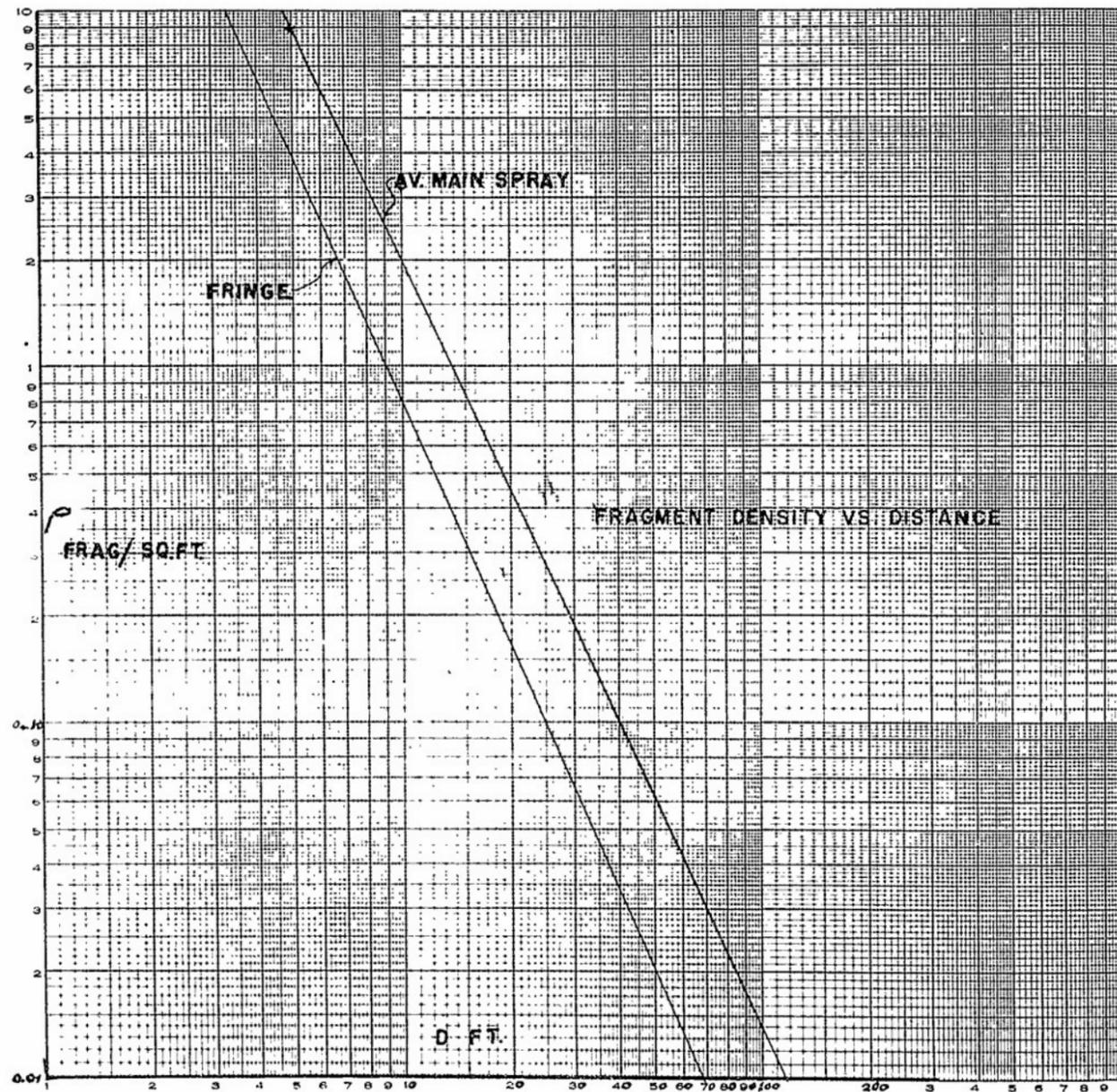


FIGURE 14

component area was then recorded. Dividing the observed number of "A" (or "B") kills on the component by the density of fragments then yielded the observed vulnerable area for "A" (or "B") damage for the component.

TABLE II

Observed Average Zonal Vulnerable Areas (ft²)
(75mm HE, M48 vs. B-25)

Component	Zone	Nos. of Rds.		A _v (ft ²)		B _v (ft ²)	
		Front	Rear	"A" Damage	Rear	"B" Damage	Rear
Engine	E1	11	0	0	0	1.36	0
	E2	0	5	0	0	0	7.49
	E3	0	5	0	0	0	3.22
	E4	96	63	0.34	0.05	1.79	1.11
	E5	27	22	1.02	0	1.38	0
Pilot	B1	5	0	1.18	0	1.18	0
	B2	50	13	1.77	1.88	1.77	1.88
	B3	0	33	0	0.25	0	0.25
	B4	18	3	1.41	3.51	1.41	3.51
Forw. Fuselage	Z > 0	55	41	0.06	0	0.061	0
	Z < 0	18	11	0	0	0	0
Mid Fuselage	Z > 0	56	42	0	0	0	0
	Z < 0	19	14	0	0	0	0
Aft Fuselage	Z > 0	46	40	0	0	0	0
	Z < 0	16	13	0	0	0	0
Near Inboard Wing	Z > 0	54	46	0	0	0	0
	Z < 0	19	13	0	0	0	0
Near Outboard Wing	Z > 0	54	37	0	0	0	0
	Z < 0	14	12	0	0	0	0
Far Inboard Wing	Z > 0	62	49	0	0	0	0
	Z < 0	20	16	0	0	0	0
Far Outboard Wing	Z > 0	60	49	0	0	0	0
	Z < 0	20	15	0	0	0	0
Empennage	Z > 0	29	22	0	0	0	0
	Z < 0	14	7	0	0	0	0

Each burst position fell into one of the zones described above for each of the components. It was then possible to classify by zone, on each of the components, the individual observed vulnerable areas for each burst. The averages of these zonal vulnerable areas are presented in Table II.

Vulnerability of Fuel System. Fuel tank fires usually were caused by the impact of more than one fragment and required a more careful treatment. Table III lists the observed data for the six fires obtained with previously undamaged tanks.

TABLE III

Density Group	Range ft.	N_R No. of Rounds Producing Frag- ment Hits on Fuel Tank Area	N_F No. of Fires Ob- served	$\frac{N_F}{N_R}$	Average Assess- ment of Fires	
					P_A percent	P_B percent
0 - .10	∞-40	122	0	0	0	0
.11 - .20	39-28	51	2	.039	0	12.5
.21 - .30	27-33	37	2	.054	75	100
.31 - .60	22-17	16	2	.125	0	0

The points, $\frac{N_F}{N_R}$, were used to fit curves representing the probability of obtaining a fire as a function of density and as a function of distance. These curves are illustrated in Figures 15 and 16, respectively.

It was assumed that the severity of a fire, as reflected in the "A" and "B" assessments of fires, should increase with the fragment density. Since only C fires were observed it was decided to use a smooth function to represent the probability of an "A" (or "B") kill as a function of density or of distance. However, this smooth function was chosen to have the same average assessment of fires as was actually observed. The smooth function was made asymptotic to a probability of 90% with increasing density, for both "A" and "B" assessments of fires. Then, for any density or distance, the product of the probability of getting a fire times the probability of an "A" (or "B") kill when a fire occurs is the overall probability of getting an "A" (or "B") kill due to fuel fire.

Fragment Vulnerability Device.

The determination of the expected number of fragment strikes on an aircraft component is a laborious task if performed mathematically. A mechanical device was therefore developed to reproduce the problem to scale.¹ This device is shown in Figures 17 and 18. The long horizontal bar at the top of the device represents the shell trajectory in the vicinity of the target. The center of the dial at the end of this bar represents the burst position. The scale model of the target is oriented and located with respect to the burst position as desired to simulate any experimental or assumed spacial relationship.

The thin rod with pointed end and the scale passing through the dial center are then oriented relative to the shell trajectory to one of the boundary angles of the main or fringe fragment sprays. This angle is read on the dial and the angular setting is locked by a set screw. As the dial plus transverse rod is rotated about the shell trajectory as axis, the rod traces in space the cone describing the chosen fragment spray boundary.

¹For an ingenious method of accomplishing the same objective by photographic techniques, See Technical Report No. 458, of the Research and Development Division, New Mexico School of Mines, page A-40.

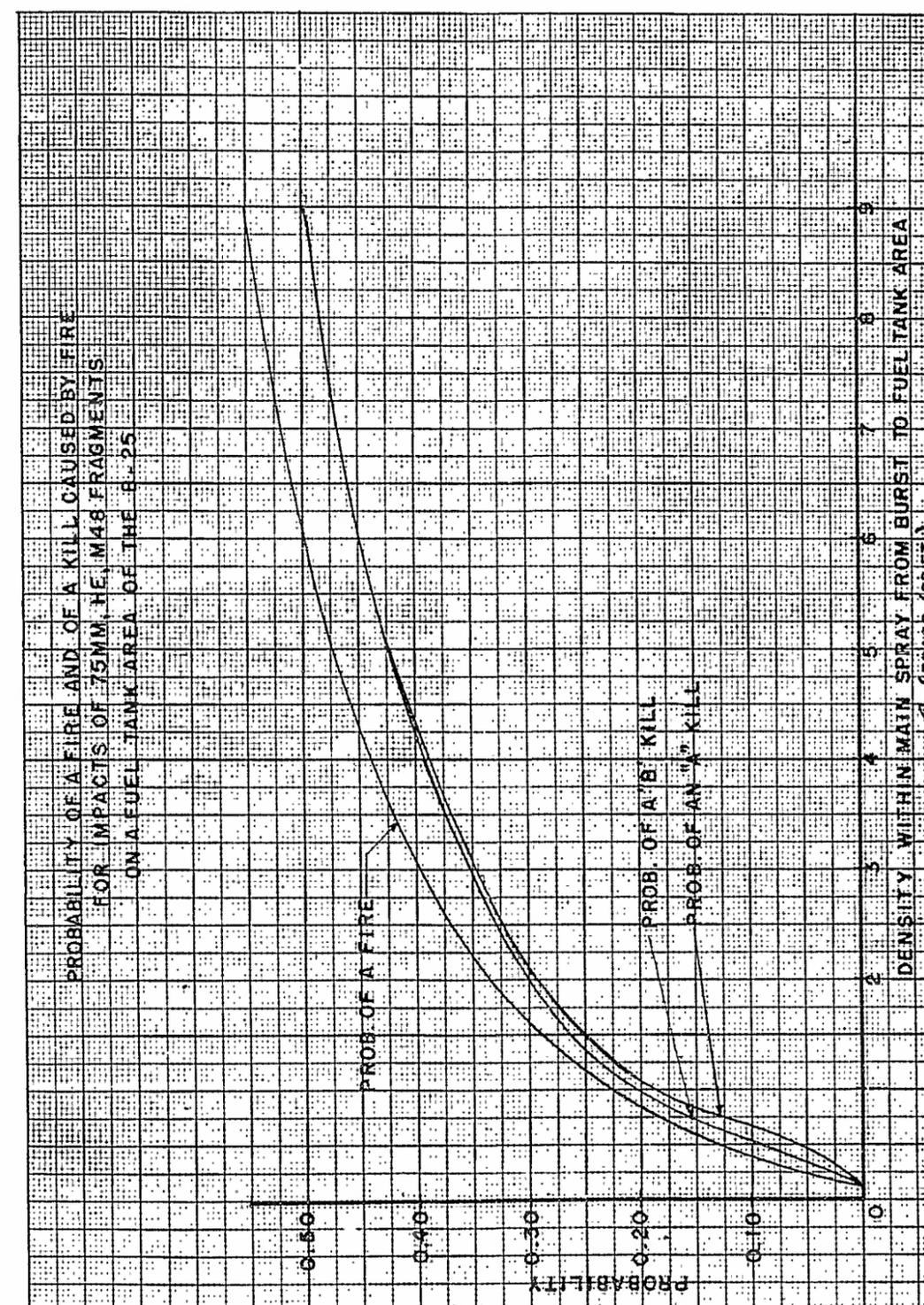


FIGURE 15

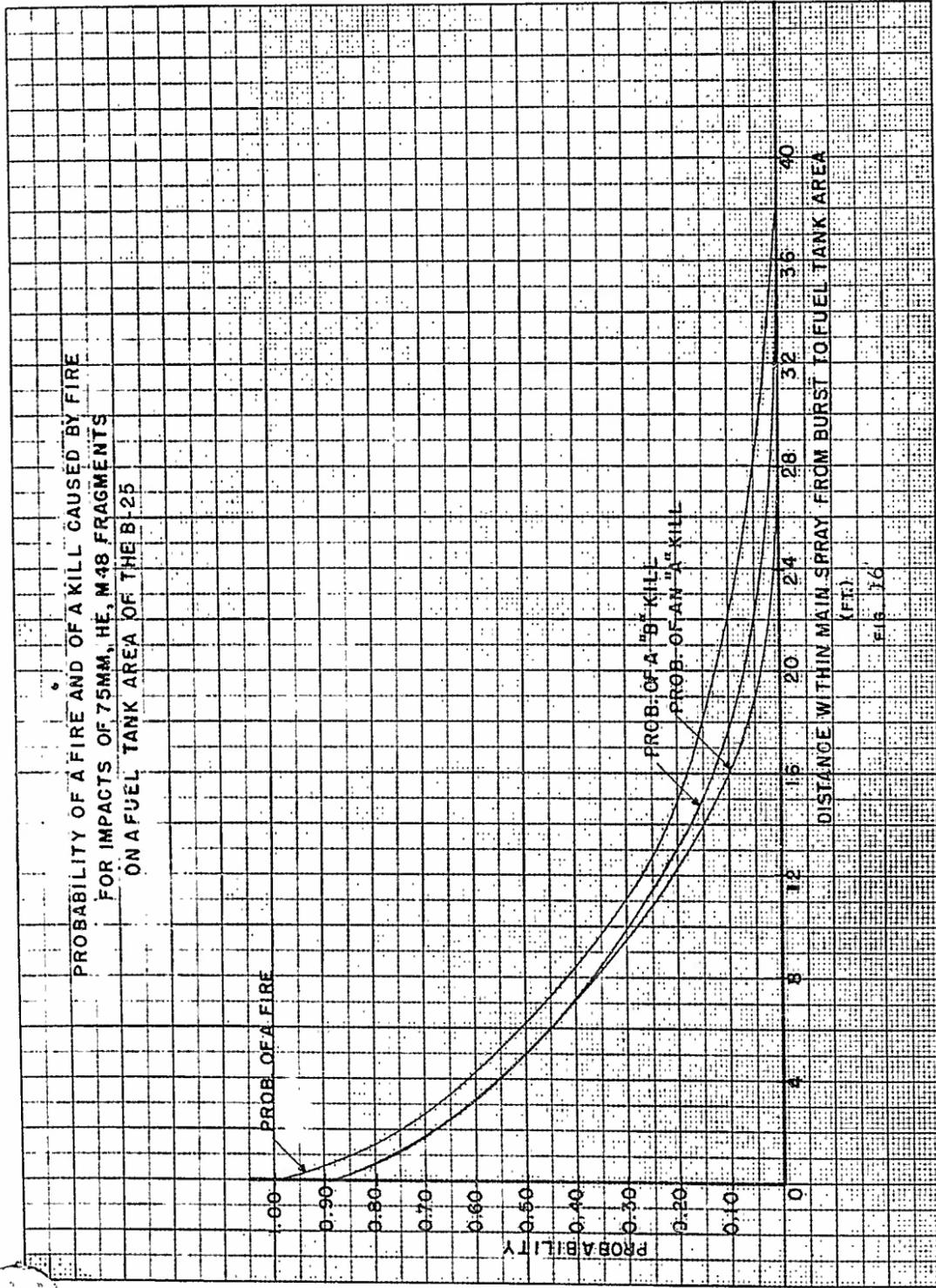


FIGURE 16

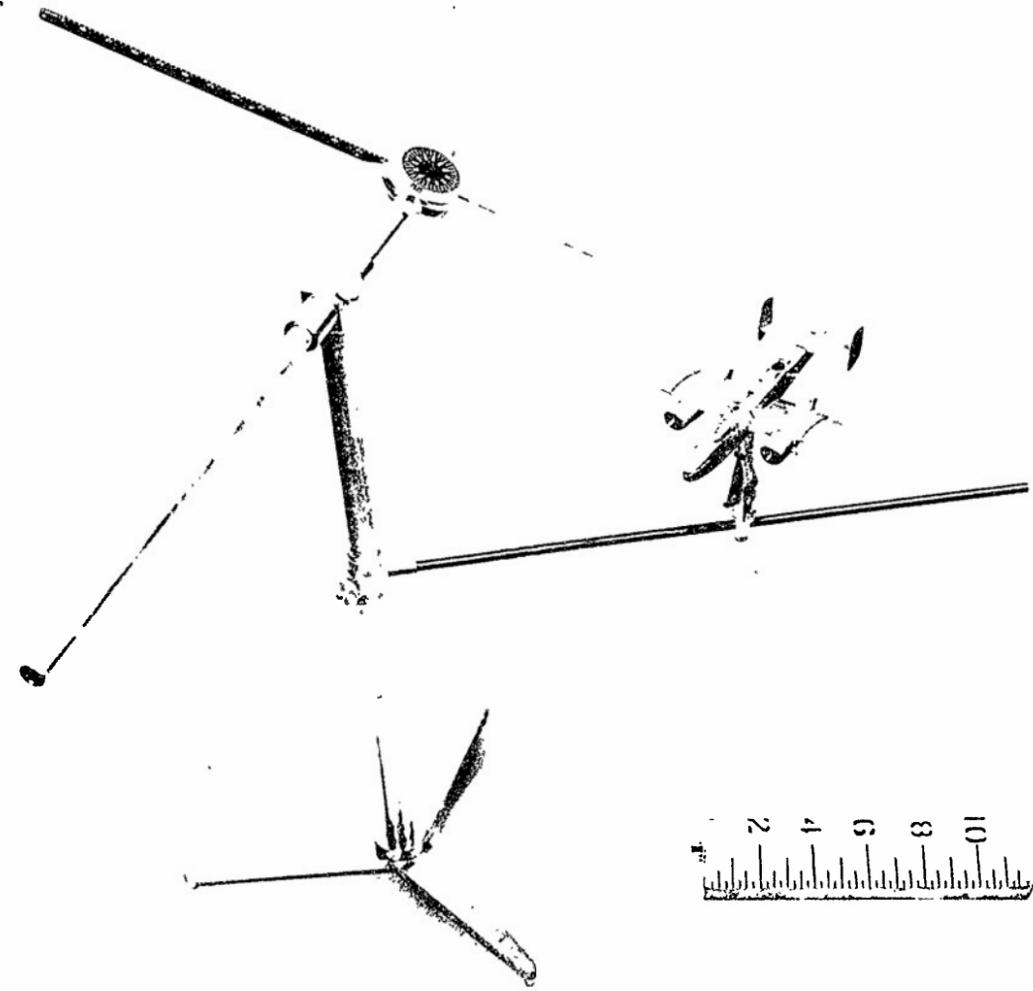


FIGURE 17

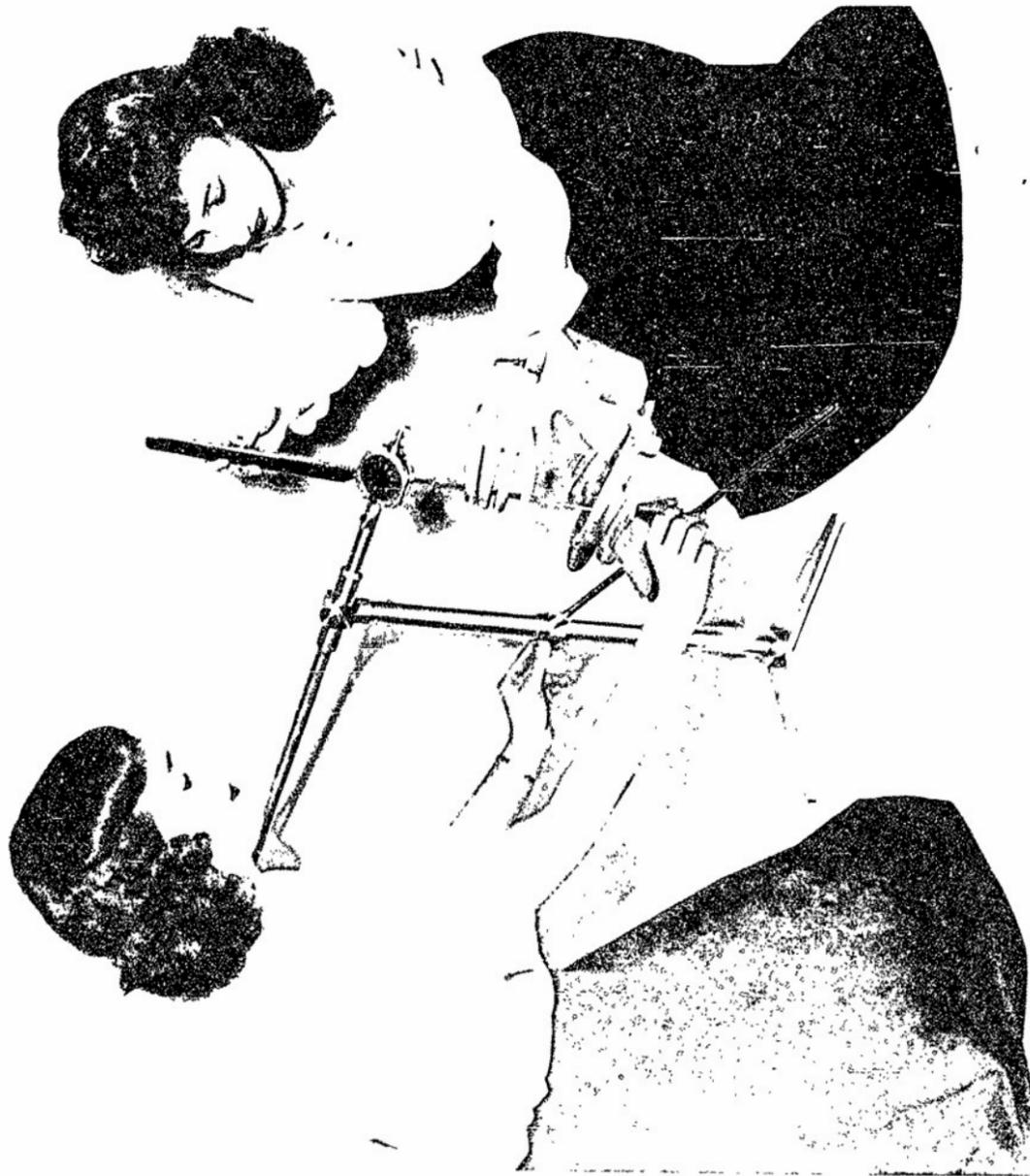


FIGURE 18

The pointed rod slides freely through the dial center, and its extension, read against the linear scale, indicates the distance from the burst point to the pointed end of the rod. If the point is held against the aircraft surface as the dial assembly is rotated about the trajectory axis, the point traces on the aircraft the intersection of the boundary of the fragment spray with the aircraft surface. Simultaneously the distance of each point on the intersection from the burst point may be read on the scale.

For any burst position relative to the target the components of the aircraft struck by each portion of the fragment spray are thus easily determined, as is the distance from the burst point to each component. The density of potentially lethal fragments is then known, and the expected number of lethal hits may be computed. The probability of at least one lethal hit on each component may then be determined.

Calculation of Conditional Probabilities.

Once the zonal vulnerabilities are obtained for the major components of the aircraft it is not difficult to obtain the overall probability of obtaining a kill on the composite aircraft. At this point the zonal vulnerabilities may be used to synthesize the vulnerability of the same type of aircraft used to obtain the data on component damage (the B-25 in this case), or to synthesize the vulnerability of any other aircraft with similar components, even if these are differently arranged. Since the 75mm firings are to serve as a check point for comparison with an independent estimate to be made on the basis of controlled fragmentation results, the simplest aircraft target to use is the B-25 itself.

The calculation of probability contours requires that the overall probability of a kill on the plane be obtainable for any arbitrary point of burst about the B-25.

The procedure is as follows: The direction of flight and the position of shell-burst is simulated to scale on the fragment vulnerability device (Figures 17 and 18). The chosen point of burst will fall into a zone for each of the major aircraft components. By means of the fragment vulnerability device, the distance, and hence the density of fragments in the side spray, is obtained for impacts on each of the major components. Since $\rho A_v = K$, the average zonal vulnerable area of the component may be used to obtain K , the expected number of kills on the component due to the shell burst. Then e^{-K} is the probability that the component survives and $1 - e^{-K}$ is the probability of at least one kill on the component.

For any given burst it is thus possible to obtain the probability of at least one kill on each of the major components. If $P_{A_{E1}} = 1 - e^{-K_{A_{E1}}}$ is the probability of at least one "A" kill on the near engine and $P_{A_{E2}} = 1 - e^{-K_{A_{E2}}}$ is the probability of an "A" kill on the far engine then $(P_{A_{E1}})(P_{A_{E2}})$ is the probability that the burst causes an "A" kill to both engines. Similarly, $(P_{A_{P1}})(P_{A_{P2}})$ is the probability of causing "A" damage to both pilots. Since usually $P_{A_{P1}} = P_{A_{P2}}$, the probability of "A" damage to both pilots is $(1 - e^{-K_{A_{P1}}})^2$.

The probability of killing each of the singly vulnerable components, fuel and structure, is simply $1 - e^{-K_{A_{SV}}}$ where $K_{A_{SV}}$ is the expected number of "A" kills on the singly vulnerable component.

If it is assumed that the plane suffers "A" damage if both engines, or both pilots, or any of the singly vulnerable components suffer "A" damage, then the probability that the burst resulted in an "A" kill to the plane is:

$$P_A = 1 - \left\{ \left[1 - P_{AF1} \right] \left[1 - P_{AF2} \right] \left[e^{-K_{AS1}} \right] \left[e^{-K_{AS2}} \right] \left[e^{-K_{AS3}} \right] \left[e^{-K_{AS4}} \right] \right. \\ \left. \left[1 - (1 - e^{-K_{AE1}})(1 - e^{-K_{AE2}}) \right] \left[1 - (1 - e^{-K_{AP1,2}}) \right] \right\}$$

where P_{AF1} and P_{AF2} are the probabilities of "A" kills on the plane due to the fuel tank area in the near and far wing respectively. They are obtained by use of the Figures 15 and 16. K_{AS1} , K_{AS2} , K_{AS3} and K_{AS4} are the expected numbers of "A" kills on the plane due to the forward, middle and aft fuselage structure and empennage, respectively. K_{AE1} and K_{AE2} are expected numbers of "A" kills on the near and far engines, respectively, and K_{AP1} is the expected number of "A" kills on one pilot.

Contours of constant probability for "B" damage were prepared for firings from the front and rear. These contours were sketched into various views of the aircraft to relate the three dimensions. For firing from the front, Figure 19 illustrates shell bursts in the XY plane at $Z = 0$ (plane of the wings); Figure 20 shows the effect of bursts in the YZ plane at $X = 0$; and Figures 21 - 28 indicate shell bursting in XZ planes at $Y = -15, -10, -5, 0, 5, 10, 15$ and 20 feet respectively. Origin of the coordinate system remained, as previously, the intersection of the nose of the aircraft with the line passed thru the center of gravity parallel to the fuselage.

Similar sketches were made to cover firing from the rear. Figure 29 shows the effect of bursts in the XY plane; Figure 30 indicates shell bursting in the YZ plane; and Figures 31 - 36 show the effect of bursts in XZ planes at $Y = 15, 20, 25, 30, 35,$ and 40 feet respectively.

For purpose of illustration and comparison, contours for "A" damage were prepared for bursts in the plane $Y = 0$ for firing from the front (Figure 37) and in the plane $Y = 25$ for firing from the rear (Figure 38). These were the vertical planes in which the greatest "B" damage was observed.

In general, the contours for any of the planes, $Y = \text{constant}$, were prepared with the aid of auxiliary graphs which were used for interpolation to get even values of the probabilities. For any plane, a graph was prepared with probability of a kill as the ordinate and radial distances as the abscissa. A separate curve was prepared for each radial angle. For a series of radial angles, points were selected at various radial distances and a curve fitted to these points for each radial angle. The distances along each radius were then read which yielded even probabilities of a kill, (.05, .10, .20, . . .). The points thus obtained were used to obtain the probability contours. These contours were prepared as a "shake-down" problem to set up computational procedures and familiarize personnel with the methods employed. The "B" damage contours were computed in detail, although they are of less eventual interest than the "A" contours, because

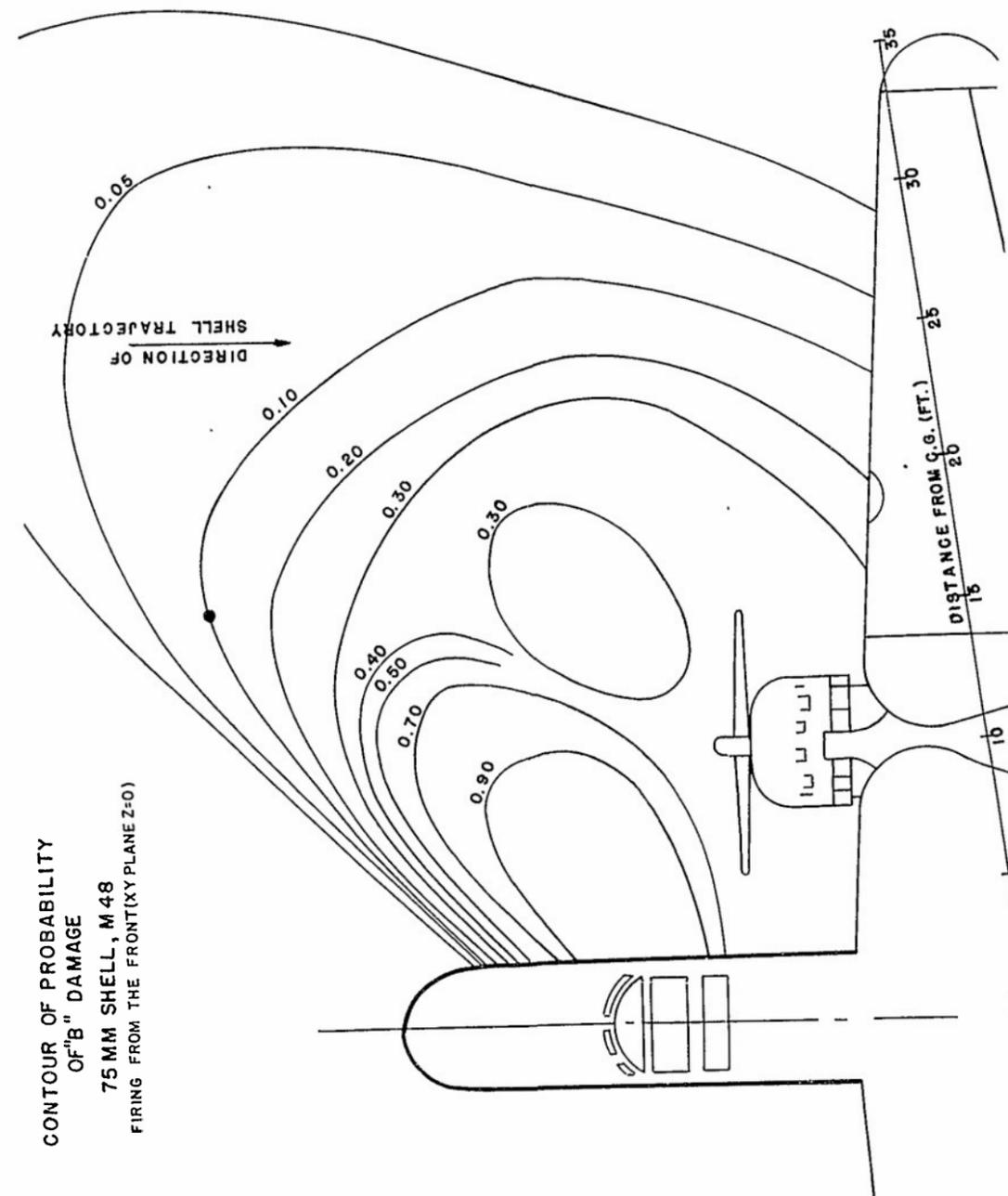
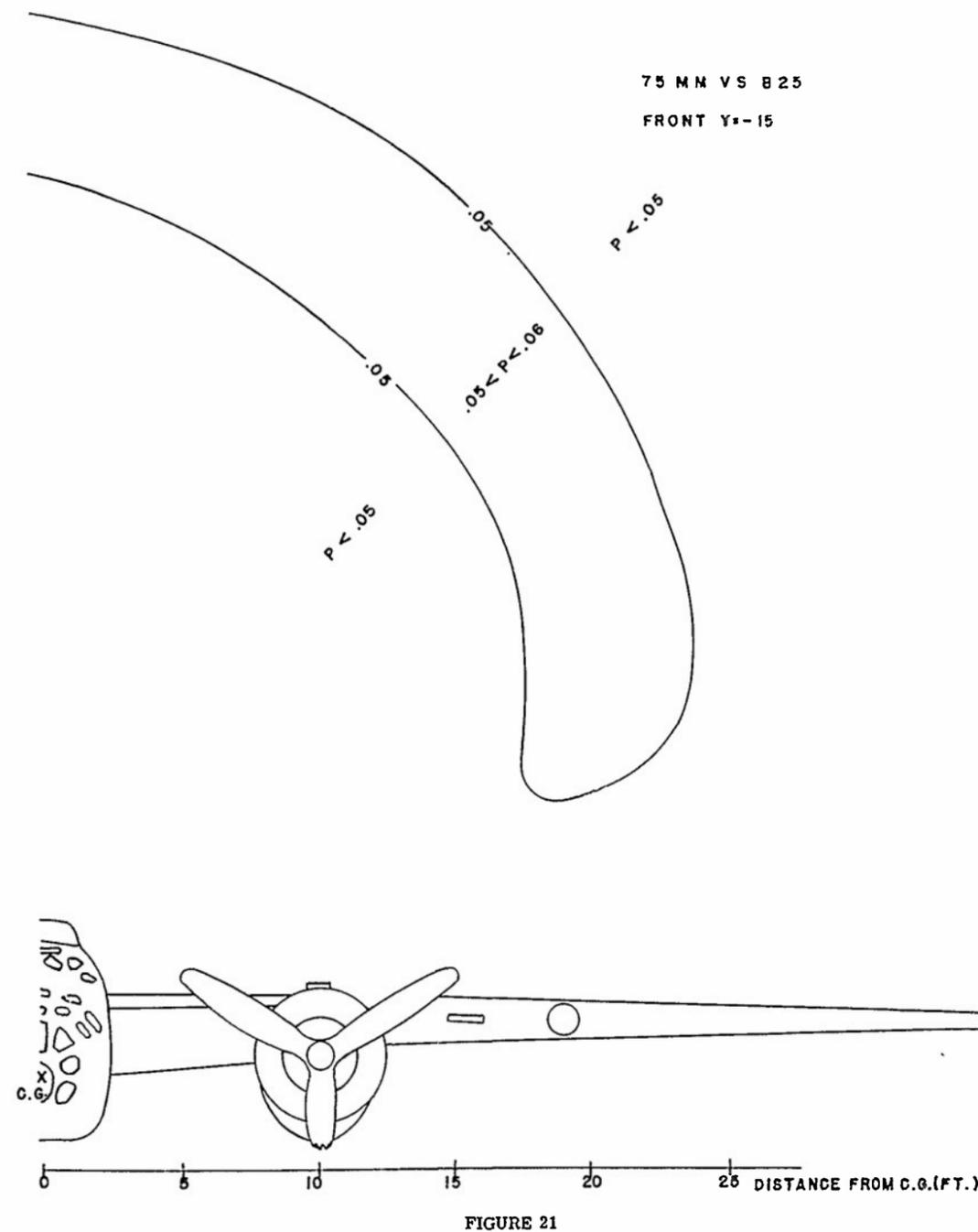
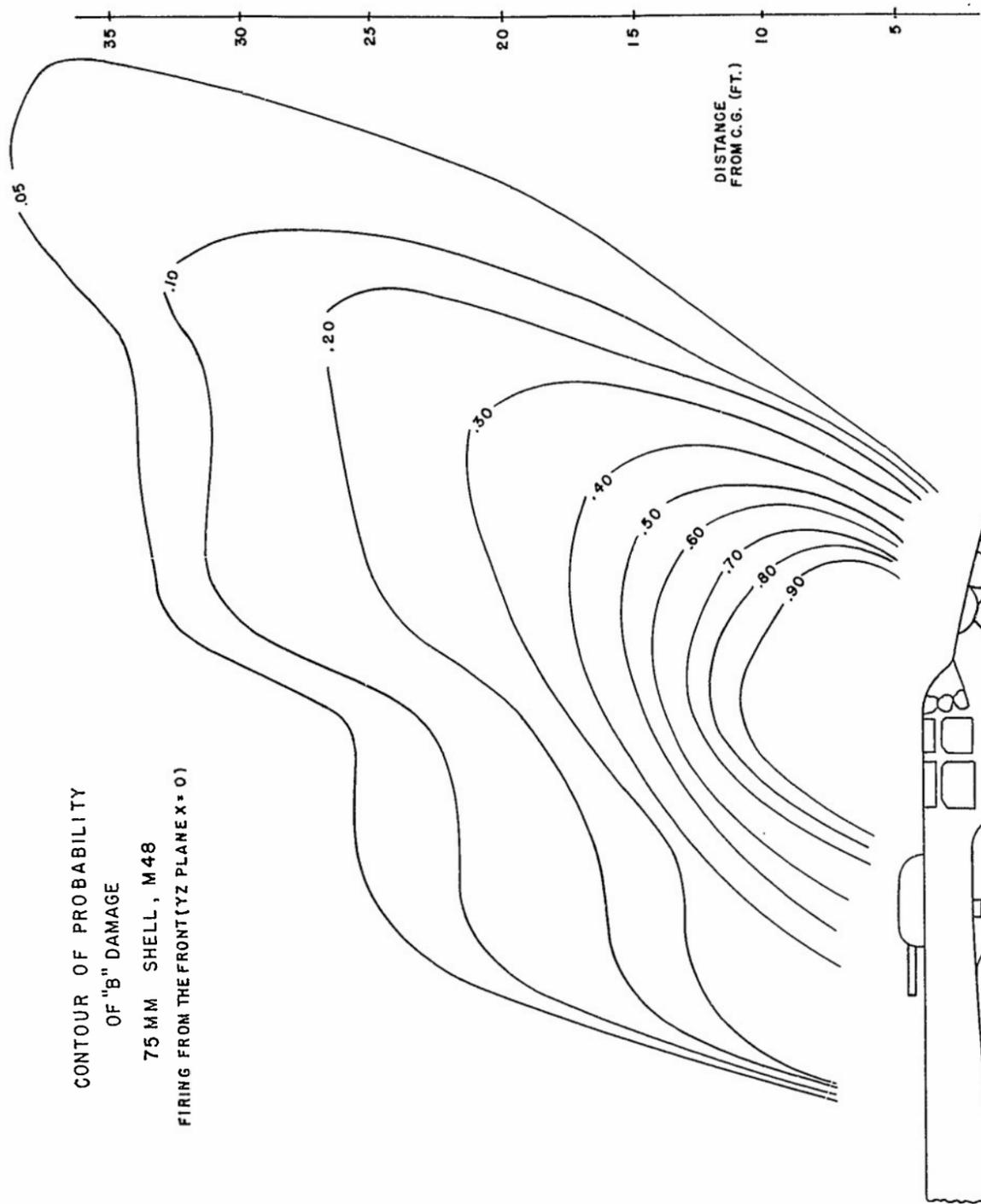


FIGURE 19



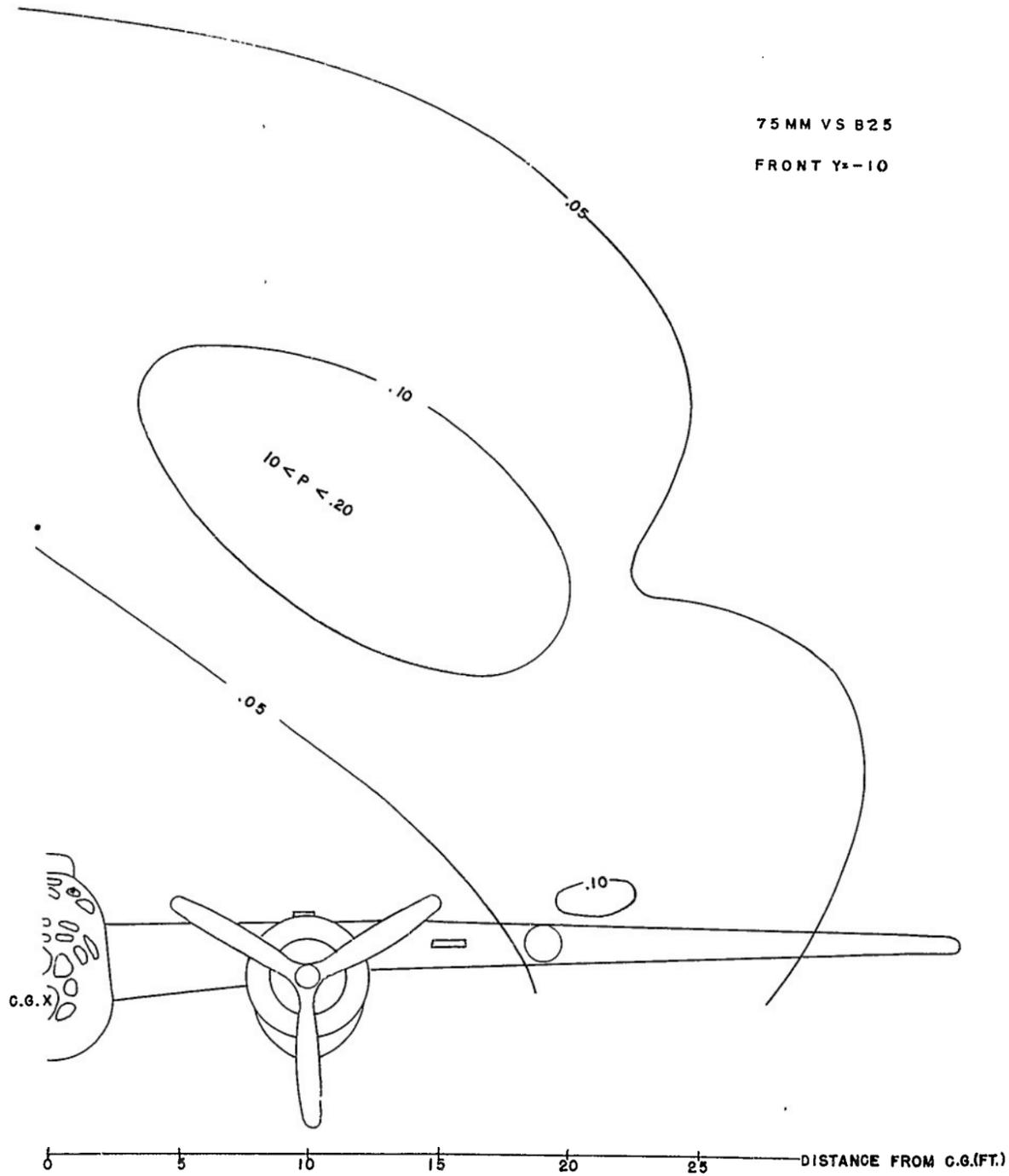


FIGURE 22

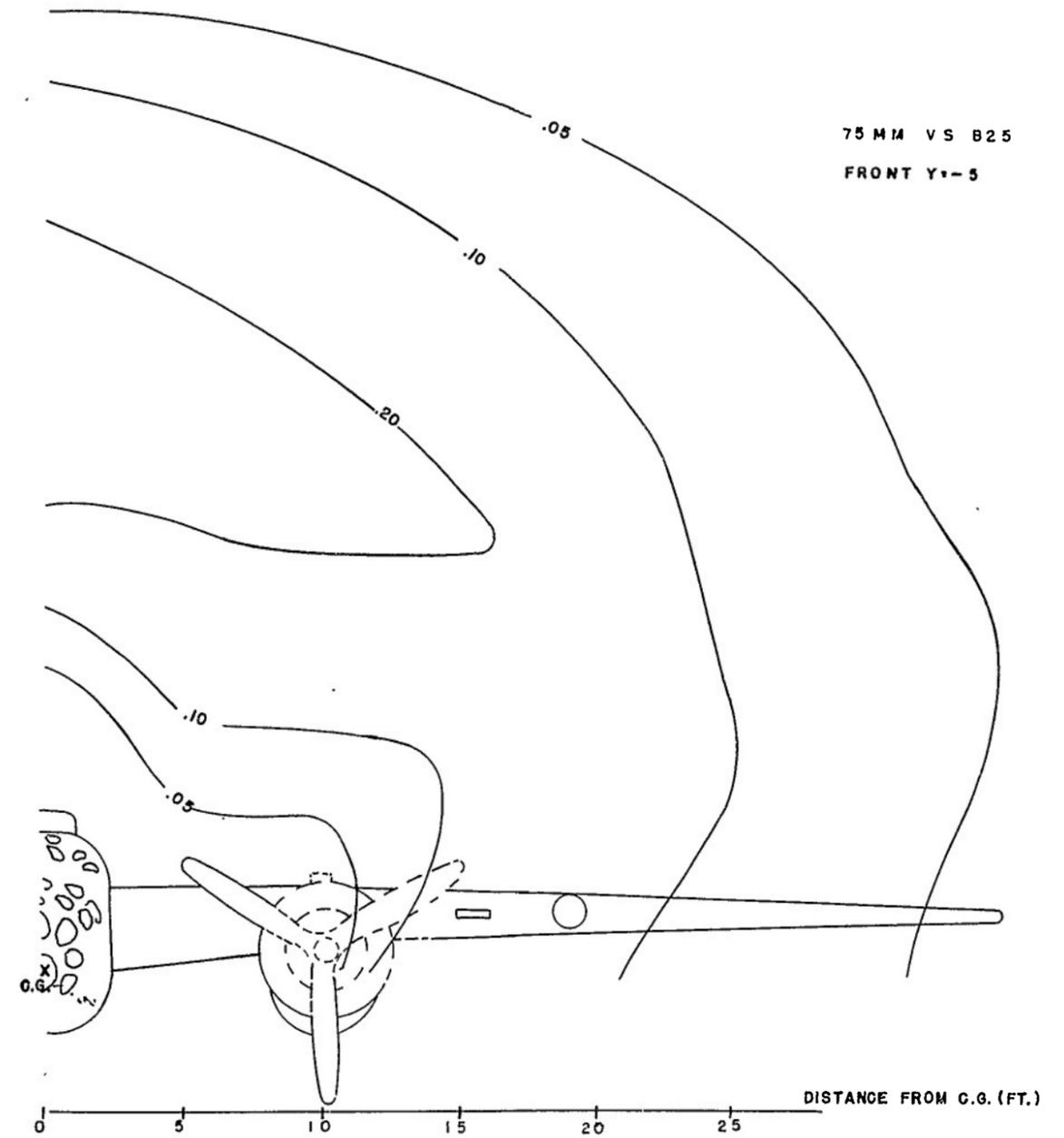


FIGURE 23

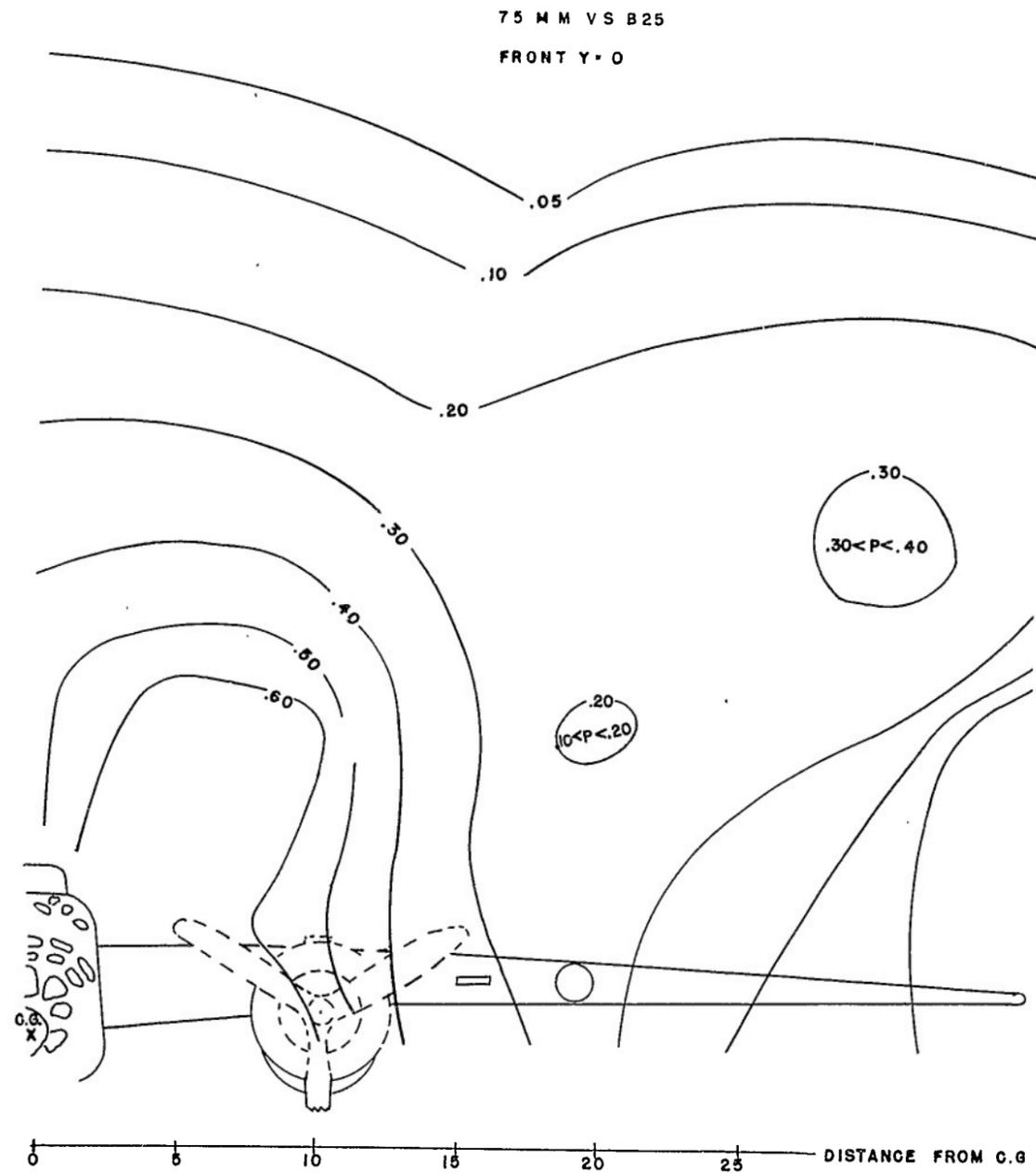


FIGURE 24

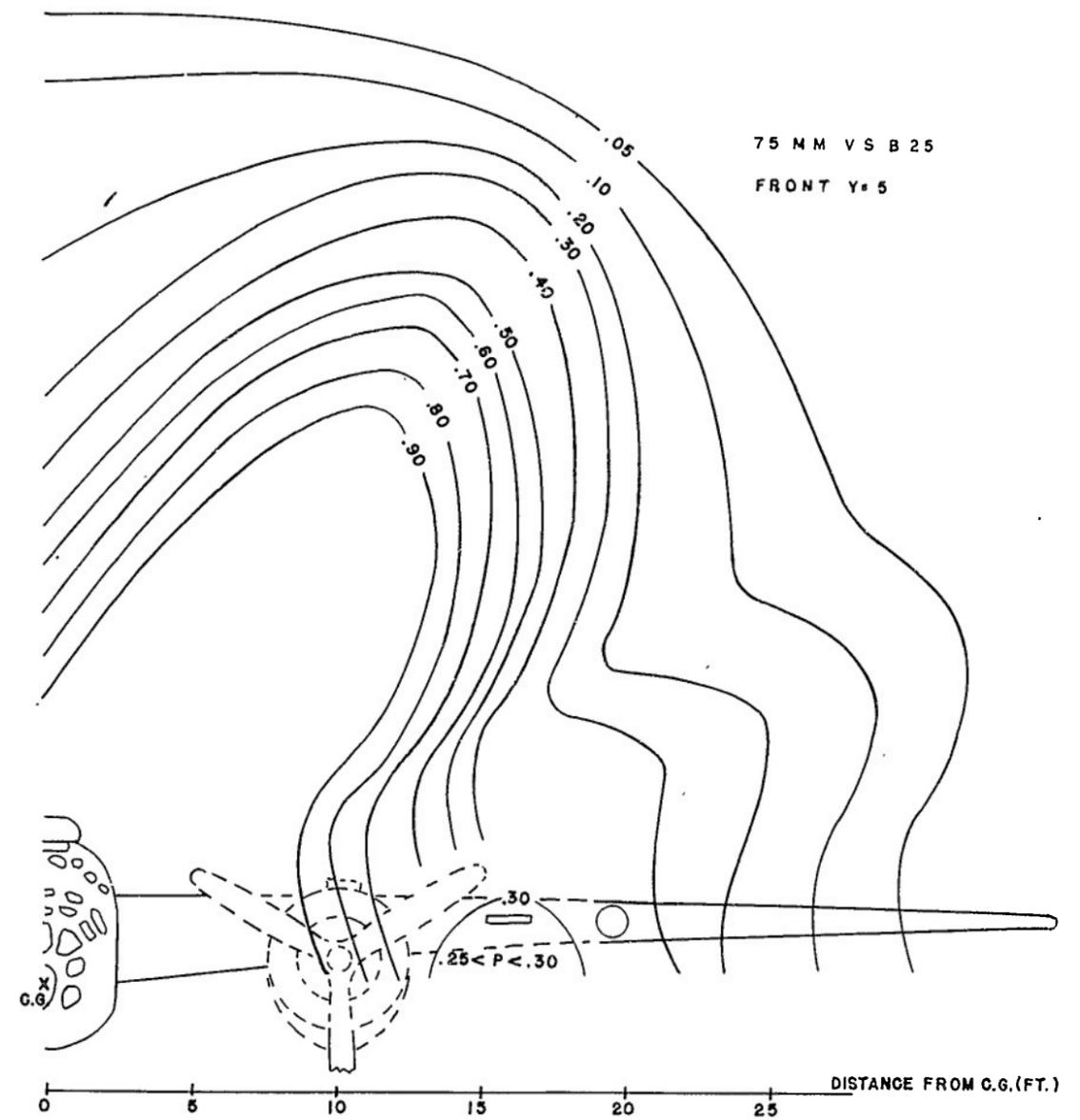


FIGURE 25

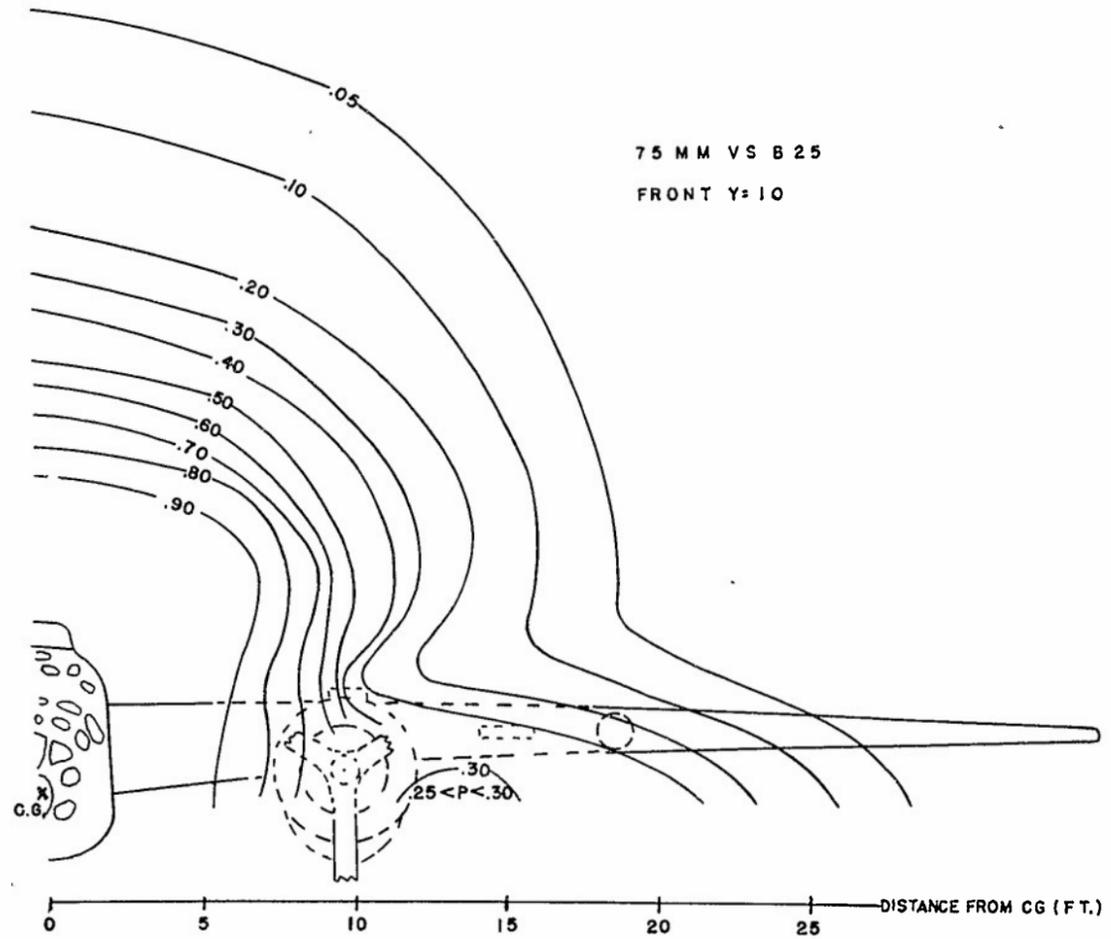


FIGURE 26

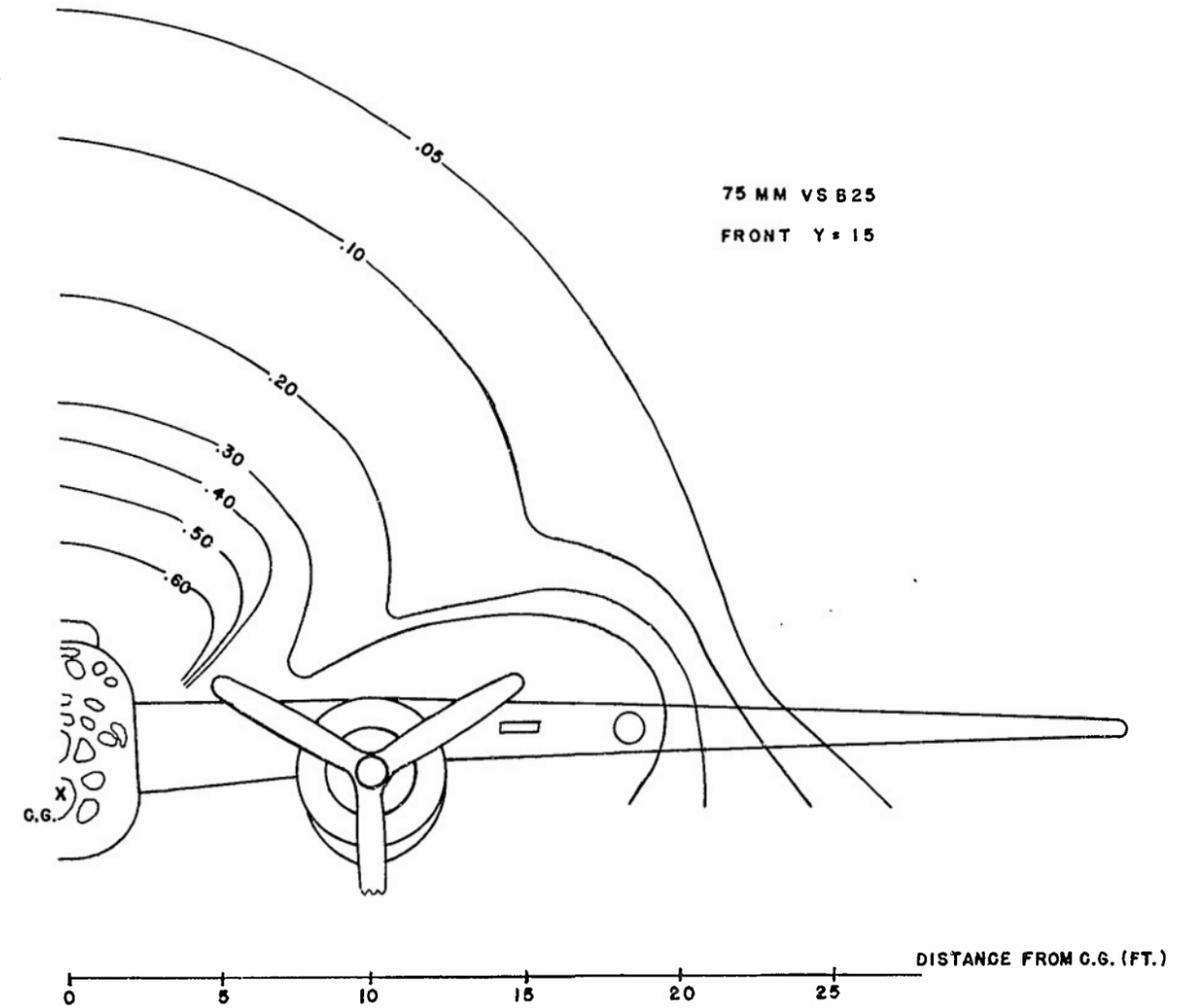


FIGURE 27

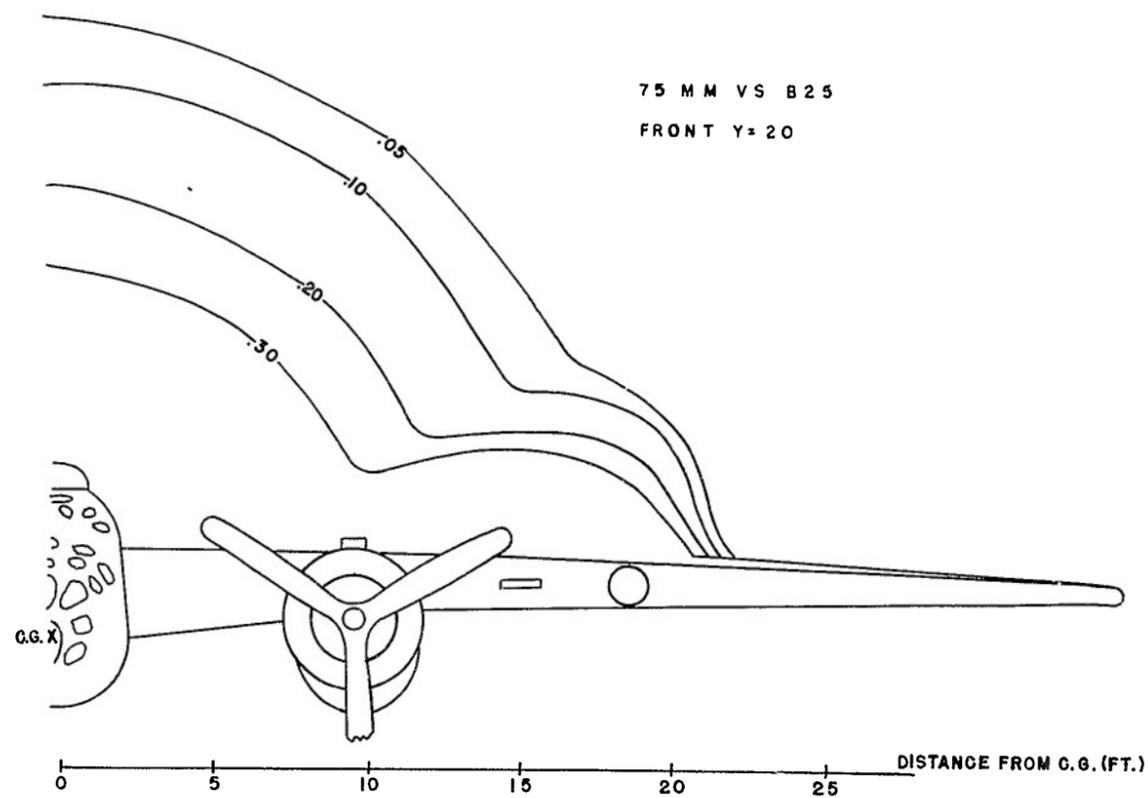


FIGURE 28

the "B" vulnerable areas were the first available. It is anticipated that a set of "A" contours will be prepared when reduction of data on vulnerability of aircraft to bursts below the aircraft is completed.

It is already apparent that computation will be considerably simplified if contours are plotted on conical surfaces rather than the vertical planes used in the present report. Such procedure will minimize the now present complication of components moving in and out of main and fringe sprays as the burst point is moved in a vertical plane. It will also replace many of the peculiarly shaped contours by contours which are approximately circular. A redesign of the fragment vulnerability device to handle such conical surfaces is planned.

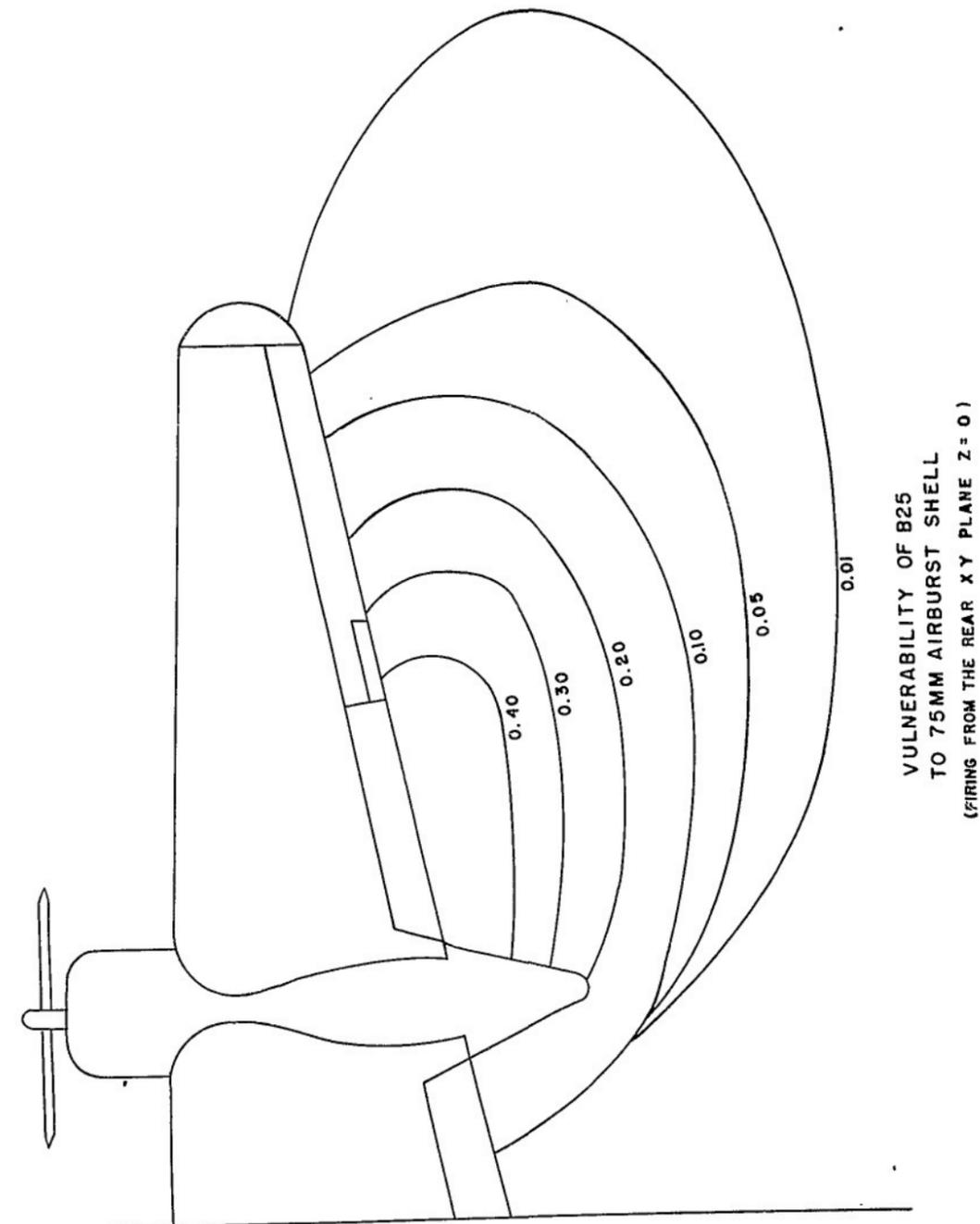


FIGURE 29

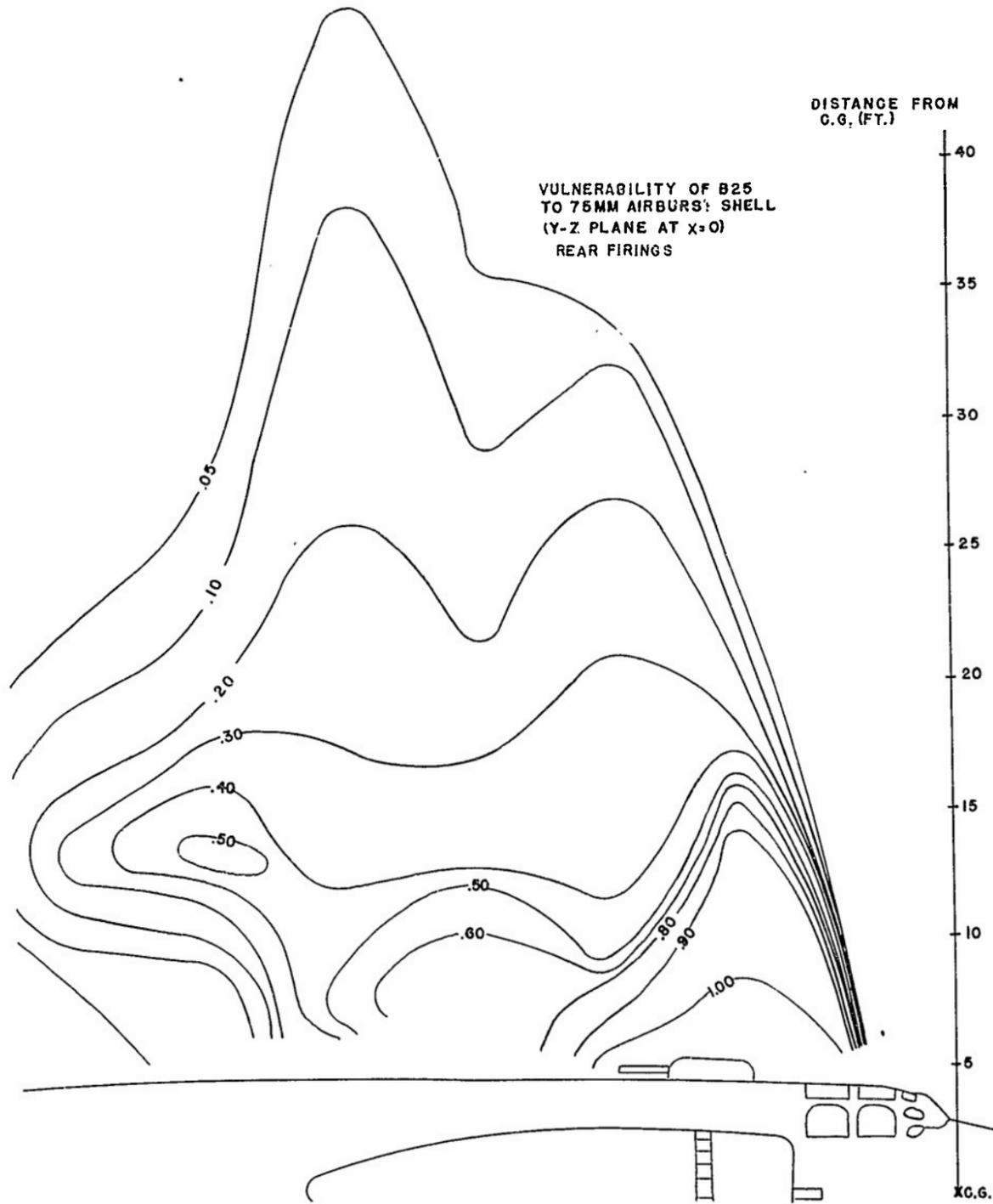


FIGURE 30

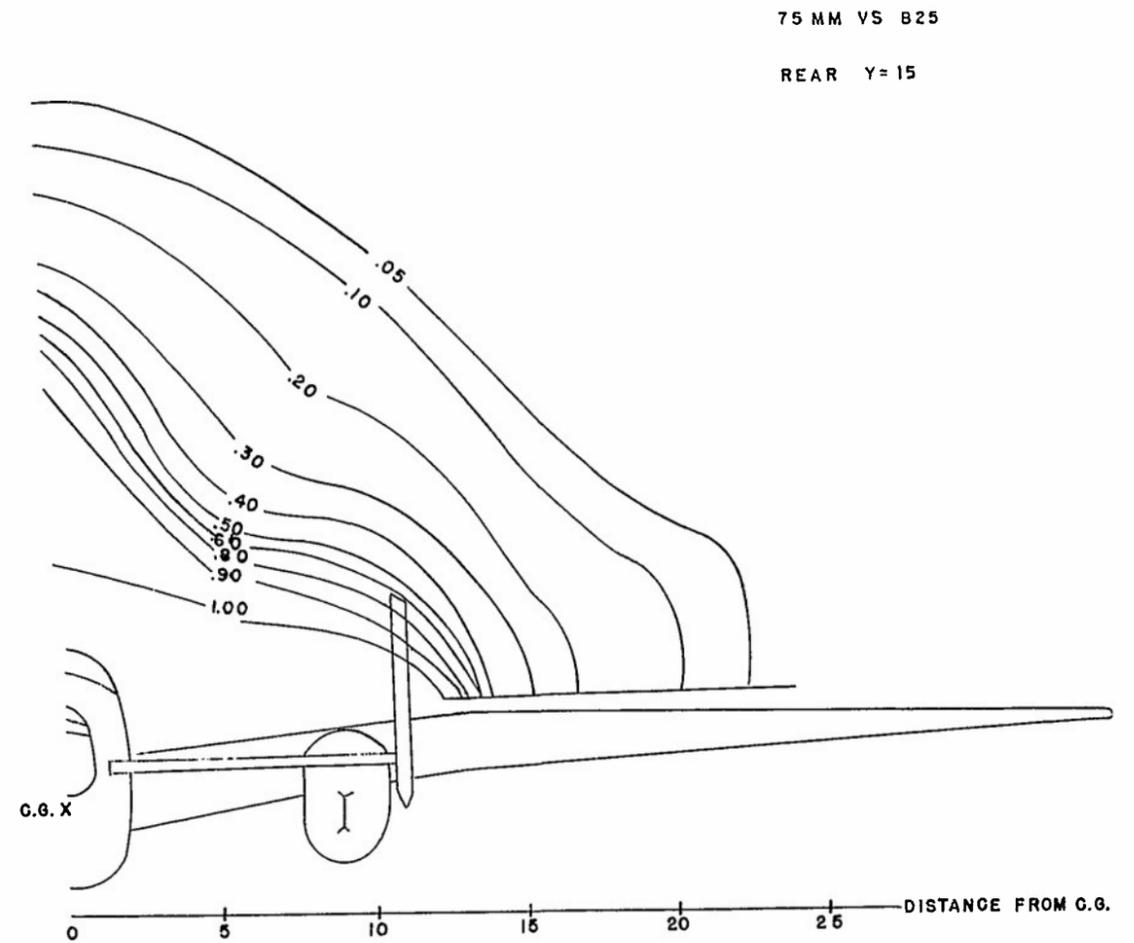


FIGURE 31

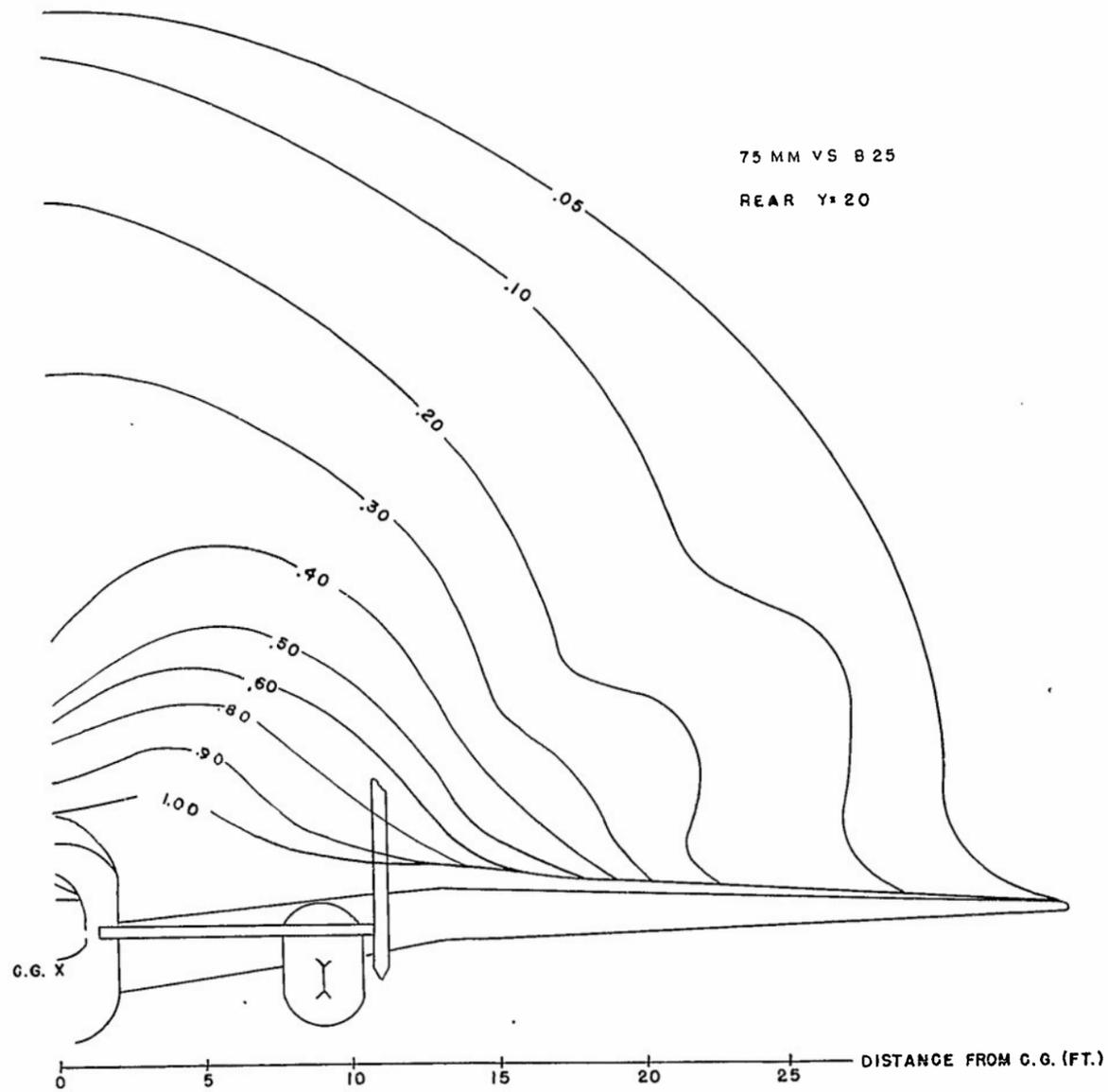


FIGURE 32



FIGURE 33

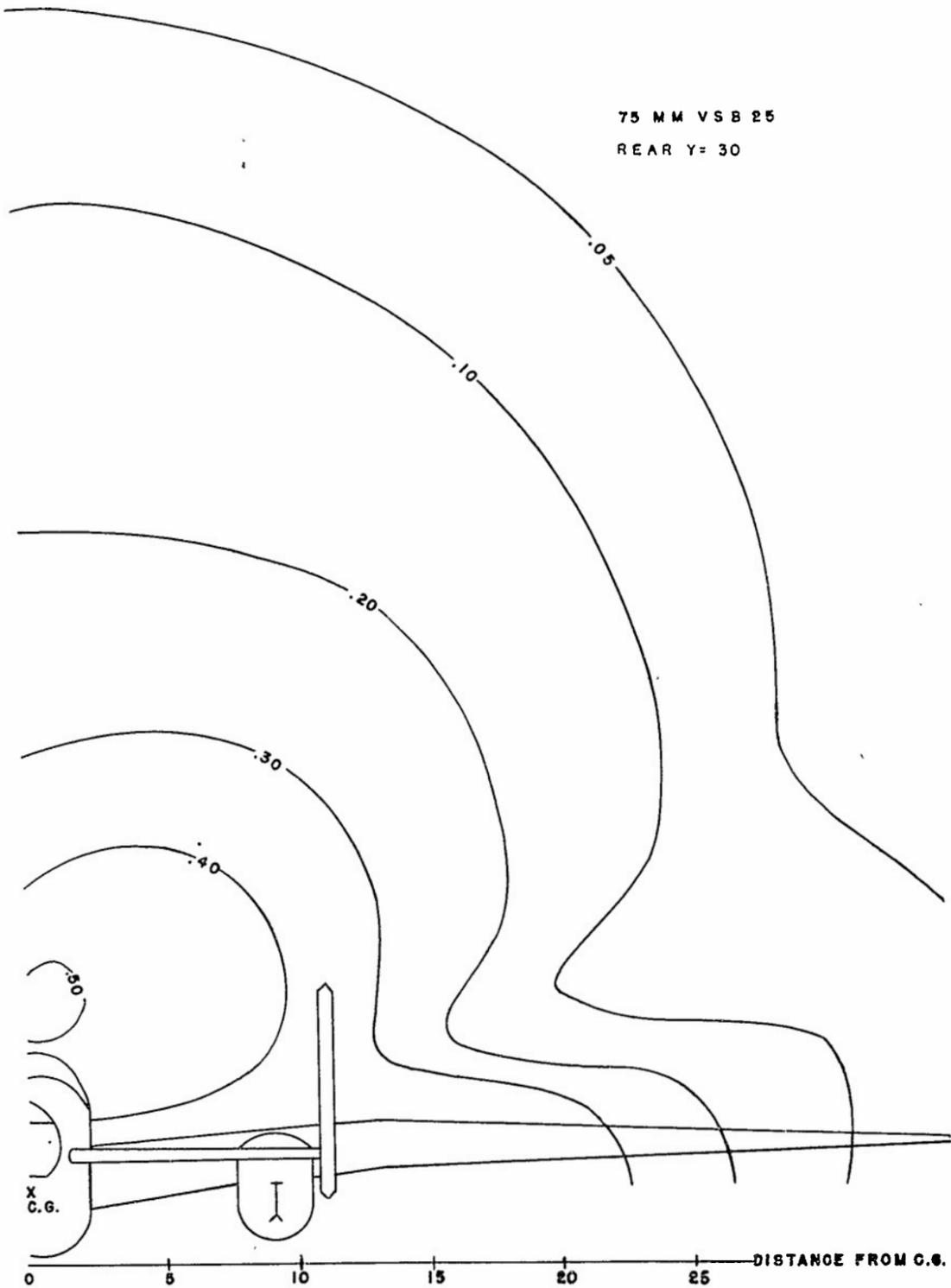


FIGURE 34

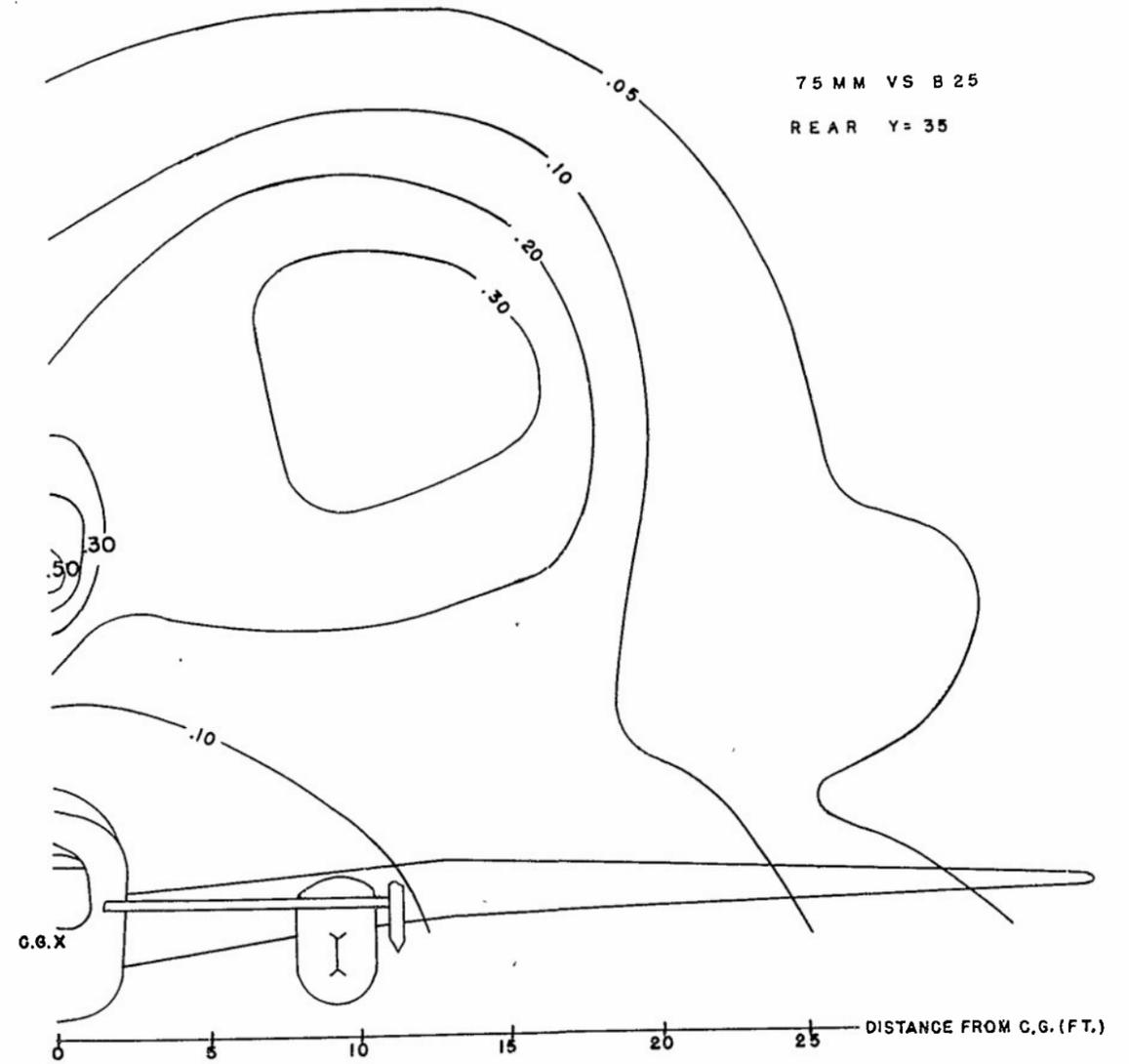


FIGURE 35

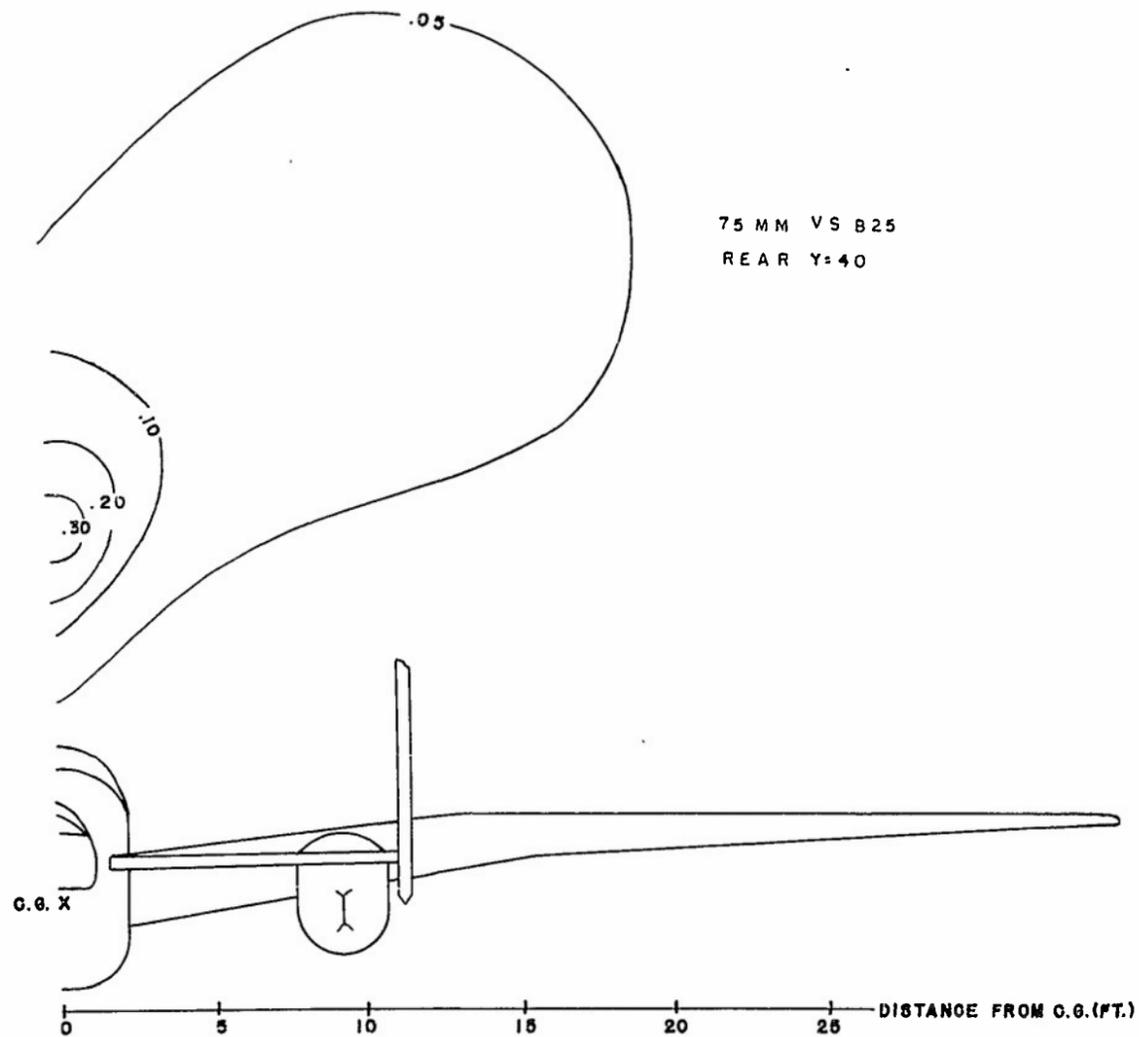


FIGURE 36

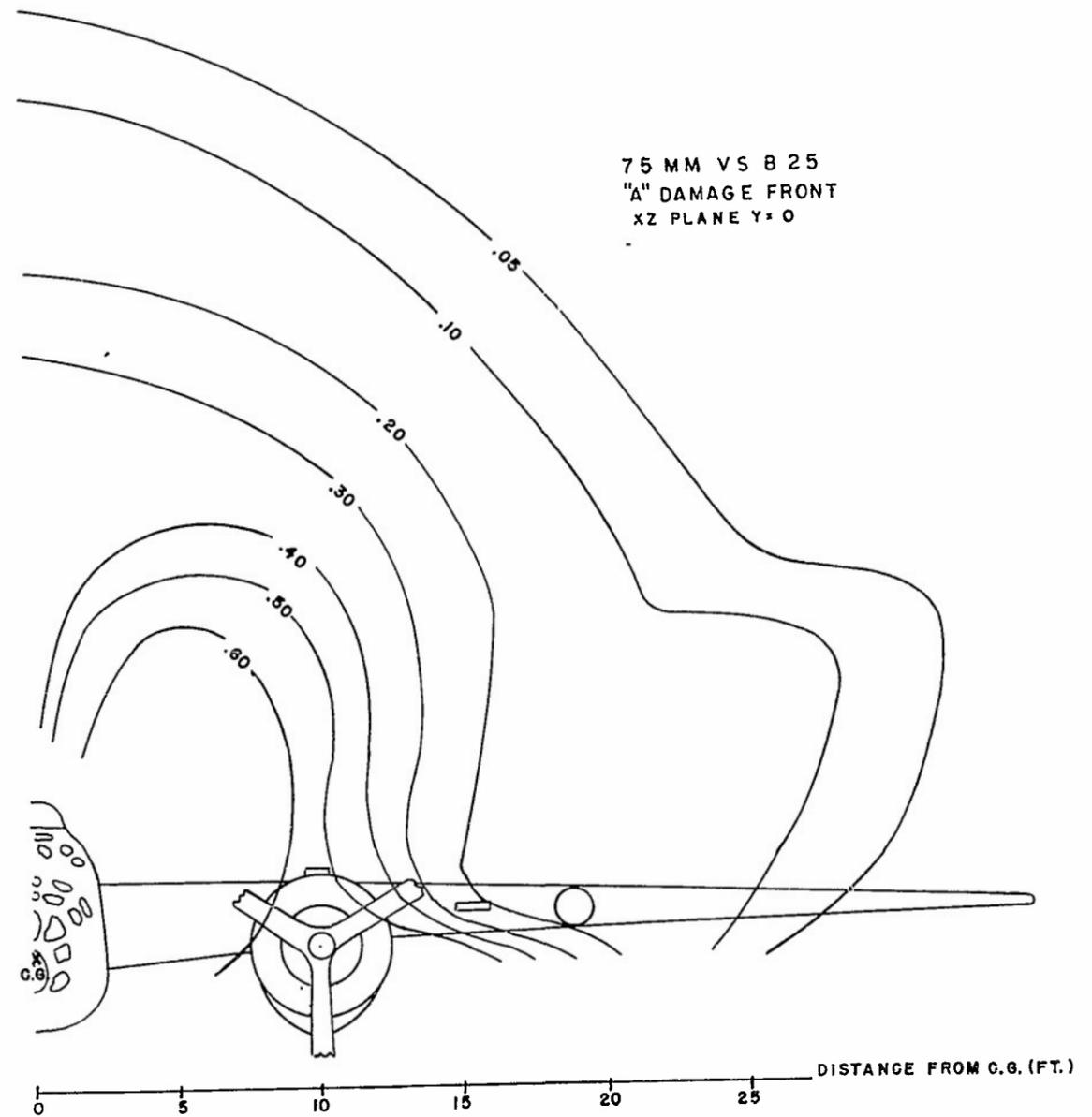


FIGURE 37

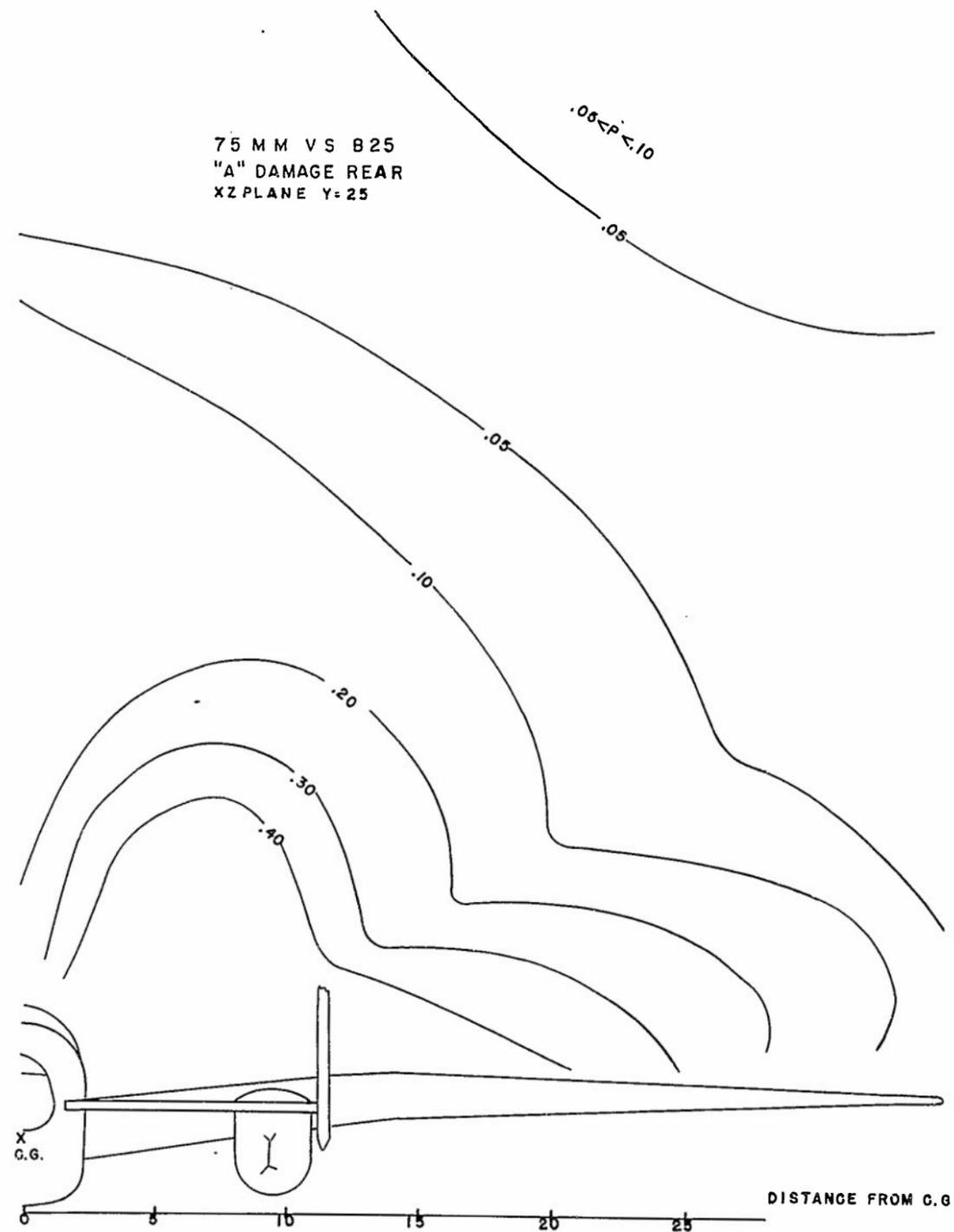


FIGURE 38

The plotted contours were combined in models for the two directions of fire to indicate the three dimensional probability surfaces. These are illustrated in Figures 39 - 42. To further enhance visualization of the overall surfaces of probability about the aircraft, a three-dimensional contour model was constructed, using transparent material. This unit is pictured in Figure 43. Construction of a model in Plaster of Paris has also been considered.

LETHAL AREAS

Suppose that a burst occurs with the center of gravity of the target at the point (X, Y, Z) in a rectangular coordinate system with origin at the point of burst, the Z axis lying along the shell trajectory. Then from the contours given in another portion of this report the conditional probability $p_c(X, Y, Z)$ that the burst causes a kill on the airplane may be obtained. If this probability is multiplied by the probability that the target lies at (X, Y, Z) when the burst occurs and the product is summed over all space, the probability that a round fired at the airplane will destroy it is obtained. This is

$$P_k = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_c(X, Y, Z) P_b(X, Y, Z) dX dY dZ. \quad (1)$$

Now if the probability of a burst at X, Y, Z is substantially constant in that volume of space where the conditional probability $P_c(X, Y, Z)$ is not zero, (1) may be written

$$P_k = \text{constant} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_c(X, Y, Z) dX dY dZ$$

and the quantity $\int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} P_c(X, Y, Z) dX dY dZ$ is referred to as the lethal volume of the shell-target combination.

If the round always bursts so that Z is completely defined by X, Y (for example a proximity fuze always bursting on a particular surface with respect to the target) a lethal area may be similarly defined as

$$A_L = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} p_c(X, Y) dX dY \quad (2)$$

This definition encounters practical difficulties when $p_c(X, Y)$ does not decrease rapidly with increasing X, Y but for the purposes of the present report is perfectly adequate.

Assuming first, bursts on that vertical plane through the target at which the target is most vulnerable the following approximate values of lethal area are obtained for bursts on trajectories parallel to the target's axis. These areas were obtained by very rough summation over the appropriate contours.

	Lethal Area for Bursts in Plane \perp to Target Long. Axis	
	Attack from Front	from Rear
A-damage	900 ft ²	900 ft ²
B-damage	1600 ft ²	1100 ft ²

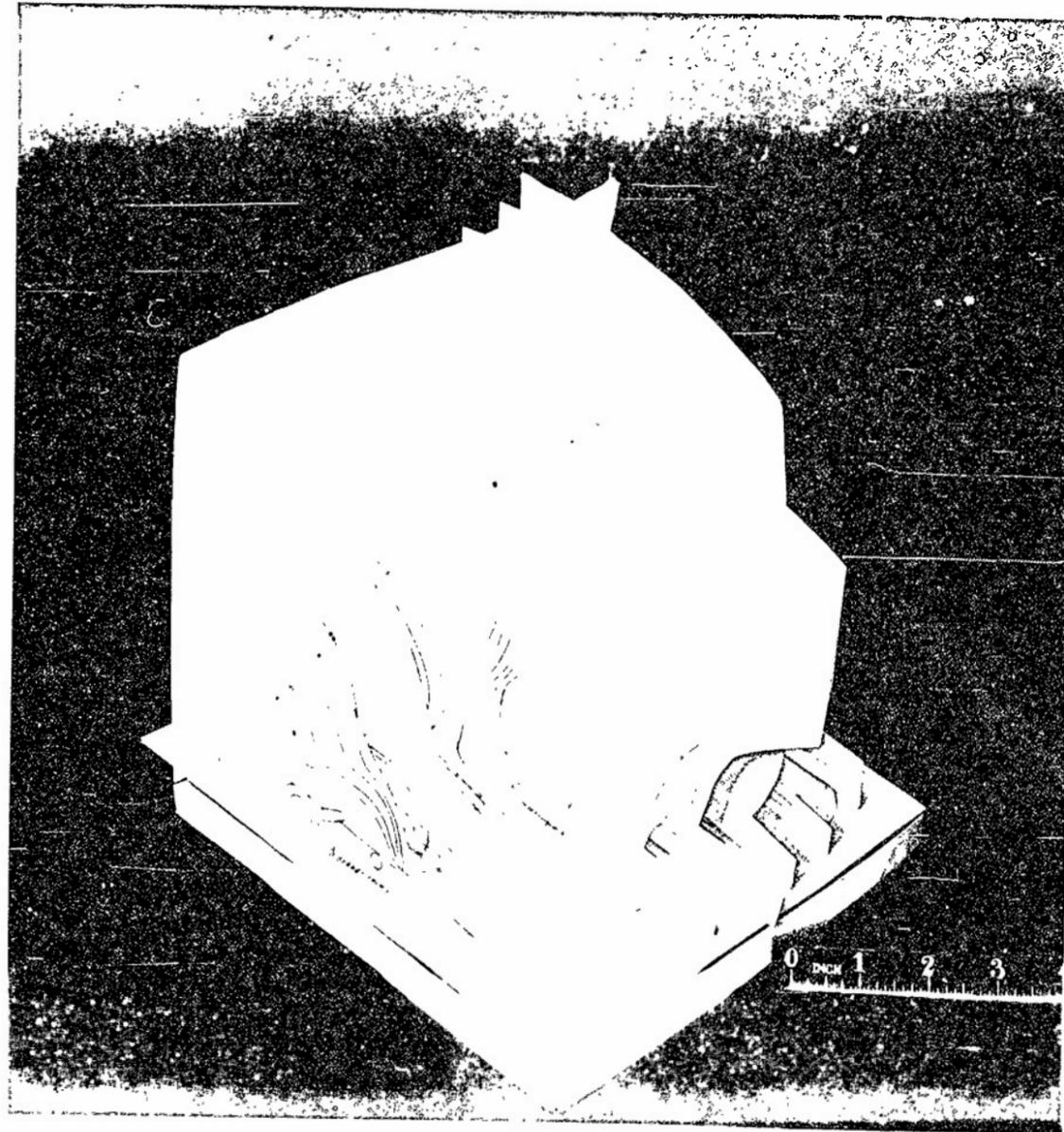


FIGURE 39

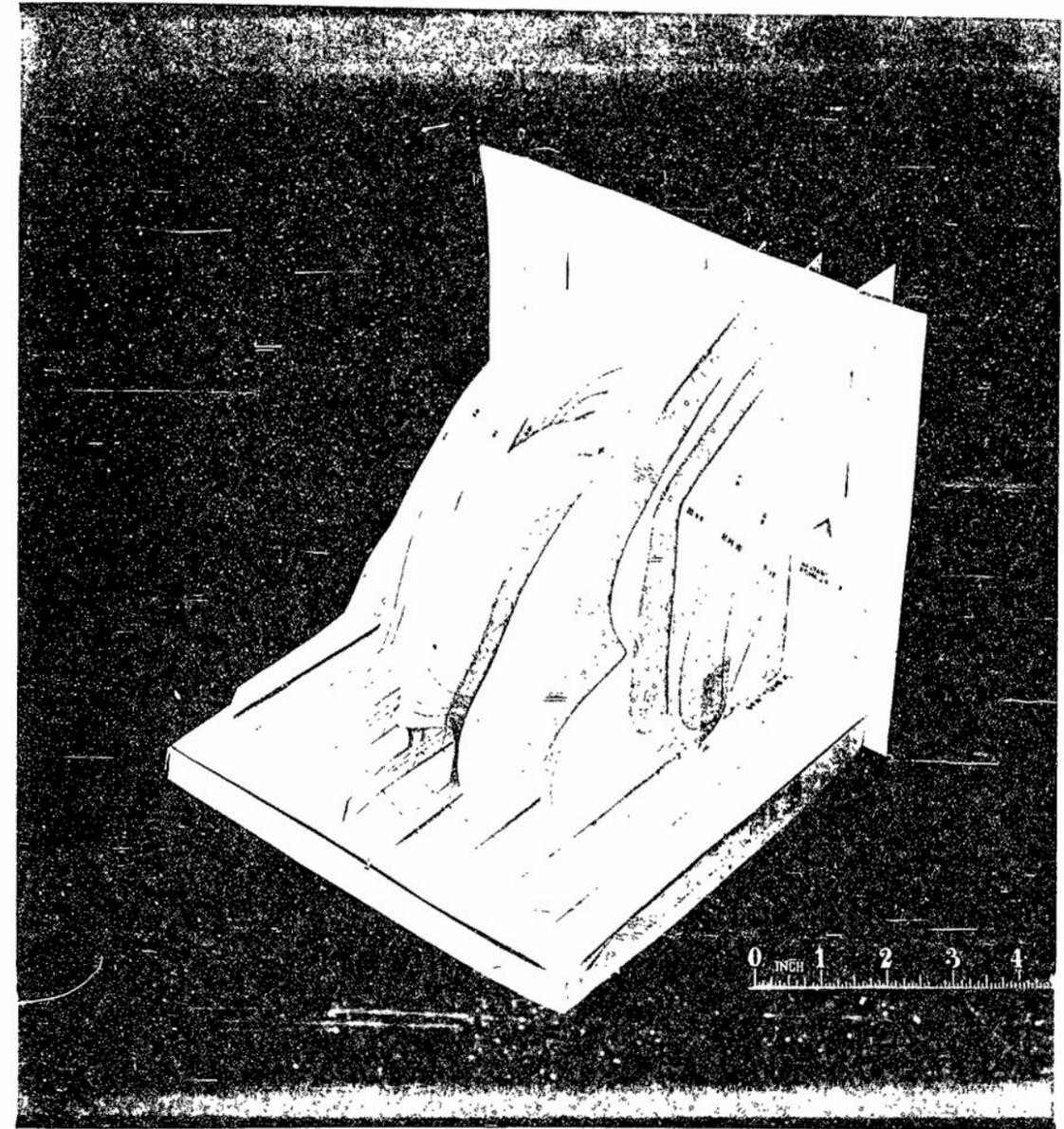


Figure 40. Three-dimensional Representation of Constant Probability Contours for Category "B" Kill Firing from the Front (75mm AC vs. B-25).

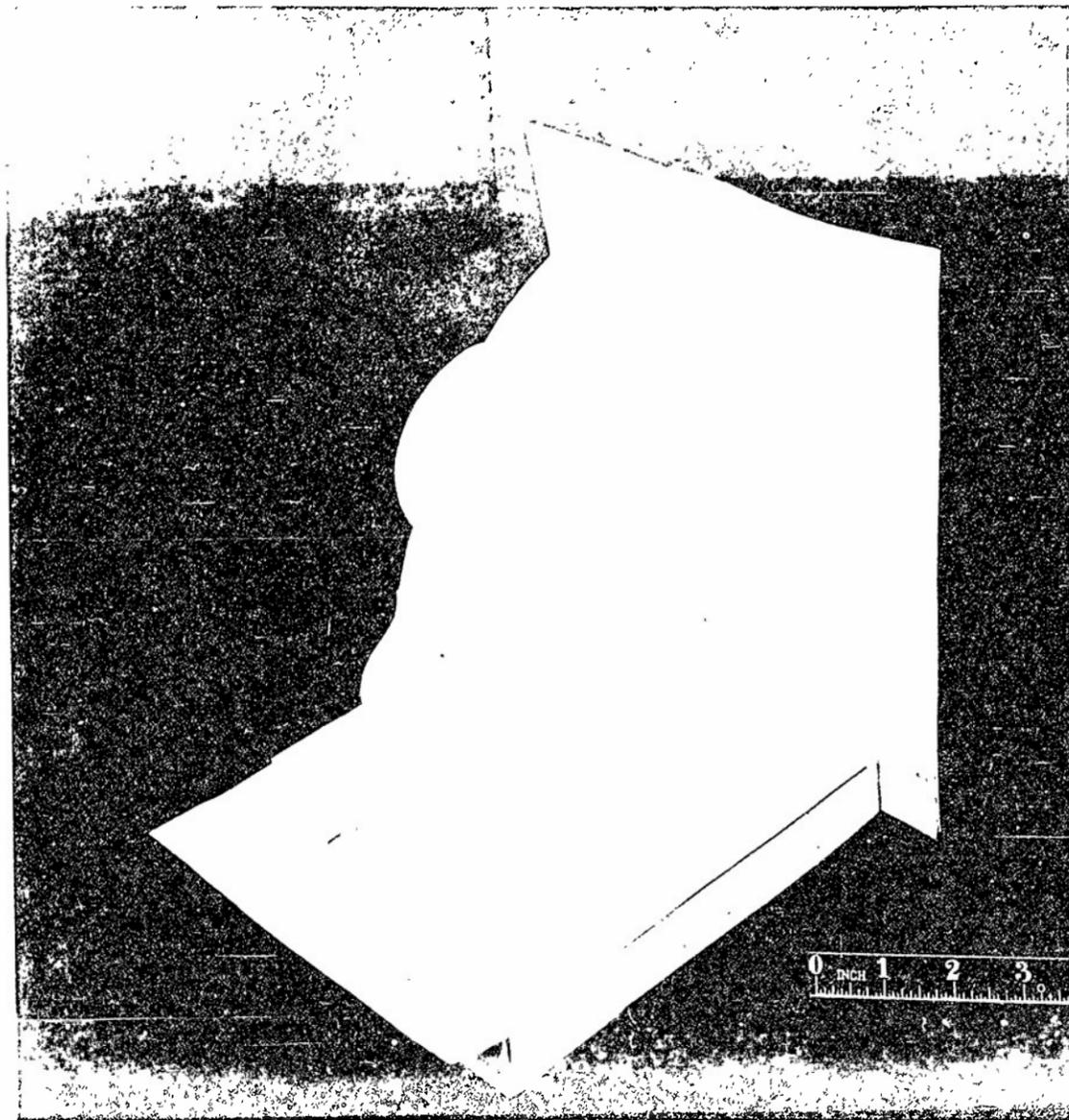


Figure 41. Three-dimensional Representation of Constant Probability Contours for Category "B" Kill Firing from the Rear (75mm AC vs. B-25).

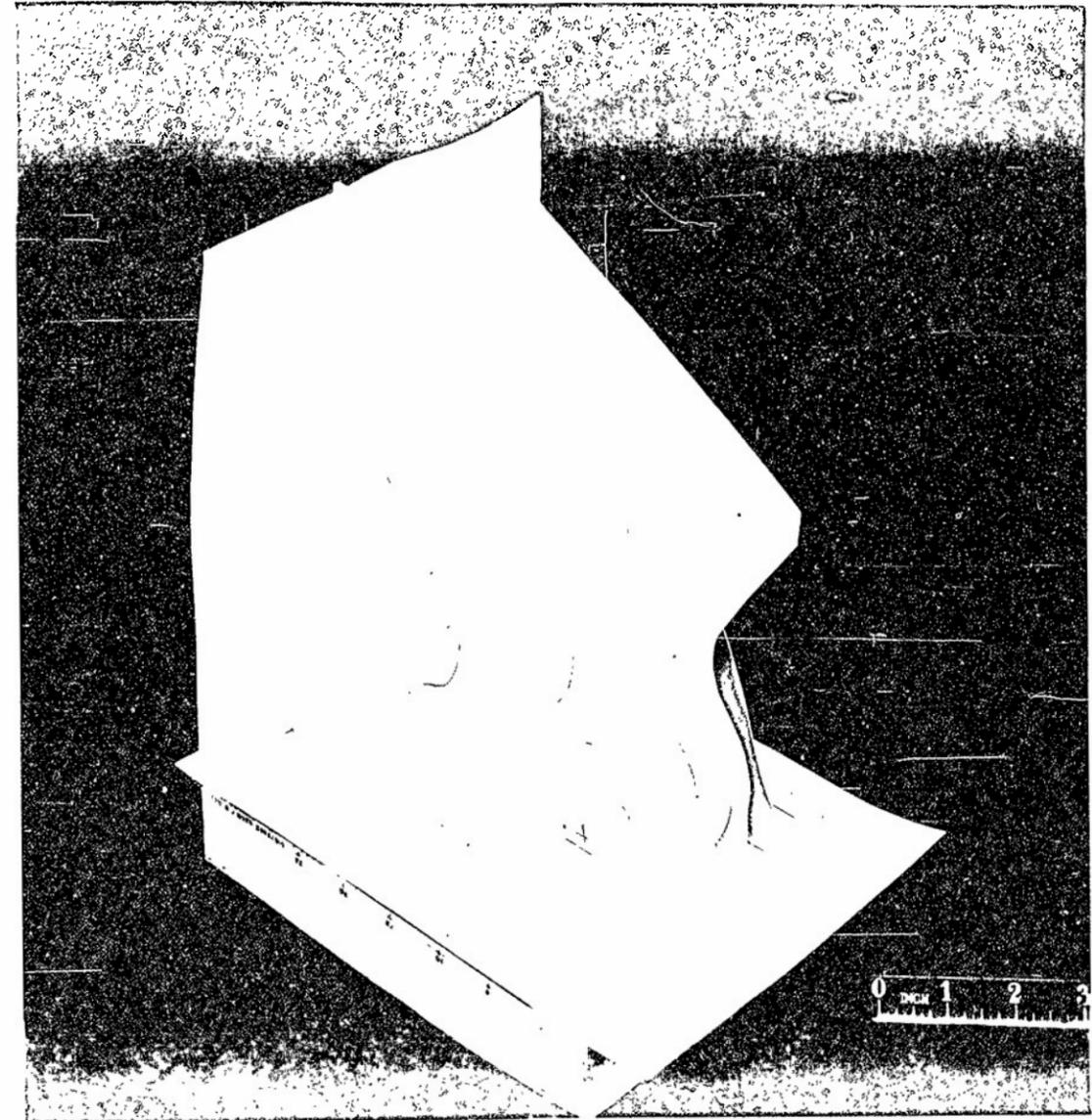


Figure 42. Three-dimensional Representation of Constant Probability Contours for Category "B" Kill Firing from the Rear (75mm AC vs. B-25).

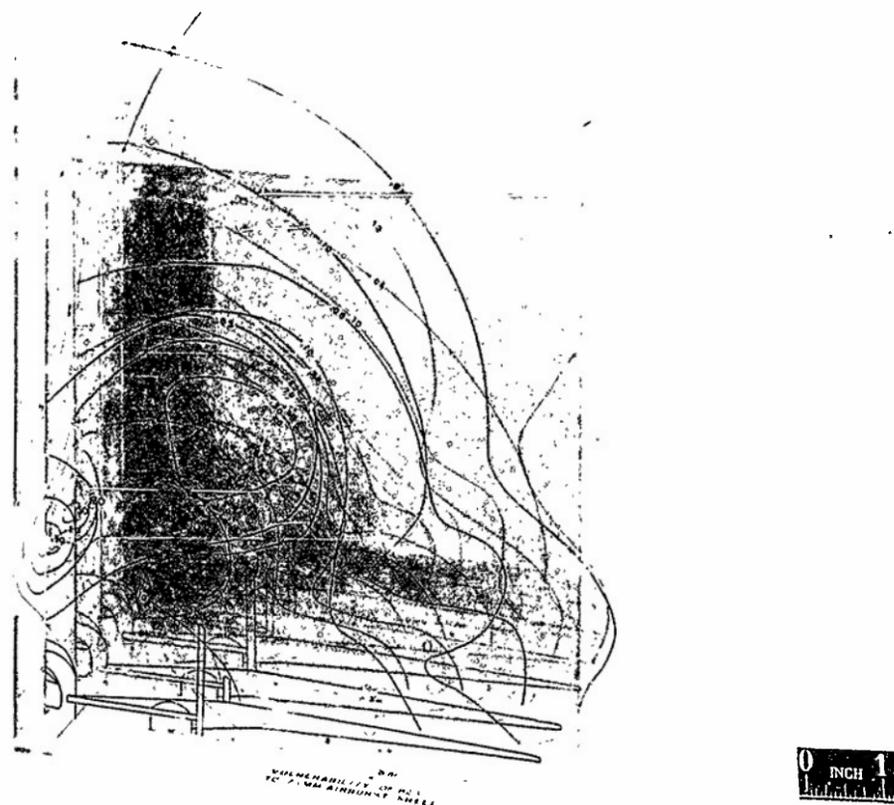


Figure 43. Probability Contour Model for Category "B" Kill (Firing from the Rear) Constructed of Transparent Materials.

If, however, the rounds always burst so as to catch the pilot's compartment in the main spray, a value of B-lethal area as large as 1700 ft^2 is obtained. However, about 1600 ft^2 may be obtained for the pilots alone, indicating that most of the vulnerability of the airplane results from pilot vulnerability. The main effect of vulnerability of engines and fuel systems is to broaden the vulnerability contours somewhat, along the fuselage axis, without greatly raising their peaks.

To indicate the comparatively small contribution of fire damage, consider, in firing from the rear, the lethal area for a fuel cell alone, assuming it to be always in the main fragment spray. It is

For fire of any class	480 ft^2
For fire resulting in B damage	310 ft^2
For fire resulting in A damage	250 ft^2

Since pilot vulnerability was indicated to be of considerable importance, it was considered important to estimate this contribution to overall aircraft vulnerability by a computational method distinct from the experimental observation of number of penetrations of the wooden dummies in the field firings.

Assuming 2 square feet of presented area of each pilot to the fragment spray, assuming both pilots to be in the main fragment spray, and assuming incapacitation caused by a fragment strike capable of perforating .04" dural with 58 ft. lbs. energy remaining after perforation of the plane, the curve of Figure 44 was obtained, showing the probability of incapacitating both pilots as a function of distance from burst point to pilots.¹ The corresponding lethal area is about 1200 square feet. The curves of Figure 44 assume an initial fragment velocity of 2750 f/s, equal to the static fragment velocity, but less than the velocity of 3800 f/s obtained from the shell detonated in flight.

To determine the extent to which pilots may be protected, the same computation was repeated, assuming $3/16$ " homogeneous armor protection for the pilots. This protection reduces the lethal area of two pilots to 300 ft^2 .

Rounds will not, of course, always burst to catch the pilot's compartment in the main fragment spray. The tolerance in permissible burst positions along the fuselage axis of the target is rather small, since the 50% B-damage contour is only about 15 ft. wide at its maximum extent in this direction. If the standard deviation of burst positions about the best burst position is 6 ft., a reasonable value for influence fuzing, the B-kill probability will be only about 0.6 as large as for perfect fuzing, and the A-kill probability may be reduced even more.

VT fuzes usually burst before the shell strikes the target even if the shell is traveling on a trajectory which would pass through the target if the fuze did not function. It is of some interest to see where these burst positions lie with respect to the computed damage contours.

¹This computation was carried out by Mr. Kenneth S. Jones. The distribution of fragment mass used in the computation was that obtained from pit tests.

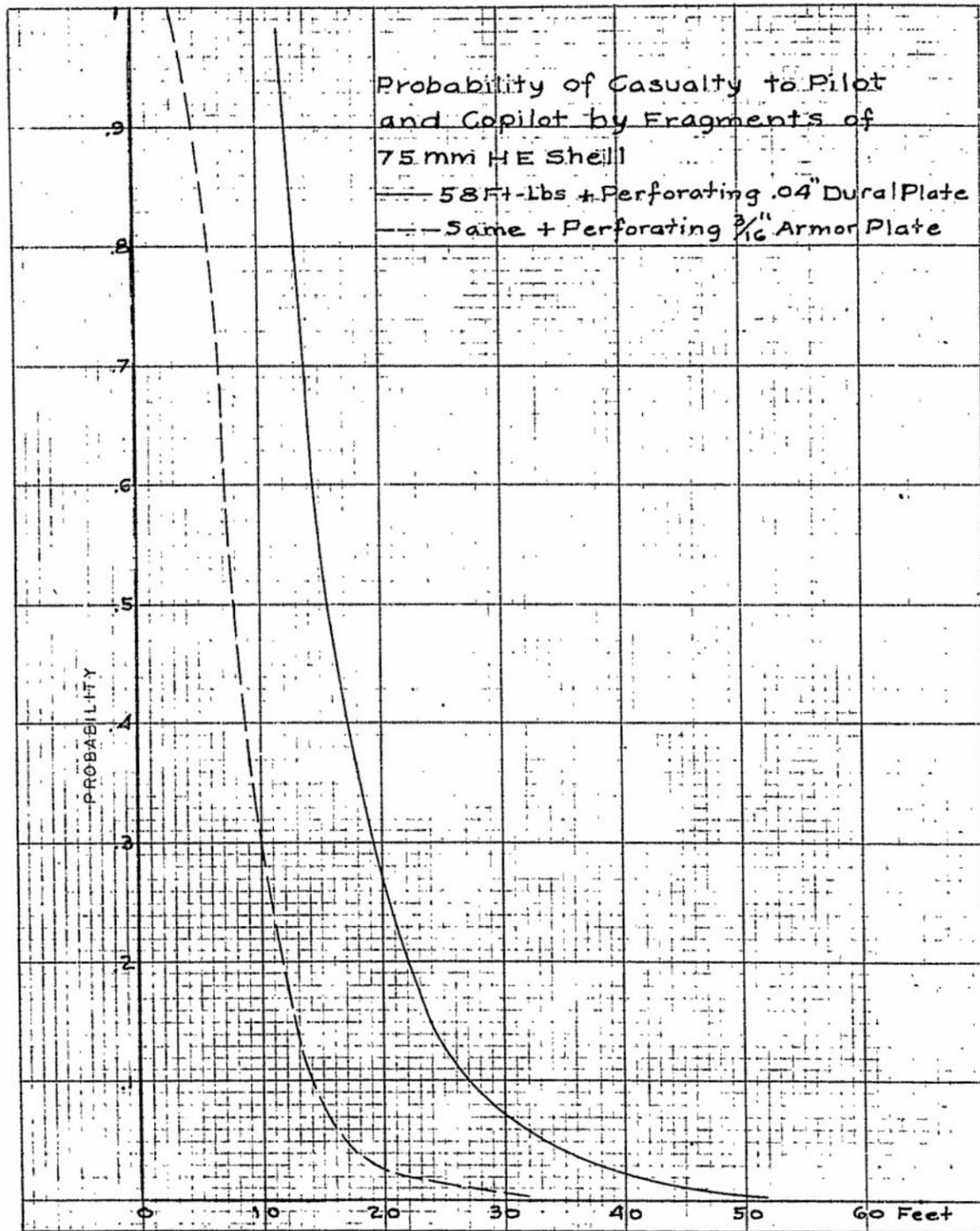


FIGURE 44

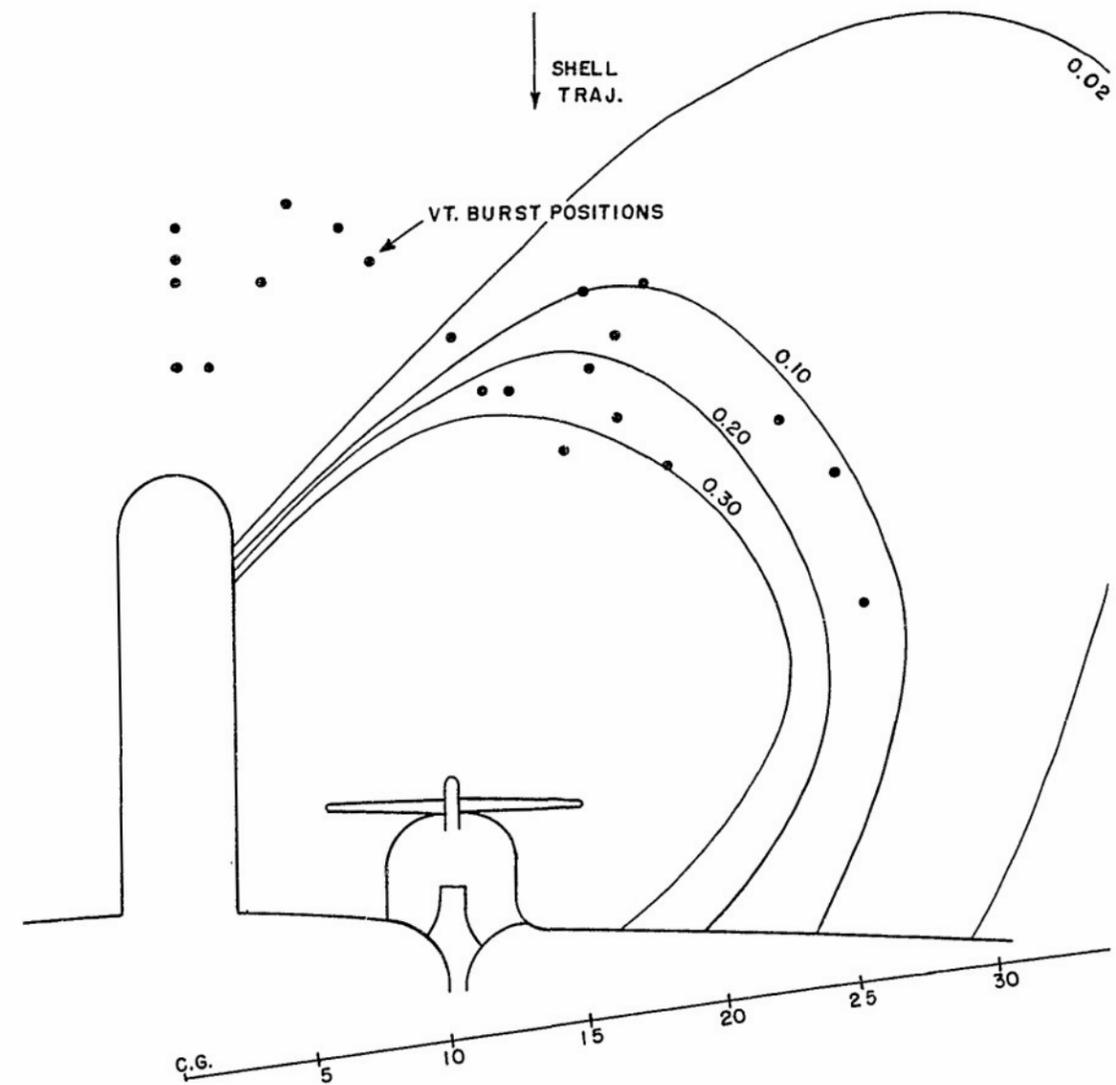


FIGURE 45

For illustrative purposes, burst points as obtained by the New Mexico School of Mines¹ for shell approaching a mock-up Nakajima target on impact trajectories have been plotted in Figure 45. These were actually 90mm shell, so the figure is purely qualitative. Also shown are damage contours for B-damage.

In general, bursts occur on contours representing low probabilities of damage. For burst directly in front of the target there would be damage caused by the nose spray of the shell, which has not been analysed in the present study.

ACKNOWLEDGMENTS

Most of the computations required for the preparation of this report were made by Mr. J. Christian and Mr. H. Kostiak. Mr. K. S. Jones assisted in the estimation of pilot vulnerability.

Mr. A. C. Todaro prepared the drawings for the fragment vulnerability device. Improvements on the original design and actual construction of the device were carried out by Mr. Richard W. Myers of the BRL Machine Shop, whose helpful comments and excellent workmanship resulted in a very useful instrument.

The validity of the data obtained from the firings against aircraft depends to a great extent on the technical knowledge and experience of the assessors and proof directors assigned to the Terminal Ballistics Branch, Arms and Ammunition Division, Development and Proof Services. The 75mm firings were conducted under the general supervision of Lt. Col. D. H. Black and Lt. Col. W. M. Tisdale and under the able direction of Mr. F. E. Watts. Assessments of damage were made under the supervision of Major H. G. Reed, USAF, Chief Assessor and Lt. (SG) M. McKinney, U.S. Navy.

Herbert K. Weiss

Herbert K. Weiss

Arthur Stein

Arthur Stein

¹Quarterly Report for the Quarter Ending 30 September 1947, Technical Report No. 494, The New Mexico School of Mines.

APPENDIX

Comparison of Vulnerable Areas of Components

Source	Date	Pilot (A-Damage)		Vulnerable Area (ft ²)		
		Shell	Aircraft	Front	Above	Rear
Aberdeen	1948	75mm M48	B-25	1.18 0	1.77 1.88	0 (front) 0.25 (rear)
New Mexico ¹	1944	75mm	SB2A	----	1.72	----
		90mm	SB2A	----	2.01	----
		5"/38	SB2A	----	3.04	----
New Mexico ²	1947	5"/38 RDX	SB2A	----	5.46	----
		5"/38	SB2C	Side 1.13	Above 1.34	Below 0.55
British ³	1943	All frags meeting a threshold criterion	Junkers	1.31	1.19	0-1.10

Comments: From the direction of attack where the pilot is most vulnerable, i.e., above, there is good agreement among the above values for vulnerable area. As the mass and/or striking velocity of a fragment increases, however, its ability to incapacitate a man should increase, but the maximum value of vulnerable area should not exceed the area presented by the man. The average presented area of the human body is about 4 ft². In view of the fact that so large a portion of the total vulnerable area of an aircraft is represented by its pilot or pilots, a more detailed examination of pilot vulnerability along the lines of British work⁴ is desirable.

¹Experiments on the Vulnerability of Military Aircraft to High Explosive Shell Fragments, etc., Tech. Monograph No. 113, Applied Physics Laboratory of Johns Hopkins University, April 1945.

²Quarterly Report for Quarter Ending 30 September 1947; Technical Report 494-A of the Research & Development Division, New Mexico School of Mines.

³"The Vulnerability of Aircraft in Flight to Fragments from Heavy AA Shell, etc." by Brown and Simm, AC 5420.

⁴"The Wounding Power of Small Fragments."

ENGINES

Source	Date	Shell	Aircraft	Vulnerable area (ft) ² *				
				E ₁ Front	E ₂	E ₃	E ₄ Above	E ₅ Below
Aberdeen	1948	75mm M48	B-25	0	0	0	0.34	1.02 (Front)
				(1.36)	(0)	(0)	(1.79)	(1.38)
New Mexico	1944	75mm M48	SB2A	0	0	0	0.05	0 (Rear)
				(0)	(7.49)	(3.22)	(1.11)	(0)
New Mexico	1944	90mm M71	SB2A	Above				
				1.10				
				(2.21)				
				1.75				
New Mexico	1947	5"/38 Comp A	SB2C	Side				
				0.52	0.62	0.34		
				(1.30)	(3.07)	(2.77)		
				1.6	2.6	2.3		
New Mexico	1947	5"/38 Comp A	B-17	Side				
				1.6	2.6	2.3		
				(3.6)	(6.6)	(7.8)		
				3.87				
New Mexico	1944	5"/38 RDX	SB2A	Above				
				5.72				
				(9.67)				
				3.87				
New Mexico	1944	5"/38 RDX	SB2A	Above				
				3.87				
				(7.56)				
				3.87				

*Figures in parentheses refer to "B" damage, others to "A" damage.

Comments: Reduction of the New Mexico 1944 values for the 75mm by the fraction indicated for their 1944-1948 5"/38 values yields estimates of 75mm vulnerable areas that are about one-third as large as the Aberdeen values for A damage, and one-half as large for B damage. A major cause of difference between the 1944 New Mexico and 1948 Aberdeen figures is lower severity of assessments for oil loss at Aberdeen.

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STRUCTURES

Source	Date	Shell	Aircraft	Vulnerable Area (ft) ² *		
				Side	Above	Below
Aberdeen	1948	75mm (M48)	B-25		0.06 (0.06)	
New Mexico	1944	75mm (M48)	SB2A		1.54 (1.97)	
					1.58 (3.32)	
		90mm (M71)	SB2A		2.83 (7.23)	
					2.08 (4.94)	
New Mexico	1947	5"/38	SB2C	Side	0.09 (0.13)	0.42 (0.54)
				Above	0.39 (0.54)	0.42 (0.54)

*Figures in parentheses refer to "B" damage, others to "A" damage.

Comments: If the New Mexico 75mm vulnerable areas obtained in 1944 were reduced by the same amount as the 5"/38 figures obtained in 1948 over the 1944 value, the 75mm value thus estimated would be more than four times as large for the SB2A as Aberdeen has obtained for the B-25. The difference between the Aberdeen values and the estimated 1948 New Mexico values may be accounted for by the difference in structure between the SB2A and B-25. The chief sources of structural damage by fragments are those associated with the oxygen and hydraulic systems, and these have not been serious in the B-25.

The 1944 New Mexico structural assessments included estimates of probable failure to return to base if gun, gunner, or ammunition is hit, etc. At Aberdeen such damage is not included as a source of "A" or "B" damage but is instead reflected as a loss in fire power for the assumed combat. Thus if the bomber were attacked by a fighter, damage to armament will be considered in the overall evaluation of the outcome of the encounter.

It is believed that the present assessment procedures at both establishments are essentially in agreement. In addition, each installation describes damage so carefully that changes in severity of assessment as more information becomes available can always be made.

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