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BALLISTIC SUMMARY - PART II  
THE SCALE EFFECT AND THE OGIVE EFFECT

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NAVAL PROVING GROUND  
DAHLGREN, VIRGINIA

Captain David I. Hedrick, USN  
Commanding Officer

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NPG Report No. 4-46

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BALISTIC SUMMARY - PART II  
THE SCALE EFFECT AND THE OGIVE EFFECT

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Lieutenant, USNR

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NPG Report No. 4-46

BALLISTIC SUMMARY - PART II  
THE SCALE EFFECT AND THE OGIVE EFFECT

1. For some years the Naval Proving Ground has been assiduously engaged in the study of the penetration of armor by projectiles. Pursuance of this work to conclusive results must be predicated upon well substantiated theories defining the performances of the materials involved under the various possible conditions.

2. Particularly necessary in the more immediately practical field of armor study and evaluation is the need for dependable plate penetration charts or tables. In 1943 Lieut. A. V. Hershey, USNR was assigned the task of preparing such charts. In prosecution of the assigned task he conducted an exhaustive study, employed for the first time new methods of attack and developed new theories concerning the phenomena incident to the penetration of plates by projectiles.

3. During the latter years of World War II, Lieut. Hershey prepared a series of nine reports which are being published by the Naval Proving Ground under titles as follows:

(1) ANALYTICAL SUMMARY. PART I. THE PHYSICAL PROPERTIES OF STS UNDER TRIAXIAL STRESS.

Object: To summarize the available data on the physical properties of Class B Armor and STS under triaxial stress.

(2) ANALYTICAL SUMMARY. PART II. ELASTIC AND PLASTIC UNDULATIONS IN ARMOR PLATE.

Object: To analyze the propagation of undulations in armor plate; to summarize previous analytical work and to add new analytical work where required in order to complete the theory for ballistic applications.

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(3) ANALYTICAL SUMMARY. PART III. PLASTIC FLOW IN ARMOR PLATE.

Object: To analyse the plastic flow in armor plate adjacent to the point of impact by a projectile.

(4) ANALYTICAL SUMMARY. PART IV. THE THEORY OF ARMOR PENETRATION.

Object: To summarize the theory of armor penetration in its present state of development, and to develop theoretical functions which can be used as a guide in the interpretation of ballistic data.

(5) BALLISTIC SUMMARY. PART I. THE DEPENDENCE OF LIMIT VELOCITY ON PLATE THICKNESS AND OBLIQUITY AT LOW OBLIQUITY.

Object: To compare the results of ballistic test with the prediction of existing formulae, and with the results of theoretical analysis; to find the mathematical functions which best represent the fundamental relationship between limit velocity, plate thickness, and obliquity at low obliquity.

(6) BALLISTIC SUMMARY. PART II. THE SCALE EFFECT AND THE OGIVE EFFECT.

Object: To determine the effect of scale on ballistic performance, and to correlate the projectile nose shape with the results of ballistic test.

(7) BALLISTIC SUMMARY. PART III. THE WINDSHIELD EFFECT, AND THE OBLIQUITY EFFECT FOR COMMON PROJECTILES.

Object: To analyse the action of a windshield during impact, and to develop mathematical functions which best represent the ballistic performance of common projectiles.

(8) BALLISTIC SUMMARY. PART IV. THE CAP EFFECT, AND THE OBLIQUITY EFFECT FOR AP PROJECTILES.

Object: To determine the action of a cap during impact, and to develop mathematical functions which best represent the ballistic performance of AP projectiles.

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(9) BALLISTIC SUMMARY. PART V. THE CONSTRUCTION OF PLATE PENETRATION CHARTS OR TABLES.

Object: To summarize the results of analysis in the form of standard charts or tables.

4. The opinions and statements contained in these reports are the expressions of the author, and do not necessarily represent the official views of the Naval Proving Ground.

*David I. Hedrick*

DAVID I. HEDRICK  
Captain, USN  
Commanding Officer

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## P R E F A C E

### AUTHORIZATION

The material in this report has been basic to the construction of plate penetration charts. It was authorized by BuOrd letter NP9/A9 (Re3) dated 9 January 1943.

### OBJECT

To determine the effect of scale on ballistic performance, and to correlate the projectile nose shape with the results of ballistic test.

### SUMMARY

Limit velocities for perforation at different scales, but with geometrically similar combinations of plate and projectile, vary logarithmically with the dimensions of the plates or projectiles. The scale effect may be correlated with the effect of strain rate on stress in the armor steel.

A change in nose shape from one projectile design to another has an effect on the depth to which the projectiles penetrate into homogeneous plate at striking velocities less than limit, and modifies also the limit velocity for perforation. If a series of projectiles be arranged in the order of depth of penetration, they appear also in the correct order of limit velocity.

The ellipsoid, the ogive, the cone, and the cylinder are all special cases of a two-parameter family of surfaces. The nose shapes of service projectiles may also be represented to within a few hundredths of a caliber by members of this same family. Corresponding to each projectile nose shape there exists an ellipsoidal nose shape which would have the same ballistic properties as the actual nose shape. In the correlation of ballistic performance, the two parameters of the general family of nose shapes may be reduced to a single parameter, the ratio of major axis to minor axis for the equivalent ellipsoid. Values for the parameters have been computed for the projectiles of interest to the service.

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## I INTRODUCTION

It was assumed for many years by the U. S. Navy that all projectile designs are equivalent in ballistic performance as long as they are undeformed. This assumption was fully justified before the modern AP projectile development program, because there were in reality only minor variations in projectile design. The projectiles of recent interest have varied, however, from cal. 30 small arms ammunition at one extreme to flat nosed major caliber bombs at the other, and differences in projectile design can no longer be ignored in any accurate analysis.

A few of the variables which enter into the analysis of armor penetration are the mass of the projectile, the diameter of the projectile, the thickness of the plate, the shape of the projectile nose contour and the ductility of the plate material. The conditions of impact are defined by the obliquity and the striking velocity. The results of impact in an incomplete penetration are summarized by the depth of penetration, which is measured from the tip of the projectile, at the instant of maximum travel, to a reference plane which is tangent to the plate just outside of the coronet but inside of the dish. The results of impact in a complete penetration are summarized by the remaining velocity. From the results of impact may be derived the limit velocity, or that striking velocity which would just put the major portion of the projectile completely through the plate with zero remaining velocity.

The individual values of depth of penetration and limit velocity for each impact vary capriciously from impact to impact partly because of fluctuations in plate quality. The average values of depth of penetration and limit velocity vary continuously however with the dimensions and shape of the projectile.

The limit velocities for non-deforming monobloc projectiles, with geometrically similar combinations of plate and projectile, decrease on the average with increase in the dimensions of the plates or projectiles. The decrease in limit velocity with increase in scale is partly the result of a simultaneous decrease in static tensile strength. As the plate thickness is increased, the difficulty of control during manufacture increases, and the thick plates are usually heat treated to a low hardness in order to avoid brittle failure on impact. The limit velocity for a ductile plate is primarily a function of the dynamic tensile strength and a plate may have several limit velocities, even for the same static tensile strength, if the microstructure is varied. The existence of a true scale

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effect would only be revealed by a series of ballistic tests with geometrically similar monobloc projectiles fired against geometrically similar pieces sliced from the same thick plate. Such tests would require a difficult machining operation.

An approximate estimate of the scale effect may be derived, nevertheless, from existing ballistic data for nondeforming projectiles all with nearly the same nose shape but tested against different plates. Corrections may be applied to the data for small variations in nose shape, but measurements of the actual dynamic tensile strengths are not available. Corrections for variations in tensile strength must therefore be based on the assumption that the relationship between dynamic tensile strength and static tensile strength follows the general trend for steels of constant microstructure. Corrections<sup>4</sup> for tensile strength should be applied only in part to data for plates whose hardness is near the critical hardness for brittle failure, and should probably be omitted altogether from comparisons between Class B armor and STS. Thus, specimens of Class B armor have been found by the group at the California Institute of Technology to have nearly the same dynamic tensile strengths as specimens of STS, even though the static tensile strengths varied from 98000 (lb)/(in)<sup>2</sup> for the Class B armor to 116000 (lb)/(in)<sup>2</sup> for the STS.

The limit velocity for non-deforming pointed projectiles decreases on the average as the sharpness of the point is increased and plate failure in each impact occurs with the formation of a star crack. The limit velocity for non-deforming round nosed projectiles, on the other hand, decreases on the average as the nose contour approaches a flat cylinder, and plate failure in each impact usually occurs with the formation of a punching or plug. The existence of an ogive effect is revealed by a series of ballistic tests with monobloc projectiles of various nose shapes all fired against the same plate. The number of such tests which have been completed is sufficient to outline the general trends of the ogive effect.

Details of these ballistic data, which best illustrate the scale effect and the ogive effect have been released in previous reports, references (1) to (3) but are summarized in Tables III to VII in the present report.

A semiquantitative theory of armor penetration has been completed for the 3" AP M79 projectile, and details of the theory will be released in later reports. The results of the theory are used in the

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present report to interpret the results of test. The 3" AP M79 projectile is the most extensively investigated monobloc projectile, and has therefore been used as the reference standard for comparisons.

## II THE BALLISTIC PARAMETERS

The results of ballistic test may conveniently be summarized in terms of a number of ballistic parameters. The impact parameter  $F_S$ , the plate penetration coefficient  $F(e/d, \theta)$ , and the residual velocity function  $F_R$  may all be defined in terms of the projectile mass  $m$ , the projectile diameter  $d$ , the plate thickness  $e$ , the obliquity  $\theta$ , the striking velocity  $v_S$ , the limit velocity  $v_L$ , and the remaining velocity  $v_R$  by the equations

$$F_S = \frac{m^{\frac{1}{2}} v_S \cos \theta}{e^{\frac{1}{2}} d}$$

$$F(e/d, \theta) = \frac{m^{\frac{1}{2}} v_L \cos \theta}{e^{\frac{1}{2}} d}$$

$$F_R = \frac{m^{\frac{1}{2}} v_R \cos \theta}{e^{\frac{1}{2}} d}$$

These parameters are convenient to use in the representation of ballistic data, since they are directly proportional to velocity, and do not vary rapidly with plate thickness or obliquity.

Of more fundamental significance are the impact energy parameter  $U_S$ , the limit energy function  $U(e/d, \theta)$ , and the residual energy function  $U_R$ , which are defined in terms of  $F_S$ ,  $F(e/d, \theta)$  and  $F_R$

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by the equations

$$U_S = \left(\frac{e}{d}\right) F_S^2$$

$$U(e/d, \theta) = \left(\frac{e}{d}\right) F^2(e/d, \theta) = \frac{mv_L^2 \cos^2 \theta}{d^2}$$

$$U_R = \left(\frac{e}{d}\right) F_R^2$$

These parameters are proportional to the kinetic energy of the projectile at normal obliquity.

Ballistic performance may be interpreted with equal validity in terms of either of the functions  $F(e/d, \theta)$  or  $U(e/d, \theta)$ . The projectile mass in the functions is expressed in (lb), the projectile diameter is expressed in (ft), the plate thickness in (ft), and the limit velocity in (ft)/(sec).

The scale effect for a given projectile is best represented by the ratio  $1+\sigma$  between the limit energy function for the given projectile and the limit energy function for a 3" projectile of the same geometrical shape. The ogive effect is similarly represented by the ratio  $1+\omega$  between the limit energy function for the given projectile and the limit energy function for a projectile of the same caliber but with the nose contour of the 3" AP M79 projectile. The ratio between the limit energy function for any projectile and the limit energy function for the 3" AP M79 projectile is then equal to the product  $(1+\sigma)(1+\omega)$ .

The limit energy function for the standard projectile at low obliquity is given<sup>4</sup> by the equation

$$U(e/d, \theta) = \left(\frac{e}{d}\right) \Phi^2 \theta \cos \theta$$

in which  $\Phi$  is a function of  $e/d$  and  $\theta$  is a function of  $\theta$ . The functions  $\Phi$  and  $\theta$  are expressed graphically by Figures (1) and (2).

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The shape of any projectile nose contour is defined analytically by a relationship between the cylindrical polar coordinates  $r$  and  $s$  of a point on the surface of the projectile. The distance  $r$  is measured from the axis of the projectile, and the distance  $s$  is measured from a plane perpendicular to the axis, through the tip of the nose. The coordinates  $r, s$  are illustrated in Figure (3). The dimensions of the nose contour are the radius  $a$  of the bourrelet, and the length  $b$  of the nose from bourrelet to tip.

The ellipsoid, the ogive, and the cone are special cases of a two-parameter family of surfaces, whose general equation is

$$\frac{s}{a} = \frac{b}{a} \left( 1 - \sqrt{1 - \alpha \frac{r}{a} - (1-\alpha) \frac{r^2}{a^2}} \right)$$

The two parameters in the equation are  $b/a$  and  $\alpha$ .

The equation for an ellipsoid is

$$\frac{s}{a} = \frac{b}{a} \left( 1 - \sqrt{1 - \frac{r^2}{a^2}} \right)$$

for which the value of  $\alpha$  is zero. The ratio  $b/a$  is the ratio between the major axis and the minor axis of the ellipsoid.

The equation for an ogive\* is

$$\frac{s}{a} = \frac{b}{a} \left( 1 - \sqrt{1 - \left(1 - \frac{a^2}{b^2}\right) \frac{r}{a} - \frac{a^2 r^2}{b^2 a^2}} \right) \quad (1)$$

---

\*According to the strictest definition, the ogive is a surface of revolution described by the arc of a single circle which is tangent to the bourrelet.

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The parameters  $b/a$  and  $\alpha$  for an ogive are given in terms of the radius  $R$  of the arc by the equations

$$\frac{b}{a} = \frac{1}{a} \sqrt{R^2 - (R-a)^2} = \sqrt{2\frac{R}{a} - 1}$$

and

$$\alpha = 1 - \frac{a^2}{b^2} = \frac{\frac{R}{a} - 1}{\frac{R}{a} - \frac{1}{2}}$$

The equation for the cone is

$$\frac{z}{a} = \frac{b}{a} \left( \frac{r}{a} \right)$$

for which the value of  $\alpha$  is equal to +2. The ratio  $b/a$  is the ratio between the altitude of the nose and the radius of the base.

The flat nose or cylinder is obtained from the general equation, for any value of  $\alpha$ , by setting  $b/a$  equal to zero.

The nose contours of service type projectiles may also be represented to within a few hundredths of a caliber by members of the same family. Values of the parameters  $b/a$  and  $\alpha$  have been chosen for all of the projectiles of ballistic interest. The parameters have been so chosen that the volume contained between the projectile nose contour and a circumscribed cylinder is the same for the approximate contour as for the actual contour. The volume of the circumscribed cylinder is  $\pi a^2 b$ , while the volume contained in the space between the projectile nose contour and the circumscribed cylinder is given by the integral

$$2\pi \int_0^a z r dr$$

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The ratio between the two volumes is given for the approximate contour in terms of  $\alpha$  by the equation

$$\frac{2\pi \int_0^a x r dr}{\pi a^2 b} = \frac{\frac{2}{3}\alpha^2 - \frac{4}{3}\alpha + \frac{1}{3}}{(1-\alpha)^2} + \frac{\frac{1}{3}\alpha(2-\alpha)^2}{(1-\alpha)^2} \cos^{-1} \frac{\alpha}{2-\alpha} \quad (2)$$

Values of this ratio have been computed for a series of values of  $\alpha$  and are listed in Table II. The ratio between the two volumes is found for the actual contour by numerical integration.

The values of  $b/a$  and  $\alpha$  for service type projectiles were found by a process of successive approximations. From trial values of  $b/a$  and  $\alpha$  were calculated points on a trial contour, which was then compared graphically with the actual contour. The parameters were readjusted until the distance between the two contours was reduced to a minimum. The final values for  $b/a$  and  $\alpha$  are listed in Table I and are plotted in Figure (4). The final trial contours for a few of the projectiles, are compared with the actual contours in Figures (5) to (16), where the trial contours are represented by dotted lines and the actual contours are represented by solid lines.

### III STATISTICAL ANALYSIS OF THE BALLISTIC DATA

Separation of the scale effect and the ogive effect from the effects of variations in plate quality requires a statistical analysis of the ballistic data.

If the impact energy parameter  $U_S$  in any impact happens to be less than the limit energy function  $U(e/d, \theta)$ , the impact is an incomplete penetration, but if the impact energy parameter  $U_S$  happens to be more than the limit energy function  $U(e/d, \theta)$ , the impact is a complete penetration. The ballistic data at major caliber scale usually consist of two impacts on each plate, whose values of  $U_S$  bracket the value of  $U(e/d, \theta)$ . The actual bracket may usually be replaced by a narrower estimated bracket, which is based on the depth of penetration and the remaining velocity of the projectile. The brackets vary in width from plate to plate, and the wide brackets deserve less statistical weight than the narrow brackets.

If the limit energy function  $U(e/d, \theta)$  fluctuates from plate to plate in accordance with the normal law of errors, then the frequency of occurrence of an individual deviation  $\beta$  from the true mean  $u$  for all plates is given by the expression

$$\frac{h}{\sqrt{\pi}} e^{-h^2 \beta^2}$$

in which  $h$  is the precision constant of the fluctuation.

If a pair of impacts at two different values of  $U_S$  were repeated an unlimited number of times on different plates, each time with the same two values of  $U_S$ , then the value of  $U(e/d, \theta)$  would fall between the two values of  $U_S$  with a frequency equal to

$$\frac{1}{\sqrt{\pi}} \int_{h\epsilon^*}^{h\epsilon^0} e^{-\beta^2} d\beta$$

in which  $\epsilon^*$  is the deviation of the smaller value of  $U_S$  from the mean value of  $U(e/d, \theta)$ , and  $\epsilon^0$  is the deviation of the larger value of  $U_S$ .

The collected ballistic data consist of a group of brackets, each with a different pair of values for  $U_S$ . If a group of  $n$  pairs of impacts were repeated an unlimited number of times, each time with the same set of values for  $U_S$ , then the limit energy function would fall between the two values of  $U_S$  on every pair of impacts in the group with a frequency  $N$  which is given by the product

$$N = \Pi \left( \frac{1}{\sqrt{\pi}} \int_{h\epsilon_k^*}^{h\epsilon_k^0} e^{-\beta^2} d\beta \right)$$

in which  $\epsilon_k^*$  and  $\epsilon_k^0$  are the deviations of the two values of  $U_S$  in the  $k^{\text{th}}$  pair of impacts. A particular group of limit determinations would occur with the greatest frequency in that series of plates for which  $N$  is a maximum with respect to variations in  $u$  and  $h$ . The most likely values

of  $u$  and  $h$  are therefore those which satisfy the conditions

$$-\frac{1}{hN} \left( \frac{\partial N}{\partial u} \right) = \Sigma \frac{e^{-h^2 \epsilon_k^0{}^2} - e^{-h^2 \epsilon_k^{*2}}}{\int_{h\epsilon_k^0}^{h\epsilon_k^*} e^{-\beta^2} d\beta} = 0$$

$$+\frac{h}{N} \left( \frac{\partial N}{\partial h} \right) = \Sigma \frac{h\epsilon_k^0 e^{-h^2 \epsilon_k^0{}^2} - h\epsilon_k^* e^{-h^2 \epsilon_k^{*2}}}{\int_{h\epsilon_k^0}^{h\epsilon_k^*} e^{-\beta^2} d\beta} = 0$$

If  $\epsilon_k^*$  is nearly equal to  $\epsilon_k^0$ , these equations are simplified to the equations

$$-\frac{1}{hN} \left( \frac{\partial N}{\partial u} \right) = -2\Sigma h\epsilon_k e^{-\frac{1}{2}h^2(\epsilon_k^0 - \epsilon_k^*)^2} = 0$$

$$+\frac{h}{N} \left( \frac{\partial N}{\partial h} \right) = \Sigma e^{-\frac{1}{2}h^2(\epsilon_k^0 - \epsilon_k^*)^2} - 2\Sigma h^2 \epsilon_k^2 e^{-\frac{1}{2}h^2(\epsilon_k^0 - \epsilon_k^*)^2} = 0$$

in which  $\epsilon_k$  is the average of  $\epsilon_k^*$  and  $\epsilon_k^0$ . In the limit with  $\epsilon_k^*$  equal to  $\epsilon_k^0$ , the equations are further simplified to the conventional equations of least squares

$$-\frac{1}{hN} \left( \frac{\partial N}{\partial u} \right) = -2\Sigma h\epsilon_k = 0$$

$$+\frac{h}{N} \left( \frac{\partial N}{\partial h} \right) = n - 2\Sigma h^2 \epsilon_k^2 = 0$$

The values of  $u$  and  $h$  for a particular group of data are found from the above equations of maximum likelihood by successive approximations.

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The standard deviation of an individual value of  $U(e/d, \theta)$  from the mean value  $u$  is given in terms of the precision constant  $h$  by the expression

$$\frac{1}{\sqrt{2h}}$$

#### IV THE SCALE EFFECT

The instantaneous velocities of all projectiles, at any particular stage of penetration, are almost, though not quite, the same for geometrically similar combinations of plate and projectile. The duration of any stage of penetration varies therefore almost inversely with the dimensions of the plate or projectiles. The distributions of strain in the armor around the noses of all projectiles, at the given stage of penetration, are geometrically similar. The strain rates for all projectiles at the given stage of penetration, also vary, therefore, almost inversely with the dimensions of the system. The stress in the armor may be represented as a logarithmic function of strain rate in the range of strain rates which occur during projectile impact. Direct measurements of the variation of stress with strain rate for several steels are plotted in Figure (17). The stress in STS increases approximately 4% per unit increase in the natural logarithm of strain rate, in the range of strain rates greater than 200 (sec)<sup>-1</sup>.

The function which was therefore chosen in 1944 by the Naval Proving Ground to represent the relationship between the scale effect  $\sigma$  and the projectile diameter  $d$  is given by the equation

$$\sigma = - (.04 \pm .02) \log(4d) \quad (3)$$

Equation (3) is basic to NPG Sk 650. It is represented in Figure (18) by Curve I.

The nearest approach to a scale model of a 3" AP M79 projectile in STS is represented by the data in Table III for the cal .60 Expr. Dm 51 projectile in Plate No. N-1. The cal .60 projectile has the same ogive as the 3" projectile, but differs in the type of carrier. (The cal .60 projectile has a base cup, whereas the 3" projectile has a rotating band.) Plate No. N-1 was a nickel-chromium alloy plate of standard STS compo-

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tion with 0.27% carbon. The data for Plate No. N-1 give a value of  $\sigma$  which agrees accurately with the predictions of Equation (3). Plate No. H-4, on the other hand, was a chromium molybdenum alloy plate with 0.50% carbon, and the data for Plate No. H-4 give a larger value of  $\sigma$ .

Values of  $\sigma$  have been derived from the various groups of data in Tables III to VII, simultaneously with values of  $\omega$ . The average values of  $\sigma$  are plotted for comparison in Figure (18), both with and without correction to a standard static tensile strength of 115000 (lb)/(in)<sup>2</sup>. Each uncorrected average value is bracketed in the figure by a pair of open symbols whose distance apart is twice the standard deviation of the mean value. The data indicate the existence of a real scale effect, of the magnitude predicted by theory.

A statistical analysis has been made of the data in Table VII for AP bombs. The ratio  $(1+\sigma)(1+\omega)$ , between the limit energy function for the AP bombs and the limit energy function for the 3" AP M79 projectile, is tabulated in the ninth column of the table. The statistical weight to be assigned to each ratio is listed in the tenth column. The ratio fluctuates about a weighted mean of .924 with a standard deviation of .08. The precision constant of the fluctuation is equal to 9. Some of the plates in this series may have had hardnesses above the critical hardness for brittle failure, and the mean value of the ratio  $(1+\sigma)(1+\omega)$  is probably therefore too small.

## V

### THE OGIVE EFFECT

Data on the depth of penetration  $p$  of projectiles into Class B armor and STS have been collected during routine ballistic tests. The average data may be represented by curves which express the ratio  $p/d$  as a function of the ratio  $v_S/v_L$ , with a separate curve for each value of  $e/d$ . A study of the data for all projectiles has indicated that, at striking velocities near limit, the penetration curves for two different projectile shapes are nearly parallel, and only differ from each other by a constant difference in  $p/d$ . The curves for one projectile shape may be obtained from the curves for a different shape by a vertical shift. A set of standard curves have been derived from all the data, and are plotted in Figure (19). There exists for each nose contour a correction  $g$  which, when added to the value of  $p/d$  taken from Figure (19), gives the correct mean value of  $p/d$  for the given contour. A value for  $g$  has been selected to represent each of the projectiles which have been adequately investigated, and the values of  $g$  are listed in Table I.

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Values of the ogive effect  $\omega$  have been derived from the various groups of data in Tables IV to VII, simultaneously with values of  $\sigma$ .

The two most thoroughly investigated monobloc projectiles which are listed in the tables are the uncapped 37mm AP M51B2 projectile and the 3" AP M79 projectile. The ratio  $(1+\sigma)(1+\omega)$  between the limit energy function for the 37mm projectile and the limit energy function for the 3" projectile was found to have a mean value of  $1.082 \pm .01$  in a range of  $e/a$  from .4 to 1.7. The corresponding value of  $\omega$  is 0.033.

The values of  $g$  and  $\omega$  depend on both the parameters  $b/a$  and  $\alpha$ . Thus, the 8" AP Mk 19-1 projectile and the 8" AP Mk 19-4 projectile have nearly the same values of  $b/a$ , but entirely different values of  $g$ . Similarly the 3" Expr. Dw 53 projectile and the 3" Expr. Dw 55 projectile both have nearly equal values of  $\omega$  which are distinctly not zero, yet the values of  $b/a$  for these two projectiles straddle the value of  $b/a$  for the 3" AP M79 projectile. If the points in a plot of  $\alpha$  vs  $b/a$  such as Figure (4) be marked with the average values of  $g$  or  $\omega$  for each projectile, then it is found that series of contours of equal ballistic performance may be drawn in the plot which are not inconsistent with the data collected to date. Each of the contours of equal ballistic performance crosses the axis  $\alpha = 0$  at a value of  $b/a$  equal to the ratio of major axis to minor axis for that ellipsoid which would have the same ballistic properties as another projectile on the same contour. The ratio  $b^*/a$  of the major axis to the minor axis for the equivalent ellipsoid is expressed empirically in terms of the parameters  $b/a$  and  $\alpha$  for the actual projectiles, by the equation

$$\frac{b^*}{a} = \frac{\frac{b}{a}}{\sqrt{1 - 1.2\alpha + .6\alpha^2}} \quad (4)$$

Values of  $b^*/a$  for various projectiles are listed in Table I, and one contour of equal ballistic performance has been plotted in Figure (4). The penetration parameter  $g$  and the ogive effect  $\omega$  are plotted against  $b^*/a$  in Figures (20) to (22). Inspection of the figures shows that the ballistic performance varies consistently with  $b^*/a$ .

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The ratio  $l/w$ , between the limit energy function for a pointed projectile and the limit energy function for the standard projectile, was found to decrease with increase in  $b^*/a$ , at a rate which varied with  $e/d$ . The rate of variation of  $l/w$  with  $b^*/a$  at  $0^\circ$  obliquity was apparently zero at some value of  $e/d$  between .244 and .65, and increased with increase in  $e/d$ .

The ratio  $l/w$ , between the limit energy function for a blunt projectile and the limit energy function for the standard projectile, was found to decrease with decrease in  $b^*/a$ .

The properties of the ogive effect for a pointed projectile in a thick plate may be interpreted in terms of the plastic flow of the plate material adjacent to the point of impact. A disturbance in the interior of a solid medium is propagated by two waves which move with different velocities. The leading wave is a compressional or longitudinal wave, while the trailing wave is an equivoluminal or transverse wave. The velocity of propagation of the longitudinal wave is determined primarily by the bulk modulus, while the velocity of propagation of the transverse wave is determined by the rate of work hardening. A longitudinal wave originates at the surface of the Projectile, but both longitudinal waves and transverse waves are reflected wherever the longitudinal wave reaches a free surface. The velocity of propagation of a longitudinal wave is everywhere greater than the velocity of the projectile, whereas the velocity of propagation of a transverse wave is zero at a distance of approximately one tenth caliber from the surface of the impact hole, but increases with distance from the impact hole to a velocity greater than the velocity of the projectile. There is a zone next to the impact hole which is reached only by the longitudinal wave.

The plastic flow in this zone is nearly irrotational, but the transverse waves at a distance from the point of impact are able to maintain the plate material in a state of equilibrium. The plastic energy which would be required in the limiting case of pure irrotational flow, has been found by calculation to be greater than the energy which would be required in the limiting case of pure equilibrium flow, by an amount which is zero at an  $e/d$  of 0.5, but increases with increase in  $e/d$ . Approximately half of the plastic work on the medium in a plate of caliber thickness is actually performed under conditions of irrotational flow, and half is performed under conditions of equilibrium flow. An increase in the length of the projectile nose contour increases the duration of impact and increases the relative amount of equilibrium flow, with a consequent decrease in the amount of plastic work for perforation.

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Ductile failure by shear occurs in the armor near the point of impact. The plate failure begins with the formation of a star crack near a pointed projectile, and a circular crack near a blunt projectile. The plastic energy required to open the petals of a star crack is spread out to a distance from the impact hole, whereas the energy required to punch out a cylindrical plug is concentrated along the cylindrical surface of the plug. The energy required by a pointed projectile is therefore greater than the energy required by a flat nosed projectile.

TABLE I

| Projectile                    | Mfg.  | (lb)<br>Mass | %<br>Charge | % Cap | % WS | Cap<br>Hardness   | Drive         |               |                 | R           |
|-------------------------------|-------|--------------|-------------|-------|------|-------------------|---------------|---------------|-----------------|-------------|
|                               |       |              |             |       |      |                   | $\frac{v}{a}$ | $\frac{b}{a}$ | $\frac{b^2}{a}$ |             |
| cal .50 AP M2                 | FA    | 0.0119       | none        |       |      |                   |               |               |                 |             |
| cal .50 AP M2                 | FA    | 0.0580       | none        |       |      |                   | 0.61          | 4.2           | 6.0             | 0.76 ± 0.03 |
| cal .50 AP E-5                | FR    | 0.062        | none        | none  | none |                   | .80           | 2.24          | 3.44            |             |
| 20 mm AP C-20mm-1             | FA    | .31          | none        | 21.2  | none | 64 Rc             | .20           | 1.91          | 2.16            |             |
| 37 mm AP M51B2                | FA    | 1.68         | none        | 13.0  |      | 62 Rc             | .10           | 2.5           | 2.66            |             |
| 2 pdr AP                      | BR    | 2.4          | none        | none  | none |                   | .71           | 2.06          | 3.07            |             |
| 3" Comm Mk 3-5                | AF    | 13.0         |             | none  | none |                   | .66           | 2.65          | 4.13            |             |
| 3" Comm Mk 3-7                | A*    | 13.0         |             | none  | none |                   | .86           | 2.65          | 4.13            |             |
| 3" AP Type A                  | CS    | 14.1         | 1.4         | 11.1  | none | 54 Rc             | .10           | 1.92          | 2.04            | 0.10 ± 0.02 |
| 3" AP Type A-1                | BS    | 14.1         | 1.4         | 11.5  | none |                   | .51           | 2.02          | 2.74            |             |
| 3" AP Dw DA302-SC (Mk 11 cap) | BS    | 13.6         |             | 11.1  | none |                   | .51           | 2.02          | 2.74            |             |
| 3" AP Dw DA302-HC (Mk 11 cap) | BS    | 13.6         |             | 11.1  | none |                   | .51           | 2.02          | 2.74            |             |
| 3" AP Dw DA303 (Light cap)    | BS    | 13.9         |             | 10.4  | none |                   | .51           | 2.02          | 2.74            |             |
| 3" AP Dw DA304 (Heavy cap)    | BS    | 14.65        |             | 16.1  | none |                   | .51           | 2.02          | 2.74            |             |
| 3" AP Dw 3001 (8" AF Mk 11-1) | CS    | 14.5         |             | 5.2   | none |                   | .375          | 2.67          | 3.35            |             |
| 3" AP Mk 29 (Dw DA305)        | BS    | 13.0         |             | 16.1  | 2.6  |                   | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-1                 | CS    | 13.0         |             | 16.1  | 2.9  |                   | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-2                 | OLDS  | 13.0         |             | 16.1  | 3.0  | 58 Rc             | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-A                 | CS    | 13.0         |             | 11.5  | 2.9  |                   | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-B                 | CS    | 13.0         |             | 15.4  | 2.9  |                   | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-C                 | CS    | 13.0         |             | 10.9  | 2.9  |                   | .33           | 1.94          | 2.37            |             |
| 3" AP Mk 29-K23               | OLDS  | 13.0         |             | 16.6  | 3.0  |                   | -0.05         | 1.70          | 1.65            |             |
| 3" AP Mk 29-K34               | OLDS  | 13.0         |             | 16.1  | 3.0  |                   | -0.11         | 1.86          | 1.275           |             |
| 3" AP M61 (Dw DA301)          | CS BS | 14.8         |             | 14.3  | 2.3  | 47 Rc             | +0.82         | 1.925         | 2.97            |             |
| 3" AP M62                     | BS    | 14.8         |             | 13.9  | 2.3  | 53 Rc             | .33           | 1.94          | 2.37            |             |
| 3" AP M62                     | CHEV  | 14.8         |             | 13.9  | 2.3  | 58 Rc             | .33           | 1.94          | 2.37            |             |
| 3" AP M79                     | LT FA | 15.0         | none        | none  | none |                   | 0.824         | 2.36          | 3.68            | 0.47 ± 0.03 |
| 3" Expr Dw 52 (Hemisphere)    | FA    | 15.2         | none        | none  | none |                   | .000          | 1.00          | 1.00            |             |
| 3" Expr Dw 53 (Type A-1 body) | FA    | 15.2         | none        | none  | none |                   | .33           | 2.00          | 2.45            |             |
| 3" Expr Dw 54 (Type A body)   | FA    | 15.2         | none        | none  | none |                   | -0.09         | 1.92          | 1.32            |             |
| 3" Expr Dw 55 (Type A-1 cap)  | FA    | 15.3         | none        | none  | none |                   | +0.04         | 2.73          | 2.80            |             |
| 3" Expr Dw 56 (M51B2 cap)     | FA    | 15.3         | none        | none  | none |                   | -             | -             | -               |             |
| 3" Expr Dw 57 (Mk 11 cap)     | FA    | 15.0         | none        | none  | none |                   | -             | -             | -               |             |
| 3" Expr Dw 58 (3 oal ogive)   | FA    | 15.3         | none        | none  | none |                   | .909          | 3.32          | 3.22            |             |
| 3" Expr Dw 59 (4 oal ogive)   | FA    | 15.3         | none        | none  | none |                   | .934          | 3.88          | 5.11            |             |
| 3" AF Expr (7.5 lb flat nose) | FA    | 7.4          | none        | none  | none |                   | -             | .00           | .00             |             |
| 3" AF Expr (11 lb flat nose)  | FA    | 10.7         | none        | none  | none |                   | -             | .00           | .00             |             |
| 3" AF Expr (15 lb flat nose)  | FA    | 14.9         | none        | none  | none |                   | -             | .00           | .00             |             |
| 3" AF Expr (flat nose + WS)   | CS    | 13.0         | none        | none  | 1.6  |                   | -             | .00           | .00             |             |
| 4" Comm Mk 10-1               | HP    | 33           |             | none  | none |                   |               |               |                 |             |
| 4" Comm Mk 16-1               | HW    | 33           | 3.0         | 4.7   | 3.9  |                   | .80           | 2.50          | 3.24            |             |
| 5" Comm Mk 15-14              | JR    | 50           |             | none  | none |                   |               |               |                 |             |
| 5" Comm Mk 32-4               | CS    | 54           | 4.8         | none  | 3.0  |                   |               |               |                 |             |
| 5" Comm Mk 38-1               | CS    | 55           | 3.7         | 7.0   | 7.0  | 80 H <sub>B</sub> | .87           | 2.78          | 4.34            |             |
| 5" Comm Mk 46-1               | CS    | 55           | 3.7         | 5.0   | 6.8  |                   | .94           | 2.53          | 3.11            |             |
| 5" Comm Mk 46-2               | BS    | 55           | 3.7         | 6.8   | 6.8  |                   | .94           | 2.53          | 3.11            |             |
| 6" Comm Mk 20-2               | MP    | 105          |             | none  | none |                   |               |               |                 |             |
| 6" Comm Mk 20-4               | CS    | 105          |             | none  | none |                   |               |               |                 |             |
| 6" Comm Mk 27-1               | HS    | 105          | 2.1         | 4.0   | 5.1  |                   | .79           | 2.25          | 3.44            | 0.41 ± 0.02 |
| 6" Comm Mk 27-2               | CS    | 105          | -           | -     | 5.4  |                   | .66           | 2.61          | 4.07            |             |
| 6" Comm Mk 27-3               | MS    | 105          | 2.1         | 6.5   | 5.1  |                   | .70           | 2.525         | 3.45            |             |
| 6" Comm Mk 27-4               | MS    | 105          | 2.1         | 6.5   | 5.1  |                   | .70           | 2.525         | 3.45            | 0.43 ± 0.02 |
| 6" Comm Mk 27-5               | CS    | 105          | 2.4         | 5.2   | 5.5  |                   | .66           | 2.61          | 4.07            |             |
| 6" Comm Mk 27-6               | MS    | 105          | 2.1         | 5.7   | 5.0  |                   | .70           | 2.525         | 3.45            |             |
| 6" Comm Mk 27-7               | CS    | 105          | 2.1         | 5.2   | 5.1  |                   | .66           | 2.61          | 4.07            | 0.57 ± 0.10 |
| 6" Comm Mk 27-8 (Dw DA607)    | HS    | 105          | 2.1         | 4.0   | 5.1  |                   | .79           | 2.25          | 3.44            |             |
| 6" Comm Mk 33-1               | BS    | 105          | 2.1         | 5.2   | 5.1  |                   | .66           | 2.61          | 4.07            |             |
| 6" Comm Mk 33-2               | CS    | 105          | 2.1         | 5.2   | 5.1  |                   | .66           | 2.61          | 4.07            |             |
| 105 mm S&W M112               | BS    | 100          | 1.4         | 5.5   | 4.0  |                   |               |               |                 |             |
| 6" AP Mk 9-1                  | FS    | 105          |             | 7.5   | none |                   | .47           | 2.90          | 3.85            |             |
| 6" AP Mk 9-6                  | FS    | 105          |             | 7.5   | -    |                   | .47           | 2.90          | 3.85            |             |
| 6" AP Mk 30-1                 | CS    | 130          | 1.5         | 15.6  | 2.6  |                   | .21           | 1.77          | 2.01            |             |
| 6" AP Mk 30-2                 | MS    | 130          | 1.5         | 18.0  | 2.5  |                   | .16           | 1.635         | 2.02            |             |
| 6" AP Mk 30-3                 | HS    | 130          | 1.5         | 19.1  | 1.5  |                   | .21           | 1.77          | 2.01            |             |
| 6" AP Mk 30-4 (Dw 30911)      | HS    | 130          | 1.5         | 20.6  | 2.5  |                   | +0.17         | 1.61          | 1.73            |             |
| 6" AP Mk 30-5                 | MS    | 130          | 1.5         | 20.6  | 2.5  | 53 Rc             | -0.15         | 1.495         | 1.975           |             |
| 6" AP Mk 30-6                 | CS    | 130          | 1.5         | 19.6  | 2.7  |                   | -0.07         | 1.515         | 1.45            |             |
| 6" AP Mk 30-7                 | HS    | 130          | 1.5         | 20.6  | 2.5  | 53 Rc             | +0.12         | 1.61          | 1.73            |             |
| 102 mm AF Mk 1-1              | MS    | 120          | 1.5         | 20.0  | 2.5  |                   | -0.15         | 1.495         | 1.500           |             |

TABLE I  
(Continued)

| PROJECTILE DATA          |      |                |          |       |      |                 |       |       |                   |             |
|--------------------------|------|----------------|----------|-------|------|-----------------|-------|-------|-------------------|-------------|
| Projectile               | Mfg. | (lb)<br>Weight | % Charge | % Cap | % MS | Cap<br>Material | Drive |       |                   | g           |
|                          |      |                |          |       |      |                 | a     | b/a   | b <sup>2</sup> /a |             |
| 8" Comm Mk 14-1          | MS   | 860            | 4.2      | 4.7   | 3.6  |                 | 0.59  | 2.65  | 3.74              | 0.43 ± 0.03 |
| 8" Comm Mk 15-1          | MS   | 860            | 4.4      | 10.9  | 3.9  |                 | .49   | 2.43  | 3.26              |             |
| 8" Comm Mk 17-1          | MS   | 860            | 4.0      | -     | 3.6  |                 | .71   | 2.45  | 3.65              |             |
| 8" Comm Mk 17-2          | MS   | 860            | 4.0      | 8.7   | 3.7  |                 | .59   | 2.33  | 3.74              |             |
| 8" Comm Mk 17-3          | MS   | 860            | 4.0      | 3.7   | 3.6  |                 | .76   | 2.57  | 3.62              |             |
| 8" Comm Mk 17-4          | MS   | 860            | 4.0      | 4.1   | 3.7  |                 | .71   | 2.45  | 3.65              | 0.47 ± 0.04 |
| 8" Comm Mk 17-4 (Mod. 1) | MS   | 860            | 4.0      | 8.0   | 0.6  |                 |       |       |                   |             |
| 8" AP Mk 7-9             | MS   | 860            | 2.1      | 6.0   | 1.1  |                 | .375  | 2.69  | 3.36              |             |
| 8" AP Mk 11-1            | MS   | 860            | 2.1      | 8.5   | 1.3  | 225 MS          | .375  | 2.69  | 3.36              | 0.37 ± 0.02 |
| 8" AP Mk 19-1            | MS   | 860            | 1.4      | 12.2  | 4.6  |                 | .71   | 1.68  | 2.77              | 0.31 ± 0.02 |
| 8" AP Mk 19-2            | MS   | 860            | 1.4      | 12.3  | 4.5  |                 |       |       |                   |             |
| 8" AP Mk 19-3            | MS   | 860            | 1.4      | 16.3  | 5.1  |                 |       |       |                   |             |
| 8" AP Mk 19-4            | MS   | 860            | 1.4      | 16.7  | 9.3  |                 | .16   | 1.635 | 2.02              | 0.10 ± 0.03 |
| 8" AP Mk 19-5            | MS   | 860            | 1.4      | 17.2  | 9.0  |                 | .16   | 1.635 | 2.02              |             |
| 8" AP Mk 19-6            | MS   | 860            | 1.4      | 16.7  | 6.3  |                 | .16   | 1.635 | 2.02              |             |
| 8" AP Mk 20-1            | MS   | 860            | 1.3      | 12.6  | 4.6  |                 |       |       |                   |             |
| 8" AP Mk 20-2            | MS   | 860            | 1.3      | 12.2  | 4.5  |                 |       |       |                   |             |
| 8" AP Mk 20-3            | MS   | 860            | 1.3      | 16.2  | 5.1  |                 |       |       |                   |             |
| 8" AP Mk 20-5            | MS   | 860            | 1.3      | 17.1  | 5.1  |                 |       |       |                   |             |
| 8" AP Mk 21-1            | MS   | 335            | 1.5      | 17.3  | 2.3  | 53 Rc           | .12   | 1.735 | 1.665             |             |
| 8" AP Mk 21-2            | MS   | 335            | 1.5      | 17.0  | 1.4  | 53 Rc           | .12   | 1.46  | 1.69              |             |
| 8" AP Mk 21-3            | MS   | 335            | 1.5      | 17.3  | 1.3  | 53 Rc           | .12   | 1.735 | 1.665             |             |
| 12" AP Mk 14-6           | MS   | 875            | 2.6      | 5.7   | 1.1  |                 | .67   | 2.90  | 3.65              |             |
| 12" AP Mk 15-6           | MS   | 870            | 2.6      | 6.2   | 0.6  |                 | .67   | 2.90  | 3.65              | 0.52 ± 0.04 |
| 12" AP Type A-1          | MS   | 1140           | 1.5      | 13.0  | 1.2  |                 | .31   | 2.00  | 2.42              |             |
| 12" AP Mk 18-1           | MS   | 1140           | 1.5      | 10.9  | 1.2  |                 | .09   | 1.84  | 1.94              |             |
| 14" AP Mk 16-2           | MS   | 1500           | 1.5      | 8.5   | 2.1  |                 | .70   | 2.18  | 3.24              | 0.40 ± 0.04 |
| 14" AP Mk 16-3           | MS   | 1500           | 1.5      | 8.5   | 2.1  |                 | .59   | 2.20  | 3.10              |             |
| 14" AP Mk 16-4           | MS   | 1500           | 1.5      | 10.0  | 2.0  |                 | .77   | 1.96  | 2.96              | 0.37 ± 0.02 |
| 14" AP Mk 16-5           | MS   | 1500           | 1.5      | 10.1  | 2.1  |                 | .27   | 1.94  | 3.28              |             |
| 14" AP Mk 16-6           | MS   | 1500           | 1.5      | 10.2  | 2.3  |                 | .10   | 1.635 | 1.735             |             |
| 14" AP Mk 16-7           | MS   | 1500           | 1.5      | 11.6  | 2.4  |                 | +0.26 | 1.94  | 2.27              |             |
| 14" AP Mk 16-8           | MS   | 1500           | 1.5      | 12.2  | 2.3  |                 | -0.13 | 1.325 | 1.41              |             |
| 14" AP Mk 16-9           | MS   | 1500           | 1.5      | 10.1  | 2.4  |                 | +0.04 | 1.70  | 1.74              |             |
| 14" AP Mk 16-10          | MS   | 1500           | 1.5      | 10.1  | 2.4  |                 |       |       |                   |             |
| 16" AP Mk 2-1            | MS   | 2100           | 2.4      | 5.3   | 1.1  |                 | .47   | 2.90  | 3.65              |             |
| 16" AP Mk 5-4            | MS   | 2240           | 1.5      | 10.6  | 2.2  |                 | .16   | 1.745 | 1.92              |             |
| 16" AP Mk 8-1            | MS   | 2700           | 1.5      | 9.7   | 1.6  |                 | .46   | 2.12  | 2.63              |             |
| 16" AP Mk 8-2            | MS   | 2700           | 1.5      | 7.6   | 1.7  |                 | .14   | 2.04  | 2.22              |             |
| 16" AP Mk 8-3            | MS   | 2700           | 1.5      | 11.0  | 1.8  |                 | .34   | 1.90  | 2.34              |             |
| 16" AP Mk 8-4            | MS   | 2700           | 1.5      | 9.8   | 1.8  |                 | .17   | 2.17  | 2.41              |             |
| 16" AP Mk 8-5            | MS   | 2700           | 1.5      | 9.3   | 1.7  |                 | .16   | 1.97  | 2.17              |             |
| 16" AP Mk 8-6            | MS   | 2700           | 1.5      | 11.6  | 1.2  |                 | .17   | 1.65  | 2.05              |             |
| 16" AP Type B-1          | MS   | 3650           | 1.5      | 10.0  | 1.7  |                 | .06   | 2.03  | 2.10              |             |
| 1000 lb AP Bomb Mk 33    |      | 975            | 15.0     | none  | none |                 | .91   | 2.51  | 3.94              |             |
| 1600 lb AP Bomb Mk 1-1   | MS   | 1540           | 15.0     | none  | none |                 | .89   | 2.57  | 4.03              |             |

$$\% \text{ Charge} = \frac{\text{Weight of Explosive}}{\text{Total Weight}} \times 100$$

$$\% \text{ Cap} = \frac{\text{Weight of Cap or Hood}}{\text{Total Weight}} \times 100$$

$$\% \text{ MS} = \frac{\text{Weight of Manganese}}{\text{Total Weight}} \times 100$$

Manufacturers

AF - American Cast and Foundry Co.  
MS - Bethlehem Steel Co.  
MR - British.  
MK - Budd Wheel Co.  
CHV - Chevrolet Division, General Motors Corp.  
CS - Crucible Steel Co.  
FA - Frankford Arsenal.  
FS - Fifth Sterling Steel Co.  
BP - Harrisburg Pipe and Pipe Bending Co.  
LN - Lingsmill Band Co.  
LT - The Letourneau Co.  
MP - Machine Products Co.  
MS - The Midvale Co.  
OLD6 - Oldsmobile Division, General Motors Corp.  
PA - Planting Arsenal  
PR - Princeton Range

a and b/a are parameters in the approximate equation for the nose contour, such that b/a is the ratio of length to semidiameter of the approximate nose contour, and  $1/2\pi(b/a)$  is the cotangent of the semiangle at the tip of the nose.

b<sup>2</sup>/a is the ratio of major axis to minor axis of the equivalent ellipsoidal nose.

g is the increase, due to difference in nose shape, of the ratio p/d, where p is the depth of penetration at striking velocities less than limit, and d is the projectile diameter.

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Table II  
Parameters of the Ogive

| R<br>(Calibers) | $\frac{b}{a}$ | $\alpha$ | $\frac{2\pi \int_0^a r^2 dr}{\pi a^3 b}$ |
|-----------------|---------------|----------|------------------------------------------|
| .5              | 1.000         | 0        | $\frac{1}{3}$                            |
| .6              | 1.183         | .286     | .3682                                    |
| .8              | 1.483         | .545     | .4019                                    |
| 1.0             | 1.732         | .666     | .4184                                    |
| 1.2             | 1.949         | .737     | .4282                                    |
| 1.5             | 2.236         | .800     | .4371                                    |
| 2.0             | 2.646         | .857     | .4454                                    |
| 3.0             | 3.317         | .909     | .4530                                    |
| 4.0             | 3.873         | .933     | .4566                                    |
| $\infty$        | $\infty$      | 1.000    | .4667                                    |

BALLISTIC DATA

Table III - Plate penetration coefficients for cal .60 monobloc projectiles at normal obliquity vs homogeneous plate corrected for tensile strength to 115000 (lb)/(in)<sup>2</sup> tensile strength. (Reference (1))

| Projectile Type | d    | Plate No. | Brinell Hardness | $\frac{e}{d}$ | Uncorrected              |                          | Corrected                |                                   | 1+c   | 1+e   |
|-----------------|------|-----------|------------------|---------------|--------------------------|--------------------------|--------------------------|-----------------------------------|-------|-------|
|                 |      |           |                  |               | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ | $(10^{-6})U(\frac{e}{d}, \theta)$ |       |       |
| AP Dw 51        | "566 | N-1       | 248              | 1.45          | 54000                    | 53000                    | 53000                    | 40.7                              | 1.067 |       |
| AP Dw 51        | "    | H-4       | 255              | 1.52          | 56100                    | 54600                    | 54600                    | 45.4                              | 1.139 | 1.000 |
| AP Dw 53        | "    | "         | "                | 1.52          | 56500                    | 54900                    | 54900                    | 45.8                              |       | 1.012 |
| AP Dw 54        | "    | "         | "                | 1.52          | 56200                    | 54700                    | 54700                    | 45.5                              |       | 1.006 |
| AP Dw 55        | "    | "         | "                | 1.52          | 56800                    | 55200                    | 55200                    | 46.4                              |       | 1.023 |
| AP Dw 58        | "    | "         | "                | 1.52          | 53800                    | 52300                    | 52300                    | 41.6                              |       | .918  |
| AP Dw 59        | "    | "         | "                | 1.52          | 53000                    | 51500                    | 51500                    | 40.3                              |       | .891  |

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Table IV - Plate penetration coefficients for geometrically similar scale model service type 2 pdr. projectiles at normal obliquity vs homogeneous plate corrected for tensile strength to 115000 (lb)/(in)<sup>2</sup> tensile strength. Ogival radius = 1.40 calibers. (Reference (2))

| d     | Plate No. | Brinell Hardness | $\frac{e}{d}$ | Uncorrected              |                          | Corrected                |                          | $(10^{-3}) y(\frac{e}{d}, \theta)$ | $(1+\alpha)(1+\alpha)$ |
|-------|-----------|------------------|---------------|--------------------------|--------------------------|--------------------------|--------------------------|------------------------------------|------------------------|
|       |           |                  |               | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ |                                    |                        |
| 2996  | 2970      | 259              | .757          | 53300                    | 51500                    | 51500                    | 20.1                     | 1.175                              |                        |
| "     | 2975      | 250              | .977          | 54400                    | 53200                    | 53200                    | 27.8                     | 1.184                              |                        |
| "     | 2976      | 267              | 1.418         | 55800                    | 53400                    | 53400                    | 40.4                     | 1.083                              |                        |
| "     | 2980      | 257              | 1.831         | 57600                    | 55900                    | 55900                    | 57.2                     | 1.096                              |                        |
| 2940  | 2973      | 250              | .536          | 53700                    | 52600                    | 52600                    | 14.83                    | (1.33)                             |                        |
| "     | 2976      | 267              | .777          | 52400                    | 50100                    | 50100                    | 19.50                    | 1.105                              |                        |
| "     | 2980      | 257              | 1.004         | 54000                    | 52300                    | 52300                    | 27.5                     | 1.137                              |                        |
| "     | 2988      | 255              | 1.501         | 54900                    | 53200                    | 53200                    | 42.5                     | 1.059                              |                        |
| "     | 2994      | 239              | 2.055         | 59400                    | 58700                    | 58700                    | 66.1                     | 1.082                              |                        |
| 2990  | 2980      | 257              | .548          | 51600                    | 50000                    | 50000                    | 13.70                    | (1.20)                             |                        |
| "     | 2986      | 255              | .819          | 51400                    | 49800                    | 49800                    | 20.3                     | 1.081                              |                        |
| "     | 2994      | 259              | 1.121         | 54400                    | 51900                    | 51900                    | 30.2                     | 1.090                              |                        |
| "     | 3003      | 265              | 1.610         | 55400                    | 53200                    | 53200                    | 45.6                     | 1.035                              |                        |
| "     | 3011      | 258              | 2.139         | 58500                    | 56600                    | 56600                    | 68.5                     | 1.063                              |                        |
| 17565 | 2994      | 269              | .709          | 50000                    | 47700                    | 47700                    | 16.13                    | 1.021                              |                        |
| "     | 3003      | 265              | 1.019         | 51300                    | 49300                    | 49300                    | 24.6                     | 1.008                              |                        |
| "     | 3011      | 258              | 1.353         | 53900                    | 52100                    | 52100                    | 36.7                     | 1.048                              |                        |
| "     | 3011      | 259              | 2.013         | 55600                    | 53700                    | 53700                    | 58.0                     | .979                               |                        |

Table V - Plate penetration coefficients for 2 pdr. projectiles with tangent ogives of various calibers radius, at normal obliquity vs homogeneous plate, corrected for tensile strength to 115000 (lb)/(in)<sup>2</sup> tensile strength. (Reference (2))

| Original Radius | d     | Plate No. | Brinell Hardness | $\frac{d}{D}$ | Uncorrected              |                          | Corrected                |                          | $(2.0^{-0.5})U(\frac{d}{D}, \theta)$ | $(1+\epsilon)(1+\mu)$ |
|-----------------|-------|-----------|------------------|---------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------------------|-----------------------|
|                 |       |           |                  |               | $F(\frac{d}{D}, \theta)$ | $F(\frac{d}{D}, \theta)$ | $F(\frac{d}{D}, \theta)$ | $F(\frac{d}{D}, \theta)$ |                                      |                       |
| 1.00            | 17565 | 448       | 262              | 1.029         | 51000±1000               |                          | 49200                    | 24.9                     |                                      | 1.000                 |
| 1.40            | "     | "         | "                | 1.029         | 50800±300                |                          | 49000                    | 24.7                     |                                      | .992                  |
| 2.00            | "     | "         | "                | 1.029         | 49800±200                |                          | 48000                    | 23.7                     |                                      | .982                  |
| 1.00            | 17565 | 1467      | 266              | 1.534         | 57500±400                |                          | 55000                    | 45.4                     |                                      | 1.123                 |
| 1.40            | "     | "         | "                | 1.534         | 55200±100                |                          | 53500                    | 43.9                     |                                      | 1.063                 |
| 2.00            | "     | "         | "                | 1.534         | 54000±200                |                          | 51700                    | 41.0                     |                                      | .992                  |

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Table VI - Plate penetration coefficients for uncapped 37mm AP M51B2 projectiles, 3" AP M79 projectiles, and other 3" monobloc projectiles vs Class B armor or STS corrected for tensile strength to 115000 (lb)/(in)<sup>2</sup> tensile strength. (Reference (3))

| Projectile                   | Plate Number | Tensile Strength | $\theta$ | $\frac{r}{d}$ | Uncorrected<br>$F(\frac{r}{d}, \theta)$ | Corrected<br>$F(\frac{r}{d}, \theta)$ | $(10^{-8}) U(\frac{r}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|------------------------------|--------------|------------------|----------|---------------|-----------------------------------------|---------------------------------------|------------------------------------|------------------------|
| 3" AP M79                    | 1478         | 123000           | 30°      | .655          | 43300±500                               |                                       | 12.28                              | .996                   |
| 3" AP Type A-cap             | "            | "                | 5.5°     | .652          | 46500±500                               |                                       | 14.10                              | .995                   |
| "                            | "            | "                | 29.5°    | .652          | 44000±1000                              |                                       | 12.62                              | 1.028                  |
| 37mm AP M51B2-cap            | 8333*        | 98500            | 1°       | .754          | 47400±500                               | 49900                                 | 18.77                              | 1.104                  |
| 3" AP M79                    | 9475         | 107000           | .5°      | 1.68          | 51500±500                               | 52600                                 | 46.5                               | 1.000                  |
| 3" Expr Dw 59 (4 cal. ogive) | "            | "                | .5°      | 1.69          | 46800±300                               | 49800                                 | 41.9                               | .895                   |
| 37mm AP M51B2-cap            | 40228        | 105000           | 1°       | 1.379         | 50400±300                               | 52000                                 | 37.3                               | 1.036                  |
| 3" AP M79                    | "            | "                | 30°      | .669          | 40700±200                               | 42000                                 | 11.80                              | .935                   |
| 37mm AP M51B2-cap            | 40497        | 112000           | .5°      | 1.007         | 50100±100                               | 50500                                 | 25.7                               | 1.060                  |
| 3" AP M79                    | "            | "                | 29.7°    | .489          | 41200±200                               | 41600                                 | 8.46                               | .995                   |
| 37mm AP M51B1-cap            | 40500        | 120000           | 2°       | 1.005         | 50900±100                               | 50200                                 | 25.3                               | 1.047                  |
| 3" AP M79                    | "            | "                | 29.8°    | .488          | 41000±200                               |                                       | 8.20                               | .967                   |
| 3" Expr (15 lb. flat nose)   | "            | "                | 1°       | .488          | 28600±200                               |                                       | 3.99                               | .405                   |
| "                            | "            | "                | 30°      | .488          | 30500±500                               |                                       | 4.54                               | .535                   |
| "                            | "            | "                | 45°      | .496          | 32600±200                               |                                       | 5.27                               | .567                   |

\* Section from the center of a 10.5" plate.

Table VI - (Continued)

| Projectile                  | Plate Number | Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-6}) U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|-----------------------------|--------------|------------------|----------|---------------|-----------------------------------------|---------------------------------------|------------------------------------|------------------------|
| 37mm AP M51B2-cap           | 40502        | 105000           | 1°       | 1.017         | 46800±500                               | 50300                                 | 25.7                               | 1.048                  |
| 3" AP M79                   | "            | "                | 15°      | .495          | 43800±100                               | 45400                                 | 10.20                              | 1.013                  |
| "                           | "            | "                | 20°      | .495          | 42100±100                               | 43500                                 | 9.37                               | .995                   |
| "                           | "            | "                | 30°      | .490          | 40200±200                               | 41700                                 | 8.52                               | 1.000                  |
| 3" AP M79                   | 40819        | 117000           | 29.5°    | .507          | 41300±200                               | 41700                                 | 8.82                               | .986                   |
| 3" Expr. (15 lb. flat nose) | "            | "                | 30°      | .507          | 31200±300                               | 32100                                 | 5.22                               | .566                   |
| 3" Expr. (15 lb. 150° cone) | "            | "                | 31°      | .510          | 33900±200                               | 34900                                 | 6.21                               | .700                   |
| 3" AP M79                   | 40916        | 113000           | 29.5°    | .498          | 41300±200                               | 41700                                 | 8.66                               | .992                   |
| 3" Expr. (15 lb. flat nose) | "            | "                | 30°      | .501          | 32000±200                               | 32100                                 | 5.16                               | .589                   |
| "                           | "            | 87000            | 30°      | .502          | 29300±200                               | 32100                                 | 5.17                               | .589                   |
| 37mm AP M51B2-cap           | 55909        | 118000           | 0°       | .835          | 47900±300                               |                                       | 19.16                              | .996                   |
| "                           | "            | "                | 19.5°    | .838          | 47800±300                               |                                       | 19.00                              | 1.048                  |
| "                           | "            | "                | 30.3°    | .841          | 44300±500                               |                                       | 16.50                              | .997                   |
| 3" AP M79                   | "            | "                | 2°       | .408          | 43500±500                               |                                       | 7.72                               | 1.008                  |
| 3" AP Type A-cap            | "            | "                | 8°       | .409          | 44000±1000                              |                                       | 7.92                               | 1.041                  |
| 37mm AP M51B2-cap           | 56360        | 123000           | 3°       | .433          | 40700±1000                              |                                       | 7.17                               | .857                   |
| "                           | "            | "                | 31°      | .433          | 38500±500                               |                                       | 6.42                               | .905                   |
| 37mm AP M51B2-cap           | 60919        | 123000           | 2°       | .443          | 47800±200                               |                                       | 10.12                              | 1.175                  |
| "                           | "            | "                | 29.5°    | .444          | 41800±500                               |                                       | 7.75                               | 1.041                  |
| 3" AP Type A-cap            | "            | "                | 10°      | .212          | 34000±500                               |                                       | 2.45                               | 1.028                  |
| "                           | "            | "                | 31°      | .213          | 30500±500                               |                                       | 1.98                               | .957                   |

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Table VI - (Continued)

| Projectile                     | Plate Number | Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-3}) H(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+w)$ |
|--------------------------------|--------------|------------------|----------|---------------|-----------------------------------------|---------------------------------------|------------------------------------|-------------------|
| 37mm AP M51B2-cap              | 83880        | 122000           | 4°       | .504          | 48900±200                               |                                       | 12.00                              | 1.168             |
| "                              | "            | "                | 30.5°    | .504          | 43300±500                               |                                       | 9.45                               | 1.076             |
| 3" AP M79                      | "            | "                | 4°       | .244          | 36900±200                               |                                       | 3.32                               | 1.061             |
| 3" Expr. Dw 52 (Hemisphere)    | "            | "                | .5°      | .244          | 34900±500                               |                                       | 2.97                               | .940              |
| 3" Expr. Dw 53 (Type A-1 body) | "            | "                | 2°       | .244          | 36500±500                               |                                       | 3.27                               | 1.033             |
| 3" Expr. Dw 54 (Type A body)   | "            | "                | 1.5°     | .244          | 35900±500                               |                                       | 3.14                               | .994              |
| 3" Expr. Dw 55 (Type A-1 cap)  | "            | "                | 4°       | .244          | 36900±200                               |                                       | 3.32                               | 1.053             |
| 3" Expr. Dw 56 (M51B2 cap)     | "            | "                | 0°       | .244          | 35800±200                               |                                       | 3.14                               | .994              |
| 3" Expr. Dw 57 (Mk 11 cap)     | "            | "                | 5°       | .244          | 36200±300                               |                                       | 3.20                               | 1.015             |
| 3" Expr. Dw 58 (3 cal. ogive)  | "            | "                | .5°      | .244          | 37900±300                               |                                       | 3.49                               | 1.102             |
| 3" Expr. Dw 59 (4 cal. ogive)  | "            | "                | 1°       | .244          | 37300±200                               |                                       | 3.39                               | 1.074             |
| 3" Expr. (11 lb. flat nose)    | "            | "                | 3°       | .244          | 35500±500                               |                                       | 3.08                               | .972              |
| 3" AP M79                      | "            | "                | 45°      | .244          | 31400±500                               |                                       | 2.40                               | .949              |
| 3" Expr. Dw 52 (Hemisphere)    | "            | "                | 45°      | .244          | ± 35600                                 |                                       | >3.09                              | >1.245            |
| 3" Expr. Dw 53 (Type A-1 body) | "            | "                | 45°      | .244          | ± 33800                                 |                                       | <2.79                              | <1.122            |
| 3" Expr. Dw 54 (Type A body)   | "            | "                | 45°      | .244          | ± 35300                                 |                                       | >3.04                              | >1.224            |
| 3" Expr. Dw 55 (Type A-1 cap)  | "            | "                | 45°      | .244          | 33500±200                               |                                       | 2.74                               | 1.103             |
| 3" Expr. Dw 56 (M51B2 cap)     | "            | "                | 45°      | .244          | 31600±1000                              |                                       | 2.44                               | .981              |
| 3" Expr. Dw 57 (Mk 11 cap)     | "            | "                | 45°      | .244          | 31300±1000                              |                                       | 2.39                               | .962              |
| 3" Expr. Dw 58 (3 cal. ogive)  | "            | "                | 45°      | .244          | 30100±1000                              |                                       | 2.21                               | .890              |
| 3" Expr. Dw 59 (4 cal. ogive)  | "            | "                | 45°      | .244          | 30100±1000                              |                                       | 2.21                               | .890              |
| 3" AP M79                      | 87207        | 125000           | 0°       | .809          | 44500±500                               |                                       | 16.02                              | .866              |
| "                              | "            | "                | 30°      | .809          | 43100±500                               |                                       | 15.03                              | .946              |
| 3" AP Type A-cap               | "            | "                | 1°       | .819          | 45000±500                               |                                       | 16.58                              | .882              |
| 3" AP Type A-1-cap             | "            | "                | 28.5°    | .819          | 45000±500                               |                                       | 16.58                              | 1.013             |
| 37mm AP M51B2-cap              | 87547        | 130000           | 3°       | 1.34          | 55500±1000                              | 53100                                 | 37.8                               | 1.082             |

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Table VI - (Continued)

| Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected              | Corrected                | $(10^{-2})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|------------------|----------|---------------|--------------------------|--------------------------|-----------------------------------|------------------------|
|                  |          |               | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ |                                   |                        |
| 122000           | 4°       | .504          | 48800±200                |                          | 12.00                             | 1.168                  |
| "                | 30.5°    | .504          | 43300±500                |                          | 9.45                              | 1.076                  |
| "                | 4°       | .244          | 36900±200                |                          | 3.32                              | 1.051                  |
| "                | .5°      | .244          | 34900±500                |                          | 2.97                              | .940                   |
| "                | 2°       | .244          | 36600±500                |                          | 3.27                              | 1.033                  |
| "                | 1.5°     | .244          | 35900±500                |                          | 3.14                              | .994                   |
| "                | 4°       | .244          | 36900±200                |                          | 3.32                              | 1.053                  |
| "                | 0°       | .244          | 35900±200                |                          | 3.14                              | .994                   |
| "                | 5°       | .244          | 36200±300                |                          | 3.20                              | 1.015                  |
| "                | .5°      | .244          | 37800±300                |                          | 3.49                              | 1.102                  |
| "                | 1°       | .244          | 37300±200                |                          | 3.39                              | 1.074                  |
| "                | 3°       | .244          | 35500±500                |                          | 3.08                              | .972                   |
| "                | 45°      | .244          | 31400±500                |                          | 2.40                              | .969                   |
| "                | 45°      | .244          | ≥ 35600                  |                          | >3.09                             | >1.245                 |
| "                | 45°      | .244          | ≤ 33800                  |                          | <2.79                             | <1.122                 |
| "                | 45°      | .244          | ≥ 35300                  |                          | >3.04                             | >1.224                 |
| "                | 45°      | .244          | 33500±200                |                          | 2.74                              | 1.103                  |
| "                | 45°      | .244          | 31600±1000               |                          | 2.44                              | .981                   |
| "                | 45°      | .244          | 31300±1000               |                          | 2.39                              | .962                   |
| "                | 45°      | .244          | 30100±1000               |                          | 2.21                              | .890                   |
| "                | 45°      | .244          | 30100±1000               |                          | 2.21                              | .890                   |
| 125000           | 0°       | .809          | 44500±500                |                          | 16.02                             | .866                   |
| "                | 30°      | .809          | 43100±500                |                          | 15.03                             | .946                   |
| "                | 1°       | .819          | 45000±500                |                          | 16.58                             | .882                   |
| "                | 28.5°    | .819          | 45000±500                |                          | 16.58                             | 1.013                  |
| 130000           | 3°       | 1.34          | 55500±1000               | 53100                    | 37.8                              | 1.089                  |

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Table VI - (Continued)

| Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-8})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|------------------|----------|---------------|-----------------------------------------|---------------------------------------|-----------------------------------|------------------------|
| 130000           | 1°       | .650          | 47300±200                               |                                       | 14.54                             | 1.026                  |
| "                | 4°       | .650          | 44800±700                               |                                       | 13.05                             | .920                   |
| "                | 1°       | .649          | 48800±200                               |                                       | 15.46                             | 1.092                  |
| "                | 0°       | .649          | 48300±300                               |                                       | 15.14                             | 1.070                  |
| "                | 0°       | .649          | 47400±200                               |                                       | 14.58                             | 1.030                  |
| "                | 1°       | .650          | 46400±200                               |                                       | 13.99                             | .987                   |
| "                | 1°       | .650          | 45900±300                               |                                       | 13.69                             | .966                   |
| "                | 3°       | .651          | 46100±200                               |                                       | 13.84                             | .974                   |
| "                | 30°      | .652          | 43800±500                               |                                       | 12.51                             | 1.025                  |
| "                | 30°      | .652          | 45400±200                               |                                       | 13.44                             | 1.101                  |
| "                | 30°      | .652          | 45800±200                               |                                       | 13.68                             | 1.120                  |
| "                | 30°      | .652          | 45000±200                               |                                       | 13.20                             | 1.081                  |
| "                | 30°      | .652          | 44000±500                               |                                       | 12.82                             | 1.034                  |
| "                | 30°      | .652          | 43000±800                               |                                       | 12.06                             | .987                   |
| 116000           | 1°       | 1.387         | 53300±300                               | 53000                                 | 38.4                              | 1.080                  |
| "                | 30°      | .659          | 43200±200                               | 43000                                 | 12.18                             | .985                   |
| 113000           | 2°       | .510          | 48300±200                               | 48600                                 | 12.04                             | 1.151                  |
| 119000           | 1°       | .944          | 50800±300                               | 50200                                 | 23.8                              | 1.062                  |
| "                | 2°       | .455          | 45800±200                               |                                       | 9.54                              | 1.064                  |
| "                | 30°      | .455          | 40700±200                               |                                       | 7.54                              | .980                   |
| "                | 35°      | .460          | 39800±200                               |                                       | 7.29                              | .985                   |
| "                | 45°      | .460          | 41600±200                               |                                       | 7.96                              | 1.115                  |
| "                | 5°       | .457          | 33000±1000                              |                                       | 4.98                              | .555                   |
| "                | 3°       | .454          | 30300±500                               |                                       | 4.17                              | .466                   |
| "                | 10°      | .456          | 30900±200                               |                                       | 4.35                              | .565                   |
| "                | 0°       | .459          | 26800±500                               |                                       | 3.30                              | .363                   |

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Table VI - (Continued)

| Tensile<br>Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected              | Corrected                | $(10^{-6})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|---------------------|----------|---------------|--------------------------|--------------------------|-----------------------------------|------------------------|
|                     |          |               | $F(\frac{e}{d}, \theta)$ | $F(\frac{e}{d}, \theta)$ |                                   |                        |
| 124000              | 30°      | .347          | 39000±200                |                          | 5.28                              | 1.036                  |
| 117000              | 4°       | .673          | 48600±100                | 48300                    | 15.70                             | 1.063                  |
| "                   | .5°      | .326          | 40300±300                |                          | 5.29                              | .985                   |
| "                   | 30.5°    | .673          | 44100±500                | 43900                    | 12.97                             | 1.026                  |
| "                   | 30°      | .326          | 34900±200                |                          | 3.97                              | .862                   |
| 118000              | 0°       | .206          | 34300±100                |                          | 2.42                              | 1.061                  |
| "                   | 0°       | .207          | 34900±200                |                          | 2.52                              | 1.092                  |
| "                   | 45°      | .206          | 29200±500                |                          | 1.76                              | .973                   |
| "                   | 45°      | .206          | 23400±200                |                          | 1.13                              | .625                   |
| 132000              | 5°       | 1.375         | 55000±800                | 52400                    | 37.8                              | 1.053                  |
| 119000              | 3°       | .541          | 46500±200                |                          | 11.70                             | 1.038                  |
| "                   | 30°      | .540          | 42000±800                |                          | 9.52                              | .986                   |
| "                   | 3°       | .260          | 35800±200                |                          | 3.33                              | .931                   |
| "                   | 8°       | .259          | 33800±200                |                          | 2.96                              | .843                   |
| "                   | 28.5°    | .260          | 33500±500                |                          | 2.92                              | .936                   |
| "                   | 44.5°    | .263          | 31500±1000               |                          | 2.61                              | .915                   |
| 115000              | 30°      | .662          | 43900±200                | 43900                    | 12.76                             | 1.023                  |
| "                   | 30°      | .662          | 41100±300                | 41100                    | 11.18                             | .897                   |
| "                   | 31°      | .656          | >39300                   | >39300                   | >10.13                            | >.831                  |

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Table VI - (Continued)

| Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-8})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|------------------|----------|---------------|-----------------------------------------|---------------------------------------|-----------------------------------|------------------------|
| 85000            | 0°       | .657          | 43700±200                               | 48500                                 | 15.45                             | 1.074                  |
| "                | 20°      | .660          | 40000±200                               | 44400                                 | 13.01                             | .932                   |
| "                | 29.8°    | .657          | 37900±200                               | 42100                                 | 11.64                             | .941                   |
| 119000           | 30°      | .650          | 38800±1000                              |                                       | 9.78                              | .803                   |
| "                | 30°      | .658          | 41800±200                               |                                       | 11.50                             | .930                   |
| 106000           | 1°       | .827          | 48900±200                               | 50300                                 | 20.9                              | 1.100                  |
| 132000           | 3°       | .431          | 42800±500                               |                                       | 7.90                              | .950                   |
| "                | 0°       | .422          | 27600±200                               |                                       | 3.27                              | .395                   |
| 130000           | 0°       | 1.036         | 50900±400                               |                                       | 26.8                              | 1.070                  |
| "                | 1°       | .505          | 46100±300                               |                                       | 10.73                             | 1.040                  |
| 123000           | .5°      | .669          | 47000±200                               | 46600                                 | 14.53                             | .987                   |
| "                | 1°       | .673          | 29000±1000                              | 28800                                 | 5.58                              | .377                   |
| 127000           | 1°       | 1.055         | 49500±400                               | 47800                                 | 24.1                              | .940                   |
| 108000           | 0°       | 1.36          | 49500±200                               | 50600                                 | 34.8                              | .984                   |
| "                | 0°       | 1.39          | 50800±200                               | 51900                                 | 37.4                              | 1.031                  |
| "                | 0°       | 1.39          | 51200±500                               | 52300                                 | 38.0                              | 1.048                  |
| "                | 0°       | 1.39          | 50900±200                               | 52000                                 | 37.6                              | 1.036                  |
| "                | 0°       | 1.39          | 47900±500                               | 48900                                 | 33.2                              | .916                   |
| "                | 0°       | 1.365         | 47200±200                               | 48200                                 | 31.7                              | .890                   |
| 109000           | 1.5°     | .980          | 45500±200                               | 46300                                 | 21.0                              | .896                   |

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Table VI - (Continued)

| Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-8})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ |
|------------------|----------|---------------|-----------------------------------------|---------------------------------------|-----------------------------------|------------------------|
| 116000           | 0°       | 1.63          | 53000±500                               | 53000                                 | 45.8                              | 1.023                  |
| "                | .5°      | 1.615         | 53200±200                               | 53200                                 | 45.7                              | 1.035                  |
| "                | .5°      | 1.62          | 50700±500                               | 50700                                 | 41.6                              | .940                   |
| 97000            | 4.5°     | 1.69          | 52300±300                               | 55400                                 | 51.9                              | 1.113                  |
| "                | 3°       | .819          | 46100±200                               | 48800                                 | 19.50                             | 1.042                  |
| "                | 20°      | .823          | 44400±300                               | 47000                                 | 18.18                             | 1.028                  |
| "                | 30°      | .823          | 43700±500                               | 46300                                 | 17.64                             | 1.087                  |
| 121000           | 0°       | 1.016         | 49400±500                               | 48500                                 | 23.9                              | .976                   |
| "                | 1°       | 1.02          | 50000±1000                              | 49100                                 | 24.6                              | .999                   |
| 101000           | 0°       | 1.35          | 48700±100                               | 50900                                 | 35.0                              | 1.000                  |
| 101000           | 0°       | 1.35          | 49700±200                               | 51900                                 | 36.4                              | 1.040                  |

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Table VII - Plate Penetration Coefficients for AP Bombs vs Class B Plate corrected for tensile strength to 115000 (lb)/(in)<sup>2</sup> Tensile Strength at 15°C.

| Bomb          | Plate Number | Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-8})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ | $-\frac{1}{8}A^2(4\theta^0 - \frac{e}{d})^2$ | $\cos \theta$ |
|---------------|--------------|------------------|----------|---------------|-----------------------------------------|---------------------------------------|-----------------------------------|------------------------|----------------------------------------------|---------------|
| 12" SAP M58A1 | X8651        | 121000           | 21°      | .160          | $\geq 26200$                            |                                       | >1.10                             | > .85                  |                                              | .934          |
| 12.2" SAP T5  | 3A737A1      | 107000           | 20°      | .162          | $\leq 36000$                            | <36900                                | <2.20                             | <1.66                  |                                              | .940          |
| "             | "            | "                | 20°      | .328          | 37000±1000                              | 37900                                 | 4.71                              | .93                    | .68                                          | .940          |
| 12" AP Mk 33  | 8372         | 110000           | 20°      | .396          | 38000±2000                              | 38700                                 | 5.94                              | .865                   | .66                                          | .940          |
| "             | KK148        | 109000           | 25°      | .461          | $\leq 41500$                            | <42400                                | <8.30                             | <1.010                 |                                              | .908          |
| "             | "            | "                | 29°      | .460          | $\leq 42100$                            | <43000                                | <9.51                             | <1.080                 |                                              | .975          |
| "             | "            | "                | 24.5°    | .463          | 41400±300                               | 42300                                 | 8.29                              | 1.000                  | .98                                          | .910          |
| "             | "            | "                | 30°      | .463          | 41000±200                               | 41900                                 | 8.14                              | 1.034                  | .99                                          | .866          |
| "             | KK203        | 113000           | 19.5°    | .484          | 43500±200                               | 44000                                 | 9.38                              | 1.023                  | .99                                          | .943          |
| "             | "            | "                | 30°      | .484          | $\leq 38600$                            | <39000                                | <7.36                             | < .88                  |                                              | .866          |
| "             | KK719        | 113000           | 30°      | .273          | 33000±200                               | 33200                                 | 3.01                              | .895                   | .99                                          | .866          |
| "             | TT813        | 113000           | 30.5°    | .273          | 31000±700                               | 31200                                 | 2.66                              | .795                   | .91                                          | .862          |
| "             | 53C425A1     | 127000           | 29.5°    | .417          | $\leq 38500$                            |                                       | <6.19                             | < .904                 |                                              | .870          |
| "             | 53C164A1     | 108000           | 20°      | .479          | $\leq 42400$                            | <43400                                | <9.02                             | <1.004                 |                                              | .940          |
| "             | 35K601A1     | 115000           | 30°      | .266          | 31200±300                               | 31200                                 | 2.59                              | .809                   | .99                                          | .866          |
| "             | 33G051A1     | 114000           | 29.5°    | .261          | 30900±300                               | 31000                                 | 2.49                              | .806                   | .99                                          | .870          |
| 14" AP C-20   | 5A457A3      | 108000           | 15°      | .378          | 40000±500                               | 40900                                 | 6.32                              | .962                   | .97                                          | .966          |

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Table VII - (Continued)

| Bomb        | Plate Number | Tensile Strength | $\theta$ | $\frac{e}{d}$ | Uncorrected<br>$F(\frac{e}{d}, \theta)$ | Corrected<br>$F(\frac{e}{d}, \theta)$ | $(10^{-8})U(\frac{e}{d}, \theta)$ | $(1+\sigma)(1+\omega)$ | $-\frac{1}{2}A^2(e_g^2 - \frac{1}{2}f^2)$ | cos $\theta$ |
|-------------|--------------|------------------|----------|---------------|-----------------------------------------|---------------------------------------|-----------------------------------|------------------------|-------------------------------------------|--------------|
| 14" AP Mk 1 | 8943         | 103000           | 20.5°    | .500          | 43000±700                               | 44700                                 | 9.99                              | 1.056                  | .94                                       | .937         |
| "           | "            | "                | 24.5°    | .500          | 40400±200                               | 42000                                 | 8.82                              | .958                   | .92                                       | .910         |
| "           | "            | "                | 30°      | .504          | 37600±200                               | 39100                                 | 7.70                              | .870                   | .99                                       | .866         |
| "           | "            | "                | 29.5°    | .502          | 40200±500                               | 41800                                 | 8.77                              | .990                   | .97                                       | .870         |
| "           | KE834        | 112000           | 25°      | .397          | 39000±1000                              | 39300                                 | 6.14                              | .923                   | .89                                       | .906         |
| "           | 3B427A3      | 112000           | 25°      | .407          | ≤ 40500                                 | ≤ 41100                               | ≤ 6.88                            | ≤ 1.000                |                                           | .906         |
| "           | 4B586A3      | 112000           | 25°      | .401          | 36500±200                               | 37000                                 | 5.49                              | .819                   | .99                                       | .206         |
| "           | 31C177A1     | 106000           | 29.5°    | .464          | 39200±200                               | 40400                                 | 7.57                              | .952                   | .99                                       | .870         |
| "           | "            | "                | 29.5°    | .464          | ≥ 39000                                 | ≥ 40200                               | ≥ 7.50                            | ≥ .943                 |                                           | .870         |

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VII

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(Ballistic Data)

- (1) "Armor Penetration of cal .60 Bullets of Various Contours", H. W. Zuker and T. A. Read, Frankford Arsenal Report No. R-615. (May, 1945)
- (2) "The effect of the shape of the head of AP shot on critical velocities for penetration at normal" R. MacPhail, Proof and Development Establishment, Valcartier, P. Q. Canada (May 1943). "Second Progress Report on the Investigation of Scale Effect in Armour Penetration. Effect of Hardness on Plate Performance". D. G. Sopwith, A. F. C. Brown, and V. M. Hickson, National Physical Laboratory Report No. 50 (February, 1943). "Third Progress Report on the Investigation of Scale Effect in Armour Penetration. Firing Trials at Normal attack with geometrically similar Shot against Homogeneous Armour of varied Hardness." A. F. C. Brown and V. M. Hickson, National Physical Laboratory Report No. 79 (September, 1944).
- (3) "Penetration of Homogeneous Armor by 3" Flat Nosed Projectiles" NPG Report No. 7-43 (April 1943). "The Effect of Nose Shape on Ballistic Performance of 15 lb. 3" AP Solid Shot Against Homogeneous Armor Plate", NPG Report No. 2-43.
- (4) "Ballistic Summary. Part I. The Dependence of Limit Velocity on Plate Thickness and Obliquity at Low Obliquity". NPG Pamphlet Report No. 2-46 (March, 1946).

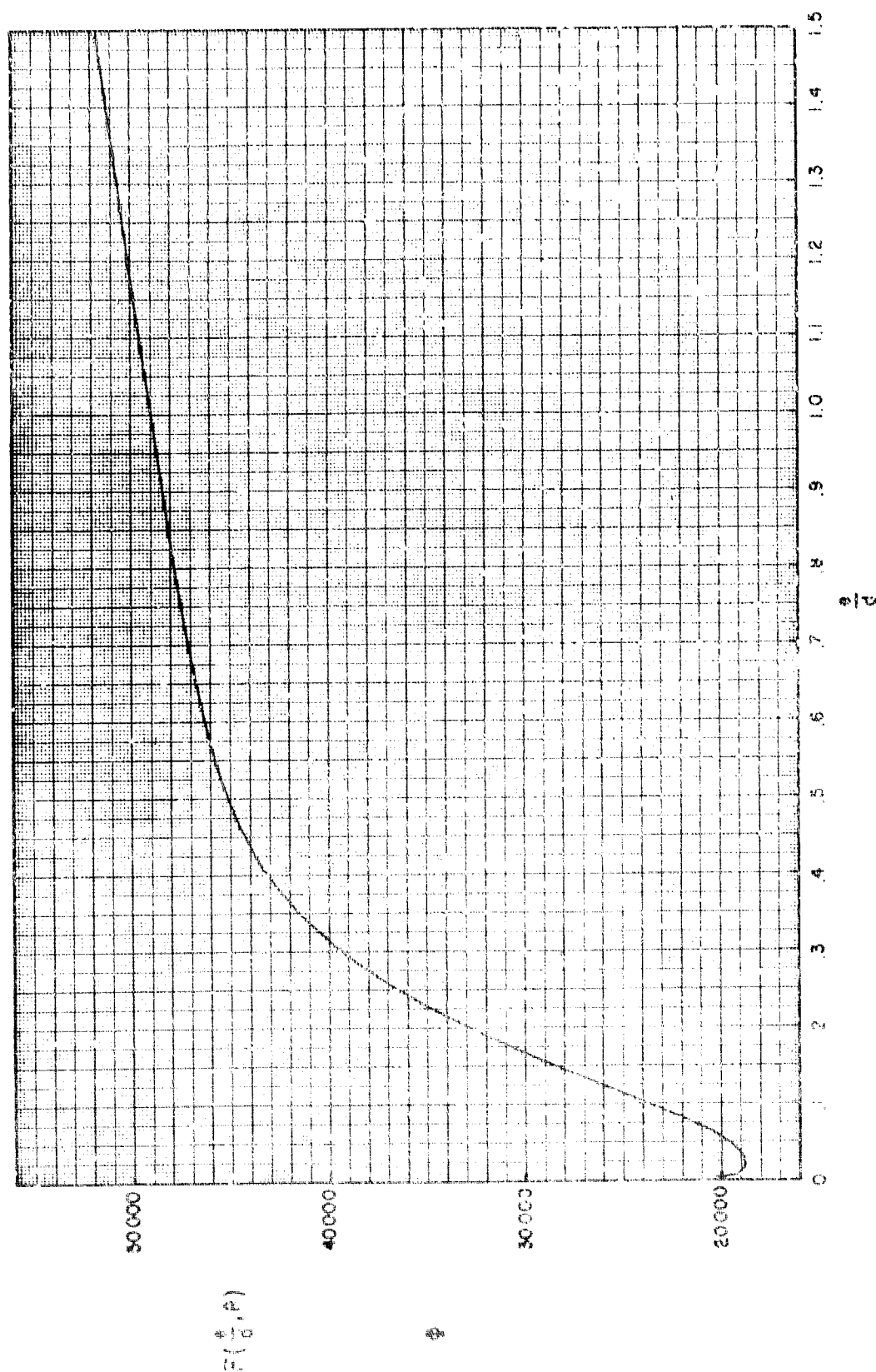
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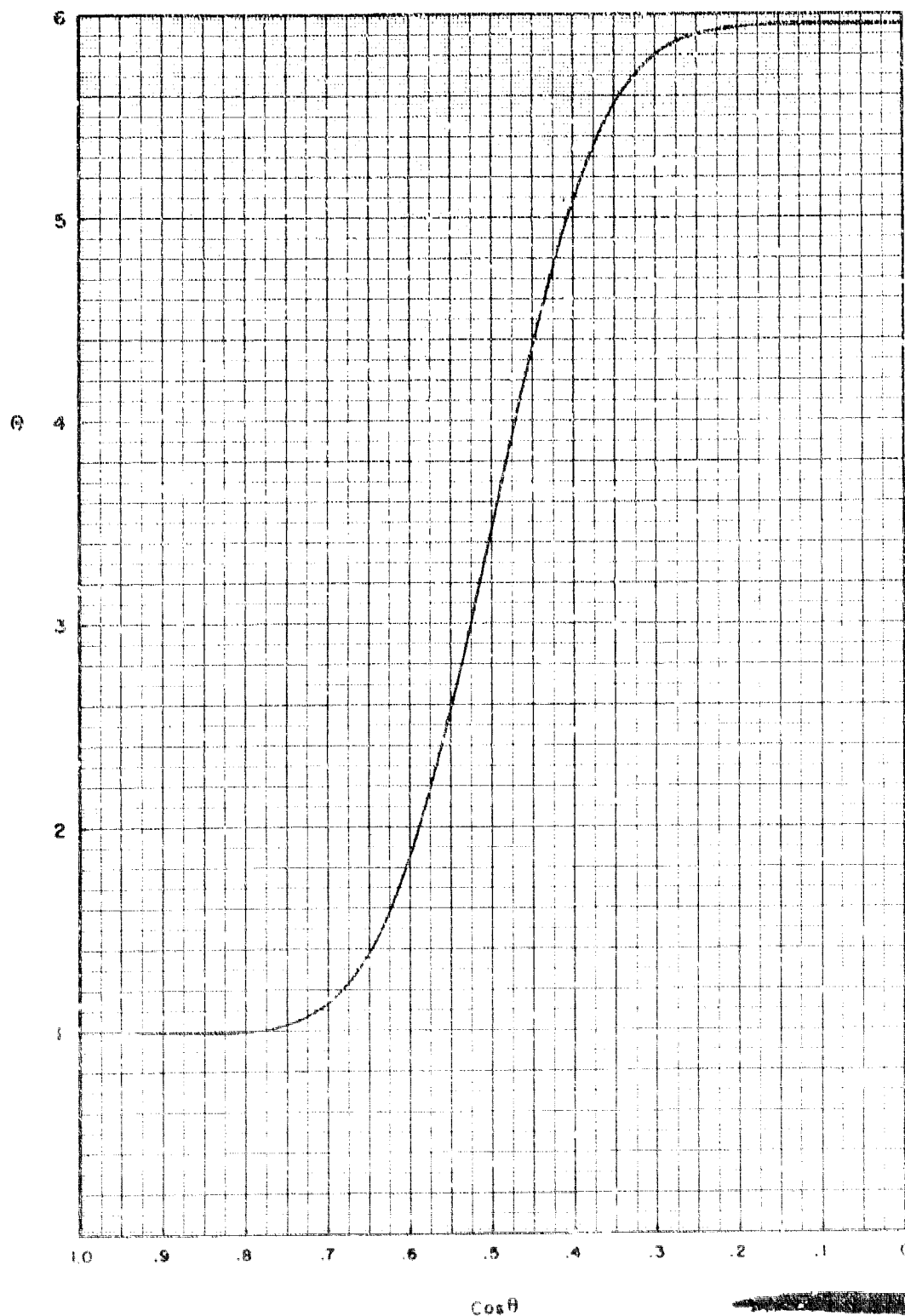
FIGURE (1)

# THE PLATE PENETRATION COEFFICIENT FOR 0° OBLIQUITY

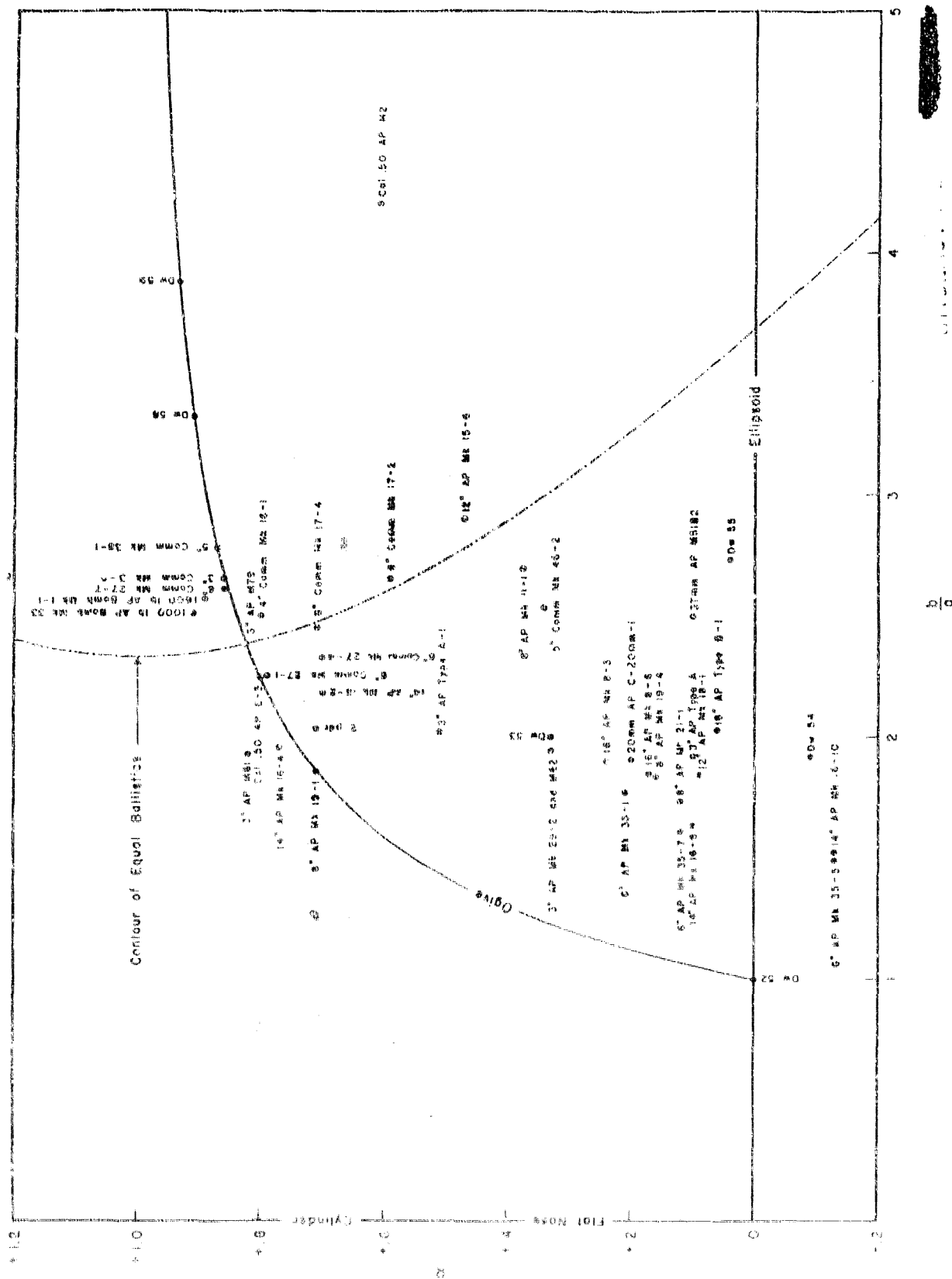
Standard Experimental Curve for 3" AP M79 Projectile vs STS of 115000 (lb)/(in)<sup>2</sup> Tensile Strength at 15°C



THE OBLIQUITY FUNCTION  $\Theta$   
3" AP M79 Projectile in Homogeneous Plate



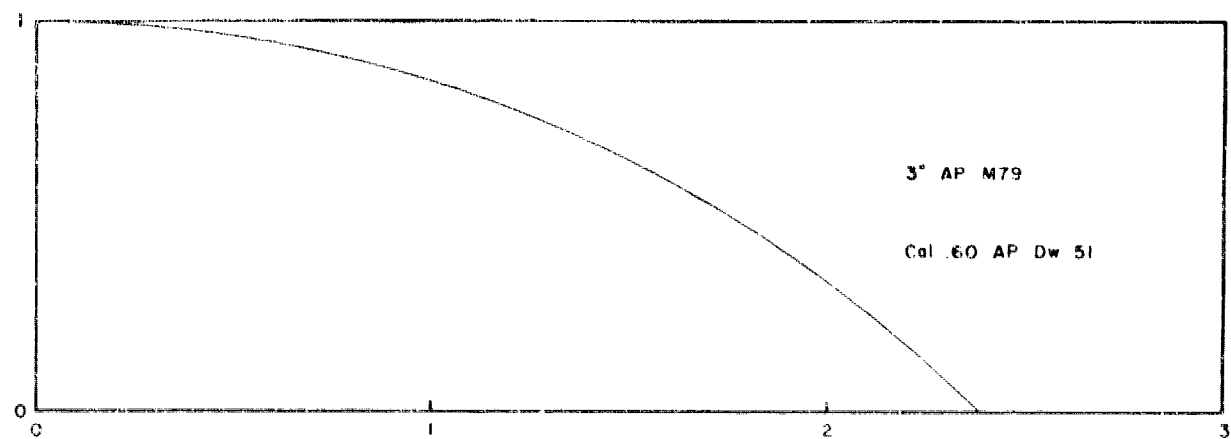
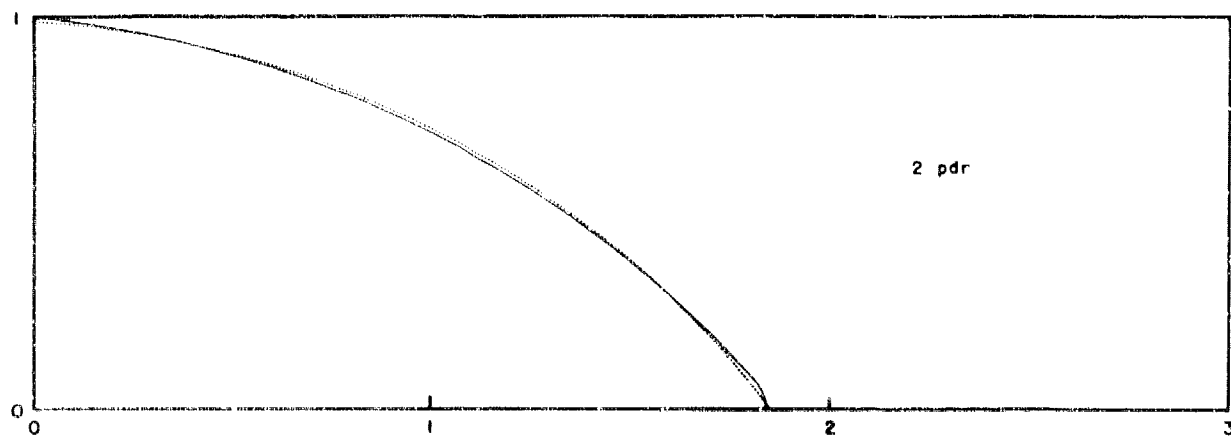




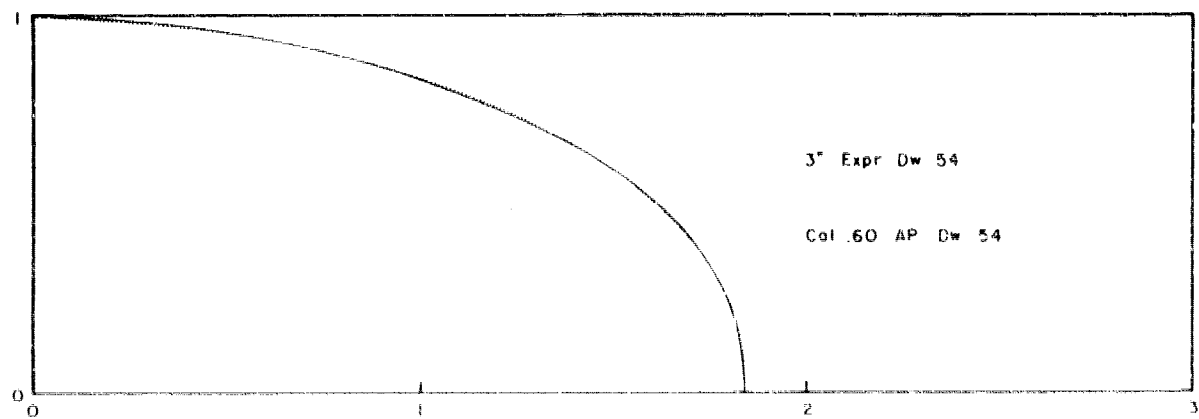
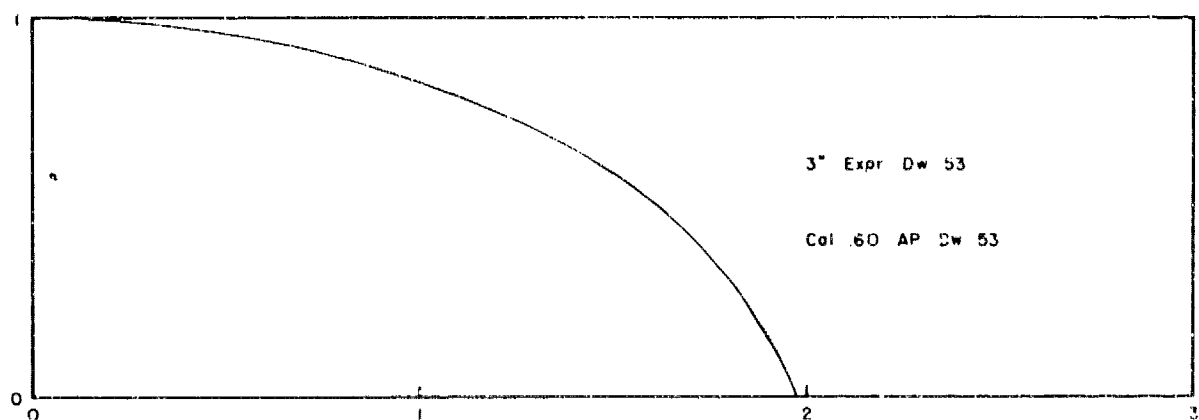
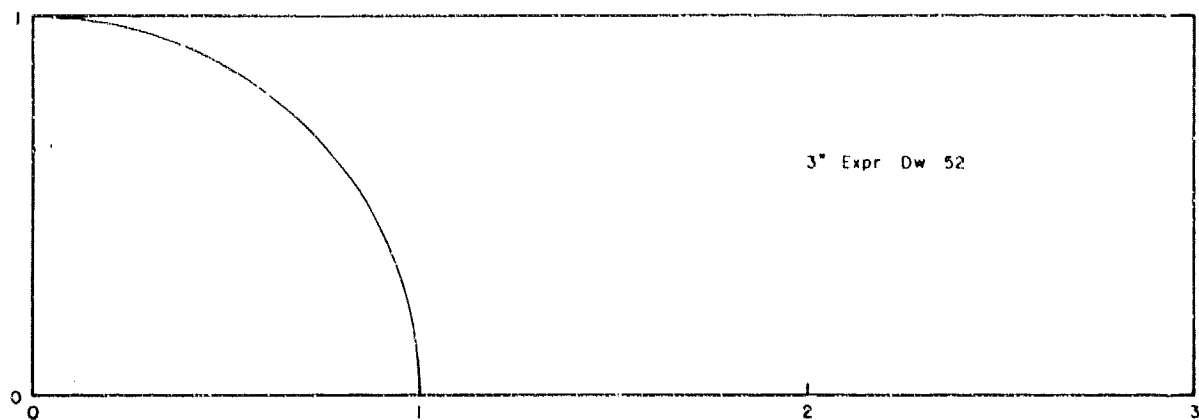
KPG PHOTO NO. 3030 (APL)

# PROJECTILE NOSE CONTOURS

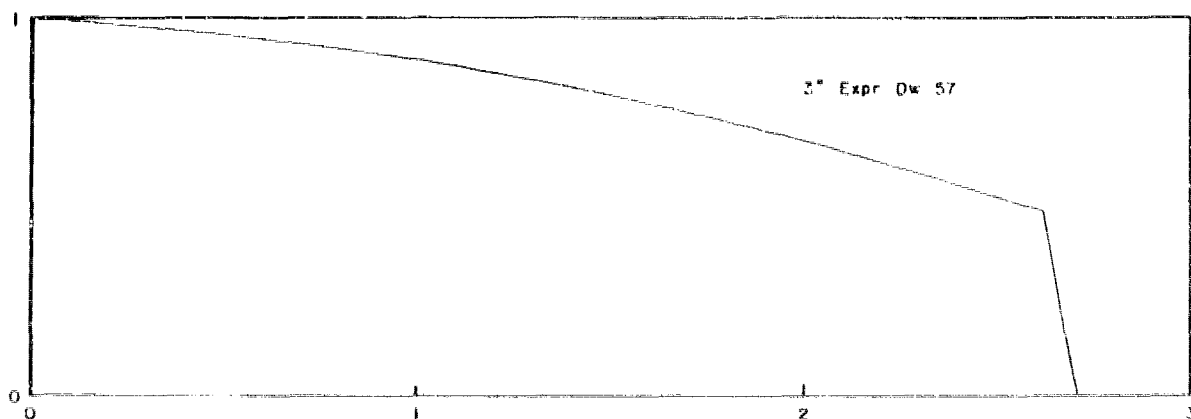
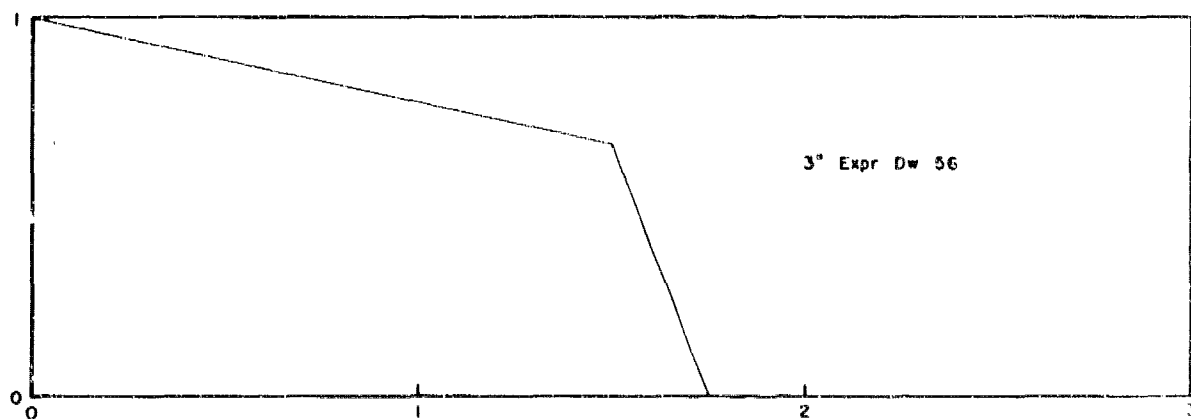
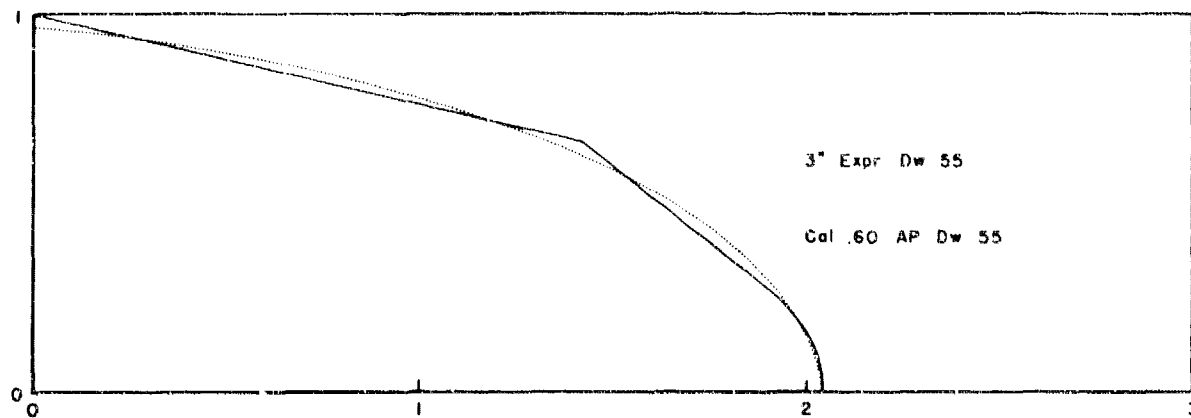
FIGURE 15)



PROJECTILE NOSE CONTOURS



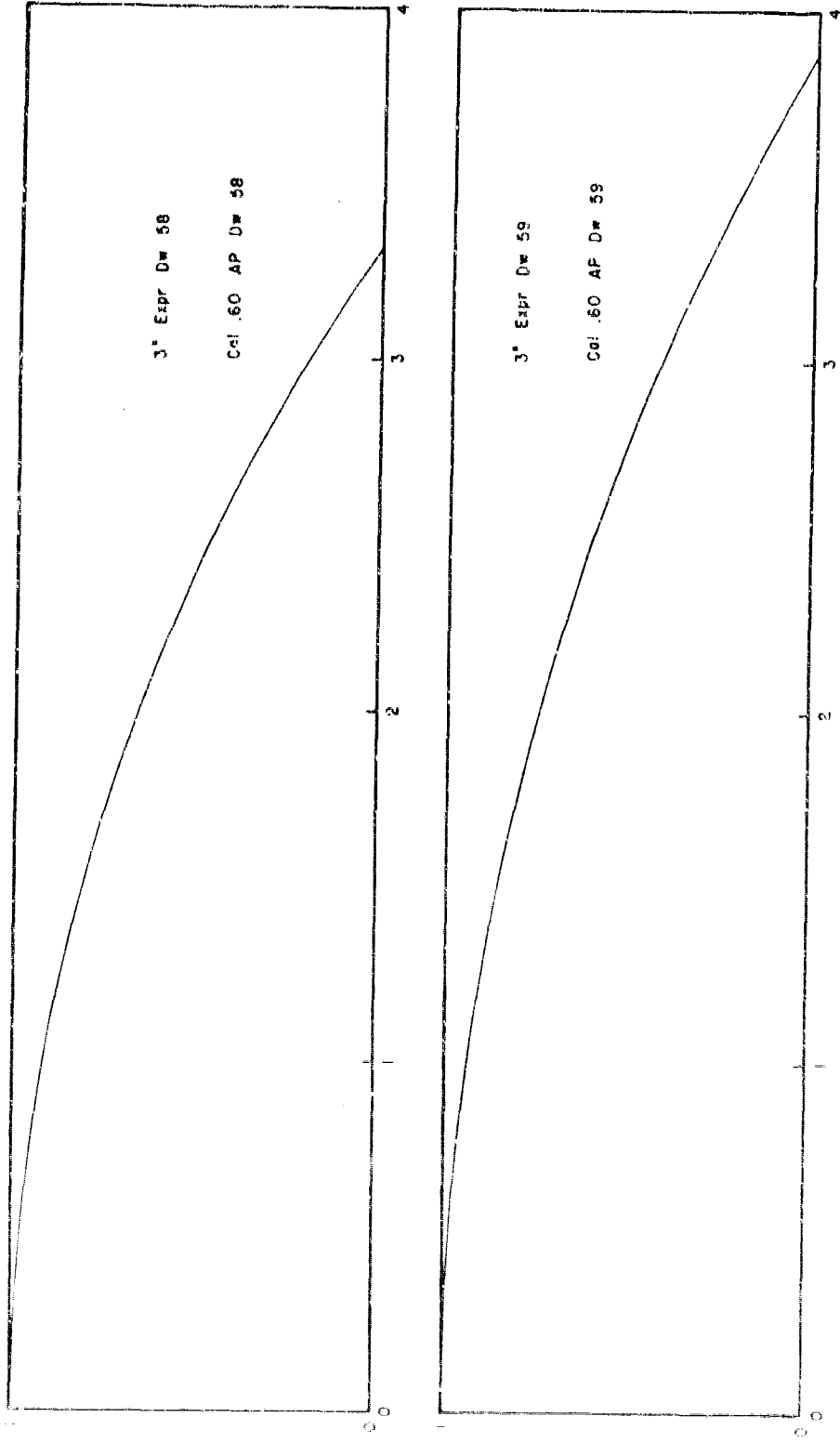
# PROJECTILE NOSE CONTOURS



NPG PHOTO NO. 3033 (APL)

PROJECTILE NOSE CONTOURS

FIGURE (8)

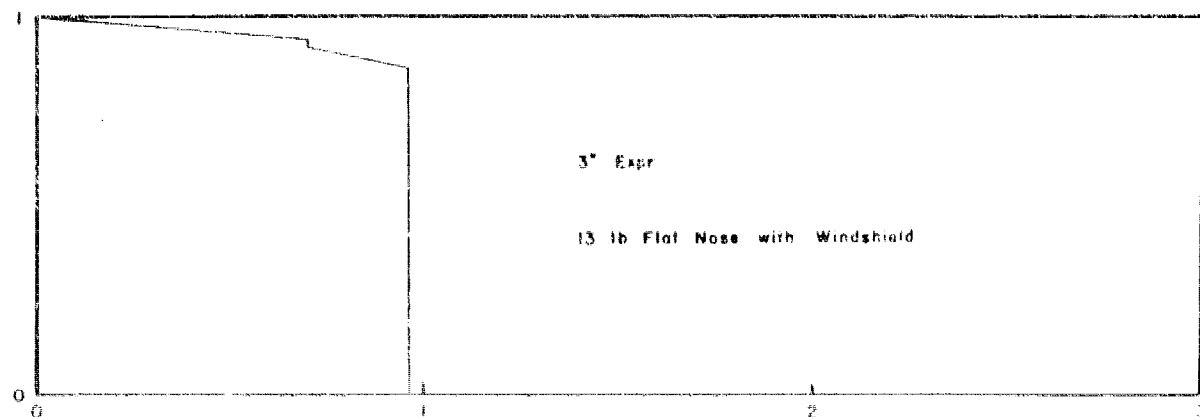
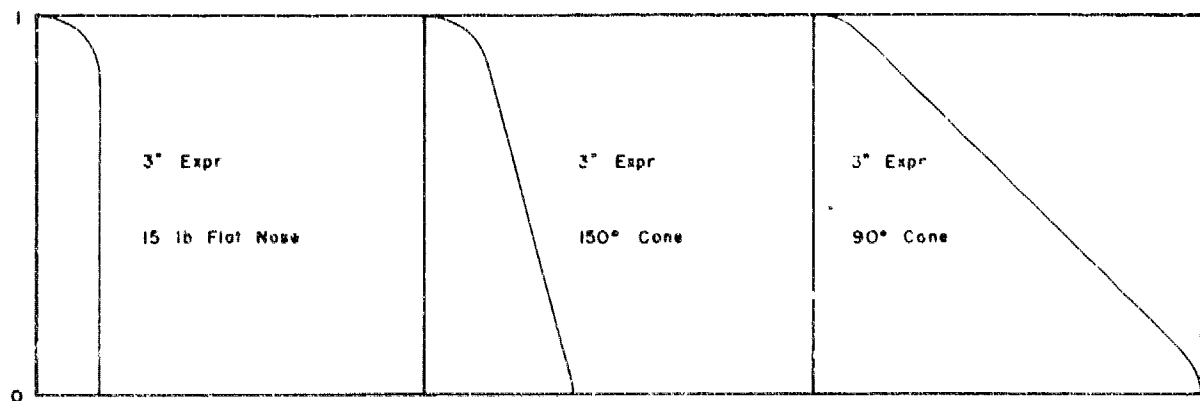


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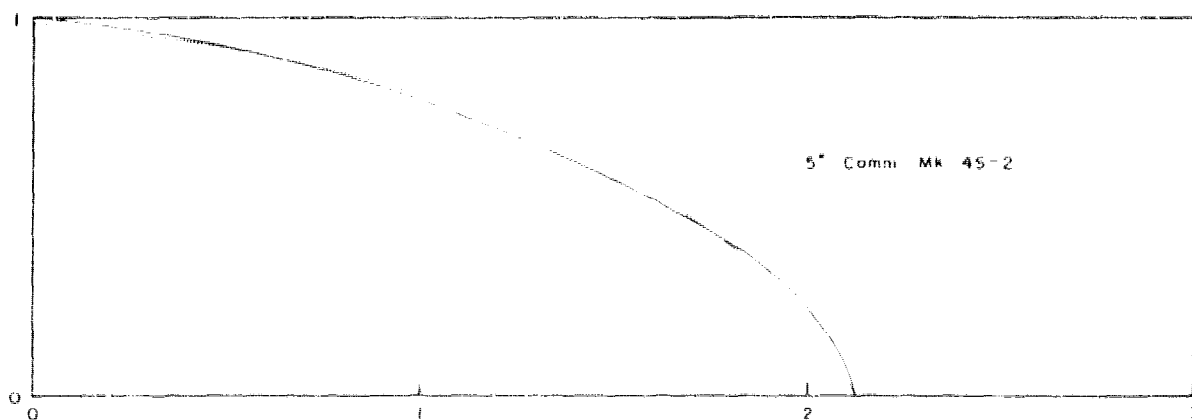
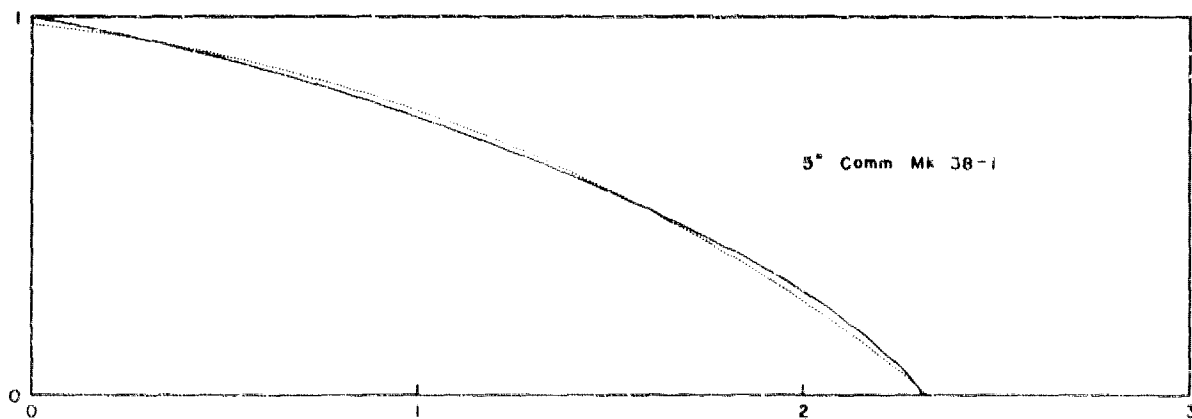
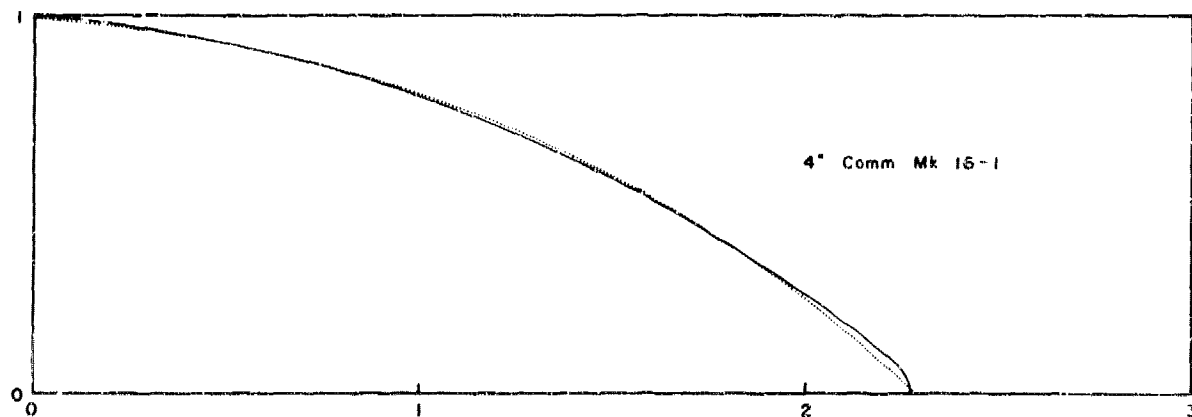
# PROJECTILE NOSE CONTOURS

FIGURE (9)

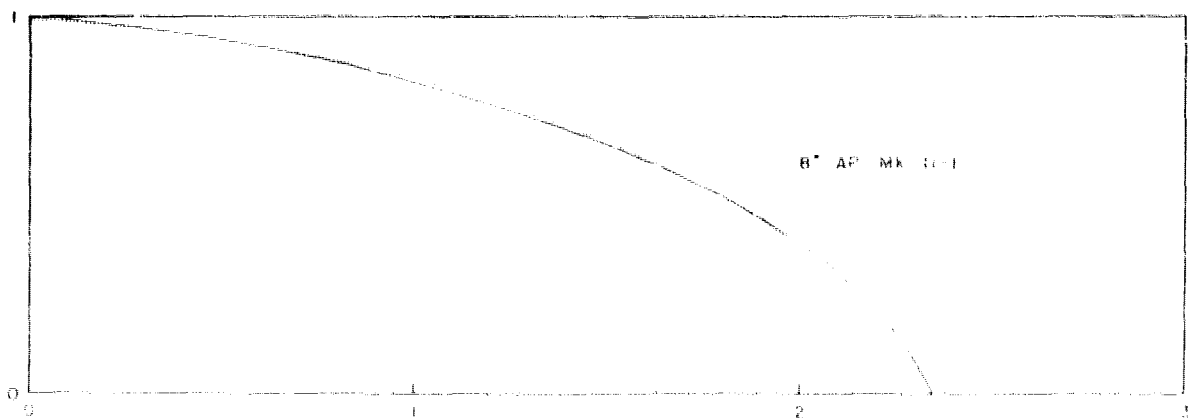
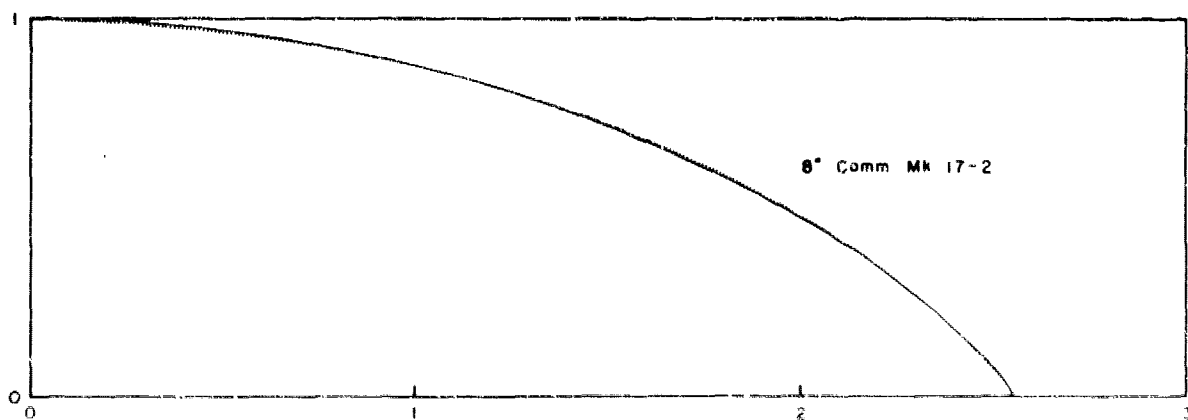
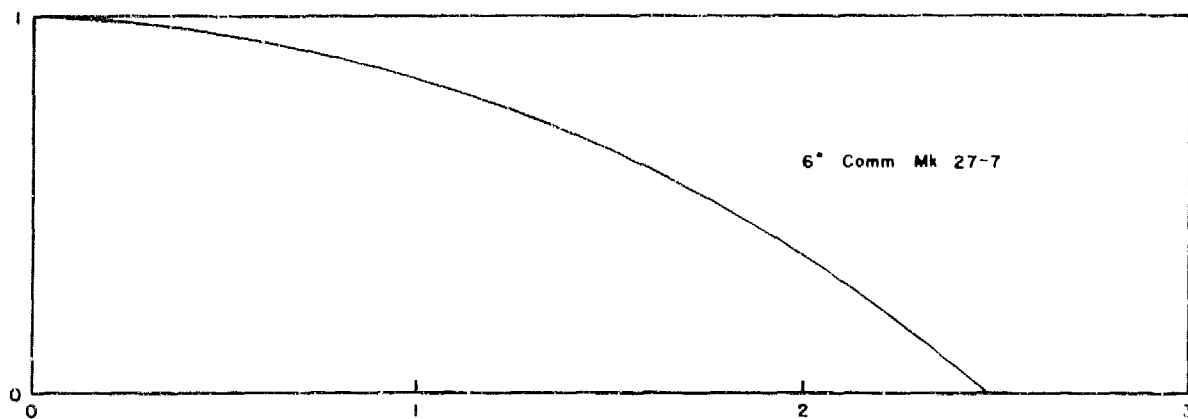


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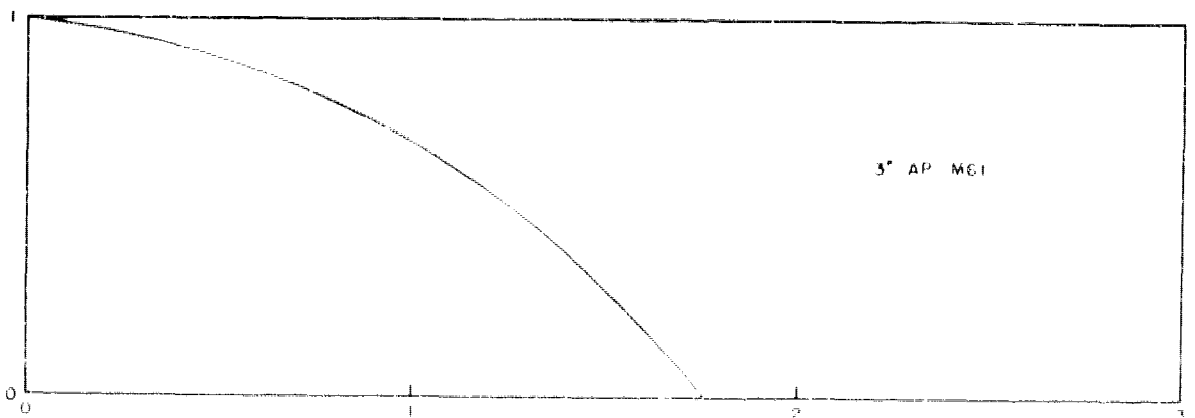
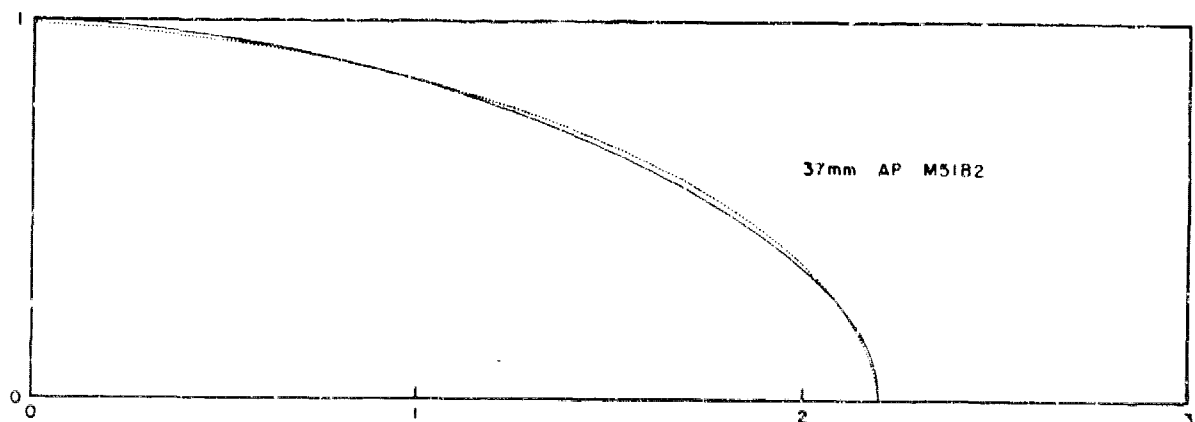
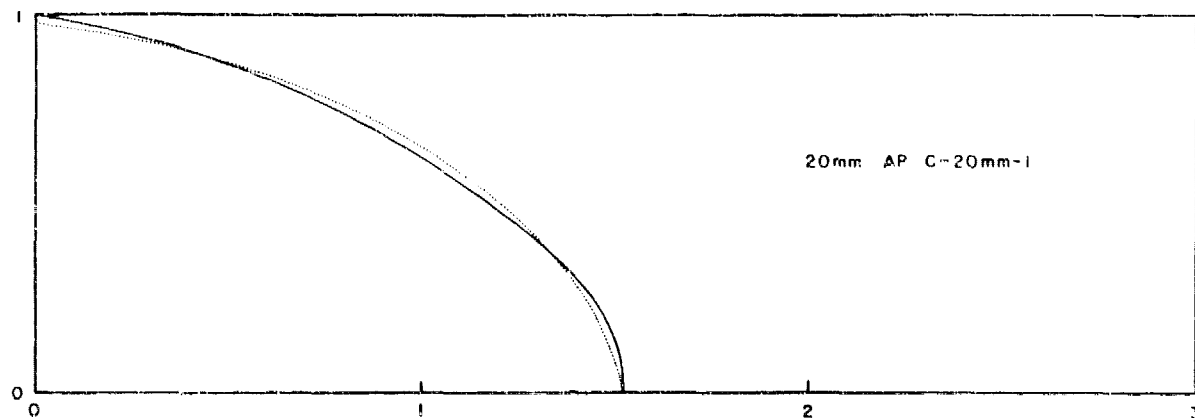
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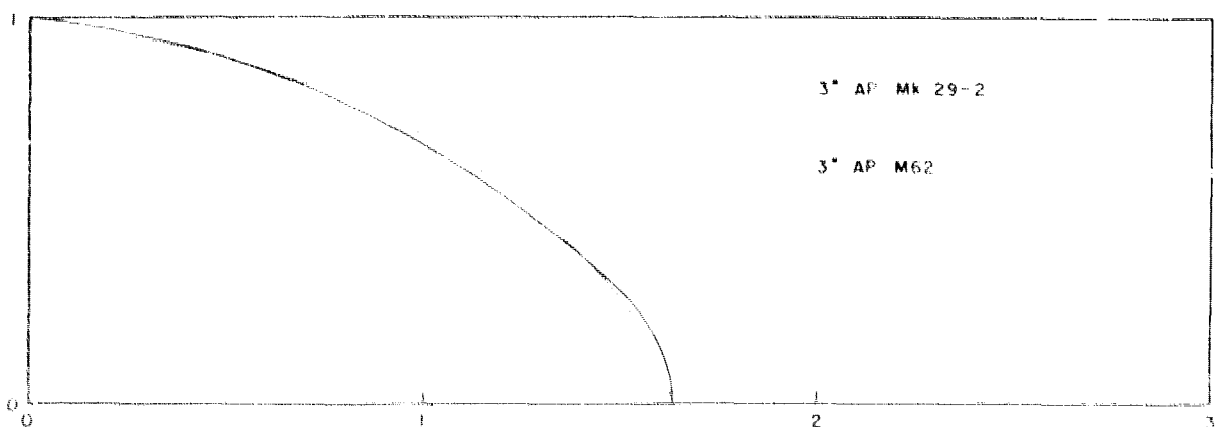
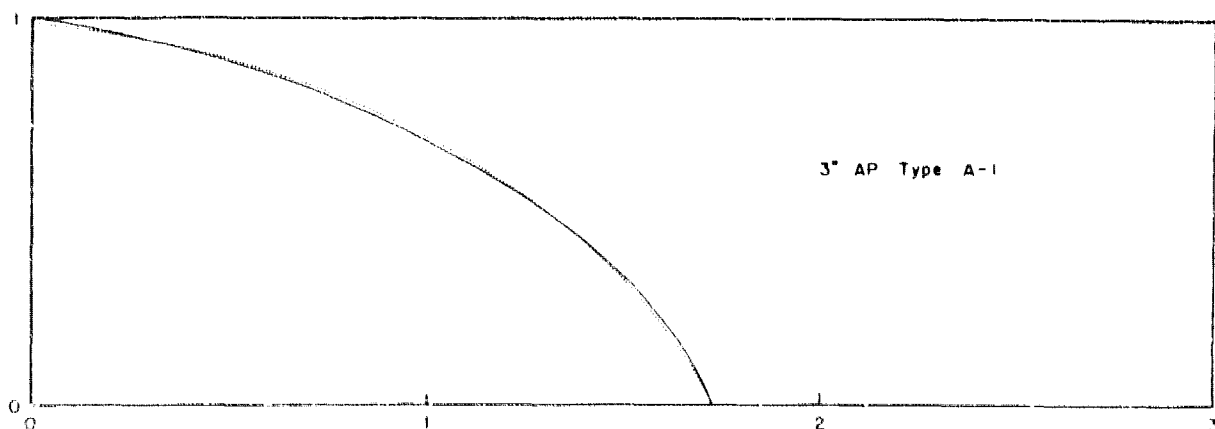
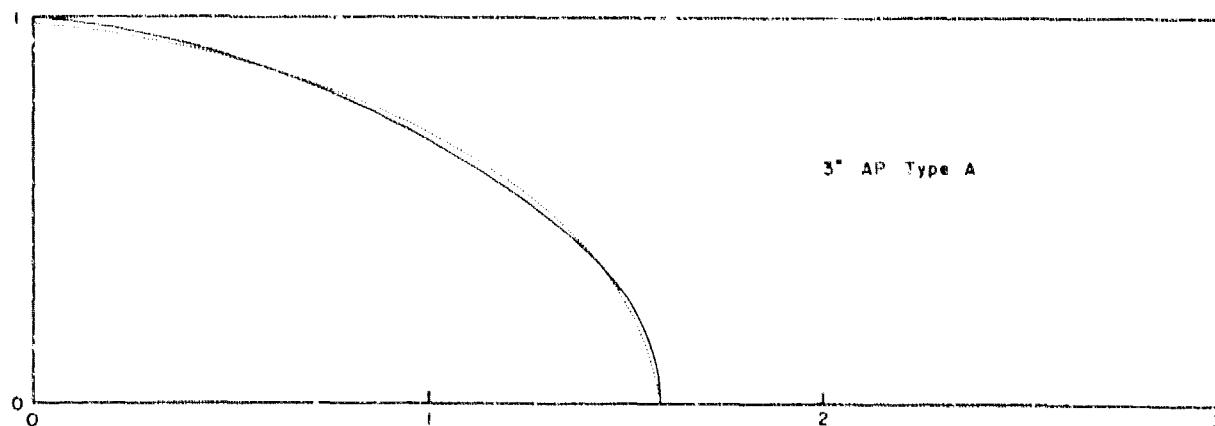
# PROJECTILE NOSE CONTOURS



# PROJECTILE NOSE CONTOURS



PROJECTILE NOSE CONTOURS

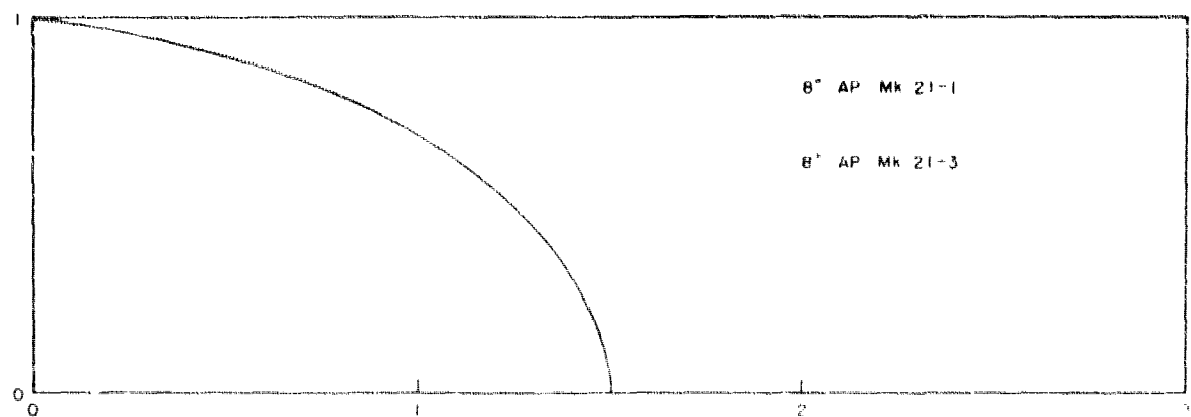
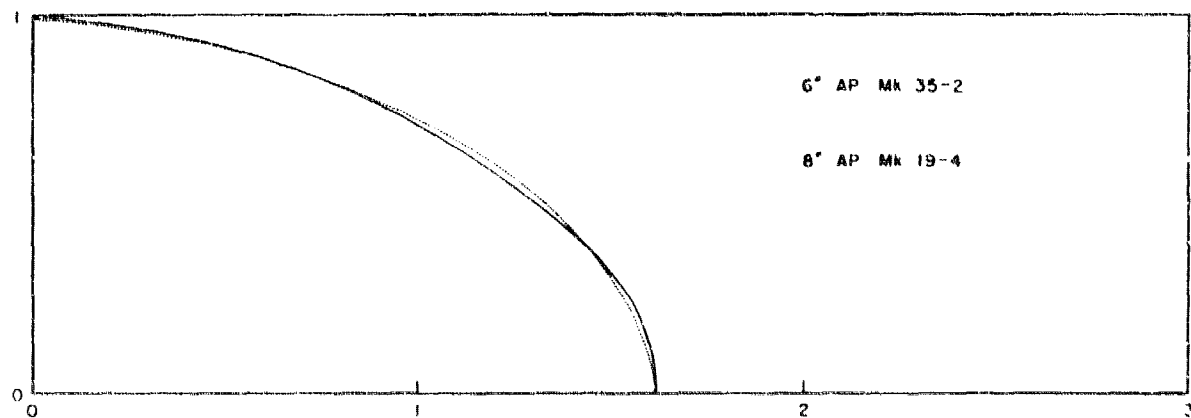
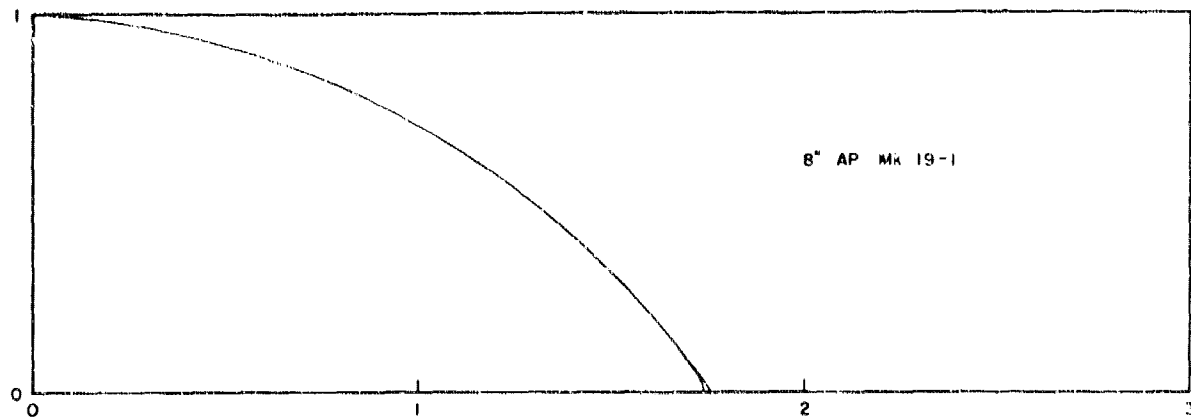


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NPG PHOTO NO. 3038 (APL)

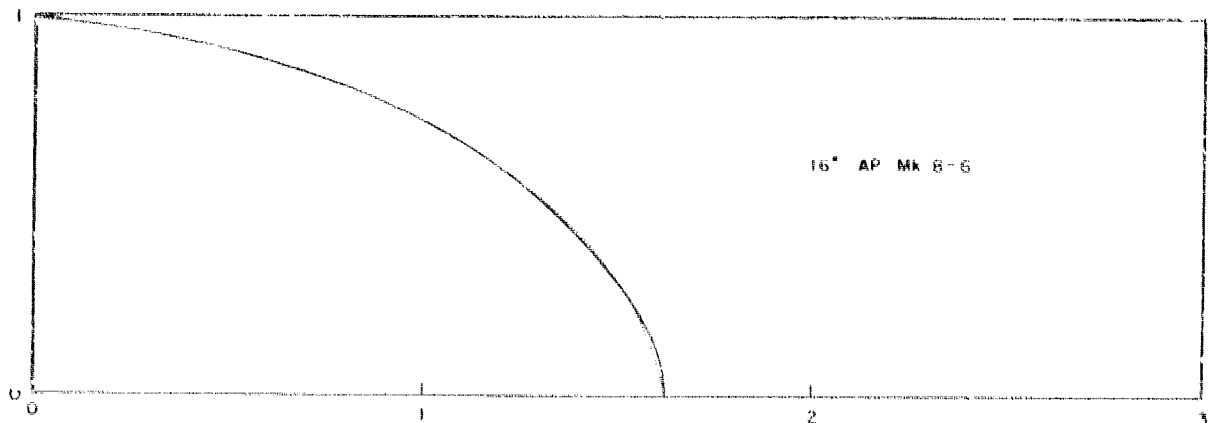
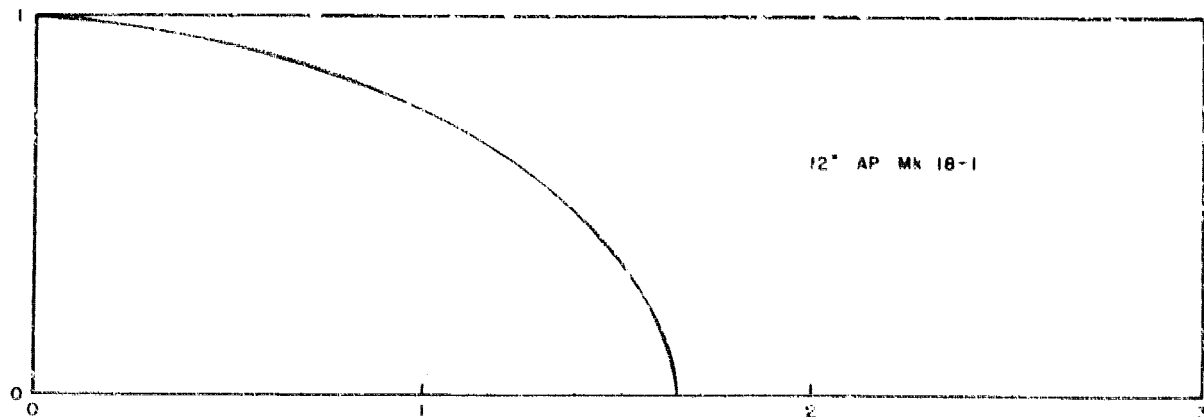
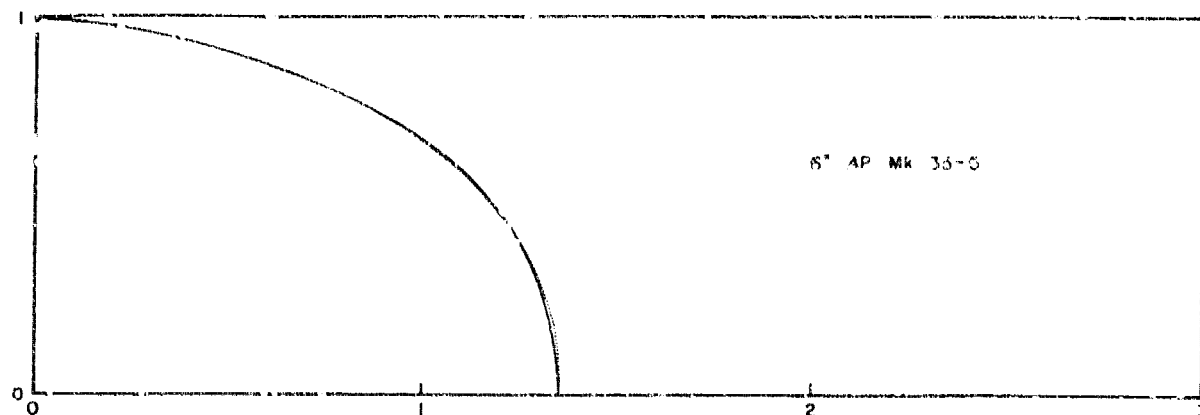
# PROJECTILE NOSE CONTOURS

FIGURE (14)

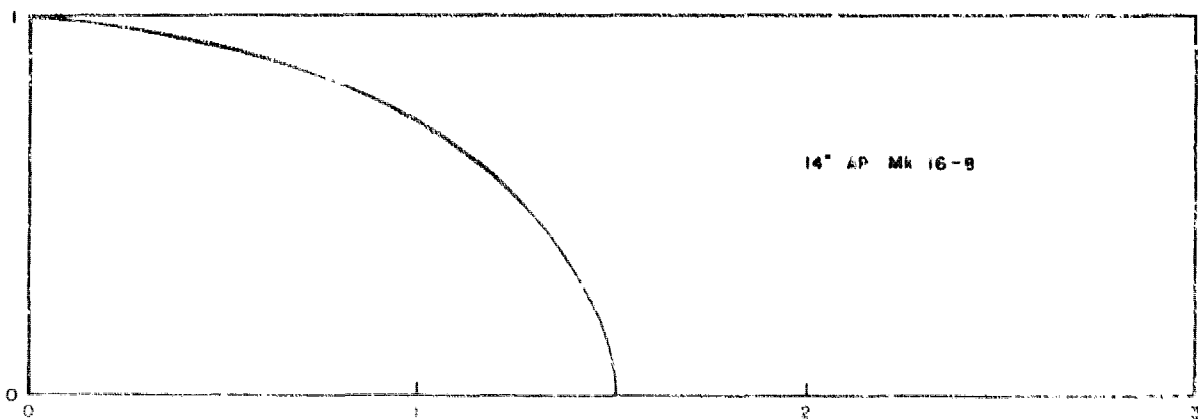
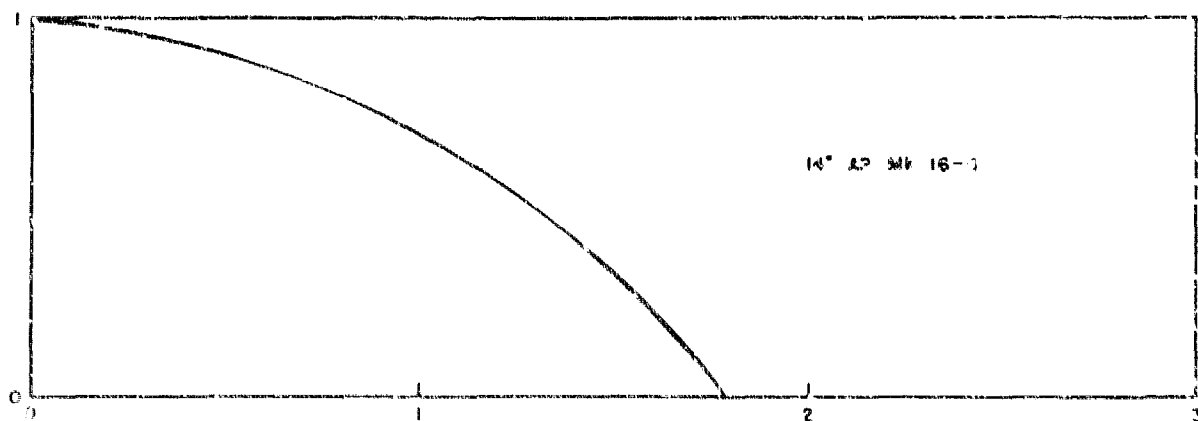
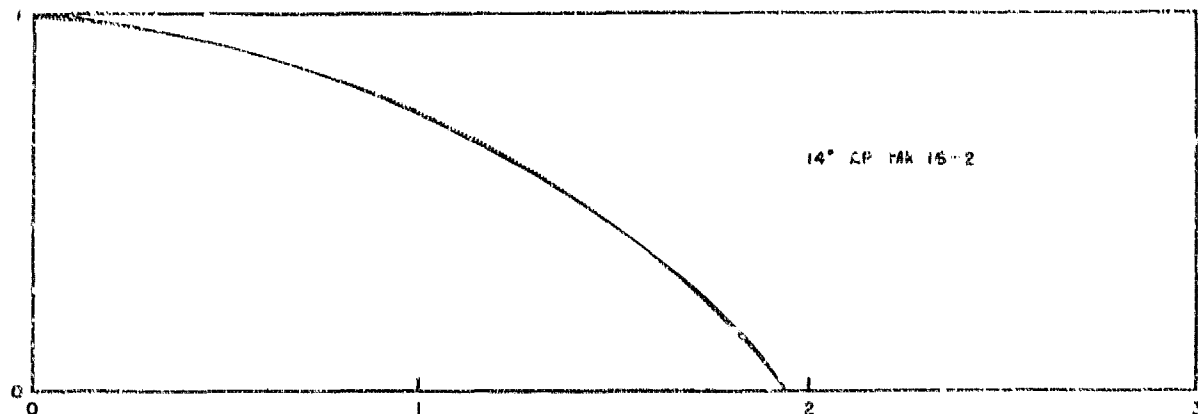


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PROJECTILE NOSE CONTOURS



(15-53511)

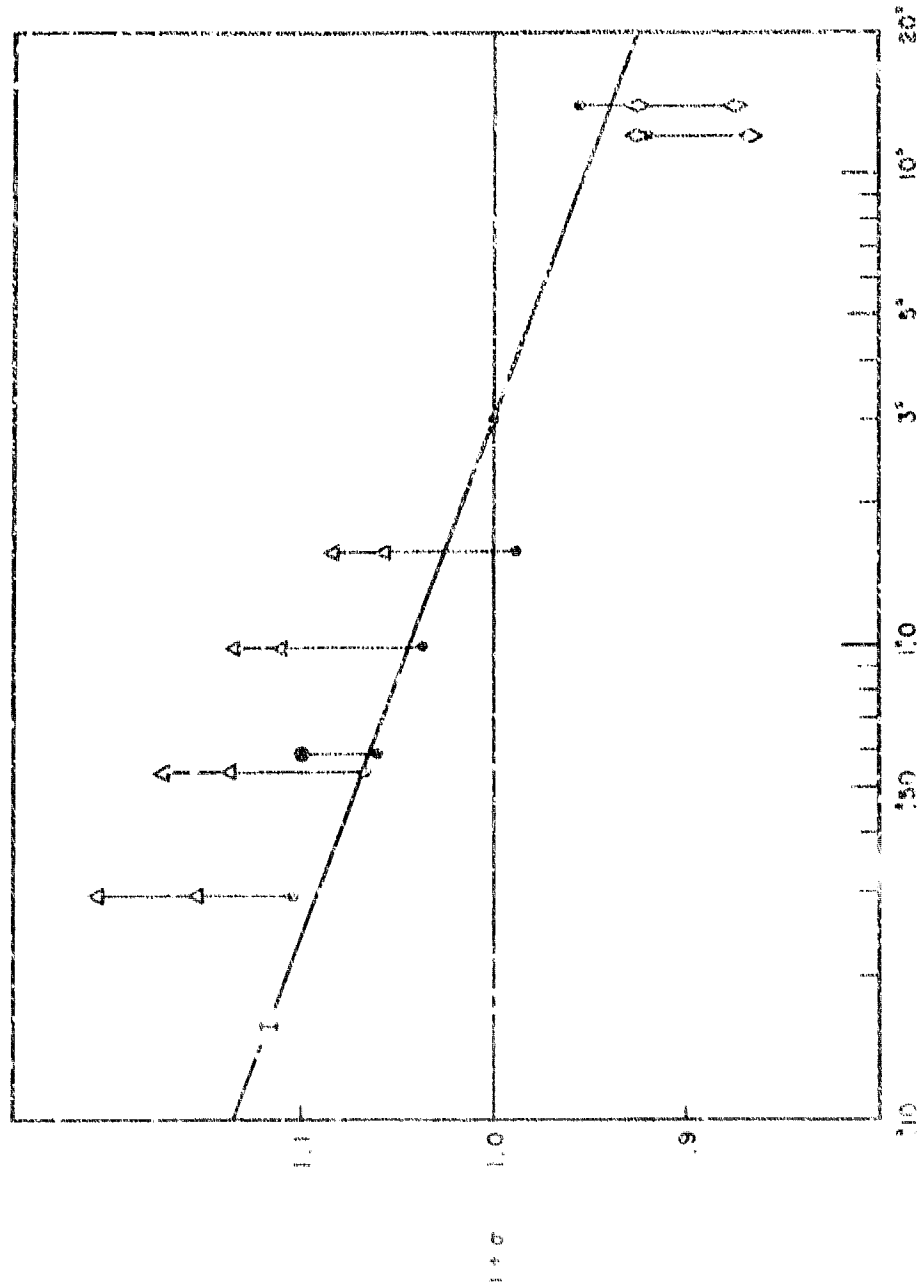


NPS PHOTO NO. 3043 (APL)

# THE SCALE EFFECT

FIGURE 4B

Monobloc Projectiles vs Homogeneous Plate, corrected to 115000 (lb)/(in)<sup>2</sup> Static Tensile Strength



Caliber

CURVE 1 Basic Formula of NPS Sk 530

$$\sigma_s = (0.4) \log(4d)$$

Monobloc Projectiles, corrected

Col 50 Exptl Dm 51 Projectile, uncorrected

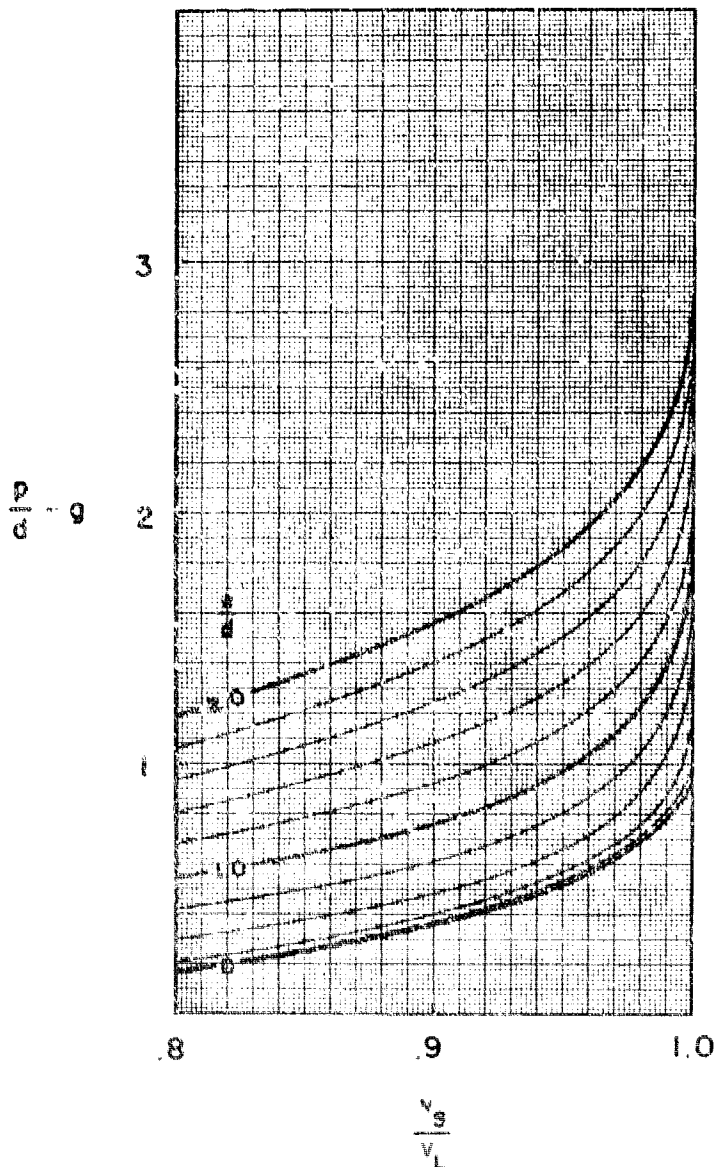
Scale Model 2 pdr Projectile

Major Caliber AP Bomb

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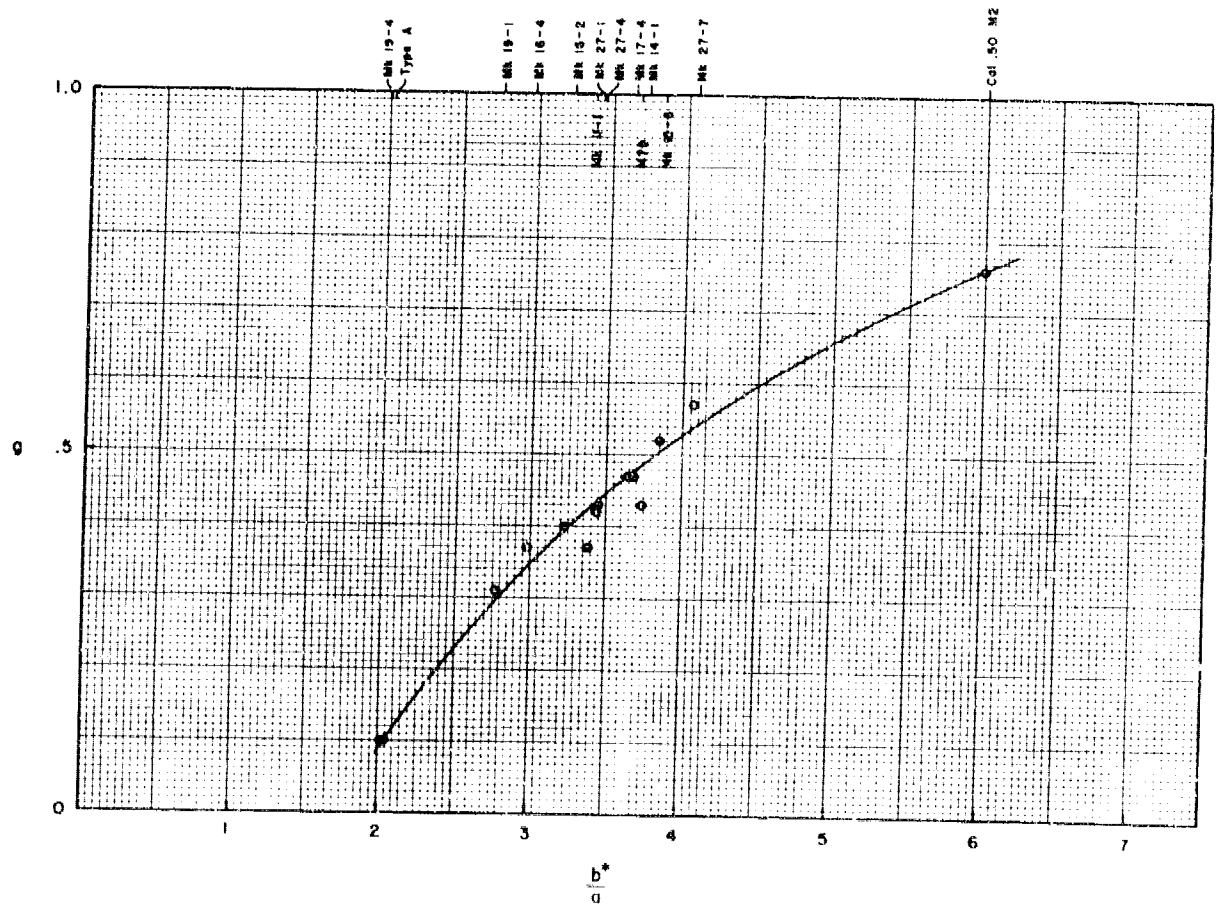
## THE DEPTH OF PENETRATION

Undeformed Projectiles in Homogeneous Plate at Low Obliquity



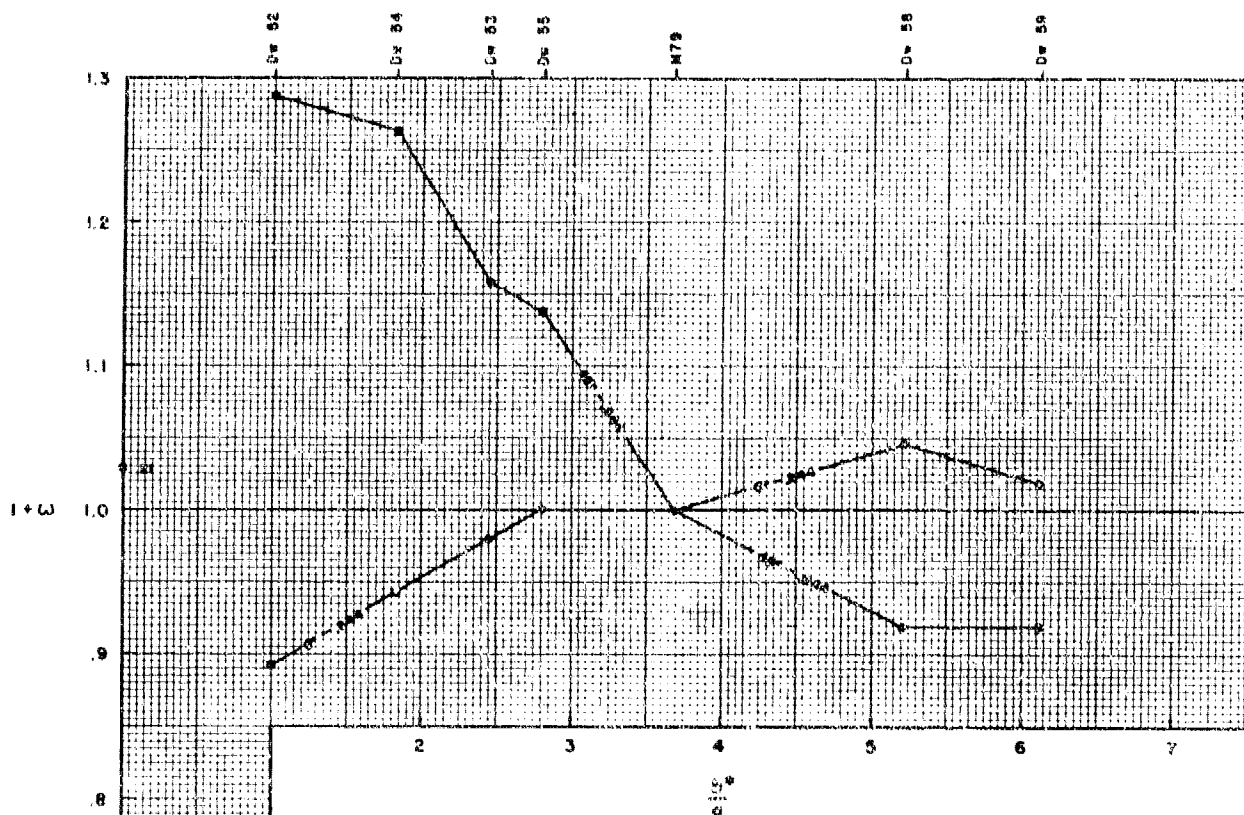
- $e$  = plate thickness
- $d$  = projectile diameter
- $p$  = depth of penetration
- $v_s$  = striking velocity
- $v_L$  = limit velocity
- $g$  = increase in  $p/d$  due to difference in nose shape

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THE EFFECT OF NOSE SHAPE ON DEPTH OF PENETRATION IN HOMOGENEOUS PLATE

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WFO PHOTO NO. 3048 (APL)

FIGURE (21)

### THE OGIVE EFFECT

3" Monobloc Projectiles vs STS at  $\epsilon/d < .5$

○ 3" Projectiles at  $0^\circ$  Obliquity

● " " " "  $45^\circ$  " "

$\alpha/d$  as indicated

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