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Declassification authority: NAVY DECLASS MANUAL, 11 DEC 2012, 02 SERIES

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May 19, 1943

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Report No. 0-2068

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NAVY DEPARTMENT

Eleventh Partial Report

on

Light Armor

Yaw Versus Bullet Protection for Homogeneous Steel Armor Plates, Tipping Screen Data, and a Discussion of 24 ST Aluminum Deflector Plates.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

No. of Pages: Text 15 Tables 6 Plates 15

Authorization: BuOrd letter S13-1(4/173)(CB), 13 Dec. 1943.

Date of Investigation: - September 1941 - May 1943

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ABSTRACT

This report discusses two methods of bullet protection for aircraft which, under certain conditions, may possess considerable weight advantage compared to more orthodox methods of protection. The methods discussed are use of aluminum alloy deflector plates at high obliquity and the use of a tipping screen plus internal armor at several feet spacing. Bullet protection velocity limits are measured on the basis of fragments not penetrating a metal fragment screen behind the test plate. Limits of this type are furnished for 24 ST Aluminum at 70 and 77 degrees obliquity. The effects of using Alclad aluminum alloy sheets, of penetration by other bullets than the AP type, and the effects of plate mounting are discussed. Six yaw versus bullet protection limit curves are furnished for homogeneous steel armor at normal impact. Several methods of tipping bullets are compared. It is shown perforated tipping screens may be considerably more efficient than equal weight solid screens in average amounts of yaw produced.

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Subject: Bullet penetration resistance of 24 ST Aluminum at high obliquity and of various materials with yawed projectiles.

Introduction:

1. This problem was authorized by reference (a). This reference and others of pertinent interest are as follows:

(a) BuOrd lettr. S13-1(4(173)(Q8) of 12-13-34.
(b) NRL Report No. 0-1540, 19 June, 1939(5th Partia
(c) NRL Report No. 0-1600, 21 Mar., 1940(7th Partial)
(d) NRL Report No. 0-1745, 22 May, 1941(8th Partial)
(e) Aberdeen Proving Ground Report #220, "Characteristics of Tipping Screens", July 3, 1941.
(f) NRL Report No. 9-1778,4 Sept.,1941(9th Partial)
(g) BuAer Specs. SR-35B, 22 April, 1942. "Aircraft Armor Installations".
(h) "Armour and Its Attack by Artillery", C. Orde Brown, Capt. Late Royal Artillery, Royal Artillery Institute, 1887.
(i) BuOrd lettr. S13-1(4)(Re3) 17 April, 1943.

2. Reference (i) requested any information available at this laboratory on the effects of yaw upon armor penetration not previously submitted, be furnished to the Bureau of Ordnance together with a definition of the limit velocity criterion used in collecting the data. At the time of receipt of reference (i) a somewhat more extensive report including the requested information was in preparation. It is felt the presentation of the information dealing with yawed projectiles along with the additional data for 24 ST Aluminum at high obliquities will not detract from its usefulness to the interested Bureaus.

3. An early opinion on the effect of obliquity upon weight efficiency of protection by armor was given in 1887 by Capt. C. Orde Brown, Late Royal Artillery, reference (h). Capt. Brown stated tests in 1861 of wrought iron plates demonstrated a plate at normal impact defended a given vertical area about as well as thinner but necessarily larger plates at angles until the glancing angle is reached. For attack on single plate armor structures, modern materials do not appear to have brought forth many exceptions to the above rule, even when extended considerably with respect to the obliquity range. Where unusual armor structures or very high obliquities are to be

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considered, much depends upon what is meant by "the expected attack" and upon whether the protection against this expected attack is to be total or partial. By placing single plates of armor obliquely and by various peculiar armor structures, test data have been obtained which yield very high values of energy required for penetration per unit weight of armor in the path of the projectile, compared to what may be obtained with single flat plates at normal impact. Whether the large armor weight savings suggested by such high protection weight efficiency figures can be realized in some instances depends upon the extent to which the limitations of these unusual armor arrangements permit the desired degree of protection to be obtained over the range of the expected attack.

4. For light armor bullet protection, the best "single plate at normal impact" material is face hardened bullet proof steel (FH-BPS). Among the special bullet protection arrangements which compare favorably with FH-BPS mounted normal to the expected attack, three may be mentioned which are outstanding because of their possible high protection weight efficiency and because of their relative simplicity with respect to materials and design. These are high strength aluminum alloy plate at high obliquity, FH-BPS at 45 degrees obliquity, and divided armor consisting of a tipping screen and a plate with several feet spacing between. This report discusses the first and last of these three arrangements.

5. As an aid to comparing various methods of stopping or ricocheting bullets with respect to their weight efficiency, a quantity, P_1, was defined and used in references (c), (d), and (f). This quantity is calculated from the projectile energy at limit velocity divided by a volume. The volume is taken to be the volume of steel equivalent in weight to the plate material shadowed by the cross section of the bullet along its trajectory. For the small caliber AP bullets mainly considered in this report, the jacket is ignored and this calculation is made as if the projectile consisted only of the central hardened steel dart. For possible arrangements using steel or aluminum alloy to stop AP bullets at about 2500 ft/sec velocity, a few P_1 values are as follows:

Material	P_1 (10^3 lbs/in^2)
Mild Steel, 0° obliquity	~340
STS (250 Brinell), 0° obliquity	460
FH-BPS, " "	655
FH-BPS, 45° obliquity	1030
24 ST Aluminum, 70° obliquity	1320

[redacted]

On an average yaw basis some tipping screen plus armor plate combinations appear to have P_1 values of about 1,000,000 lbs/in^2.

6. At high obliquities of impact the 24 ST Aluminum alloy fusilage covering of aircraft may ricochet small caliber bullets. According to the above table, the weight efficiency of the occasional protection thereby obtained is extremely high compared with other methods of armoring. Obviously, a plate at 70° obliquity to the expected attack, to give complete protection, must be thick enough to stop the lowest anticipated obliquity. Thus, if the cone of protection, as defined in reference (g), has a total included angle of 30 degrees, the thickness must be sufficient for 55 degree attack while the area coverage must be obtained at least with respect to the 70 degree point of view. Under such conditions the actual weight efficiency of protection, as distinguished from P_1 values, figures to be slightly worse than FH-BPS mounted normal to the attack. Under circumstances where the cone of protection is specially limited it may be possible, on the other hand, to obtain substantial increase in the weight efficiency of bullet protection by use of aluminum alloy at high obliquity. In order to make possible a better appraisal of the possibilities and limitations of bullet protection of this type, this report contains data for AP bullets at 70 and 77 degree obliquities against various thicknesses of 24 ST Aluminum, a comparison of Alclad with 24 ST Aluminum, a rough evaluation of tracer and ball ammunition penetration at high obliquity, and some data on the effects of the plate supports. In addition, a discussion of weight efficiency on a basis more appropriate than P_1 values is given. Curves for protection weight efficiency, which take approximately into account the variations in obliquity of attack implied by finite included angle cones of protection, are shown.

7. Reference (b) furnished data for evaluating effects of amounts of yaw up to about 20 degrees upon normal impact AP bullet penetrations in armor and discussed the results of trials of gratings for tumbling or breaking projectiles prior to impact upon armor. Reference (e) gives a large quantity of tipping screens data and suggests considerable gains in bullet protection for aircraft may be obtained by very careful spacing of the yaw producing element. This report continues the collection of information along these lines. A method of increasing the average yaw produced by a tipping plate element is exhibited. A study of optimum yaw screen to plate separations is shown in which the results are evaluated directly in terms of armor penetration.

[redacted]

8. A method for studying penetration by yawed projectiles with accurate control of magnitude and azimuth of yaw has considerably increased the experimental possibilities along these lines. It is now within convenient experimental practice to measure yawed bullet limit velocities at oblique angles for any fixed orientation of yaw relative to the plane of impact. Development of the technique for studying yawed bullet penetration has been recent. However, curves for limit velocity versus angle of yaw have been prepared by this method for samples of 1/8" and 1/4" STS (265 Brinell) and 1/4" and 5/16" Jessop Aircraft homogeneous armor (380 Brinell). These curves and the data used in their preparation are included in this report. Data for face hardened plate and a study of "favorable orientations" of yaw at oblique angles are incomplete and will be reported at a later date.

9. The technique used for making controlled yaw impacts involves firing into a ballistic plate testing type pendulum at close range through a blast deflector. A light upsetting plate is fastened to the rear of the blast deflector in such a position that the bullet will graze the edge of the upsetting plate. Yaw developes thereafter at a rate predictable over a range of several feet from previous experience with other rounds. Orientation of yaw at any point may be varied as desired by rotating the upsetting plate. The rate at which yaw develops depends upon bullet velocity. Good velocity control is therefore desirable both for the purpose of closely bracketing limit velocity points and for the purpose of maintaining accurate control of the yaw.

10. The criterion for limit velocity used in light armor testing with small caliber AP bullets at this laboratory is stated in a letter to the Bureau of Ordnance, 25 January 1939 as follows: "the lowest impact velocity at which the bullet, or fragments of either the bullet or plate, are projected to the rear of the plate." In practice, small pieces thrown behind the plate by the impact have been ignored when they seemed to the personnel in charge of the testing of no consequence with respect to casualties behind the plate. Beginning January 1942, in order to reduce the degree of personal judgment involved, fragments of bullet or plate were judged to be dangerous if they could penetrate a fragment screen placed several inches behind the impact. For the 70° and 77° obliquity limits on the 100 yard range, fragment screens about equivalent to .06" 24 ST Aluminum were used. For the oblique limits using the small pendulum and for all of the yawed bullet limits, 0.032" 24 ST fragment screens were

[redacted]

employed. For the AP bullets, it is believed either thickness may be used without more than 1 percent change in the reported limit velocities. In the case of the tracer and ball impacts at high obliquity, the effect upon the limit velocity of the fragment screen thickness is uncertain but is probably larger than for the AP bullets.

11. High obliquity impacts with bullets against thin sheets of aluminum alloy possess many of the distinguishing appearance features of larger caliber impacts against deck armor at the Naval Proving Ground. Plate 1 shows development and size of characteristic longitudinal cracks. The velocity for which the width of the longitudinal opening becomes just equal to the diameter of the bullets is generally a safe lower limit for the velocity sufficient to project fragments behind the plate. At 70° and 77° obliquity when a 24 ST plate is penetrated to the extent that fragments are thrown through a .06" 24 ST aluminum shield behind the plate, the longitudinal split is opened to about one and one half calibers maximum width.

12. The term "protection limit" has been applied to the limit velocities described in this report to distinguish these limits from those obtained without use of a fragment screen behind the test plate. By use of this term it is not assumed that fragments incapable of penetrating .06" 24 ST will not injure personnel. Generally there is a rapid increase of residual velocity with increase in striking velocity near the plate limit. This effect is well known for unbroken projectiles. The same trend appears in such evidence of residual fragment velocities as is at hand. In line with this effect the term "protection limit" is used with the implication that the stated limits are close to actual "injury to personnel" protection limits. Normal impact AP bullet protection limits for zero degrees yaw should not differ measurably from limits measured under Navy specifications for homogeneous armor where no plugs are thrown.

Methods and Discussion of Data

13. The data for Plates 8, 9, 11, 12 and 13 were obtained using a ballistic plate testing type pendulum similar to that described in reference (f). In these pendulum tests Cal 30 AP M1 bullets were used. The remainder of the data was obtained using a 100 yard range. For the 100 yard range tests Cal 30 AP M1922 and Cal 50 AP M1 bullets were used, except for the few rounds of ball and tracer impacts at high obliquity reported in Table 3.

14. The data for Table 1 and Plate 3 were obtained using Cal 30 AP M1922 and Cal 50 AP M1 bullets at 100 yards range. The Cal 30 bullets were fired from a 28 inch Mann barrel; the Cal 50 bullets from a Browning heavy machine gun barrel. Yaw card records taken occasionally during the tests failed to reveal more than 1/2° yaw at the 100 yards range used. Velocities were measured as in reference (d) with a modified Aberdeen Chronograph, using metal foil screens at 16 feet base length near the target. The sheets of aluminum alloy for high obliquity test were sheared to 12 inch width and clamped to a frame so that the plane containing the trajectory and the normal to plate surface (the plane of impact) was vertical with the lower edge of the plate toward the gun.

15. The plate supporting frame most used was a rigid wooden structure which provided two parallel 2" x 4" rails to which the plate was clamped at about 12 inch intervals. These rails had their long 4" faces parallel to the plane of impact and were 7 inches apart, inside to inside, or about 8½ inches apart, center to center. An additional pair of frames for plate support were used similar to the above except that the rails for one were 9 inches apart and for the other 4 inches apart measured between inside surfaces. All 70° limits were with the 7" span frame. The 9" span frame was used for all of the 77° limits. One limit at 77° was remeasured using the 4" span frame in order to determine the effect of the plate supports upon limit velocity.

16. In placing high obliquity impacts on the test plates, the regions close to the rail supports were avoided as much as was practical. The effect of the mounting and of the neighborhood of impacts to plate supports was most noticable at the 77° obliquity. Table 1 shows the effect of a change in span of support from 9 inches to 4 inches, the impacts being close to the center of the span in each case.

17. The question of where to place the limit of a plate at high obliquity when high velocity jacket fragments were thrown through the plate at velocities lower than those required for projectile penetration arose during the early part of test work summarized in Table 1. Cardboard placed behind the test plate may show tiny holes from jacket or plate material at a velocity barely sufficient to open the back of the test plate. Since the primary application in mind was aircraft armor, the usual aircraft bulkhead or pilot seat aluminum sheeting represented a convenient "dangerous" fragment indicator. About

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.06" Aluminum alloy is not so thin as to permit perforation by lead splash and inconsequential flakes of plate or bullet material. On the other hand, it is pierced by the points of darts commonly thrown behind the plate in 30 degree or yawed bullet testing, by plugs from hard steel plates, and by jacket fragments in high obliquity measurements. Within the precision of other features of the work, considerable latitude in the quality and thickness of the fragment indicator was allowable. A .06" thickness of 24 ST aluminum fragment indicator was not consistently used in all of the data furnished in this report. Occasionally 0.049" 24 ST Aluminum was used and for a time 1/2" plywood was tried so as to provide easier identification of material thrown to the rear of the plate. The Cal 30 small pendulum and yawed bullet limits were measured using a .032" 24 ST screen. The velocity of thrown pieces appeared to change rapidly with striking velocity. In general, it is felt that whether the limits of this report are called .032" 24 ST protection limits, .06" 24ST protection limits, or 1/2" plywood protection limits makes no practical difference. The limits measured for tracer and ball bullets may be exceptions to this statement. For these projectiles at high obliquity, jacket fragments were thrown through the backing screen at velocities unusually far below the velocity required for penetration by the major portion of the projectile.

19. Plate 10 shows the result of a large number of 100 yard range firings through tipping screens at a 3/8" plate fine grain Ni-Cr Carnegie tank armor. The armor plate is of the usual STS composition, oil quenched and drawn to 265 Brinell hardness. Three arrangements using 1/8" 24 ST Aluminum at 4 ft, 6 ft, and 8 ft in front of the 3/8" armor plate were used, these distances having been chosen from inspection of the curves shown in reference (e). The Aberdeen results indicated yaw should be decreasing most rapidly at about 6 ft behind the 1/8" 24 ST tipping screen. Sheets of plywood and masonite and of .064" 24 ST Aluminum at small angles were used in additional firings in a search for methods of yawing bullets with closer control of the yaw. None of the arrangements shown on Plate 10, however, give closely predictable amounts of yaw.

20. It was noticed that the probability of obtaining large bullet yaw from a tipping screen was best when the bullet struck near the edge of a previous opening. This led to a series of tests with thin gratings for tipping screens. The results are shown in Table 6 and on Plate 15. Here again, although increased average

yaw may be obtained with lighter screens, the amounts of yaw obtained are not closely controlled. Cal 50 AP M1 bullets at service velocity and 100 yards range were used for these tests. Bullet deformation rendered the yaw measurements uncertain in the case of the 1/8" unperforated 24 ST sheets at 70 degrees obliquity.

21. A method of obtaining good control of yaw was, at length, found in the use of light plates placed near the gun so that the bullet was upset by passing through the edge of the light plate. This method of producing yaw, while the most efficient of all in terms of required weights of tipping screen for a given degree of yawing, is, of course, quite impractical for use in aircraft as a means of improving light armor protection. Nevertheless, as a laboratory method of controlling yaw for the purpose of measuring penetration by yawed bullets, the method is most useful.

22. All of the protection limit versus yaw curves other than Plate 10 were obtained using a small ballistic plate, testing-type pendulum, and Cal 30 AP M1 bullets. The distance from tipping plate to the armor sample was maintained at 12¼ inches. The development of yaw was nearly linear with distance. The correction for the separation of yaw card and plate was applied with about 1 degree accuracy. At the time of impact with the plate, the bullet yaw was increasing at a rate about proportional to the magnitude of the yaw at the time of impact. For 45 degrees yaw at impact and 2000 ft/sec this rate is about 3.6 degrees per inch of bullet movement or per 4×10^{-5} seconds of time. Since, near the plate limit at these conditions, the bullet turns and slaps flatwise against the plate in a smaller interval of time, the motion of the bullet at impact should be dominated by the impact forces to such an extent that the rates of yawing used in these tests are of small importance with respect to plate penetration. Additional tests are planned in order to determine the magnitude of the rate of yawing effect upon limit measurements.

23. At normal and 30 degrees obliquity, steel armor plate limits are not measurably different for Cal 30 AP M1922 and Cal 30 AP M1. Against aircraft homogeneous armor the Cal 30 AP M2 bullet has not given consistently lower limit velocities than the other Cal 30 AP bullets, particularly at 30° obliquity or against defective plate. At 70 degrees yaw against 265 Brinell 1/8" STS, the bare Cal 30 M1 dart penetrated at about 200 ft/sec less velocity than was required for penetration when the

[redacted]

full jacketed M1 bullet was used. In view of these facts, the M2 bullet with its heavier jacket and lighter dart may, at high yaw, penetrate with relatively greater difficulty than other AP bullets. On the whole, it is felt the evidence indicates remeasurements of the Cal 30 AP M1 limit versus yaw curves of this report, using Cal 30 M2 AP bullets, would be likely to result in increased rather than decreased limit velocities and that the difference from Cal 30 AP M1922 results is probably small.

24. The Jessop experimental armor for which data is shown in this report, was obtained from the Jessop Steel Co. in the form of four - 36" x 36" plates, heat treated to about 380 Brinell hardness, one plate each of 1/4", 5/16", 3/8" and 1/2". It is understood the compositions of these plates are similar. As measured at the Naval Research Laboratory the composition of the 3/8" plate is as follows:

C	Mn	Si	Mo	Ni	Cr	Va	P	S
.31	1.43	.29	.44	.12	.74	.004	.01	.02

Limit versus yaw curves were measured using smaples from the 1/4" and 5/16" plates of this group. A 1/4" Jessop plate of better quality was furnished by Light Armor, Naval Proving Ground. The results with samples from this plate, which is of the Cr-Mo-Va type (.48% carbon), are shown on Plate 12. The advantage of the better plate quality at angles of yaw is worth noting.

25. The yawed bullet limit measurements in the ballistic pendulum were performed on 4" x 4½" sections of the selected test plate. These samples were held in place with wooden wedges in a manner similar to that used for collecting the data of reference (f). For the data of reference (f) the plates were blocked against the front pair of steel pillar supports. For the work of this report, the plates were blocked against the central pair of steel pillar supports. Sheets of .032" aluminum alloy (either 17 ST or 24 ST) were used at a distance of about two inches behind the test plates to indicate fragments. Yaw was measured at 1¼" in front of the test plate. The usual yaw card was photographic paper.

26. The yaw versus limit curve shown on Plate 10 has been drawn in without allowance for possible errors due to the four inch yaw card to plate separation and as if the penetration is not affected either by the method of producing yaw or by the tipping screen to plate distance.

[redacted]

The points on Plate 10 show no evidence that the decreasing yaw phase, which would be present in the tests for 6 feet screen to plate, is more favorable to plate penetration than the nearly constant yaw phases predicted by reference (e) for the 4 ft and 8 ft separations. Four rounds in the neighborhood of 2640 ft/sec and 24° yaw and two rounds at about 2770 ft/sec and 29° yaw suggest the relation between plate penetration and angle of yaw is less definite in this region than along earlier portions of the curve. Plate 14 shows the largest diameter of the shadow of a Cal 30 AP M1 dart projected normal to the trajectory at various degrees of yaw. Since the smallest diameter of the shadow projection is .255", a constant, this curve is approximately proportional to the projected sectional area of the whole dart at impact as a function of yaw. The shapes of the various yaw versus limit curves so far measured all show a very rough similarity to the curve of Plate 14. The large displacements to higher velocity limits of the intermediate yaw portions might be anticipated on account of the greater importance of bullet turning and bullet breakage in this region of yaw.

27. The various tipping screens tried were struck at 100 yards range with negligable yaw. It would seem that when the tipping screen is at normal impact there would be, for some rounds, no appreciable effect upon the bullet orientation of the screen perforation. Of 56 Cal 30 bullets fired through 1/8" 24 ST Aluminum at normal impact, only one round failed to show measurable yaw behind the tipping screen. Less than four degrees of yaw was recorded for a total of four rounds from this group. Tables ⑥ and ⑦ show a summary of the tipping screen results. Plate 15 compares the average yaw obtained with perforated and unperforated high obliquity tipping screens. Apparently values of $e_1 \sec \theta/d$ in the range .20 to .25 cause severe deformation of the AP bullet jacket and may in some cases tear the jacket loose from the steel dart. When severe bullet deformation occurred, the yaw could not be accurately measured. Direct overall tests with armor behind the tipping screen would, in these cases, be necessary in any event in order to estimate the value of the tipping screen in terms of protection from bullets.

28. Plate 4 shows variation of P_1 with $e_1 \sec \theta/d$ and plate 5 shows variations of P_1 with $\sin^2\theta$ for 24 ST Aluminum. These graphs are included in order to complete through 77 degrees obliquity the corresponding curves presented in reference (d).

29. Plate 7 was prepared from the Plate 5 curves

[redacted]

○ to be tables 5 and 6. Corrected 7/9/43. -JL with the aid of the trigonometric relation plotted on Plate 6. A function, E, is plotted on Plate 7 which is believed to be more appropriate than the simpler P_1 function when comparing different materials for use as deflector plates. E is the limit energy in ft lbs at its minimum within the desired cone of protection divided by equivalent steel volume in foot (inches)^2 within the projected outline of the bullet dart considered traveling along the axis of the cone of protection.

Results

30. Measurements of .06" Dural protection limits with Cal 30 and Cal 50 AP bullets against 24 ST Aluminum at high obliquity resulted in a series of limit determinations for 70 and 77 degrees obliquity. These determinations form a smooth 70 degree obliquity F_1 versus e_1 sec e/d curve. At 77 degrees the effects of proximity of impacts to plate supports and, possibly, of irregular bullet deformation led to a set of points on the F_1 versus e_1 sec e/d plot of much greater scatter. In order that a smoothed set of values might be available for further analysis, a curve, somewhat conservative from the average protection standpoint, was drawn through the 77 degree points roughly parallel to the 70 degree curve.

31. The trend toward higher P_1 values with increasing obliquity of 24 ST Aluminum is maintained from 60 degrees to 70 degrees obliquity. At 77 degrees obliquity P_1 values in some cases less and in some cases much greater than those for 70 degrees obliquity were observed.

32. Among the irregularities observed in 77 degree obliquity testing was a higher limit for .185" 24 ST Alclad against Cal 30 AP M1922 bullets than for plain .185" 24 ST against the same bullet. All other comparisons of Alclad with uncoated 24 ST show the latter resists penetration better by a considerable margin. Information from Wright Field indicated the penetrating abilities of very different bullet types at high obliquity on aluminum alloy plates were about equal. This result has been roughly verified. Table 3 shows a few measurements of protection limits with ball and tracer bullets and one limit with Cal 30 AP M2. On the basis of protection velocity limit alone the Cal 30 tracer bullet would seem to be the best and the Cal 30 AP M2 bullet the worst high obliquity penetrators of 24 ST aluminum plates. It may be noted, however, that the major portion of the projectile, particularly in the case of the tracer bullets, did not pass through the plate except at velocities well above the

[redacted]

listed protection limit.

33. A dependency of plate penetration upon the manner of plate support was noticed in the 77 degree obliquity measurements. Two limits shown in Table 1 were measured using a different span of plate support for each limit and with the impacts approximately centered between the side rails supporting the plate. A .102" 24 ST plate was cut into 18" long sections and mounted on a 9 inch span between the supporting rails for one limit and upon a 4 inch span for the other limit. The section which was held on the 4 inch span had a lower limit by 80 ft/sec than the section mounted on the 9 inch span. From the view point of plate mounting the 77 degree Cal 50 limits may be considered similar to Cal 30 limits for plates mounted on a 4 inch span of supporting rails. It will be noted these points are somewhat low in the F_1 graph of Plate 3. A decrease in the plate support effect with increasing velocity is to be expected.

34. The analysis of 24 ST Aluminum deflector plate possibilities shown on Plate 7 suggests 70 degrees obliquity to the axis of the cone of protection as a favorable angle of mounting the aluminum alloy shield. In addition, the curves shown demonstrate the regular loss in advantage of deflecting type armor as the angular range of of the expected attack is increased. The E curves of Plate 7 for a 30 degrees included angle cone of protection lie entirely lower than average good quality face hardened armor at normal impact. Other factors than those included in the preparation of Plate 7 should be considered in making comparisons of weight efficiencies of protection. For example, if the function of the protection is to prevent penetration of an enclosure there may be, as with the deck of a ship, a very restricted choice for the angle of mounting the armor. On the other hand, deflection of bullets may in some positions cause excessive damage to other vital areas. In many cases it may be possible to use the weight of aluminum fusilage covering as part of a deflecting type armor arrangement.

35. The diagram of Plate 14, which shows approximately the projected dart area as a function of yaw, is suggestive of the general shapes actually found for curves of yaw versus .032" Dural protection limit. It is, however, difficult to ascribe much significance to this similarity in view of the widely changing character of the penetration event as yaw increases. Each of the yaw versus limit curves may be conveniently divided into three main sections. These are a section neighboring on zero yaw where variation

[redacted]

of limit velocity with yaw is nearly linear, a section generally above 50 degrees yaw in which the velocity limits do not change rapidly with yaw, and a connecting section between these two in which change of limit with yaw is rapid. In the first of these three sections the process of penetration is mainly of the ductile petalling type on the types of armor studied in this report while in the high yaw section a punching action occurs. The change from a pointed penetrator at small yaw to a blunt penetrator at high yaw is accompanied by a drop in striking energy of the bullet dart at velocity limit per unit volume punched. The volume referred to by this statement was estimated from Plate 14.

36. The dominant factor along the connecting middle portion of the yaw versus limit curve appears to be break up and turning of the bullet dart. The different measured curves show a variety of shapes in this region and the prediction of penetration from a curve is less reliable. Plates 9, 10 and 13 show examples of the type of scatter one may anticipate along the middle section of yaw versus protection limit curves.

37. A considerable jacket effect upon plate penetration by small caliber AP bullets occurs at high as well as at low yaw. At 70 degrees yaw the bare darts from Cal 30 AP M1 bullets gave a lower velocity limit by 210 ft/sec than was measured using the full jacketed bullet. A jacket effect in the opposite direction of 160 ft/sec was measured for .122" equivalent steel thickness of 17 ST Aluminum. One eighth inch STS appeared 360 ft/sec superior to an equivalent weight thickness of 17 ST Aluminum against Cal 30 AP M1 bullets, but where only the darts from these bullets were used as the penetrator, a negligable difference was found.

38. Plates 11 and 12 show large differences in penetration resistance against yawed projectiles. These differences, which favor the .48 percent carbon Cr-Mo-Va plate, exceed any amount which might reasonably be laid to the thickness variation between the plates. Whether one compares the 1/4" high carbon Cr-Mo-Va plate with the 1/4" experimental Jessop plate or with the 5/16" experimental Jessop plate, the percentage difference in plate quality is least at zero yaw and greatest at 20 degrees yaw.

39. The tipping screen trials, except for those used in measuring yaw versus protection limit for 3/8" STS, were made at large angles of obliquity with Cal 50 bullets. The plan in mind was the investigation of single sheets for covering fusilages as a means of causing yaw

[redacted]

and bullet deformation. Some advantage may attend this method of using bullet tipping material since the weight of material in the usual fusilage covering can form a part of the tipping screen and, in addition, the thickened fusilage skin might prevent a number of Cal 30 projectiles from entering the fusilage. One disadvantage of the method is that higher average yaws per unit projected weight of tipping material have been obtained using tippers mounted at low obliquity than at high obliquity. One hoped-for advantage which has not as yet appeared is that small yaws may be eliminated either by asymmetry of the high obliquity impact or by the inhomogeneity of perforated sheets. The yaw values for perforated screens at high obliquity included about the same range to low values of yaw as was found for solid screens either at high or low obliquity.

40. At 70 degrees obliquity there is no question but that perforated 24 ST Aluminum tipping screens can be more efficient than solid screens of the same material and equal weight both for average yaw produced and for damaging projectiles. Arrangement of the holes in a hexagonal rather than rectangular lattice should increase the margin of superiority of the perforated screens. A considerably larger improvement may be obtainable by increasing the size of the holes. Neither the effect of hole size nor the low obliquity performance of perforated tipping screens have as yet been studied.

Conclusions and Summary

41. High obliquity aluminum alloy limits and yaw versus limit curves were measured using thin Dural fragment screens behind the test plate. Tracer bullet jacket fragments presented some difficulty, otherwise the fragment screen type limits were measurable with satisfactory precision.

42. Sufficient control of yaw to permit measurement of yawed bullet protection limits on about the same basis as oblique angle limits was obtained by close range firing methods.

43. The yaw versus protection limit measurements for homogeneous armor plates showed a change from petalling type plate penetration at low yaw to punching type plate penetration at high yaw. The usual uncertainties where fracture and turning of the bullet dart is an important factor appeared in the regions of intermediate amounts of yaw.

[redacted]

44. The methods of producing yaw by single sheet tipping screens reported here resulted in amounts of yaw which were not closely predictable. Perforated tipping screens gave increased average yaw over solid plates of the same material and equivalent weight and are a promising line for further investigation.

45. The bullet dart energy at the protection limit per unit projected equivalent steel thickness is outstandingly large for 24 ST Aluminum alloy at high obliquity. Measurements at 70 and 77 degrees obliquity showed considerably greater P_1 values than the high values previously found at 60 degrees obliquity. Analysis of a geometric difficulty in realizing increased bullet protection on aircraft by employing 24 ST deflector plates showed that cones of protection larger than 30 degrees render the deflection method unlikely to compare favorably with low obliquity bullet proof steel armor. For small cones of protection this analysis showed about 70 degrees obliquity to the axis of the cone to be the most efficient deflector plate orientation.

[redacted]

TABLE I

Protection Limits[1] at 70° and 77° Obliquity,
Cal 30 AP M1922 and Cal 50 AP M1, 24 ST Aluminum.

- 70° -

e	V_L	Estimated Gross Error	Bullet Cal.Type	$\frac{e_1 \sec \theta}{d}$	F_1	$\frac{P_1}{10^3 \text{ lbs/in}^2}$	Round
0.091	1430	= 25	.30-1922AP	.373	49,400	980	D0041
0.1265	1805	= 30	" "	.518	52,900	1123	D0046
0.183	2335	= 40	" "	.750	56,800	1300	D0052
0.248	2775	= 30	" "	1.016	58,100	1355	D0062
0.250	2025	= 40	.50 M1 AP	.610	54,700	1201	D1012

- 77° -

0.090	1835	= 25	.30-1922AP	.560	41,950	1074	D0068
0.102	2180	= 40	" "	.635	46,800	1337	D0005
0.125	2680	= 30	" "	.778	52,000	1650	D0075
0.183	2950	= 35	" "	1.139	47,300	1365	D0078
0.185	2090	= 30	.50 M1 AP	.686	43,100	1138	D1000
0.250	2615	= 30	" "	.927	46,400	1318	D1008
0.102	2100[2]	= 30	.30-1922AP	.635	45,100	1240	D0025

[1] Limits are based on use of a .06" 24 ST fragment screen 4" to 12" behind the impact.

[2] 4" span plate support. All other 77° limits are with 9" span plate support; all 70° limits are with 7" span.

$$F_1^2 = (1300)\,\frac{V_L^2 \cos \theta}{e_1 \sec \theta / d}$$

$$e_1 = \frac{e}{2.8} \qquad d = 0.255''$$

[redacted]

TABLE II

Limit Thicknesses of 24 ST Aluminum for Cal 30 AP M1922 Bullets at Various Obliquities.

$e(=e_1-\phi/2)$	Velocity (ft/sec)	$\frac{e_1}{d\cos(e_1-\phi/2)}$	P_1 (10^3 lbs/in^2)	e (inches)
0	2250	1.562	580	1.11
"	2750	2.276	594	1.62
30	2250	1.468	616	.907
"	2750	1.988	680	1.23
45	2250	1.157	783	.583
"	2750	1.540	875	.777
60	2250	.850	1061	.303
"	2750	1.154	1171	.412
70	2250	.709	1275	.173
"	2750	1.002	1351	.247
77	2250	.717	1263	.115
"	2750	.982	1377	.158

$$e = 2.8\cos(e_1-\phi/2)\ 0.255''\left(\frac{e_1}{d\cos(e_1-\phi/2)}\right)$$

TABLE III

Miscellaneous High Obliquity Limits

Material	e	Bullet Cal.	 Type	θ	V_L	Estimated Gross Error	$\frac{e_1}{d \cos \theta}$	F_1	$\frac{P_1}{10^3 \text{ lbs/in}^2}$	Round
					100 Yard Range Tests(3)					
Alclad 24 ST	.123	30	AP M1922	70	1700	30	.504	50500	1024	1510
" "	.185	"	"	"	2195	25	.758	53200	1137	1497
" "	.125	"	"	77	2480	30	.778	48100	1412	D0096
" "	.185	"	"	"	3010	30	1.151	47900	1404	D0091
" "	.185	"	AP-M2	70	2345	25	.792	56800(1)	1295(1)	1501
24 ST	.185	"	Tracer	77	2800	50	--	--	--	D0105
Alclad 24 ST	.185	"	"	70	2180	25	--	--	--	D0111
24 ST	.187	"	Ball	70	2305	30	--	--	--	D0133
"	.185	"	"	77	2850	50	--	--	--	D0109
Alclad 24 ST	.185	"	"	70	2205	30	--	--	--	D0116
					120 Pound Pendulum Tests (4)					
17 ST	.183	30	AP M1922	75	2450	30	.990	45200	1083	P1026
"	.183	"	"	80	3115	40	1.475	38500	1176	P1027
Laminated Nylon Film(2)	1.0	"	"	60	2430	30	1.137	58100	929	P979
Laminated Nylon Cloth(2)	.94	"	"	60	2130	30	1.059	52800	766	P1862

(1) Calculations assume $m/d^3 = 1360 \frac{\text{lbs}}{\text{ft}^3}$ and d = 0.244".
(2) Limit Measurement at 24° C.
(3) Limits based on .06" 24 ST fragment screen behind plate.
(4) Limits based on .032" Dural fragment screen behind plate.

TABLE IV

Miscellaneous High Yaw Limits

aterial	Equivalent steel Thickness (inches)	Yaw (degrees)	.032" Dural Velocity Limit (ft/sec)
- - Cal 30 AP M1 Bullets - -			
TS (265 Bh)	.127	76	2070 ± 20
" "	.256	57	3120 ± 30
essop (380 Bh) Exp.	.249	57	2830 ± 30
" " "	.318	80	3200 ± 35
" " (.48 C)	.268	83	3200 ± 30
17 ST Aluminum	.122	70	1640 ± 30
ylon Film Laminate	.146	70	2020 ± 30
- - Cal 30 AP M1 Darts (no jackets) - -			
STS (265 Bh)	.127	70	1820 ± 30
17 ST Aluminum	.122	70	1800 ± 30
Nylon Cloth Laminate	.146	72	1955 ± 30
Nylon Cloth Laminate (cold)[1]	.129	68	1965 ± 30

---

[1] Removed from ice box at -31° C and tested in about 60 seconds.

[redacted]

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TABLE IV

Miscellaneous High Yaw Limits

Material	Equivalent Steel Thickness (inches)	Yaw (degrees)	.032" Dural Velocity Limit (ft/sec)
- - Cal 30 AP M1 Bullets - -			
STS (265 Bh)	.127	76	2070 ± 20
" "	.256	57	3120 ± 30
Jessop (380 Bh) Exp.	.249	57	2830 ± 30
" " "	.318	80	3200 ± 35
" " (.48 C)	.268	83	3200 ± 30
17 ST Aluminum	.122	70	1640 ± 30
Nylon Film Laminate	.146	70	2020 ± 30
- - Cal 30 AP M1 Darts (no jackets) - -			
STS (265 Bh)	.127	70	1820 ± 30
17 ST Aluminum	.122	70	1800 ± 30
Nylon Cloth Laminate	.146	72	1955 ± 30
Nylon Cloth Laminate (cold)[1]	.129	68	1965 ± 30

[1] Removed from ice box at -31° C and tested in about 60 seconds.

[redacted]

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TABLE V

Tipping Screen Yaw Data

Bullet Type	Material	e	Obliquity (e)	$\frac{e_1 \sec e}{d}$	Distance to Yaw Screen	Number of Rounds	Average Yaw	Three Largest Yaws	Three Smallest Yaws
		inches	degrees		feet		degrees	degrees	Degrees
Cal 30 AP M1922	24 ST Aluminum	.125	0	.175	3-2/3	19	38	66,64,63	6,5,2
" " " "	" " "	"	"	"	5-2/3	26	33	50,46,46	14,14,0
" " " "	" " "	"	"	"	7-2/3	25	20	37,33,30	8,3,2
" " " "	" " "	.064	5	.090	3-2/3	40	23	55,42,40	7,6,6
" " " "	" " "	"	15	.093	3-2/3	14	23	37,35,26	22,21,6
" " " "	Masonite	.250	9	.177	3-2/3	14	9	33,28,17	3,1/2,1/2
Cal 50 AP M1	24 ST Aluminum	.032	53	.044	4	8	6	10,8,7	4,4,3
" " " "	" " "	"	"	"	7	9	9-1/2	19,13,12	7,5,1
" " " "	" " "	"	70	.078	7	5	11	15,12,11	11,11,5
" " " "	" " "	"	"	"	11	9	6	14,10,9	3,3,2
" " " "	" " "	"	"	"	18	8	2-1/2	7,4,3-1/2	1-1/2,0,0
" " " "	" " "	.102[1]	70	.255	2	15	29	46,43,42	10,7,2
" " " "	" " "	"	"	"	4	14	40	49,48,46	35,33,16
" " " "	" " "	"	"	"	6	14	38	45,45,44	32,23,20
" " " "	" " "	"	"	"	8	15	23	42,42,41	9,7,1
" " " "	" " "	"	"	"	9	15	20	47,41,40	2,1,0
Cal 50 AP M2	" " "	"	"	"	2	6	35	46,45,34	33,28,25
" " " "	" " "	"	"	"	4	7	43	53,51,48	39,36,30
" " " "	" " "	"	"	"	6	7	39	51,48,43	38,33,16
" " " "	" " "	"	"	"	8	7	27	45,38,32	27,16,4
" " " "	" " "	"	"	"	9	5	25	42,26,25	25,22,9
Cal 50 AP M1	" " "	.064	"	.160	2	20	5	19,16,10	0,0,0
" " " "	" " "	"	"	"	4	20	9	31,27,19	1,1,1
" " " "	" " "	"	"	"	6	22	15	33,33,30	4,2,1

TABLE V (Cont'd)

Tipping Screen Yaw Data

Bullet Type	Material	e	Obliquity (θ)	$\frac{e_1 \sec \theta}{d}$	Distance to Yaw Screen	Number of Rounds	Average Yaw	Three Largest Yaws	Three Smallest Yaws
		inches	degrees		feet		Degrees	degrees	degrees
Cal 50 AP M1	24 ST Aluminum	.064	70	.160	8	22	17	35,34,31	8,7,1
" " " "	" " "	"	"	"	9	22	18	38,35,31	8,5,1

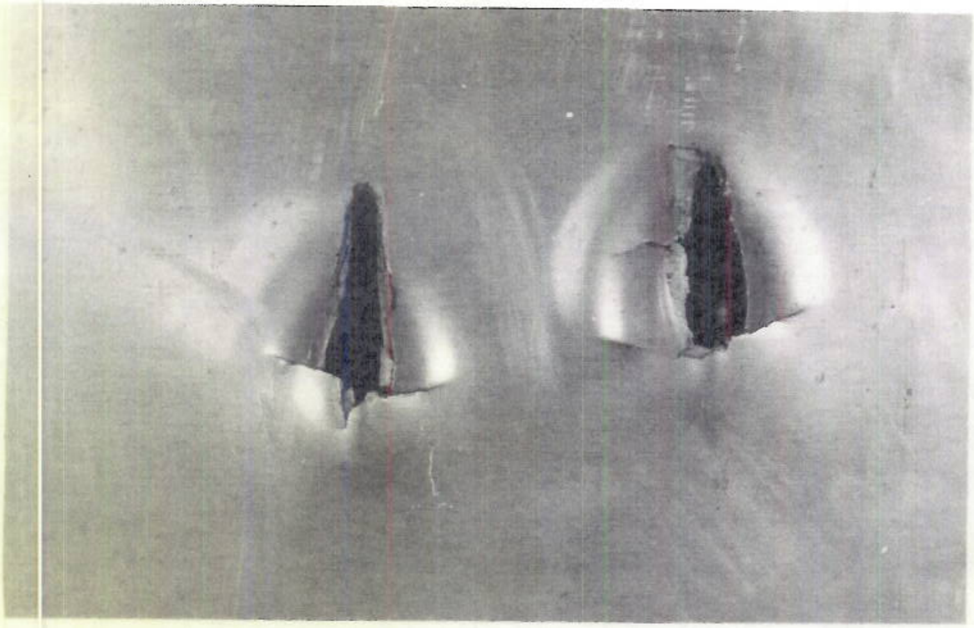
---

[1] Damage to the jacket made yaw readings uncertain. With Cal 50 AP M2 bullets the jackets were frequently stripped, the amounts of yaw then being estimated for the bare darts.

TABLE VI

Perforated 24 ST Aluminum Tipping Screens
1/4" holes, 3/8" between centers, rectangular lattice.

Bullet Type	Material	e	Obliquity (e)	e1 sec e / d	Distance to Yaw Screen	Number of Rounds	Average Yaw	Three Largest Yaws	Three Smallest Yaws
		inches	degrees		feet		degrees	degrees	degrees
Cal 50 AP M1	24 ST Aluminum	.125	70	.198	2	4	21	43,24,10,9	
" " " "	" " "	"	"	"	4	4	27	53,28,20,18	
" " " "	" " "	"	"	"	6	3	31	48,23,22	
" " " "	" " "	"	"	"	8	3	22	27,25,16	
" " " "	" " "	"	"	"	9	4	21	29,26,20,9	
" " " "	" " "	.090	"	.159	2	17	13	22,19,18	10,9,1
" " " "	" " "	"	"	"	4	18	23	35,32,30	16,15,5
" " " "	" " "	"	"	"	6	18	30	46,44,41	23,22,7
" " " "	" " "	"	"	"	8	17	33	45,43,43	24,24,11
" " " "	" " "	"	"	"	9	18	33	46,45,43	25,22,10
" " " "	" " "	.064	"	.103	2	16	5	11,10,9	1,0,0
" " " "	" " "	"	"	"	4	16	9	18,17,13	3,2,2
" " " "	" " "	"	"	"	6	16	14	24,23,20	5,2,2
" " " "	" " "	"	"	"	8	16	17	29,24,24	8,6,5
" " " "	" " "	"	"	"	9	16	17	29,27,23	8,5,5
" " " "	" " "	.032	"	.051	2	12	2	5,5,5	0,0,0
" " " "	" " "	"	"	"	4	13	4	12,9,9	1,0,0
" " " "	" " "	"	"	"	6	13	6	14,13,10	2,1,0
" " " "	" " "	"	"	"	8	13	8	15,15,13	5,3,0
" " " "	" " "	"	"	"	9	13	7	16,14,12	3,1,0



".185 24ST ALC.
CAL. 30 AP M1922
100 YDS. RANGE.

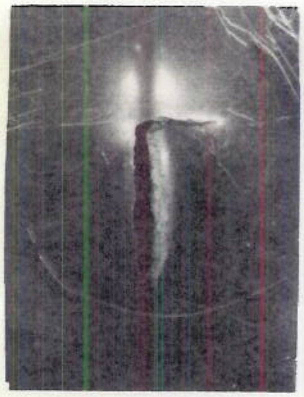
3025 FT/SEC, 77° OBL.
PIECES WENT THROUGH
FRAGMENT SCREEN.

2975 FT/SEC, 77° OBL.
EVERYTHING GLANCED OFF.

.183" 17 ST
CAL. 30 AP M1922
SMALL PENDULUM

2734 FT/SEC, 75° OBL.
DART THROUGH WITH
LARGE RESIDUAL VEL.

3115 FT/SEC, 80° OBL.



2438 FT/SEC, 75° OBL.

2363 FT/SEC, 75° OBL.

EVERYTHING GLANCED OFF.

BACKS OF $\frac{3}{16}$" ALUMINUM ALLOY HIGH OBLIQUITY IMPACTS.

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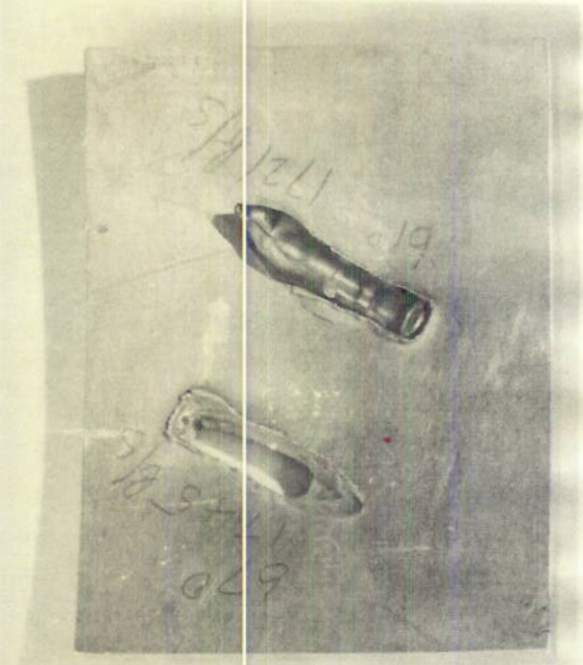
PLATE 1

".127 STS (265BH)
1981 FT/SEC, 65° YAW
1872 FT/SEC, $63\frac{1}{2}$° YAW

".317 JESSOP EXP. (380BH)
3190 FT/SEC, $84\frac{1}{2}$° YAW
3310 FT/SEC, 80° YAW

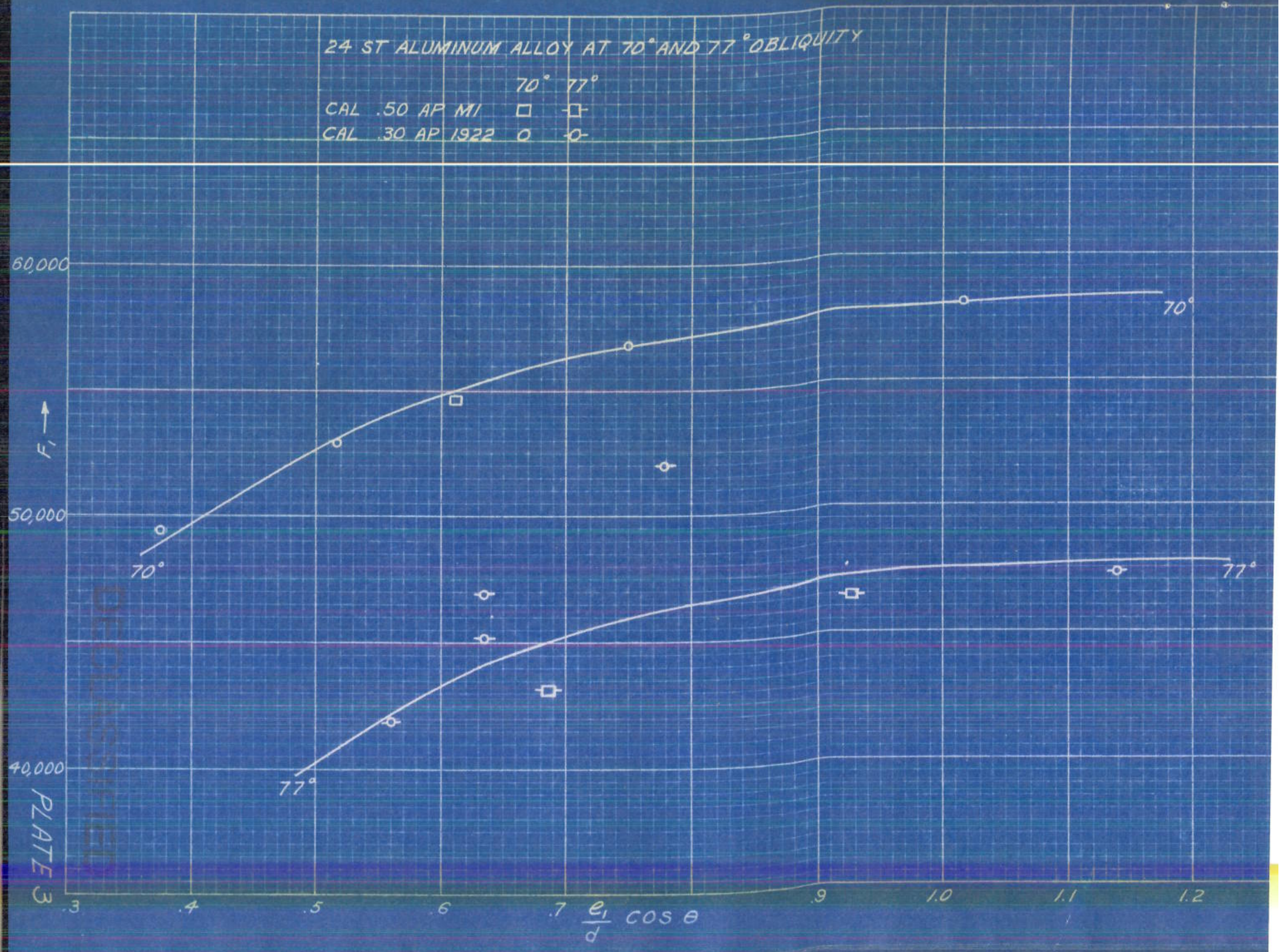


".335 17 ST ALUMINUM
1721 FT/SEC, 61° YAW
1745 FT/SEC, 67° YAW

".249 JESSOP EXP. (380BH)
1471 FT/SEC, 0° YAW. 2892 FT/SEC, 56° YAW
2521 FT/SEC, $32\frac{1}{2}$° YAW
1595 FT/SEC, 0° YAW. 1559 FT/SEC, 0° YAW
2929 FT/SEC, 52° YAW. 2495 FT/SEC, 33° YAW

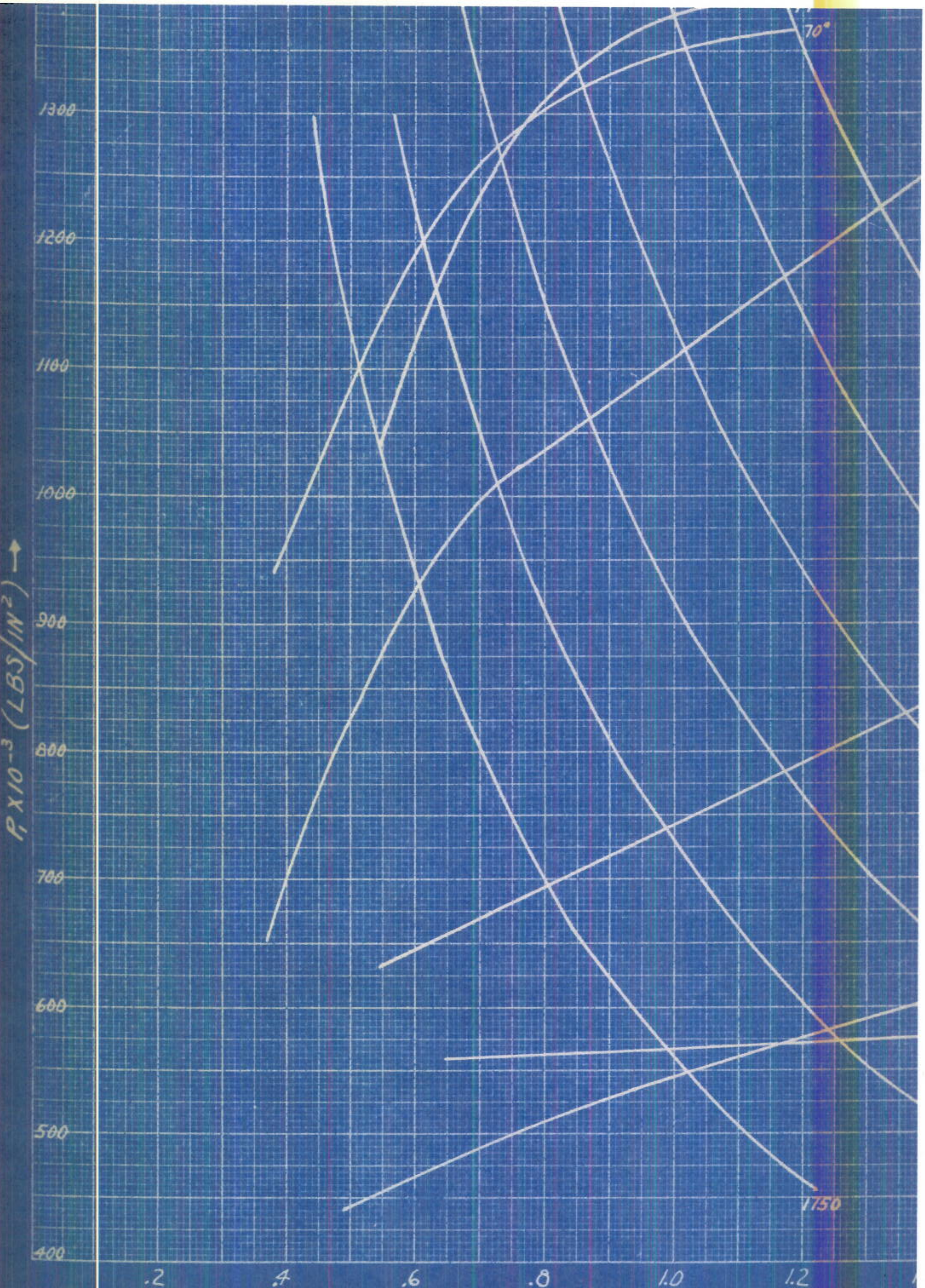
BACKS OF PLATES AFTER YAWED BULLET IMPACTS. CAL. 30 AP M1922.
SMALL PENDULUM.

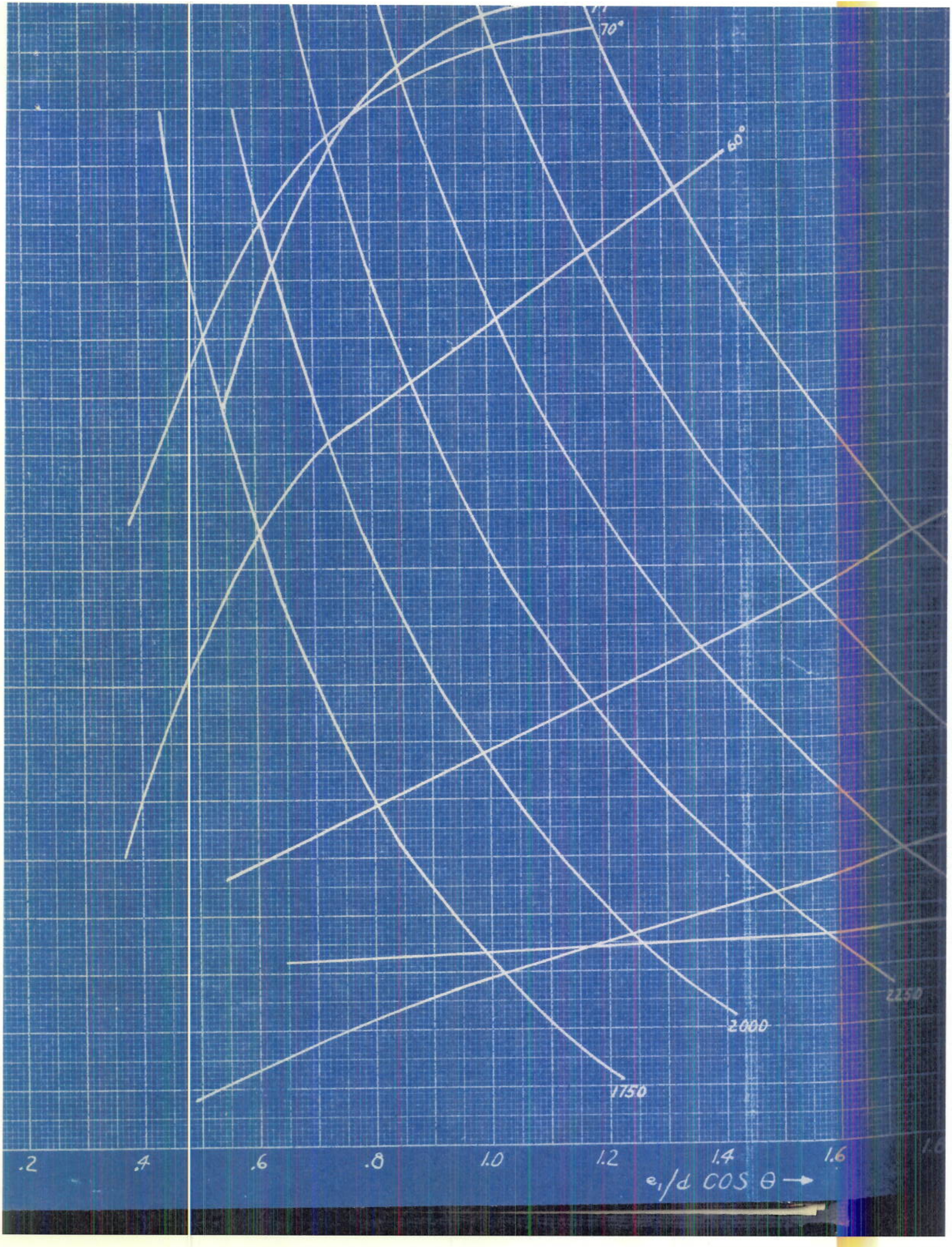
PLATE 2

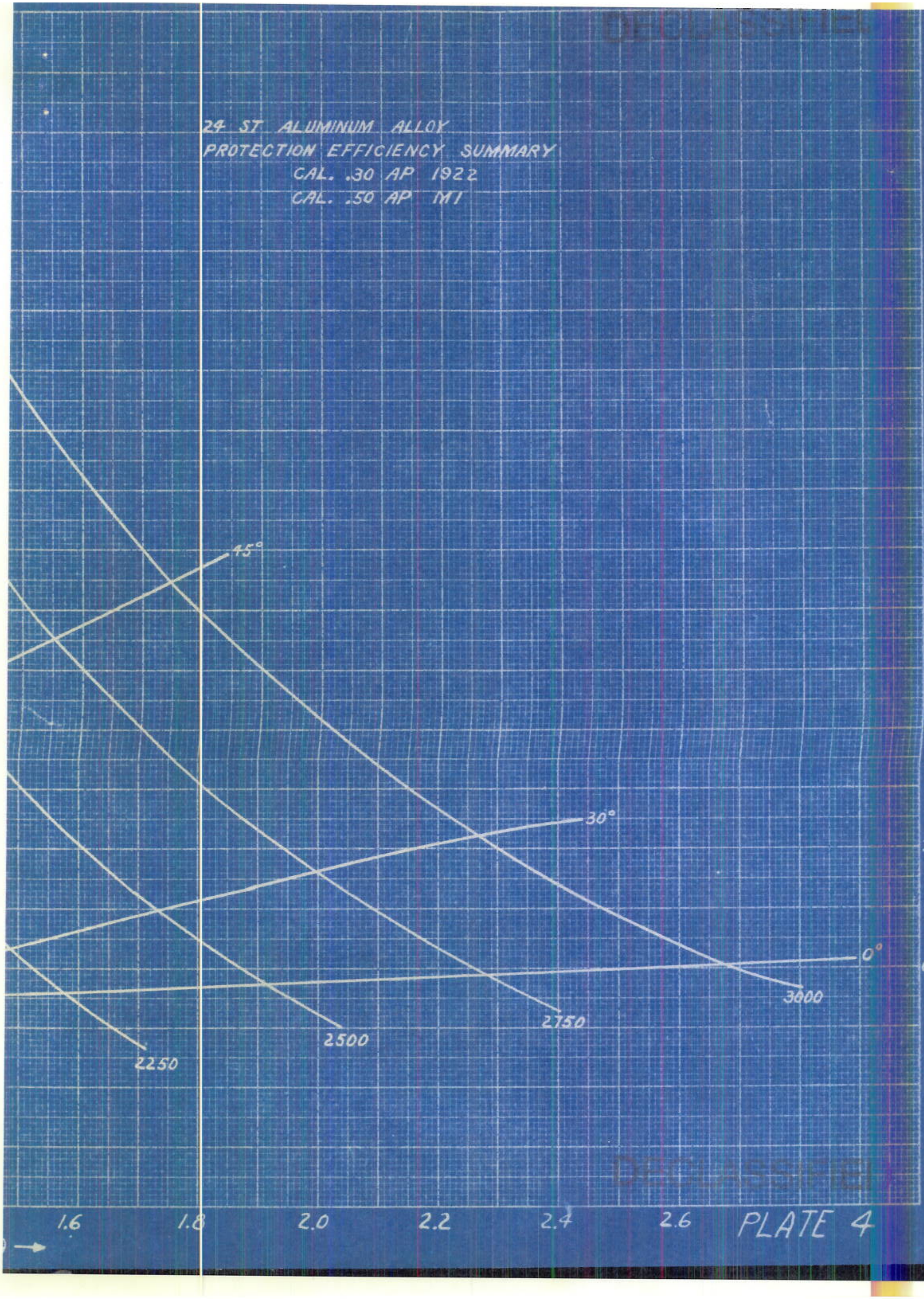


24 ST ALUMINUM ALLOY AT 70° AND 77° OBLIQUITY

PLATE 3

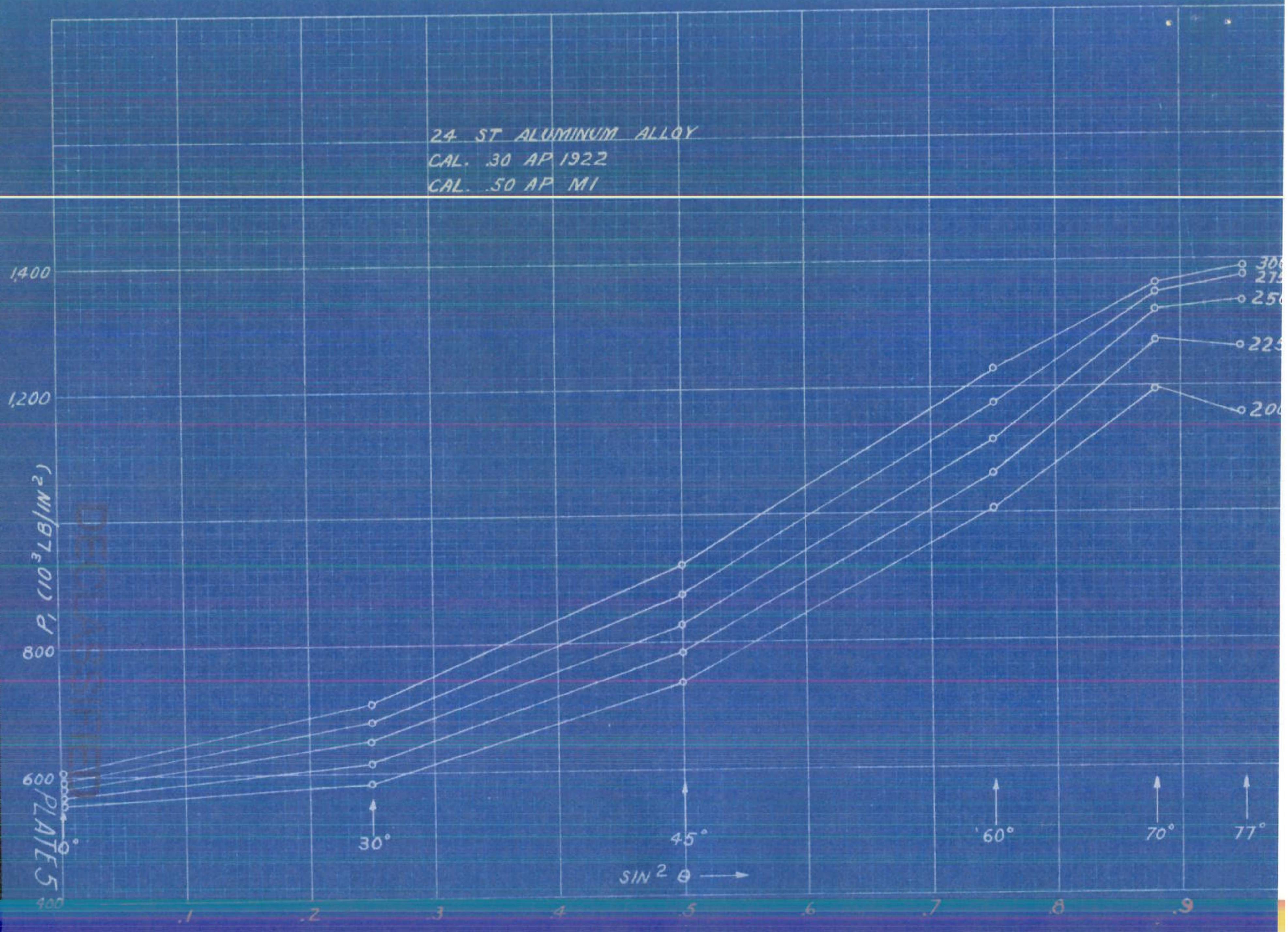

70°
1300
1200
1100
1000
900
800
700
600
500
400
$P_1 \times 10^{-3}$ (LBS/IN^2) →
1750
.2
.4
.6
.8
1.0
1.2
e_1/d


70°
60°
2250
2000
1750
.2
.4
.6
.8
1.0
1.2
1.4
1.6
e₁/d COS θ →



24 ST ALUMINUM ALLOY
PROTECTION EFFICIENCY SUMMARY
CAL. .30 AP 1922
CAL. .50 AP M1

PLATE 4



24 ST ALUMINUM ALLOY
CAL. .30 AP 1922
CAL. .50 AP M1

PLATE 5

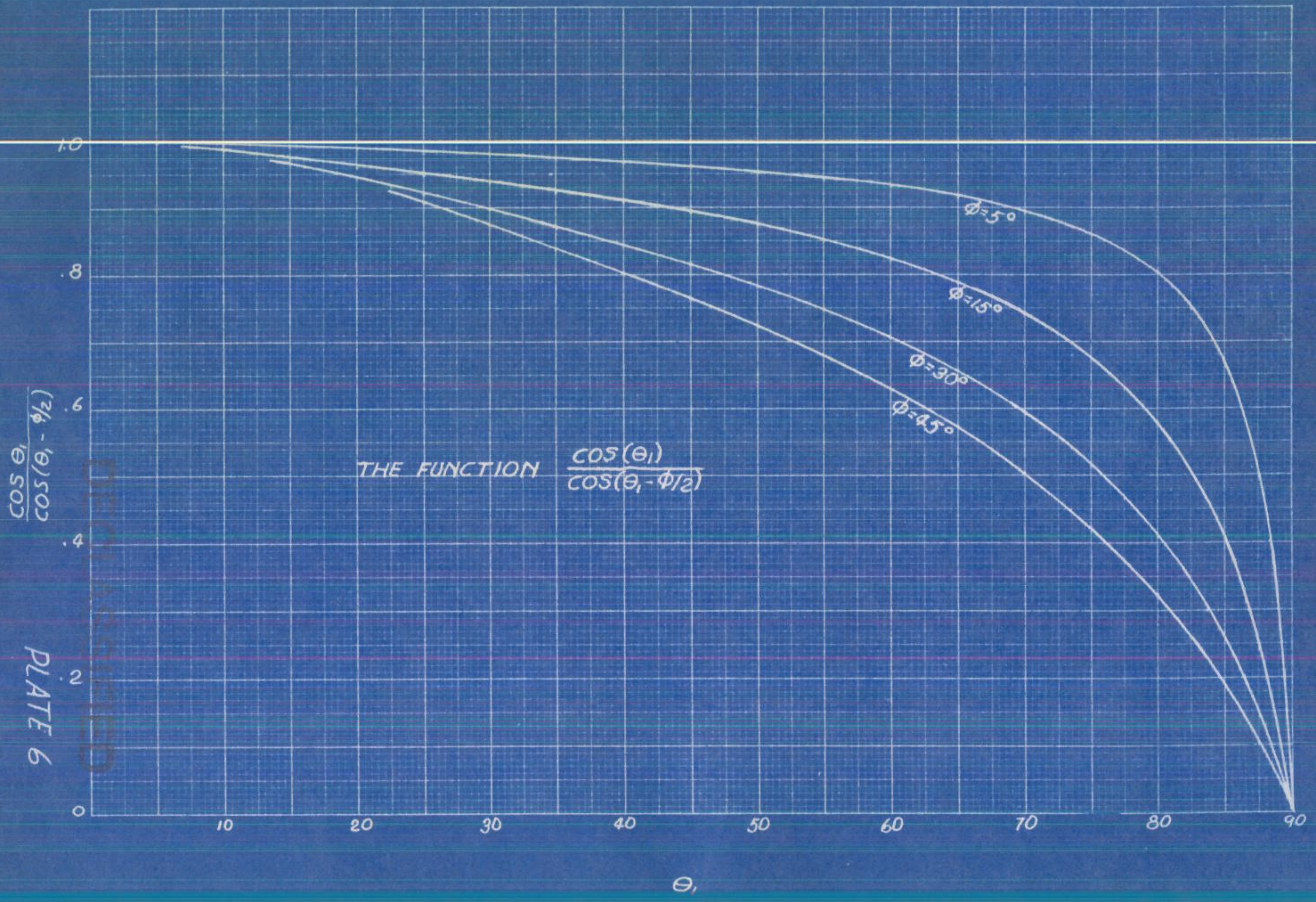
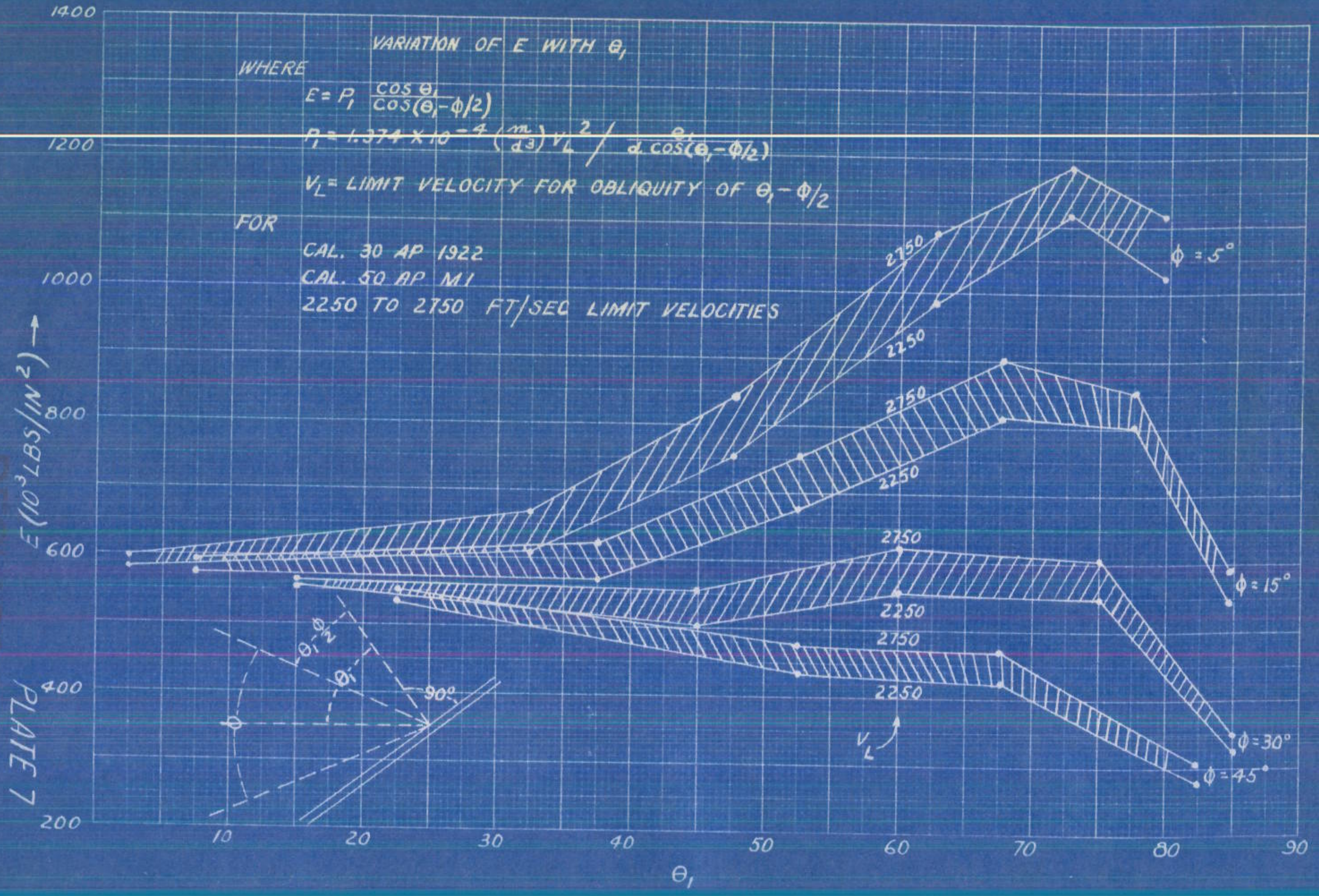

THE FUNCTION $\frac{\cos(\theta_1)}{\cos(\theta_1 - \phi/2)}$
$\frac{\cos\theta_1}{\cos(\theta_1 - \phi/2)}$
1.0
.8
.6
.4
.2
0
10
20
30
40
50
60
70
80
90
θ_1
$\phi = 5°$
$\phi = 15°$
$\phi = 30°$
$\phi = 45°$

PLATE 6



VARIATION OF E WITH θ_1

WHERE

$$E = P_1 \frac{\cos\theta_1}{\cos(\theta_1 - \phi/2)}$$

$$P_1 = 1.374 \times 10^{-4} \left(\frac{m}{d^3}\right) V_L^2 \Big/ \frac{e_1}{d \cos(\theta_1 - \phi/2)}$$

V_L = LIMIT VELOCITY FOR OBLIQUITY OF $\theta_1 - \phi/2$

FOR

CAL. 30 AP 1922
CAL. 50 AP M1
2250 TO 2750 FT/SEC LIMIT VELOCITIES

PLATE 7

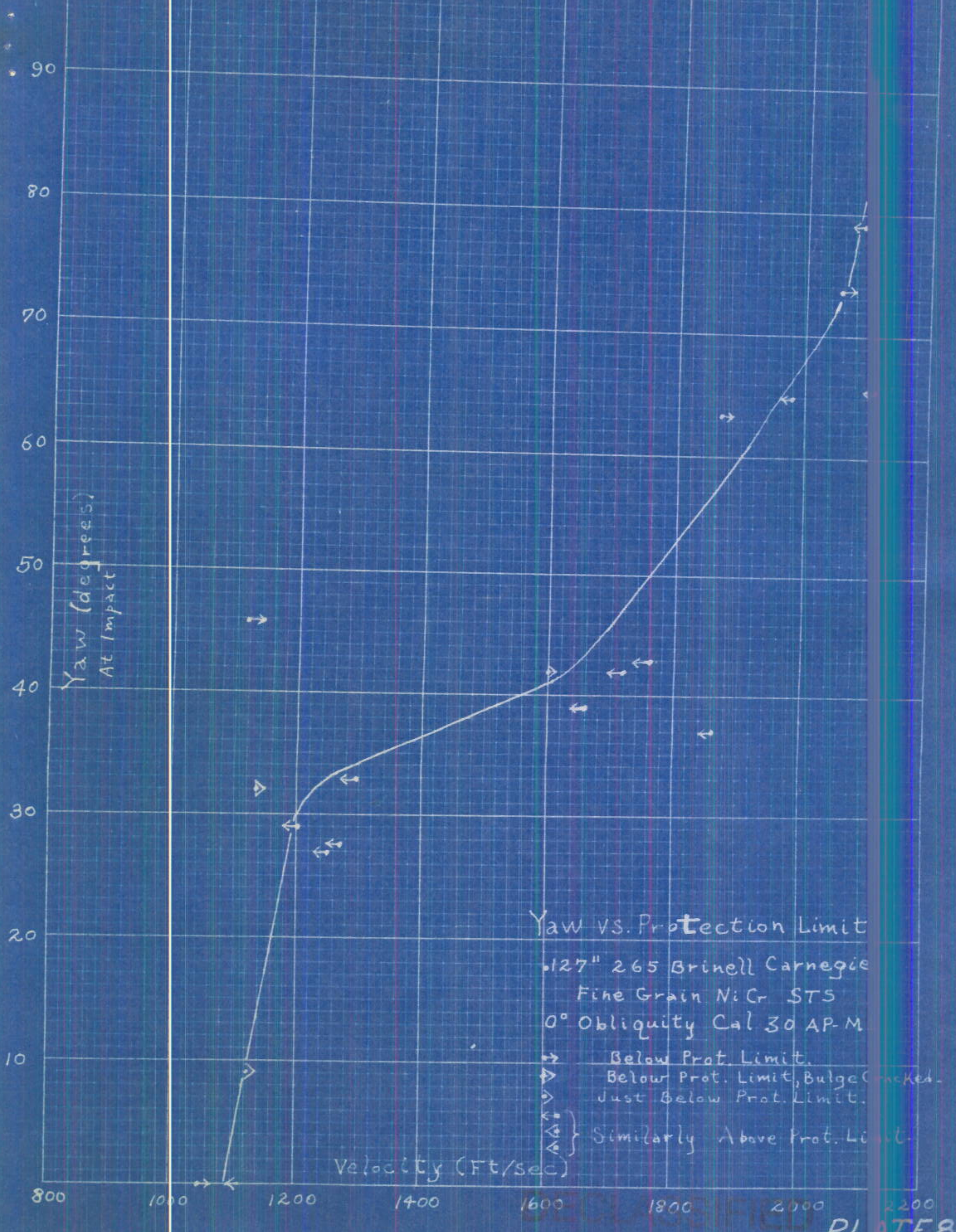

Yaw VS. Protection Limit
.127" 265 Brinell Carnegie
Fine Grain Ni Cr STS
0° Obliquity Cal 30 AP-M
Below Prot. Limit.
Below Prot. Limit, Bulge C[illegible]cked.
Just Below Prot. Limit.
Similarly Above Prot. Li[illegible]
Yaw (degrees)
At Impact
Velocity (Ft/sec)
90
80
70
60
50
40
30
20
10
800
1000
1200
1400
1600
1800
2000
2200

PLATE 8

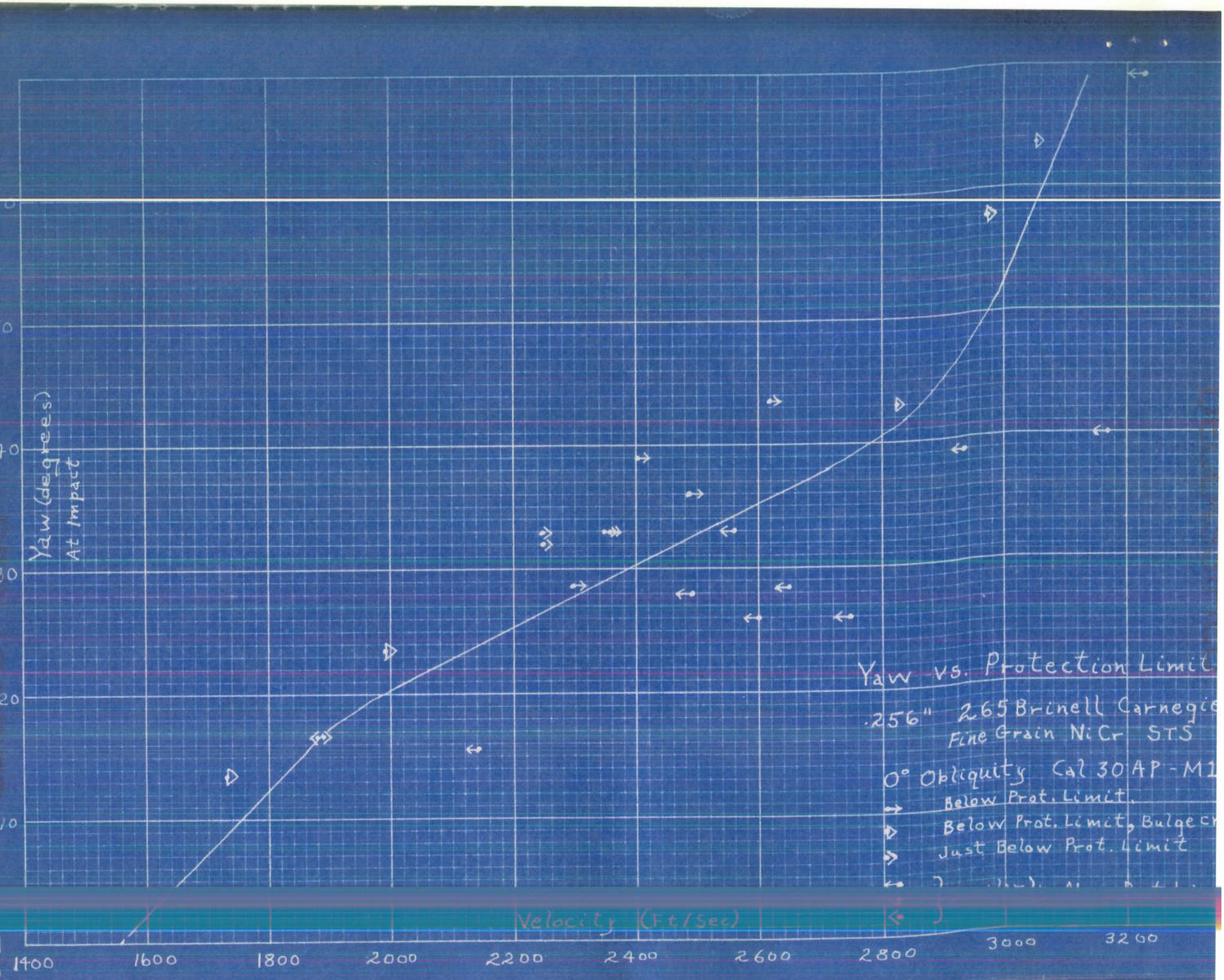
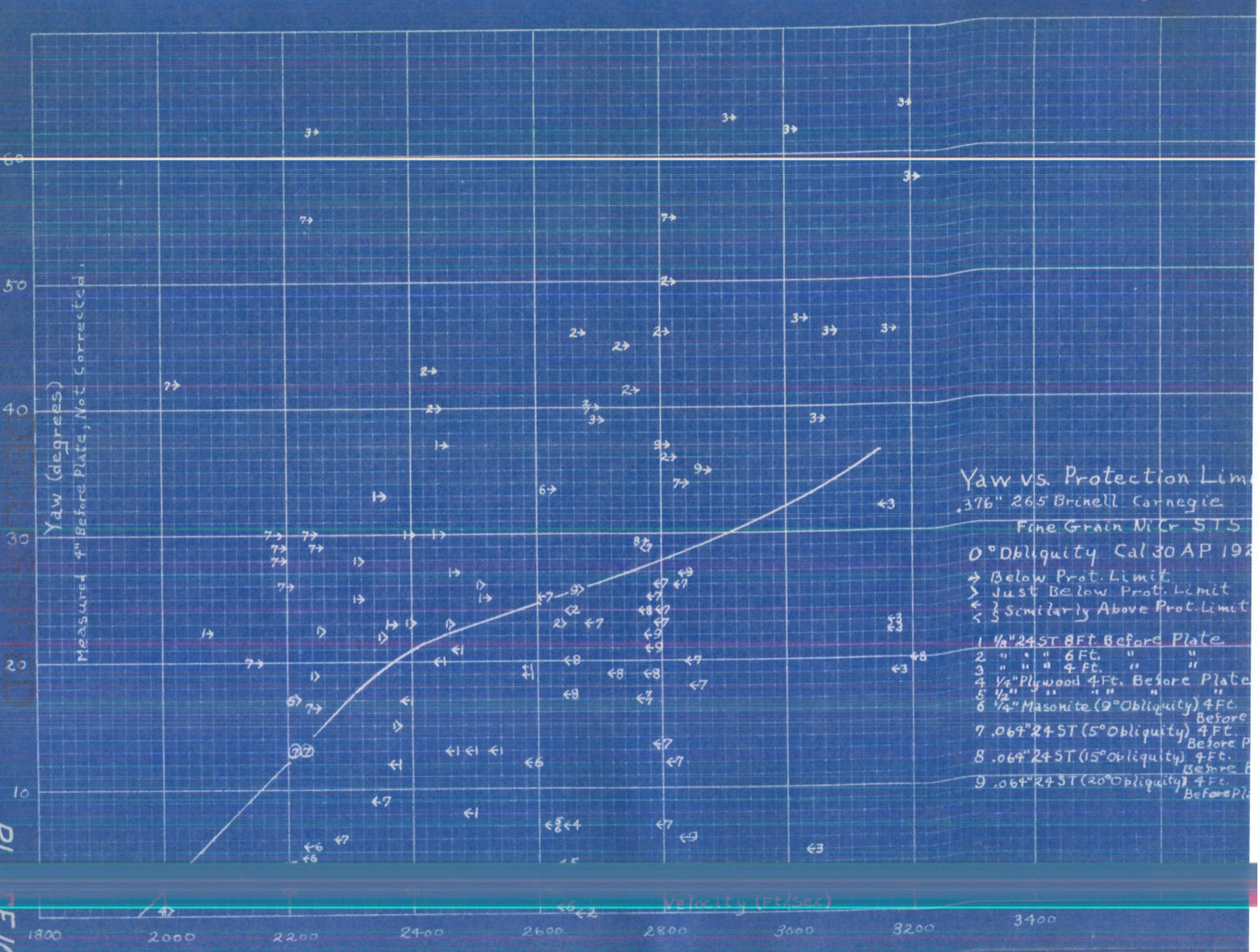

Yaw vs. Protection Limit
.256" 265 Brinell Carnegie
Fine Grain Ni Cr STS
0° Obliquity Cal 30 AP-M1
→ Below Prot. Limit.
▷ Below Prot. Limit, Bulge cr
⇒ Just Below Prot. Limit
Yaw (degrees)
At Impact
Velocity (Ft/Sec)
10
20
30
40
50
60
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200

PLATE 9



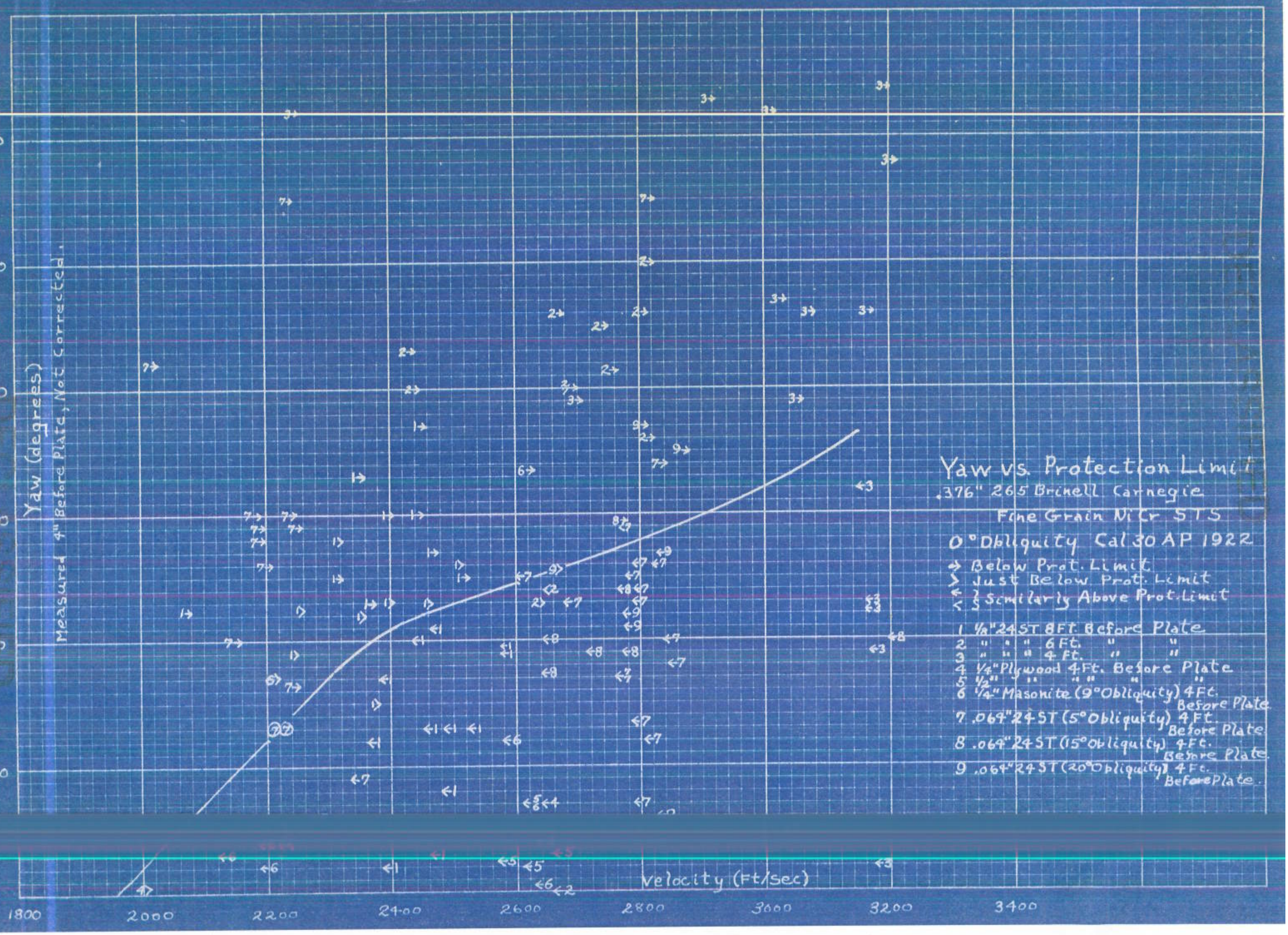
Yaw vs. Protection Lim

.376" 265 Brinell Carnegie

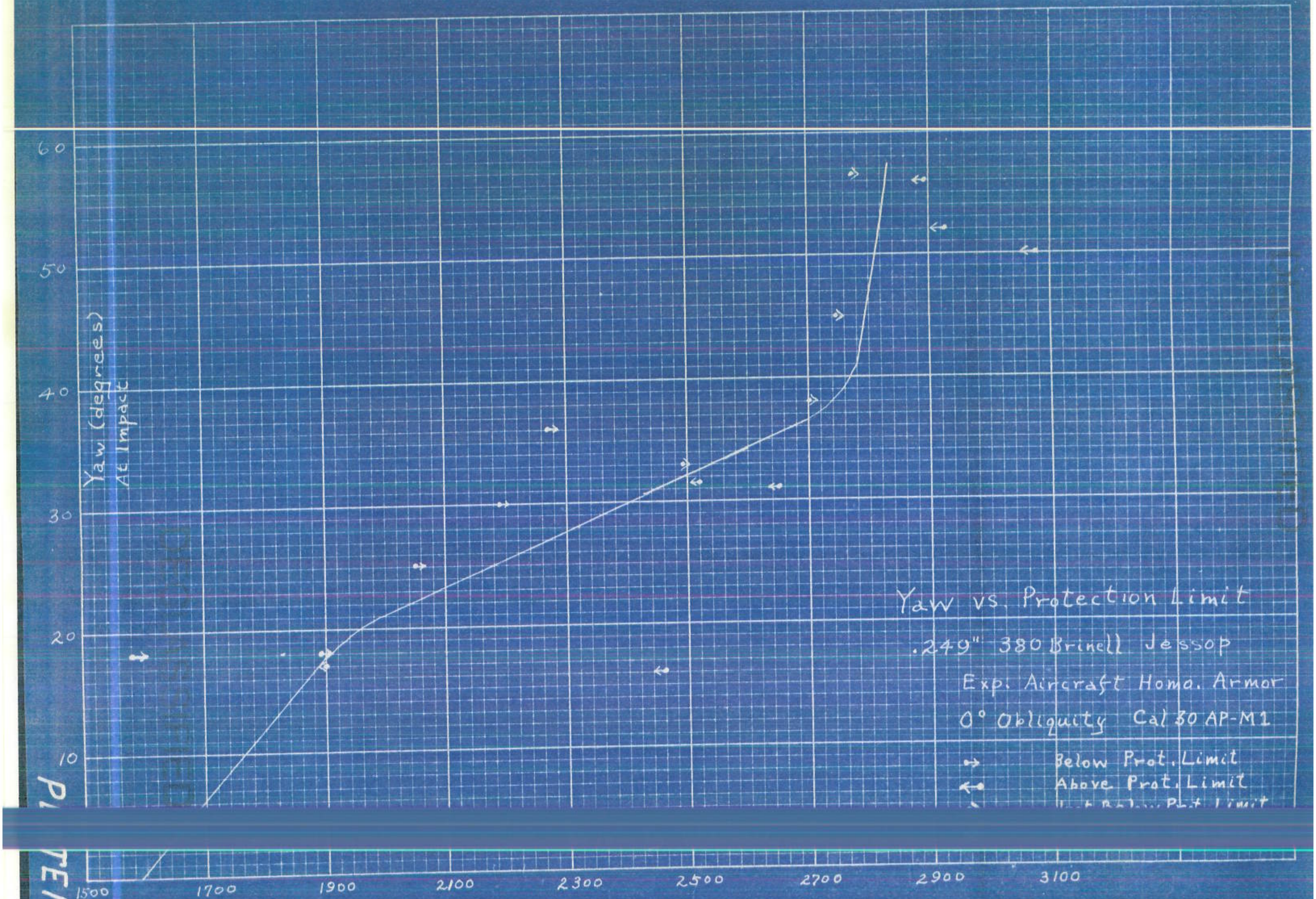
Fine Grain NiCr STS

0° Obliquity Cal 30 AP 192

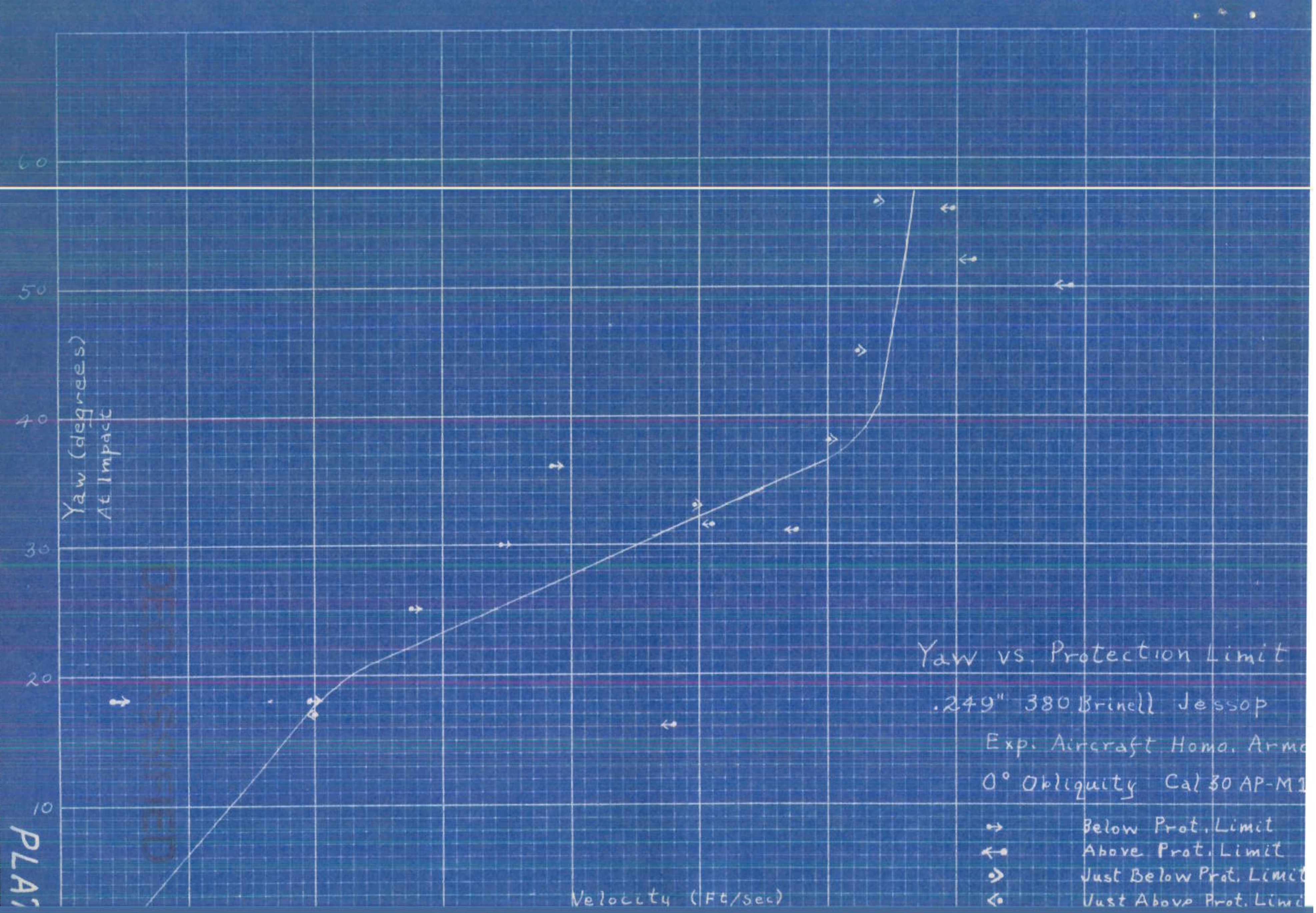
PL E10


Yaw vs. Protection Limit
.376" 265 Brinell Carnegie
Fine Grain Ni Cr STS
0° Obliquity Cal 30 AP 1922
→ Below Prot. Limit
> Just Below Prot. Limit
← } Similarly Above Prot. Limit
< }
1 1/8" 24 ST 8 Ft. Before Plate
2 " " " 6 Ft. " "
3 " " " 4 Ft. " "
4 1/4" Plywood 4 Ft. Before Plate
5 1/2" " " " " "
6 1/4" Masonite (9° Obliquity) 4 Ft. Before Plate
7 .064" 24 ST (5° Obliquity) 4 Ft. Before Plate
8 .064" 24 ST (15° Obliquity) 4 Ft. Before Plate
9 .064" 24 ST (20° Obliquity) 4 Ft. Before Plate.
Yaw (degrees)
Measured 4" Before Plate, Not Corrected.
10
20
30
40
50
60
Velocity (Ft/sec)
1800
2000
2200
2400
2600
2800
3000
3200
3400

P ATE 10


Yaw vs. Protection Limit
.249" 380 Brinell Jessop
Exp. Aircraft Homo. Armor
0° Obliquity Cal 30 AP-M1
Below Prot. Limit
Above Prot. Limit
Yaw (degrees)
At Impact
60
50
40
30
20
10
1500
1700
1900
2100
2300
2500
2700
2900
3100

PL TE11


Yaw vs. Protection Limit
.249" 380 Brinell Jessop
Exp. Aircraft Homo. Arm
0° Obliquity Cal 30 AP-M1
Below Prot. Limit
Above Prot. Limit
Just Below Prot. Limit
Just Above Prot. Limi
Yaw (degrees) At Impact
60
50
40
30
20
10
Velocity (Ft/Sec)

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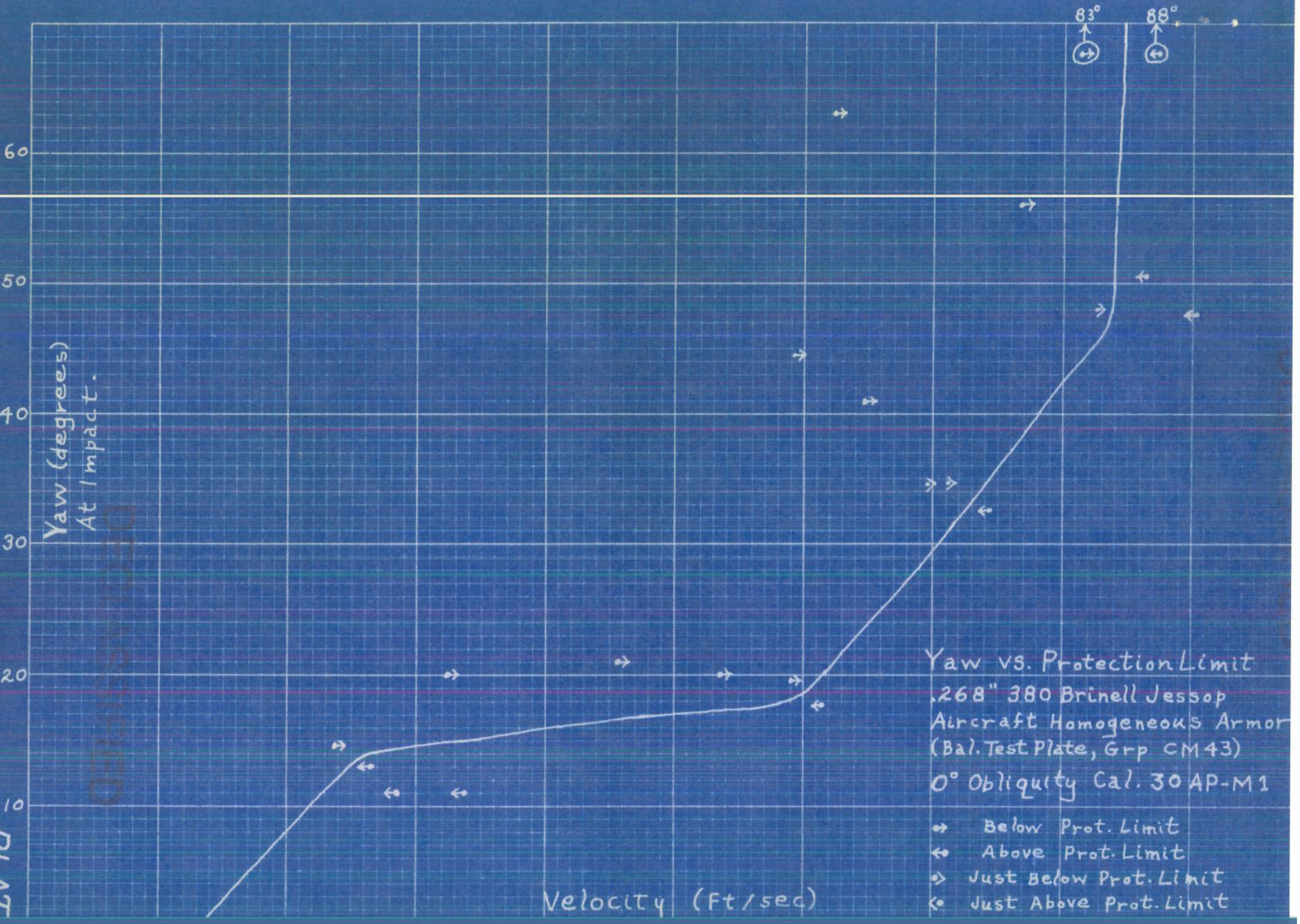
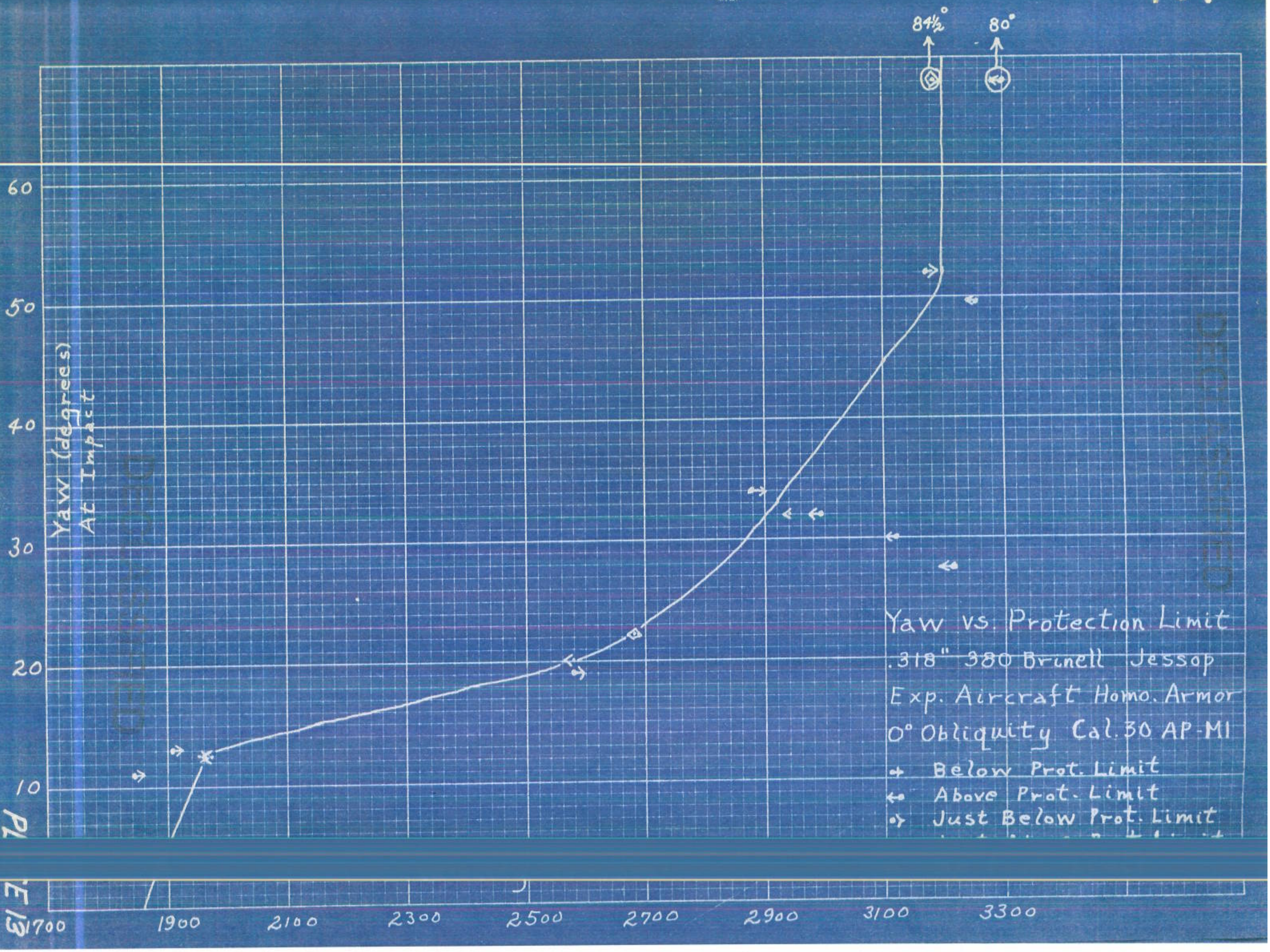
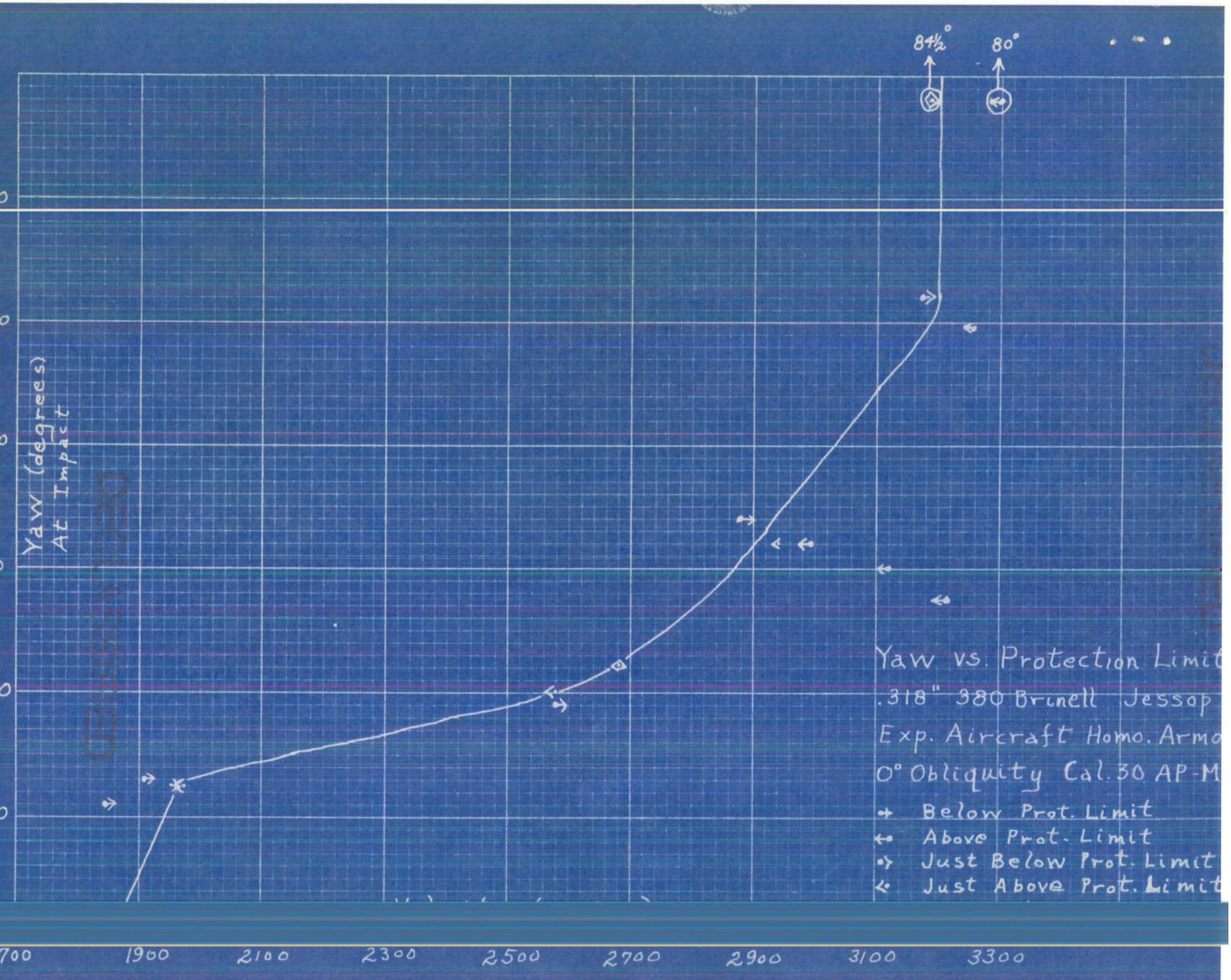

Yaw vs. Protection Limit
.268" 380 Brinell Jessop
Aircraft Homogeneous Armor
(Bal. Test Plate, Grp CM43)
0° Obliquity Cal. 30 AP-M1
Below Prot. Limit
Above Prot. Limit
Just Below Prot. Limit
Just Above Prot. Limit
Yaw (degrees) At Impact.
Velocity (Ft/sec)
10
20
30
40
50
60
83°
88°

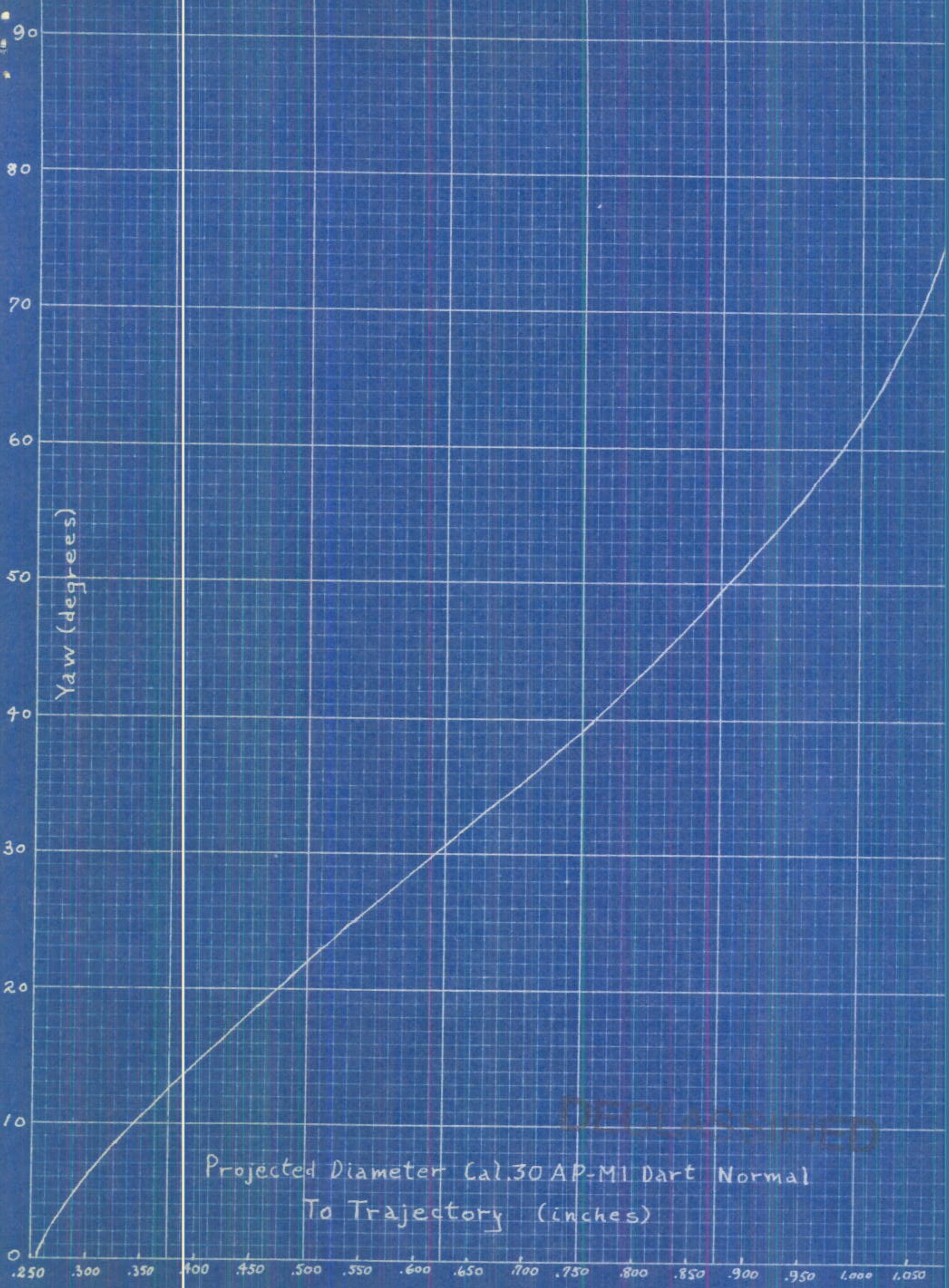
PLAT 2


Yaw vs. Protection Limit
.318" 380 Brinell Jessop
Exp. Aircraft Homo. Armor
0° Obliquity Cal. 30 AP-MI
Below Prot. Limit
Above Prot. Limit
Just Below Prot. Limit
Yaw (degrees) At Impact
84½°
80°
60
50
40
30
20
10
1700
1900
2100
2300
2500
2700
2900
3100
3300

PL E 13

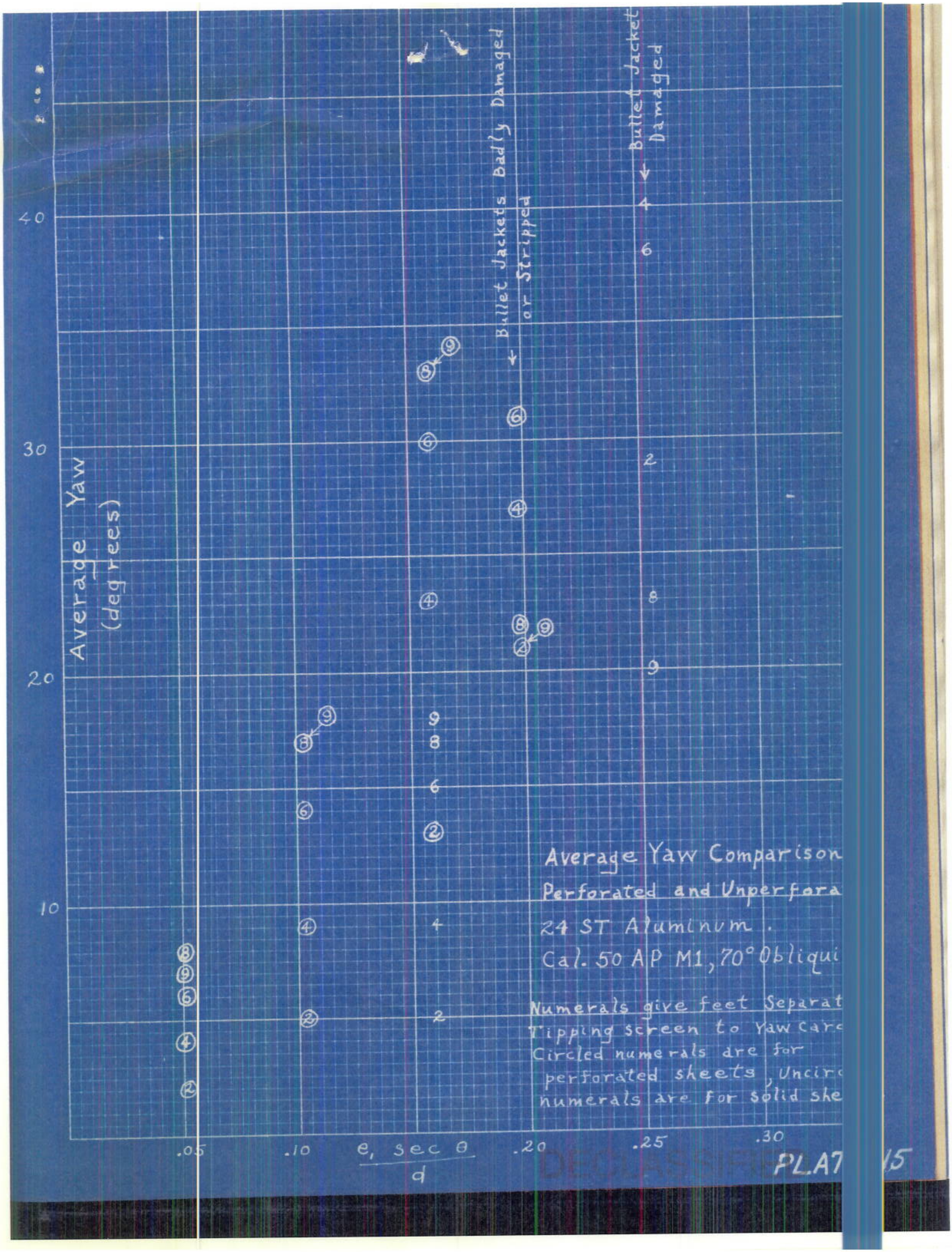

84½°
80°
60
50
40
30
20
10
Yaw (degrees)
At Impact
Yaw vs. Protection Limit
.318" 380 Brinell Jessop
Exp. Aircraft Homo. Armo
0° Obliquity Cal. 30 AP-M
→ Below Prot. Limit
←• Above Prot. Limit
•> Just Below Prot. Limit
<• Just Above Prot. Limit
1700
1900
2100
2300
2500
2700
2900
3100
3300

PLAT 3



Yaw (degrees)
0
10
20
30
40
50
60
70
80
90
.250
.300
.350
.400
.450
.500
.550
.600
.650
.700
.750
.800
.850
.900
.950
1.000
1.050
Projected Diameter Cal.30 AP-M1 Dart Normal
To Trajectory (inches)

PLA 14



Average Yaw Compariso

Perforated and Unperfora

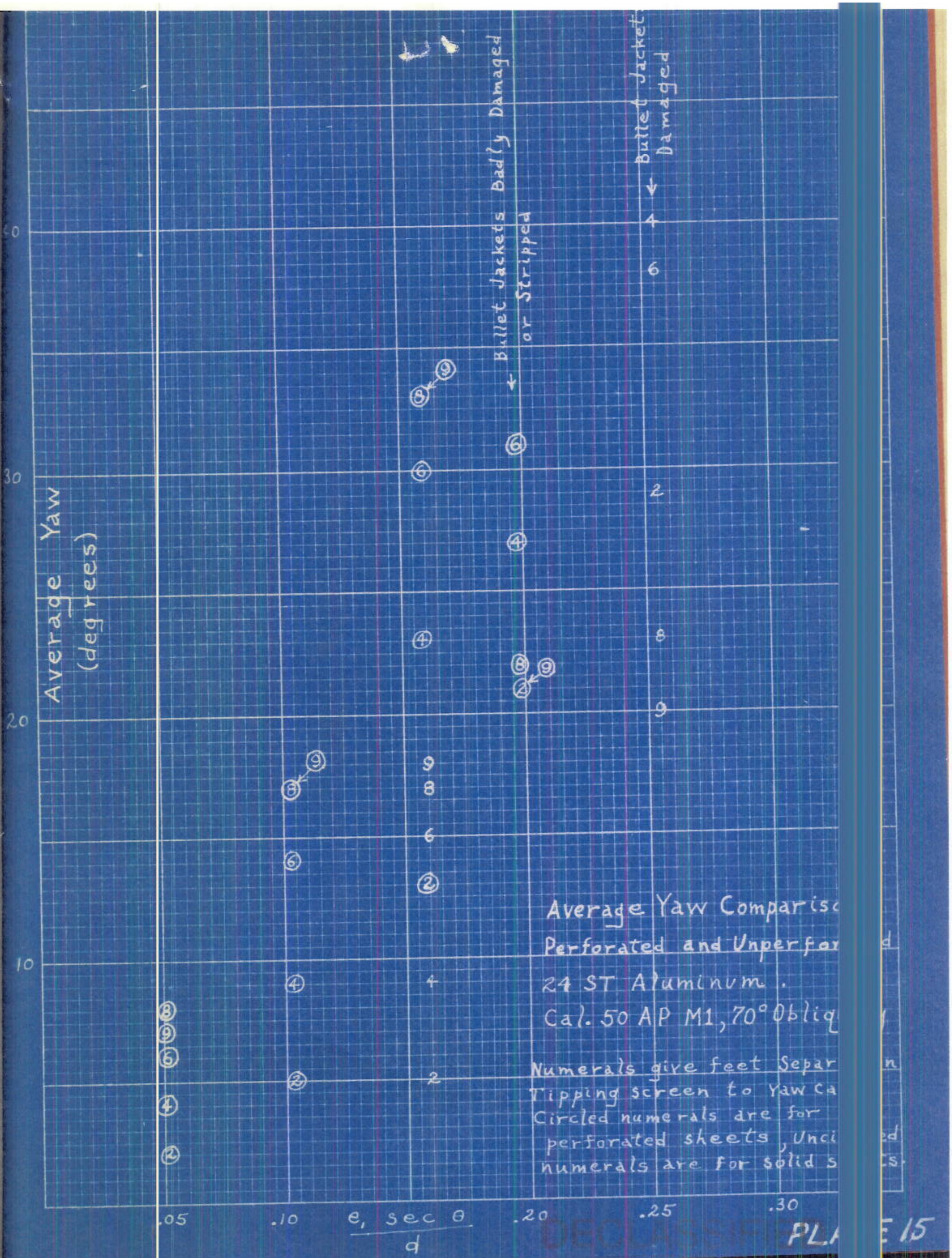
24 ST Aluminum.

Cal. 50 AP M1, 70° Obliqu

Numerals give feet Separat
Tipping screen to Yaw Car
Circled numerals are for
perforated sheets, Uncir
numerals are for solid she

DECLASSIFIED

PLAT 15



Average Yaw Compariso

Perforated and Unperfor d

24 ST Aluminum.

Cal. 50 AP M1, 70° Obliq

Numerals give feet Separ n
Tipping screen to Yaw Ca
Circled numerals are for
perforated sheets, Unci ed
numerals are for solid s ts.

PL E 15