DEPARTMENT OF THE SCIENTIFIC ADVISER TO THE ARMY COUNCIL

ARMY OPERATIONAL RESEARCH GROUP

REPORT No. 11/51.

ASSESSMENT OF FORMS OF ANTI-TANK DEFENCE.

EFFECTIVENESS OF BRITISH AND RUSSIAN TANKS.

AORG

AUGUST, 1951.

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ASSESSMENT OF FORMS OF ANTI-TANK DEFENCE

EFFECTIVENESS OF BRITISH AND RUSSIAN TANKS

Prepared by: Major R.W.Eccles, REME
W.L.Kesteven

ABSTRACT

This report is part of a general study on the "Assessment of forms of A/Tk Defence", and in it an attempt is made to derive values for British and Russian tanks of their "Measure of Effectiveness", the theory of which was evolved in AORG Report No. 21/50.

Results are obtained for the Effectiveness of the British tanks Centurion Mk. 3 and Comet vis-a-vis the Russian J.S.3 and T34/85, at ranges of 600 yds, 1000 yds and 1500 yds.

The Measure of Effectiveness does provide a comparison of the instrinsic gun/armour merits of the tanks, which should help in giving a somewhat firmer basis than previous estimates for use in the overall planning of the armoured role in anti-tank defence. However, the values obtained should not be utilised divorced from the context of this report.

The results obtained indicate that within the terms of the measure of effectiveness described in Report No. 21/50 and in this paper:-

(a) The Centurion Mk. 3 is slightly superior to the J.S.3 and superior to the T34/85.

(b) The Comet is inferior to the J.S.3. and is about equivalent to the T34/85.

The indicated superiority of British over Russian tanks is due principally to the higher rate of fire.

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ASSESSMENT OF FORMS OF ANTI-TANK DEFENCE

EFFECTIVENESS OF BRITISH AND RUSSIAN TANKS

"Assessment of Forms of A/Tk Defence" is the title of a general study, the aim of which is to produce information and evidence that will contribute to the solution of the problem:

"What is the best form of defence against Russian armoured forces?"

This is one of a series of reports that will deal with different aspects of this general study.

A general introduction to the problem has been published as AORG Report No. 20/50.

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INTRODUCTION

1. This report is virtually an appendix to AORG Report No. 21/50, "Tanks in the A/Tk. Role: A Measure of Effectiveness"; it attempts to translate the theoretical solution given in that report into quantitative figures, for two current British tanks with respect to two current Russian tanks under specific conditions.

2. The numerical results obtained for Effectiveness should be interpreted in the light of the limitations discussed in Report No. 21/50 and of the conditions detailed in this paper.

OBJECT

3. The object of the report is to indicate the manner in which the data may be obtained for calculating the measure of effectiveness defined in Report No. 21/50, and to detail the present method of calculation of this measure. In particular, to determine the Effectiveness of:-

(a) the Centurion Mk. 3 mounting the 20 pdr gun firing APDS Mk. 1 shot.

(b) the Comet mounting the 77 mm gun firing APCBC shot,

with respect to:-

(c) the Josef Stalin 3 mounting the 122 mm gun firing APBC shot.

(d) the T34 mounting the 85 mm gun firing APBC shot.

GENERAL

4. In Report No. 21/50 the Effectiveness (E) is related to the numbers of a given type of tank that would be required to meet a given number of enemy tanks on equal terms, and it is shown that the effectiveness of an allied tank (with respect to a given type of enemy tank) is measured by,

$$E = \sqrt{\frac{K_{AX}}{K_{XA}}}$$

where K_{AX} represents the mean killing power of the allied tank (A) with reference to the given enemy tank (X); and K_{XA} represents the mean killing power of the enemy tank (X) with reference to the allied tank (A). It is shown also that E may be written in the form:-

$$\sqrt{\frac{\text{allied rate of fire}}{\text{enemy rate of fire}}}\sqrt{\frac{\text{mean chance that an allied round will hit and destroy an enemy tank.}}{\text{mean chance that an enemy round will hit and destroy an allied tank.}}}$$

5. In the present paper the chance of a hit is related to that of the first round and the mean killing power of this round calculated; the rate of fire is then embodied in the calculation as the inverse of the firing interval, i.e. the time taken to load, lay and fire the first round.

6. It is essential that the assumptions and conditions upon which [illegible] values for effectiveness are obtained are appreciated (see Appendix [illegible] and it should be understood that E gives a general indication of [illegible] relative values of the intrinsic gun/armour merits only, and [illegible] cover all the additional factors which enter into armoured [illegible] results must, therefore, in no way be taken to specify the [illegible] superiority of one type of tank over another in all the [illegible] combinations of circumstances which may occur in any [illegible], number of battles or in the A/Tk role. However, since the [illegible] characteristics are the predominant features [illegible] the battle is joined, the effectiveness derived on such a [illegible] be fundamental and therefore the results should be [illegible], as a foundation upon which assessments or predictions of future [illegible] requirements, whatever their nature, may be [illegible].

7. The method of estimating effectiveness is briefly as follows:-

(a) The vulnerable area presented by the enemy tank to the allied attack is calculated at discrete intervals of 15° around the tank.

(b) The chance of the allied gun hitting these vulnerable areas at each 15° aspect is calculated.

(c) The chance of hitting is multiplied by the chance of that aspect being attacked, and the results summed for all aspects from 15° to 360°.

(d) The sum is then multiplied by the rate of fire or the inverse of the firing interval of the allied tank, to obtain K_{AX}, the mean killing power of the allied tank against the enemy tank.

(e) The process is repeated for the allied tank under enemy attack to give K_{XA}, and the square root of the ratio $\frac{K_{AX}}{K_{XA}}$ obtained for the measure of Effectiveness.

Complete details of the method of calculation are given in Appendix B.

8. The chance that a particular aspect of a tank might be attacked requires the assumption of some particular form of directional probability variation (d.p.v.). In this study a modified (elliptical) d.p.v. has been developed to conform with data from battles of the 1939-1945 War. This elliptical d.p.v. replaces the more usual Whittaker's d.p.v. (the departure from the Whittaker d.p.v., however, does not cause large alterations in the resultant effectiveness, see Appendix E). In the calculations the same d.p.v. has been used for all tanks whether allied or enemy, and no discrimination has been made in this respect between the attacker and the attacked.

9. The results presented in this paper (see also Appendix C·) include range errors for range finder only and do not include any results for visual estimation of range. This tends to favour the Russian equipments, since with a rangefinder the resultant errors on a vertical target are nearly equal for both British and Russian guns, whereas the visual estimation range errors on a vertical target are larger for the Russian than for the British guns (see Appendix 'D ').

10. In general the tendency in this report has been to over-rate the performances of Russian armour and shot by considering them equivalent to their British counterparts. This applies particularly to the penetrative powers of the Russian shot, where the Ordnance Board figures for the thickness of armour perforated are some 20% greater than those given in the Russian documents available. (See Appendix F). The data on Russian tanks and guns has, wherever possible, been obtained from the best available intelligence reports; but where no information was available the British equivalents have been used. The discrepancies between the Russian and the Ordnance Board figures for perforation are probably due to the use of different criteria or formulae. It is generally accepted that Russian armour is inferior to British homogeneous plate.

RESULTS

<u>Effectiveness.</u>

11. The following table gives values of the Effectiveness (E) for two British tanks with respect to two Russian tanks, assuming all ranges are known with rangefinder accuracy. Figures are quoted for two aiming points, (i) the centre of the hull, (ii) the centre of the largest vulnerable plate.

<u>Table 1.</u>

<u>Effectiveness:- British v Russian tanks</u>

Allied Tank	Range in yds	versus J.S. 3 (122 m/m APBC, 3 rds/min) Aiming Point		versus T.34 (85 m/m APBC, 7½ rds/min) Aiming Point	
		Centre of Hull	Vul Area	Centre of Hull	Vul Area
Centurion 3 (20 pdr APDS, 12 rds/min)	600	1.3	1.9	2.3	2.3
	1000	1.3	1.8	2.5	2.5
	1500	1.6	2.0	2.7	2.8
Comet (77 m/m APCBC 12 rds/min)	600	0.9	0.9	1.3	1.3
	1000	0.9	0.8	1.1	1.1
	1500	0.8	0.8	0.9	0.9

The figures for Effectiveness given above indicate the ratio of Russian to British tanks that would be required to give both sides an equal chance of success. Thus when E = 1.3, 10 Centurion Mk 3s are considered, on the average, to be equivalent to 13 J.S.3s.

12. In addition the effectiveness of Centurion equipped with a 17 pdr gun firing APCBC shot against the J.S.3 has been calculated. Figures quoted

below are for aiming at the centre of hull only, since this is normal training practice.

Table 2

Effectiveness:- Centurion Mk, 2 v J.S.3.

Allied Tank	Range in yds.	Versus J.S.3 (122 m/m APBC, 3 rds/min)
Centurion 2 (17 pdr APCBC, 12 rds/min)	600 1000 1500	1.2 1.0 1.0

13. The possibility that the Russians might attempt to improve the performance of the J.S.3. by up-gunning or by increasing the rate of fire has been considered, and in order to evaluate a figure for the effectiveness in these circumstances it has been assumed that the 122 mm gun of the J.S.3 is replaced firstly by the German 88 mm Kwk 43, and secondly by the 85 mm gun of the T34. The following table gives the results for the effectiveness of Centurion 3 with respect to these two hypothetical Russian tanks.

Table 3

Effectiveness:- Centurion Mk, 3 v J.S.3 with 88 m/m and 85 m/m

Allied Tank	Range in yds.	versus J.S.3 (88 m/m APCBC, 3 rds/min)	(85 m/m APBC, $7\frac{1}{2}$ rds/min)
Centurion 3 (20 pdr APDS, 12 rds/min)	600 1000 1500	1.3 1.3 1.5	1.3 1.4 1.7

Relative Effectiveness

14. The following table shows the relative effectiveness of the two British tanks Centurion Mk. 3 and Comet, on the basis of their performance against both the J.S.3 and the T34/85. These figures are derived from Table 1, and are quoted only for aiming at the centre hull.

Table 4

Relative Effectiveness:- Centurion Mk. 3/Comet on the basis of J.S.3 and T34/85

Allied Tanks	Range in yds.	On the basis of:- J.S.3	T34/85
Centurion 3 v Comet	600 1000 1500	1.5 1.5 2.1	1.7 2.2 3.0

15. A similar comparison is given for the two Russian tanks J.S.3 and T34/85 when matched against the Centurion Mk. 3 and the Comet separately. These figures are also derived from Table 1.

Table 5

Relative Effectiveness:- J.S.3/T34/85 on the basis of Centurion Mk. 3 and Comet

Enemy Tanks	Range in yds.	On the basis of:-	
		Cent. 3	Comet
J.S.3 v T34/85	600	1.8	1.5
	1000	1.9	1.3
	1500	1.7	1.3

DISCUSSION

16. It will be noted that in Table 1, the British Centurion Mk. 3 is shown as being slightly superior to the Russian Tanks; this superiority slightly increases with range because of the smaller increase in range error of the high velocity gun in the Centurion 3, which has a flatter trajectory and smaller angle of descent than the Russian guns. It will also be seen that the Comet is inferior to J.S.3 but roughly equivalent to T34/85, and that its effectiveness against these tanks slightly decreases with increase in range. In Report No. 21/50 (para. 28) it was suggested that effectiveness would not be appreciably sensitive to alterations in range and the values given in Table 1 show that the variations with range are in fact small over the operative ranges.

17. Table 1 indicates that in general there is no appreciable advantage to be gained by aiming at the vulnerable area instead of at the centre of the hull. The somewhat greater superiority of the Centurion 3 over the J.S.3 when aiming at the vulnerable area is accounted for by the fact that in the head-on position when the hull front plates of the J.S.3 are invulnerable to the 20 pdr. APDS Mk. 1, the mantlet of the turret is considered vulnerable. Thus for this aspect the chance of a kill is appreciably increased when the aiming point is raised from the centre of the invulnerable hull to the centre of the vulnerable mantlet of the J.S.3.

18. When the Centurion with the 17 pdr. is opposed to the J.S.3, Table 2 shows that the two tanks are roughly equivalent to one another. If the J.S.3 were equipped with a higher velocity gun such as the German 88 mm (as shown in Table 3), the superiority of the Centurion Mk. 3 would remain the same as against the 122 mm gun at ranges of 600 yds. and 1000 yds, but would decrease at the longer range (1500 yds.). Whereas if the lower performance 85 mm gun were installed in the J.S.3 the superiority of Centurion would be increased, although the 85 mm has a shorter firing interval (a higher rate of fire) than the 122 mm gun.

19. The general effect of the firing interval or rate of fire as between the different tanks is indicated by considering the value of E for the Centurion 3.v. J.S.3 at 600 yds. (see Table 1, E = 1.3). In order to obtain parity between the two tanks (E = 1) it would be necessary for the J.S.3 to increase its rate of fire by 60% (i.e. from 3 to 5 rds/min); on the other hand the rate of fire of Centurion 3 could be reduced by more than one third (i.e. from 12 to 7 rds/min) before the same effect is obtained. Also parity would occur when aiming at the vulnerable plates if the rates of fire of the J.S.3 and Centurion 3 were

approximately equal. The shorter firing interval and the greater accuracy of the gun account for the comparatively good performance of Comet against the J.S.3, although few of the plates on the J.S.3 are vulnerable to 77 mm APCBC attack.

20. The comparisons given in Table 4 of the two British tanks Centurion 3 and Comet on the basis of their relative performance against both J.S. 3 and T34/85, show that Centurion 3 is superior to Comet, as might have been expected in view of the higher velocity gun and heavier armour of the Centurion 3.

21. Similar comparisons, made in Table 5, of the two Russian tanks J.S. 3 and T34/85 on the basis of their relative performance against the British tanks, again give consistent results and confirm that J.S.3 is superior to the T34. In this case, however, the J.S.3 shows up even better when the comparison is made on the basis of the heavier British tank (Centurion 3), whereas in Table 4, Centurion 3 shows up better when the basis is the lighter Russian tank (T34).

22. Another point which becomes apparent in the comparison tables is that the effectiveness of the tank equipped with the higher velocity gun (Centurion 3) increases slightly with range, and the effectiveness of the tank equipped with the lower velocity gun (J.S.3) decreases with range, within the limits considered in this report.

CONCLUSION

23. The results obtained indicate that within the terms of the measure of effectiveness described in Report No.21/[illegible] and in this paper:-

(a) the Centurion Mk. 3 is slightly superior to the J.S.3 and superior to the T34/85.

(b) the Comet is inferior to the J.S. 3 and is about equivalent to the T34/85.

ACKNOWLEDGEMENT

24. Acknowledgment is made for the help and data kindly supplied by the Ordnance Board, Superintendent of Applied Ballistics, and the Fighting Vehicle Design Establishment.

Superintendent, AORG.

August 1951.

Appendix A

Assumptions and Conditions for the Calculation of the Measure of Effectiveness

The following list details the assumptions and the conditions within which the calculations of the Measure of Effectiveness are made:-

(a) All hits on armour plate at angles greater than 75° to the normal do not perforate the plate.

(b) A hit on a vulnerable armoured area perforates and destroys or "kills" the tank for that particular engagement.

(c) The distribution of shots, and therefore of hits, is bi-normal.

(d) The vertical distribution and the horizontal distribution of shots are independent of one another.

(e) All strikes are parallel to the direction of attack and are all normal to the vertical axis of the tank.

(f) The turret always points towards the direction of attack i.e. the tank is always engaging the attacker.

(g) The suspension of a tank does not contribute to nor detract from the armour protection.

(h) All armour is of the same homogeneous quality. i.e. British homogeneous plate.

(i) That Russian shot gives a penetrative performance equivalent to the best British shot.

(j) The whole of the armoured hull and turret of a tank is capable of being attacked.

(k) The mean deviation of the horizontal error in range is $15r^2$ for a rangefinder and 250r for visual estimation ('r' being the range in 1000 yds.).

(l) The guns are warm and clean i.e. the first shot is not the "warmer" but is subsequent to the warmer.

(m) The same conditions of bore-sighting and zeroing of guns apply in all cases, and that 5 shots are used for "shooting in" the gun and sight.

(n) The tanks are freely mobile; i.e. there is a possibility of all round attack.

(o) That the theory of the directional probability variation gives a reasonable measure of the probability of attack of a tank, from all directions around the tank.

Appendix B

Method of Calculation of the Measure of Effectiveness

The method utilised to assess the mean chance that a given gun mounted in a given vehicle and firing a specified type of shot will hit and destroy a specified tank is as follows:-

1. From the dimensions and angles of slope of all the external armoured plates of the hull and turret of the tank under attack, the areas presented by each of the individual plates are calculated for directions of attack at 15° intervals around the tank. (Assuming that the front of the turret always points towards the attacker at each aspect). The angle of attack of each plate of the tank is calculated for each aspect, assuming all strikes are parallel to the direction of attack and normal to the vertical axis of the tank. (See Appendix H).

2. The critical perforation curves (thickness/angle) are derived for the attacking gun at the range or ranges required. (In this report ranges of 600 yards, 1000 yards and 1500 yards are covered). (See Appendix F).

3. Using the data derived under paras 1 and 2 the presented areas of those plates which are vulnerable to the attacking gun (i.e. plates which can be perforated) are obtained for each aspect at the different ranges, (strikes at angles greater than 75° to the normal of the plate are assumed not to perforate because either the shot breaks up or it is deflected). (See App H)

4. The overall error both in elevation and traverse (i.e. height and line) of the attacking gun in its particular mount, firing a specified shot, is obtained by summing the squares of the various individual errors present in the gun, the sight, the mounting and the layer. (See Appendix G).

5. The errors in range estimation on a vertical target using both range-finder and visual means are calculated for the partigular gun and shot at the given ranges; assuming horizontal errors of $15r^2$ for the rangefinder and 250r for visual range taking; where 'r' is the range in 1000 yards. (See Appendix D).

6. A practical rate of fire of the particular gun and mounting is obtained, from which the firing interval or the time taken to load, lay and fire the gun is calculated. (Russian figures were obtained from the best available intelligence reports).

7. Utilising the directional probability variation developed in Appendix E, the vectors at each 15° are taken to represent the probability of a tank being engaged at each particular aspect when it is freely mobile.

8. Proceeding with the above data two calculations of effectiveness are made, one based on aiming at the centre of the hull and the other on aiming at the centre of the largest vulnerable plate for each aspect.

9. The presented areas of hull and turret at each aspect are reduced to two rectangles correctly disposed with respect to one another and maintaining the correct height for each, since this is the critical dimension. The vulnerable areas of the hull and turret for each aspect and range are also reduced to equivalent rectangles correctly disposed with respect to the hull and turret rectangles. (See Fig. B1).

10. The standard deviations of the gun for both elevation and traverse, are obtained from the sum of the squares of the gun and the range errors, and hence from tables the probability of a shot hitting the vulnerable area is determined, see Note B1. (Assuming normal distribution of the shots both vertically and horizontally, and that the two distributions are independent).

11. The probability of a shot hitting a vulnerable area at each aspect is multiplied by the corresponding vector of the d.p.v., thus giving a figure for the probability of a particular aspect being engaged and a vulnerable area being hit (i.e. the mean chance of a kill at each aspect).

12. The probabilities so obtained are summed for all aspects up to 360°, thus covering the horizontal attack of the tank from all points of the compass and giving the total mean chance of the tank being killed by the given attack (i.e. the overall vulnerability of th tank to that particular attack).

13. The total mean chance of the tank being killed is then multiplied by the number of rounds fired per second by the attacking gun in its particular vehicle, thus giving a value for the symbol K_{AX} (the mean killing power of the tank (A) with respect to tank (X)). See Appendix J.

14. A similar calculation is then completed for the effect of the gun mounted in tank (X) attacking the vehicle carrying the gun (A) and the value of K_{XA} obtained.

15. The square root of the ratio $\frac{K_{AX}}{K_{XA}}$ measures the effectiveness (E) of tank (A) against tank (X).

16. As an alternative to the method outlined above and in Note B1, a much simpler and more general method of calculating the probability of hitting the vulnerable area is detailed in Note B2 of this Appendix.

Note B1:- 1st Method

1. σ_e and σ_t are the standard deviations for the attacking gun for the vertical and horizontal planes respectively. They are expressed in feet on the target for a given range; σ_e includes rangefinder range errors.

2. Aiming point at Centre of Hull:- (see Fig. B1).

(a) Turret:- a_t and b_t are the vertical co-ordinates of the vulnerable area of the turret measured from the aiming point. a_t is the distance from the aiming point to the top of the vulnerable area and b_t from the aiming point to the bottom of the vulnerable area. The probability of a hit on the vulnerable area of the turret, with respect to the total vertical error of the gun is, therefore:

$$\frac{1}{2}\left\{P\frac{a_t}{\sigma_e} - P\frac{b_t}{\sigma_e}\right\}^{*} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

The horizontal co-ordinates of the turret are c_t and d_t, and they change with aspect. The position of the turret, in the broadside view, is usually forward of the centre of the hull. The distance of the centre

* This and similar expressions are evaluated from tables. P represents the normal probability area between the limits $\pm\frac{x}{\sigma}$.

line of the turret from the centre of the hull alters with aspect and this distance must be considered when evaluating c_t and d_t. If this distance be called 'z', then

$$c_t = z + \frac{\text{length of vulnerable area of turret}}{2}$$

$$d_t = z - \frac{\text{length of vulnerable area of turret}}{2}$$

If the horizontal extremities of the vulnerable area of the turret lie either side of the centre line of the hull both c_t and d_t are positive, otherwise one of them is negative. The probability of a hit on the vulnerable area of the turret with respect to the total line error of the gun, is, therefore, given by

$$\frac{1}{2}\left\{ P\frac{c_t}{\sigma_t} + P\frac{d_t}{\sigma_t} \right\} \qquad \text{.........................(2)}$$

The probability of a hit on the vulnerable area of the turret, for a given aspect, is the product of the two independent probabilities (1) and (2). This is symbolised by P_t.

(b) **Hull:-** The co-ordinates for the vulnerable area of the hull are symbolised by a, b, c and d with the subscript 'h', a_h and b_h are the vertical co-ordinates and c_h and d_h the horizontal co-ordinates.

When the aiming point is the centre of the hull only one vertical ordinate is required. In these circumstances a_h is used and its value is half the height of the vulnerable area of the hull.

The centre of the hull is not always half way along the vulnerable area of the hull, so that c_h is not always equal to d_h but $(c_h + d_h)$ = the length of the vulnerable area of the hull for different aspects. Occasions arise when the vulnerable area of the hull is wholly in front of or behind the centre of the hull, in these circumstances either d_h or c_h is negative.

The probability of a hit on the vulnerable area of the hull, for a given aspect, takes the form:-

$$\frac{1}{4}\left\{ P\frac{a_h}{\sigma_e} + P\frac{b_h}{\sigma_e} \right\}\left\{ P\frac{c_h}{\sigma_t} + P\frac{d_h}{\sigma_t} \right\} = P_h$$

The probability of a hit on the vulnerable area of a tank, for a given aspect, is $P_t + P_h = P_v$.

3. Aiming Point at Centre of Vulnerable Area:-

When the aiming point is at the centre of the vulnerable area and both turret and hull are vulnerable it is assumed that the aiming point is at the centre of the largest vulnerable area. For some aspects the turret only is vulnerable but for most aspects both turret and hull are vulnerable. In the latter case the aiming point is virtually at the centre of the vulnerable area of the hull.

The co-ordinates, as before, are symbolised by a_t, b_t, c_t and d_t for the turret and similarly, with a change of subscript, for the hull.

Since the length of the vulnerable area of the hull is often less than the total length of the hull, for a given aspect, the distance of the aiming point from the centre line of the turret is not the same as when aiming at the centre of the hull. Apart from this change c_t and d_t are evaluated, for each aspect, in the same way as before.

a_h is evaluated in the same way as before and for the same reason b_h is not used. Since the vulnerable area of the hull is symmetrical about the aiming point only c_h is required, and its value is half the length of the resolved vulnerable area.

4. In these calculations the co-ordinates are affected only by the aiming point and remain the same for all ranges for a particular aspect of a particular tank, except when variations of range alter the vulnerability for certain aspects. Otherwise a change of range affects the calculations only by altering the values of σ_e and σ_t for the attacking gun.

Note B2:- 2nd Method

1. A simpler method of calculation has also been investigated the results of which vary very little from those obtained by the original and more detailed method (see Appendix C for results). In the second method the total hull and turret areas are reduced to one equivalent rectangle (2a x 2b) for each aspect, maintaining the correct overall height (2a) and always aiming at the centre of mass. The probability of a hit on this rectangle is then assessed i.e. $P_{\frac{a}{\sigma_e}} \cdot P_{\frac{b}{\sigma_t}}$, and this probability reduced proportionately to obtain the probability of hit on the vulnerable area i.e. $P_V = \frac{A_V}{A_T} \cdot P_{\frac{a}{\sigma_e}} \cdot P_{\frac{b}{\sigma_t}}$; where A_V is the vulnerable area at a particular aspect and A_T the total target area at the same aspect. This assumes that the hits are uniformly distributed over the target rectangle.

The remainder of the calculation is carried out as before.

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APP. B

SPECIMEN CALCULATION

Centurion Mk.3 v. J.S.3

J.S.3 under attack by 20 pdr [illegible]

[illegible] Centre of Hull; Range 1500 [illegible]

Centurion Mk.3 v. J.S.3:- J.S.3 under attack by 20 pdr APDS. (Aiming Point:- Centre of Hull). (Range 1500 yards)

1. **Probability of hitting Vulnerable Area of Turret**

(Units in feet)

Aspect	Total Vulnerable Area	Turret Vulnerable Area	$\sqrt{2}\sigma_e$	a_t	b_t	$\frac{a_t}{\sqrt{2}\sigma_e}$	$\frac{b_t}{\sqrt{2}\sigma_e}$	$P\frac{a_t}{\sqrt{2}\sigma_e}$	$P\frac{b_t}{\sqrt{2}\sigma_e}$	$\frac{P\frac{a_t}{\sqrt{2}\sigma_e} - P\frac{b_t}{\sqrt{2}\sigma_e}}{2}$
0°	5.0	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
15°	5.0	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
30°	5.0	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
45°	41.95	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
60°	65.78	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
75°	72.79	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
90°	75.18	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
105°	72.79	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
120°	65.78	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
135°	59.49	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
150°	26.48	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
165°	28.91	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997
180°	29.8	2 x 2.5	2.5930	4.25	2.25	1.6390	0.8677	0.9795	0.7802	.0997

Aspect	$\sqrt{2}\sigma_t$	c_t	d_t	$\frac{c_t}{\sqrt{2}\sigma_t}$	$\frac{d_t}{\sqrt{2}\sigma_t}$	$P\frac{c_t}{\sqrt{2}\sigma_t}$	$P\frac{d_t}{\sqrt{2}\sigma_t}$	$\frac{P\frac{c_t}{\sqrt{2}\sigma_t} + P\frac{d_t}{\sqrt{2}\sigma_t}}{2}$	P_t
0°	2.4472	1.25	1.25	0.5108	0.5108	.5299	.5299	.5299	.0528
15°	2.4472	0.46	2.04	0.1880	0.8336	.2097	.7616	.4856	.0484
30°	2.4472	-0.245	2.745	-0.1001	1.1217	-.1126	.8873	.3874	.0386
45°	2.4472	-0.8584	3.3584	-0.3508	1.3724	-.3802	.9477	.2838	.0283
60°	2.4472	-1.3097	3.8097	-0.5352	1.5568	-.5509	.9723	.2107	.0210
75°	2.4472	-1.6858	4.1858	-0.6889	1.7105	-.6701	.9844	.1572	.0157
90°	2.4472	-1.8763	4.3763	-0.7667	1.7883	-.7218	.9886	.1334	.0133
105°	2.4472	-1.6858	4.1858	-0.6889	1.7105	-.6701	.9844	.1572	.015[illegible]
120°	2.4472	-1.3098	3.8098	-0.5352	1.5568	-.5509	.9723	.2107	.0210
135°	2.4472	-0.8525	3.3525	-0.3483	1.3699	-.3777	.9473	.2848	.0284
150°	2.4472	-0.245	2.745	-0.1001	1.1217	-.1126	.8873	.3874	.0386
165°	2.4472	0.4653	2.0347	0.1901	0.8315	.211[illegible]	.7604	.4862	.0485
180°	2.4472	1.25	1.25	0.5108	0.5108	.5299	.5299	.5299	.0528

2. Probability of hitting Vulnerable Area of Hull

Aspect	Hull Vulnerable Area	a_h	b_h	$\frac{a_h}{\sqrt{2}\sigma_e}$	$\frac{b_h}{\sqrt{2}\sigma_e}$	$P\frac{a_h}{\sqrt{2}\sigma_e}$	$P\frac{b_h}{\sqrt{2}\sigma_e}$	$\frac{P\frac{a_h}{\sqrt{2}\sigma_e} + P\frac{b_h}{\sqrt{2}\sigma_e}}{2}$
0°	-	-	-	-	-	-	-	-
15°	-	-	-	-	-	-	-	-
30°	-	-	-	-	-	-	-	-
45°	2.75 x 13.4364	0.75	2.0	0.2892	0.7713	.3175	.7246	.5210
60°	4 x 15.195	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
75°	4 x 16.9475	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
90°	4 x 17.5450	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
105°	4 x 16.9475	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
120°	4 x 15.195	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
135°	2.75 x 13.4364	0.75	2.0	0.2892	0.7713	.3175	.7246	.5210
	4 x 4.385	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
150°	4 x 5.37	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
165°	4 x 5.9775	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246
180°	4 x 6.2	2.0	2.0	0.7713	0.7713	.7246	.7246	.7246

Aspect	c_h	d_h	$\frac{c_h}{\sqrt{2}\sigma_e}$	$\frac{d_h}{\sqrt{2}\sigma_t}$	$P\frac{c_h}{\sqrt{2}\sigma_t}$	$P\frac{d_h}{\sqrt{2}\sigma_t}$	$\frac{P\frac{c_h}{\sqrt{2}\sigma_t} + P\frac{d_h}{\sqrt{2}\sigma_t}}{2}$	P_h	$P_v = (P_t + P_h)$	d.p.v.	Pv(d.p.v.)
0°	-	-	-	-	-	-	-	-	.0528	.097	.0051
15°	-	-	-	-	-	-	-	-	.0484	.149	.0072
30°	-	-	-	-	-	-	-	-	.0386	.088	.0034
45°	8.3963	5.0401	3.4310	2.0596	1.0	.9964	.9982	.5201	.548[illegible]	.05[illegible]	.0265
60°	9.1475	6.0475	3.7380	2.4712	1.0	.9995	.9998	.7245	.7455	.033	.0246
75°	9.5888	7.3587	3.9183	3.0070	1.0	1.0	1.0	.7246	.7403	.022	.0163
90°	9.3763	8.1687	3.8315	3.3380	1.0	1.0	1.0	.7246	.7379	.015	.0111
105°	9.5863	7.3612	3.9173	3.0080	1.0	1.0	1.0	.7246	.7403	.012	.0089
120°	9.1425	6.0525	3.7359	2.4733	1.0	.9995	.9998	.7245	.7455	.009	.0067
135°	8.3888	5.0476	3.4280	2.0626	1.0	.9965	.9982	.5214	.5498	.0075	.0041
	9.4326	-5.0476	3.8545	-2.0626	1.0	-.9965	.0018				
150°	7.065	-1.695	2.8870	-0.6926	1.0	-.6727	.1636	.1186	.15[illegible]	.006	.0010
165°	5.2538	0.7237	2.1469	0.2957	.9976	.3242	.6609	.47[illegible]	[illegible]	.006	.0032
180°	3.1	3.1	1.2668	1.2668	.9270	.9270	.9270	.67[illegible]	.72[illegible]	.00	.0022
											0.1223

Note:- $\sqrt{2}\sigma$ is used in place of σ because the best tables available evaluated the function $\frac{2}{\sqrt{\pi}}\int_0^y e^{-x^2}dx$

K_{AX} = 2. Pv(d.p.v.) x Rate of fire of Gun in Tank A 1. [illegible]

= $\frac{0.2446}{5}$ = 0.0[illegible]

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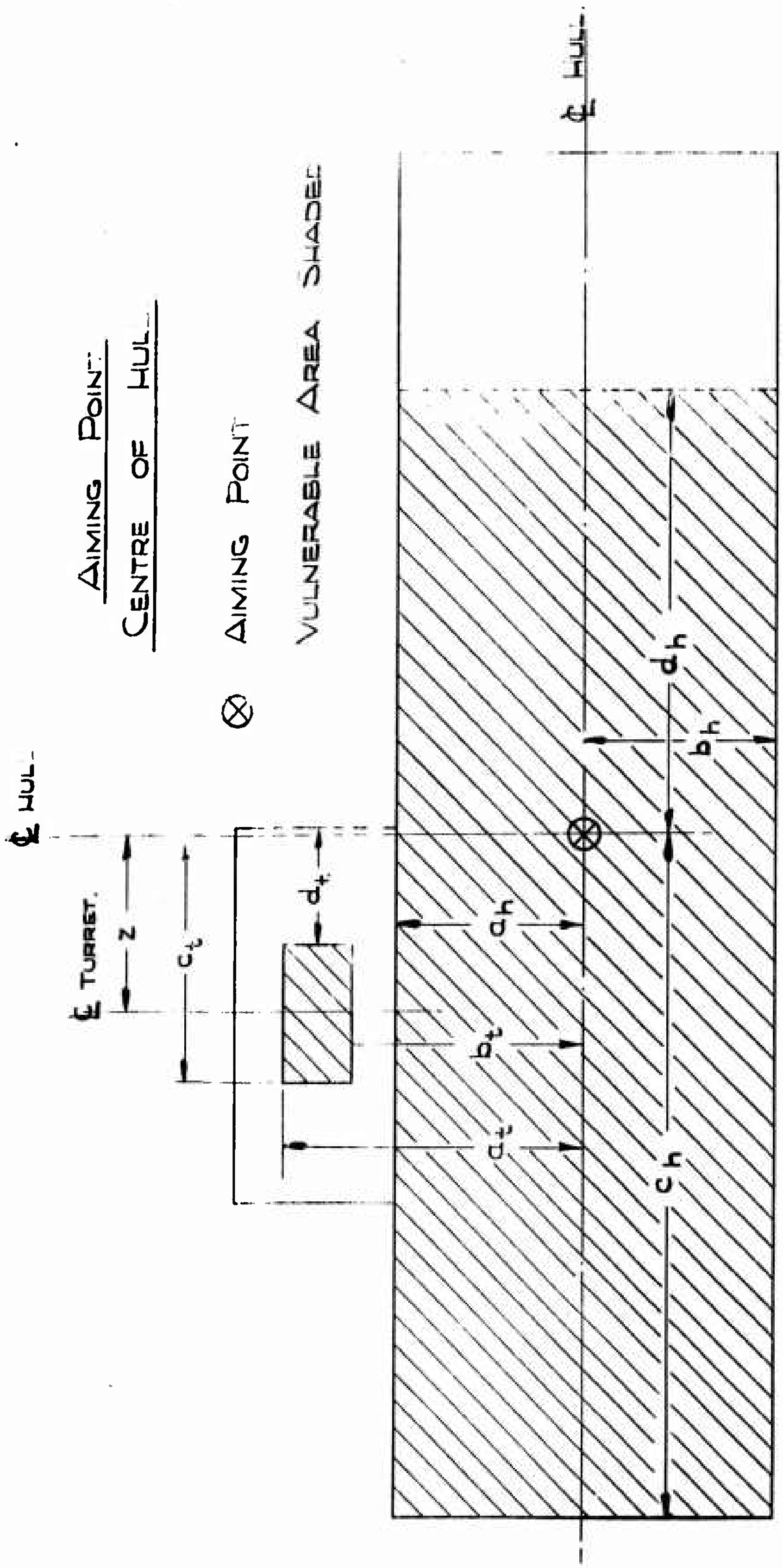
Appx. B.

Fig. B1


Aiming Point
Centre of Hull
⊗ Aiming Point
Vulnerable Area Shaded
℄ Hull
℄ Hull
℄ Turret
z
c_t
d_t
a_h
b_t
a_t
c_h
d_h
b_h

Appendix C

Results of Calculations of the Measure of Effectiveness for British and Russian Tanks.

1. TableC1 of this Appendix lists the results obtained for the effectiveness of current British and Russian tanks, by the first method detailed in Appendix B'. Results have also been included for the Centurion fitted with the 17 pdr. gun; and the hypothetical cases considered of the German KwK 43, 88 m/m gun installed in the J.S.3. and of the T34, 85 m/m gun installed in the J.S.3. (See Table C2).

2. Table C3 gives the results obtained when the shorter second method of calculation detailed in Appendix B' is used. It will be noted that the results vary very little from those obtained by the first method and when aiming at the centre of the hull.

Appx C.

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Table C1.

Effectiveness, (1st Method)

Allied Tank	Range in yds	Versus J.S.3. (122mm.APBC, 3rds/min)						Versus T34/85 (85mm.APBC, 7½rds/min)					
		Aiming Point						Aiming Point					
		Centre of Hull			Vulnerable Area			Centre of Hull			Vulnerable Area		
		K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E
Centurion 3	600	.25	.20	1.27	.42	.22	1.90	.44	.19	2.30	.45	.20	2.26
(20 pdr.APDS,	1000	.24	.18	1.31	.34	.19	1.77	.41	.17	2.46	.42	.17	2.47
12 rds/min).	1500	.22	.14	1.62	.27	.14	1.99	.36	.13	2.75	.38	.14	2.78
Comet	600	.19	.21	0.87	.19	.22	0.88	.43	.32	1.34	.43	.32	1.34
(77mm.APCBC	1000	.16	.19	0.86	.17	.20	0.84	.33	.29	1.12	.33	.30	1.11
12 rds/min).	1500	.12	.16	0.79	.13	.16	0.78	.20	.21	0.92	.20	.23	0.87
Centurion 2	600	.24	.20	1.20	.24	.22	1.11	-	-	-	-	-	-
(17 pdr.APCBC,	1000	.17	.18	0.96	.18	.19	0.94	-	-	-	-	-	-
12 rds/min)	1500	.14	.14	1.04	.15	.14	1.07	-	-	-	-	-	-

Table C2.

Effectiveness, (1st Method)

Allied Tank	Range in yds	Versus J.S.3. (88mm.APBC, 3rds/min)						Versus J.S.3. (85mm.APBC, 7½rds/min)					
		Aiming Point						Aiming Point					
		Centre of Hull			Vulnerable Area			Centre of Hull			Vulnerable Area		
		K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E	K_{AX}	K_{XA}	E
Centurion 3	600	.25	.20	1.27	.42	.22	1.90	.25	.19	1.31	.42	.20	2.10
(20 pdr.APDS	1000	.20	.18	1.31	.34	.19	1.77	.24	.17	1.40	.34	.17	1.98
12 rds/min)	1500	.22	.15	1.48	.27	.15	1.79	.22	.13	1.67	.27	.14	2.03

Table C3.

Effectiveness, (2nd Method)

Allied Tank	Range in yds.	Versus J.S.3. (122mm.APBC, 3rds/min) Aiming Point:- Centre of [illegible]		
		K_{AX}	K_{XA}	E
Centurion 3	600	.24	.18	1.27
(20 pdr./APDS	1000	.23	.18	1.31
12 rds/min)	1500	.23	.14	1.62

(K_{AX} = Allied tank firing at Russian ; K_{XA} [illegible] firing at Allied tank).

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Appendix D

Range Estimation Errors

1. It is shown in O.R.G. Report No. 225 (Sept. 45) and FVDE.RW. Report No. 81 (Feb. 48) that when the horizontal range to a target is obtained by:

(a) visual estimation

(b) a rangefinder (suitable for tank use)

the mean deviations (m.d.) to be expected are:-

(a) 250 r

(b) 15 r^2

where 'r' is the range in 1000 yds.

2. Thus the mean deviations on a vertical target at a range 'r' are given by:-

(a) 250 r.tan β_r yds $\equiv$ 750 r.tan β_r.ft.

(b) 15 r^2.tan β_r yds $\equiv$ 45 r^2 tan β_r.ft.

where 'β_r' is the angle of descent of the shot at the range 'r'.

3. In order to obtain the standard deviations of the range on a vertical target when the range is estimated by visual and rangefinder means (i.e. σ_V and σ_F), the mean deviations given above are multiplied by 1.25, assuming normal distribution of the errors. Thus the standard deviations of the range on a vertical target are given by:- σ_V = 940 r.tan β_r; σ_F = 56.4 r^2.tan β_r ft.

4. The actual standard deviations on a vertical target are:-

		RANGE 600x	RANGE 1000x	RANGE 1500x
(i) 20 pdr. APDS Mk.1.				
	β	6'	11'	17'
(a)	σ_V	1.0	3.0	7.0 ft.
(b)	σ_F	0.04	0.19	0.63 ft.
(ii) 77 m.m. APCBC:-				
	β	18'	31'	49'
(a)	σ_V	3.0	8.5	20 ft.
(b)	σ_F	0.11	0.5	1.88 ft.
(iii) 122 m.m. APBC:-				
	β	18'	31'	49'
(a)	σ_V	3.0	8.5	20 ft.
(b)	σ_F	0.11	0.5	1.88 ft.

(iv) 85 m.m. APBC:-

	β	18'	31'	49'
(a)	σ_V	3.0	8.5	20 ft.
(b)	σ_F	0.11	0.5	1.88 ft.

In case (iv) a similar performance to the 77 m.m. APCBC (m.v. = 2575 ft/sec. C_0 = 3) is assumed for the 85 m.m. APBC (m.v. = 2600 ft/sec ; C_0 = 3).

5. The calculations in this report include errors for ranges known with rangefinder accuracy only and do not include any results for visual estimation of range. This tends to favour the Russian equipments, since with a rangefinder the resultant errors on a vertical target are nearly equal for both British and Russian guns; whereas the visual estimation range errors on a vertical target are larger for the Russian than for the British guns.

6. In Fig. D1 of this Appendix are shown the expected errors on a vertical target for different ranges when the range is estimated by visual and rangefinder means. The curves plotted are for the 20 pdr APDS Mk. 1 and the Russian 122 m/m APC and illustrate the differences in the range errors to be expected from these two guns. The half heights of the Centurion 3 and the J.S.3. are also shown and it will be seen that up to 2000 yds. range the rangefinder errors for both guns are less than these half heights. On the other hand when the range is estimated visually the range errors of the opposing guns equal the half heights of the Centurion 3 and the J.S.3. at ranges of 850 yds and 1350 yds respectively. Thus the gun of the J.S.3. is liable to miss the Centurion 3 at ranges greater than 850 yds owing to visual range errors alone, whereas the gun of the Centurion 3 is not liable to miss the J.S.3. owing to these errors until the range exceeds 1350 yds.

7. Table D1 of this Appendix details some data, obtained from the Ordnance Board, of the errors in feet on a vertical target at ranges of 1000 yds and 2000 yds for guns of differing muzzle velocities and shots of various ballistic coefficients (C_0).

Table D.1.

Errors in feet on a Vertical Target for both Visual and Rangefinder Estimation of Range

(Mean Deviations)

M.V.	C_o	½		1		2		4		∞	
Ft/sec:	Range	1000^x	2000^x	1000^x	2000^x	1000^x	2000^x	1000^x	2000^x	1000^x	2000^x
1000	V	52.7	310.0	43.4	210.9	39.7	175.2	38.0	160.2	36.3	146.3
	Rf.	3.2	37.2	2.6	25.4	2.4	21.0	2.3	19.2	2.2	17.6
1500	V	31.6	119.1	23.4	127.0	19.4	94.1	17.6	77.4	16.1	64.5
	Rf.	1.9	22.9	1.4	15.2	1.2	11.3	1.1	9.3	1.0	7.7
2000	V	18.0	133.5	12.7	72.0	10.5	49.5	9.7	42.0	9.1	36.5
	Rf.	1.1	16.0	0.8	8.6	0.6	5.9	0.6	5.0	0.5	4.4
2500	V	10.6	89.2	7.5	42.3	6.5	30.1	6.3	26.6	5.8	23.8
	Rf.	0.6	10.7	0.5	5.1	0.4	3.6	0.4	3.2	0.3	2.8
3000	V	6.8	54.3	5.2	27.1	4.6	20.2	4.3	19.0	4.1	16.1
	Rf.	0.4	6.5	0.3	3.3	0.3	2.4	0.3	2.3	0.2	1.9
4000	V	3.7	22.5	3.0	13.5	2.5	10.5	2.5	10.5	2.3	9.0
	Rf.	0.2	2.7	0.2	1.6	0.2	1.3	0.1	1.2	0.1	1.1
5000	V	2.1	12.0	1.8	8.0	1.6	6.8	1.6	6.3	1.4	5.8
	Rf.	0.1	1.4	0.1	1.0	0.1	0.8	0.1	0.8	0.1	0.7

Note:- For conversion into the subtended angle at the gun

1' = 10.44" at 1000 yds.

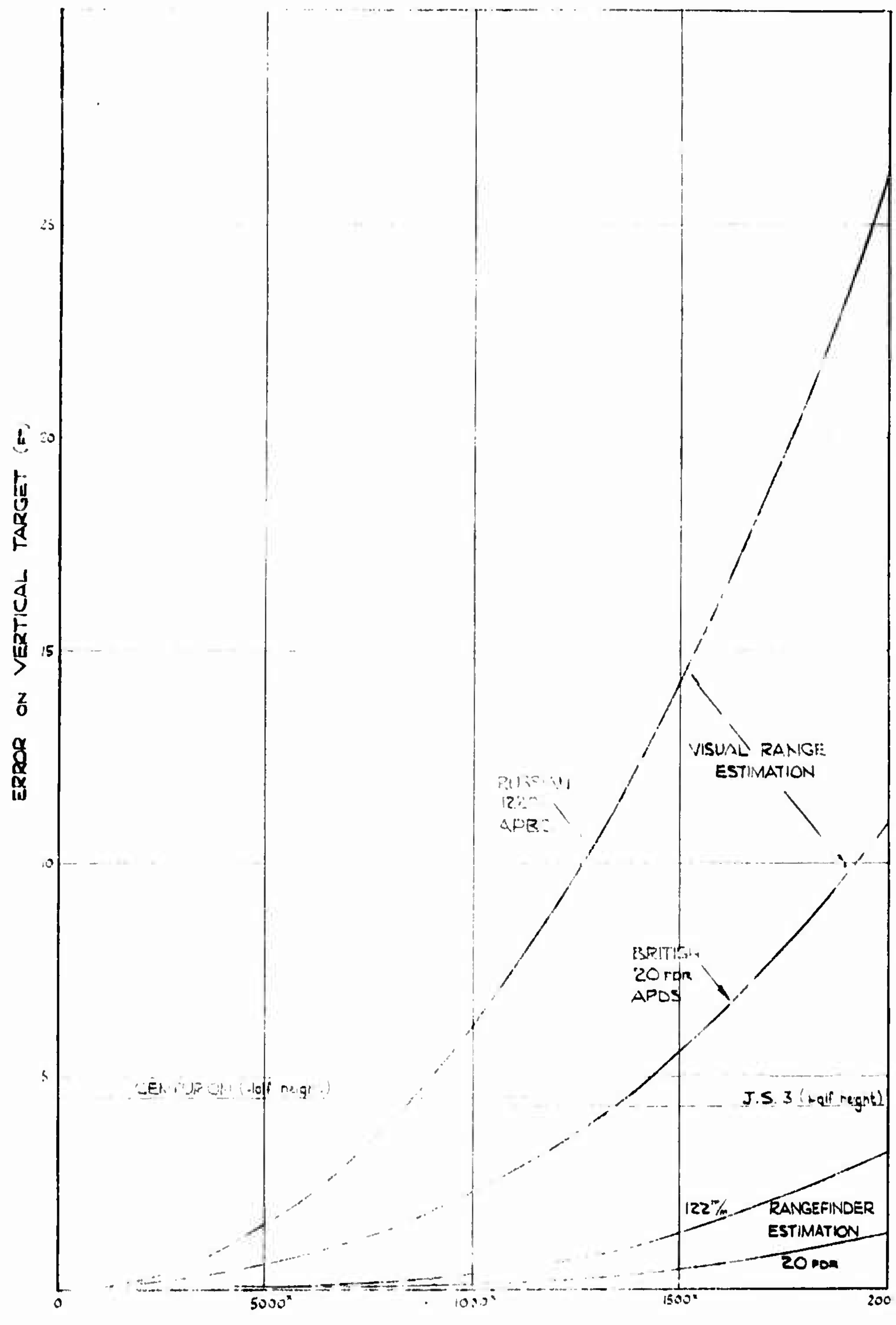
1 ft at 1000 yds = 1.15'

EFFECT OF [illegible] ESTIMATION ERRORS ON VERTICAL TARGET.

(MEAN DEVIATIONS)

[illegible] 250 r   RANGEFINDER ERROR = $15 r^2$

(r = RANGE IN 1000 YDS)



Appendix E

Directional Probability Variation

Distribution of Hits on a Tank

1. It was required to determine the probability of attack of each aspect of a tank; in this paper the aspects presented at discrete intervals of 15° around the tank; are considered, and therefore the probability of attack for each aspect [illegible] total probability over an appropriate 15° interval (i.e. 7½° on either side of each aspect).

2. A first attempt was made utilising the Whittaker directional probability variation (d.p.v.) (see ORG (W & E) Report No. 362, Chap: IV). The total area within the envelope was taken as unity and the areas of the separate 15° sectors (i.e. ± 7½° on either side of each aspect) were determined and taken as the probability of attack at the particular aspect. The analysis of these probabilities showed however that the percentage of hits on the front, sides and rear of a rectangular tank hull were 29½%, 68½% and 2% respectively, assuming a 2:5 front to side ratio, and that the number of hits was proportional to the area of the front, sides or rear exposed to the attack (see Table E1 (a) of this Appendix). These percentages did not conform to the figures obtained from a study of the 1939-45 tank casualties, which were 40% front, 55% sides and 5% rear. (See MORU Report No. 19).

3. A similar analysis was made assuming a normal distribution of the d.p.v. around the tank, in this case the percentages were found to be 31% front, 68½% sides, ½% rear. (See Table E1 (b)).

4. In order to increase the percentage of shots hitting the front of the hull to 40%, successive forms of distribution were then tried, using both cartesian and polar co-ordinates. (See Figs. E1 and E2 of this Appendix, where the probabilities at each 15° aspect are plotted as ordinates and vectors). It was found that the vectorial form tended towards an elliptical envelope of semi-axes 2:1 with the tank or pole close to one of the foci: in this form the percentages obtained were 41% front, 58% sides, ½% rear. In order, however, to increase the percentage of shots on the rear an elliptical envelope of semi-axes 20:9 was tried and found to give 39½% front, 58½% sides, 2% rear, which approximates very closely to the battle results. (See Table E1 of this Appendix).

5. Since the final elliptical form gave similar results to those obtained from a battle analysis, this modified d.p.v. was accepted for use in this particular study, the 15° vectors representing the probability of attack for each 15° aspect around the tank. This particular representation of the probability of attack at 15° intervals is termed the "Elliptical" d.p.v. (See Table E1 (d) and Fig. E2 of this Appendix).

6. It is interesting to note the effect of using Whittaker's d.p.v. in the calculation of the "Measure of Effectiveness" $\sqrt{\frac{\bar{K}_i X}{K X_i}}$, and to compare the results with those obtained using the "Elliptical" form as indicated in the following table:

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		600 yds.	1000 yds.	1500 yds.
Cent 3 v. J.S.3:-	Whittaker's d.p.v.	1.5	1.5	1.7
	Elliptical d.p.v.	1.3	1.3	1.6
Cent 3 v. T.34/85:-	Whittaker's d.p.v.	2.0	2.1	2.4
	Elliptical d.p.v.	2.3	2.5	2.8
Comet 2 v. J.S.3:-	Whittaker's d.p.v.	1.0	1.0	0.9
	Elliptical d.p.v.	0.9	0.9	0.8
Comet 2 v. T.34/85:-	Whittaker's d.p.v.	1.3	1.1	1.0
	Elliptical d.p.v.	1.3	1.1	0.9

It will be observed that the different d.p.vs do not cause major alterations in the figures obtained for effectiveness.

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Table E1

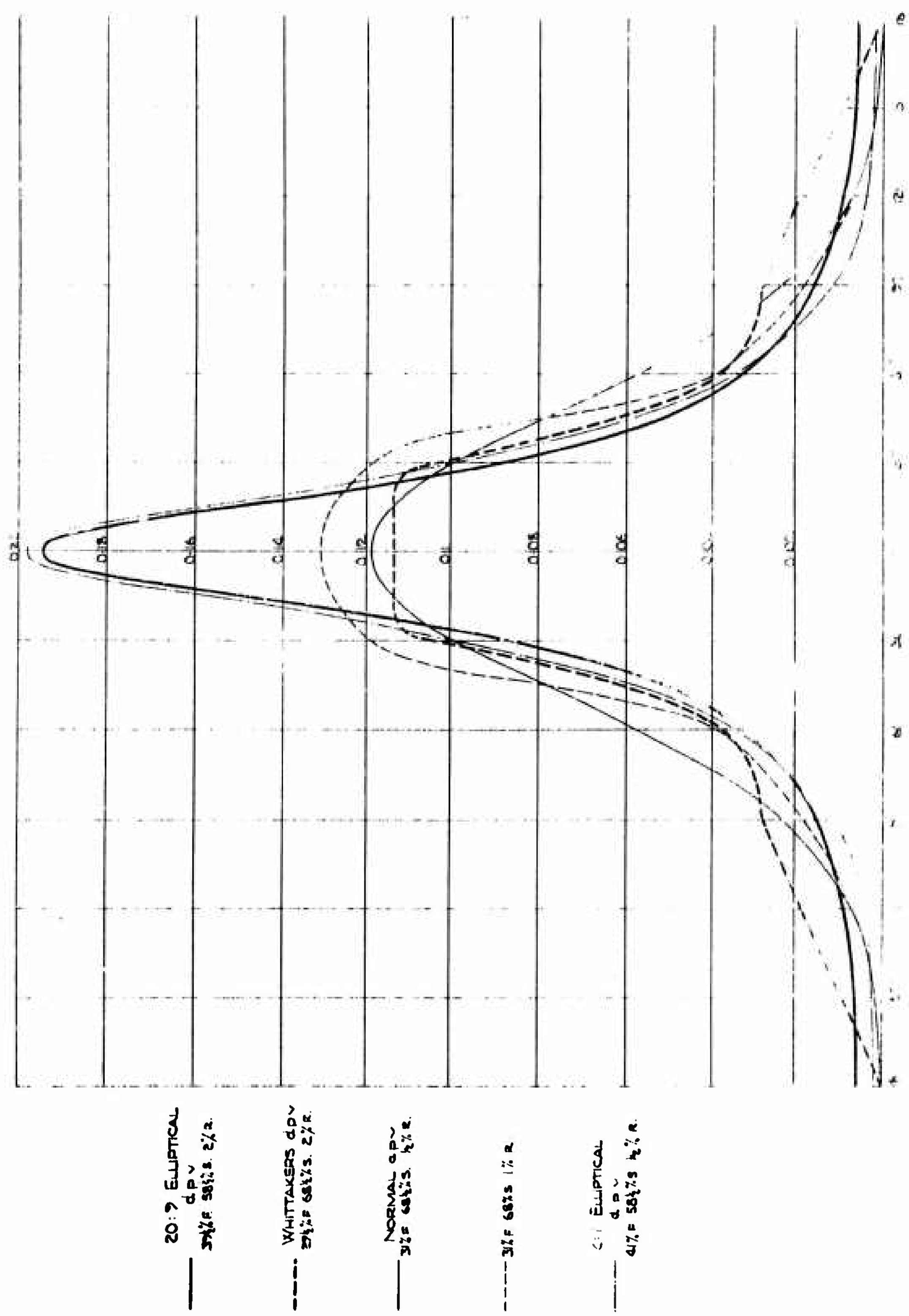
Distribution of Hits for Different Directional Probability Variations.

Aspect.	(a) Whittaker's d.p.v. d.p.v.	Front	Sides	Rear	(b) Normal d.p.v. Front	Sides	Rear	d.p.v.
0°	(x2) .0568	.0568	–	–	.0595	–	–	.0595 (x2)
15°	.1136	.0485	.0651	–	.0485	.0650	–	.1135
30°	.1030	.0265	.0765	–	.0257	.0743	–	.1000
45°	.0580	.0097	.0483	–	.0131	.0654	–	.0785
60°	.0385	.0040	.0345	–	.0060	.0525	–	.0585
75°	.0310	.0016	.0294	–	.0020	.0370	–	.0390
90°	.0280	–	.0280	–	–	.0240	–	.0240
105°	.0235	–	.0223	.0012	–	.0128	.0007	.0135
120°	.0190	–	.0170	.0020	–	.0067	.0008	.0075
135°	.0140	–	.0117	.0023	–	.0025	.0005	.0030
150°	.0095	–	.0070	.0025	–	.0015	.0005	.0020
165°	.0050	–	.0029	.0021	–	.0006	.0004	.0010
180°	(x2) .0000	–	–	.0000	–	–	.0000	.0000 (x2)
	.4999	.1471	.3427	.0100	.1548	.3423	.0030	.5000
		29½%	68½%	2%	31%	68½%	½%	

Aspect.	(c) 2:1 Elliptical d.p.v. d.p.v.	Front	Sides	Rear	(d) 20:9 Elliptical d.p.v. (FINAL) Front	Sides	Rear	d.p.v.
0°	(x2) .0990	.0990	–	–	.0970	–	–	.0970 (x2)
15°	.1580	.0675	.0905	–	.0636	.0854	–	.1490
30°	.1000	.0257	.0743	–	.0226	.0654	–	.0880
45°	.0590	.0100	.0490	–	.0087	.0433	–	.0520
60°	.0345	.0035	.0310	–	.0034	.0296	–	.0330
75°	.0210	.0011	.0200	–	.0011	.0209	–	.0220
90°	.0110	–	.0110	–	–	.0150	–	.0150
105°	.0060	–	.0057	.0003	–	.0114	.0006	.0120
120°	.0040	–	.0036	.0004	–	.0081	.0009	.0090
135°	.0030	–	.0025	.0005	–	.00625	.00125	.0075
150°	.0025	–	.00185	.00065	–	.0048	.0017	.0065
165°	.0010	–	.00057	.00043	–	.00345	.00255	.0060
180°	(x2) .0005	–	–	.0005	–	–	.003	.0030 (x2)
	.4995	.2068	.2900	.0028	.1964	.2936	.01	.5000
		41½%	58%	½%	39½%	58½%	2%	

(Front: Sides ratio = 1: 2.5)

DIAGRAM OF PROBABILITIES OF ATTACK AT 15° INTERVALS



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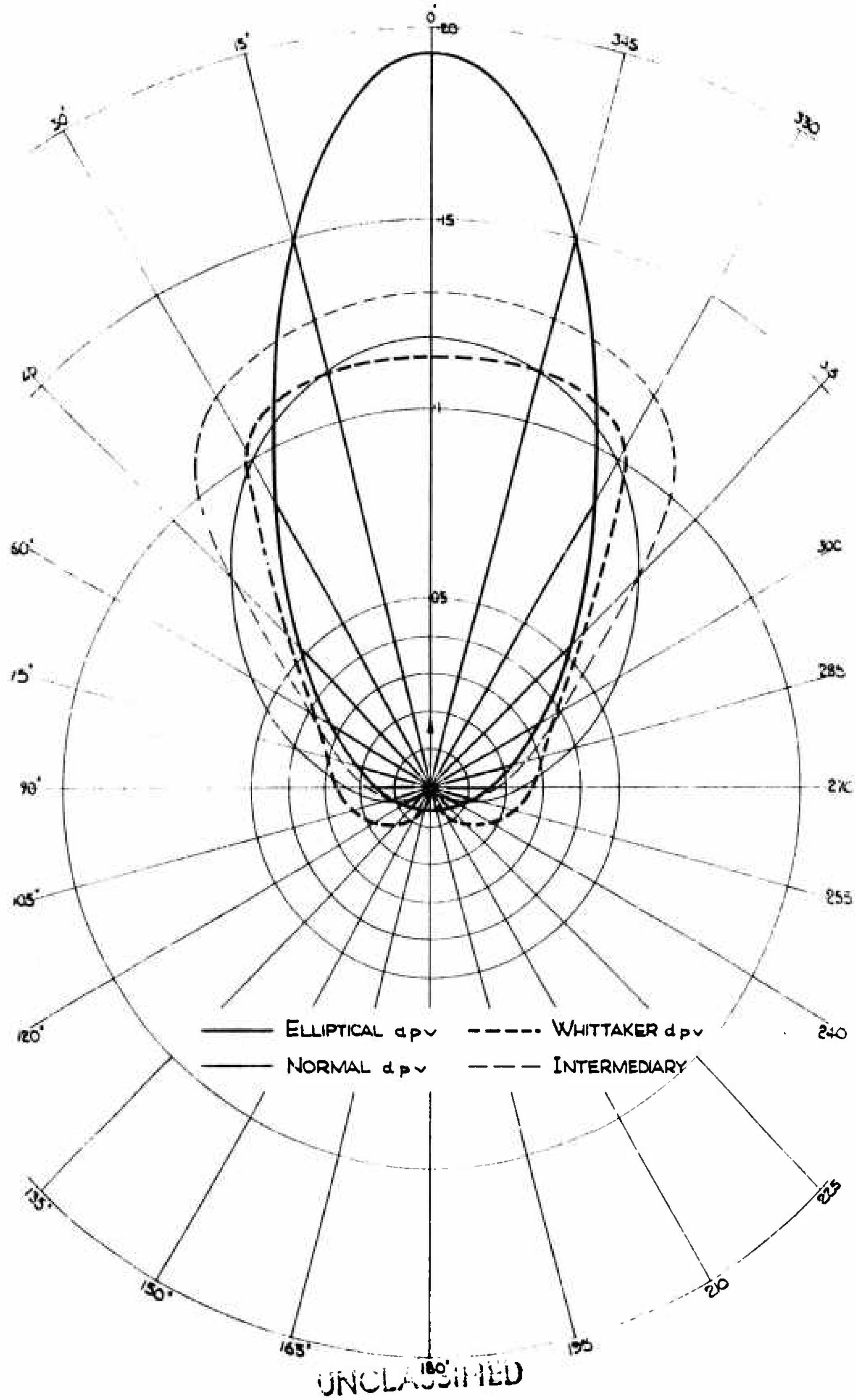
APPX. E.

FIG. E 2.

VECTORIAL DIAGRAM OF PROBABILITIES AT 15° INTERVALS.



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Appendix F

Armour Plate Perforation Performance of Guns

1. In order to obtain comparative performance figures for the guns considered in this paper, it is assumed that all armour is of the same standard as British homogeneous plate and that all Russian AP shot has an equivalent performance to the British 17 pdr APCBC.* It is also assumed that no perforations occur at angles of strike greater than 75° from the normal to the plate.

2. For the calculation of the different thicknesses of armour plate perforated by the various guns and shot at all angles of attack at various ranges the modified De Marre formula is used, i.e.:-

$$\frac{wv^2\cos^2\theta}{Cd^3} = \left[\frac{T}{d}\right]^{1.43}$$

where w = weight of striking shot : θ = angle of strike from the normal to the plate.

v = velocity of strike : d = diameter of perforation.

T = thickness perforated : C = factor depending on θ

3. If T_N and T_θ are the thicknesses of plate perforated at normal and at θ, and C_N and C_θ are the corresponding values of C, then for a given range,

$$\frac{T_\theta}{T_N} = \left[\frac{C_N}{C_\theta}\right]^{0.7} . \cos^{1.4}\theta$$

$$\text{i.e.} \quad \frac{T_\theta}{T_N} = c. \cos^{1.4}\theta$$

where $c = \left[\frac{C_N}{C_\theta}\right]^{0.7}$ and varies with θ.

Thus for a given (or constant) range when the variation of 'c' with θ is resolved the form of the ratio $\frac{T_\theta}{T_N}$ is also determined. It is necessary to resolve the continuous change of 'c' from 0° to 75° since only a few particular values of C have been established for different guns and shot.

4. In order to determine the form of 'c' for all values of θ up to 75°, sets of values of T_θ were calculated from the de Marre formula for separate ranges (i.e. separate values of 'v') using the known values of $\log_{10} C$ supplied by S.A.B. for different angles of attack (θ). Hence values of 'c' were derived by dividing T_θ by $T_N \cos^{1.4}\theta$; then the mean value of 'c' was obtained for each angle θ, distinguishing between the different types of shot i.e. APCBC and APDS.

* The data on Russian guns has, wherever possible, been obtained from the best available intelligence reports; but where no information was available the British equivalents have been used. The discrepancies between the Russian and Ordnance Board figures for perforation are probably due to the use of different criteria or formulae.

5. The mean values of 'c' were then plotted against θ and the best smooth curve drawn through the points to give the form of 'c' with θ. (See Figs F1 and F2 of this Appendix). In the case of the 20 pdr APDS Mk. I, the form of 'c' was made similar to that for the 17 pdr APDS, but conforming to the only known values of C_N and C_{55} for the 20 pdr APDS Mk. I. (See Fig. F2).

6. Using the values of 'c' obtained in Figs. F1 and F2 and multiplying by $\cos^{1.4}\theta$ smooth graphs of $\frac{T_\theta}{T_N}$ were constructed for both APCBC and APDS shot. (See Figs. F5 and F6). These graphs were then utilised to produce the required curves of thickness perforated at all angles of attack for ranges of 600 yds., 1000 yds, and 1500 yds., from the Ordnance Board figures of normal perforation. (See Figs. F7, F8, F9 and F10).

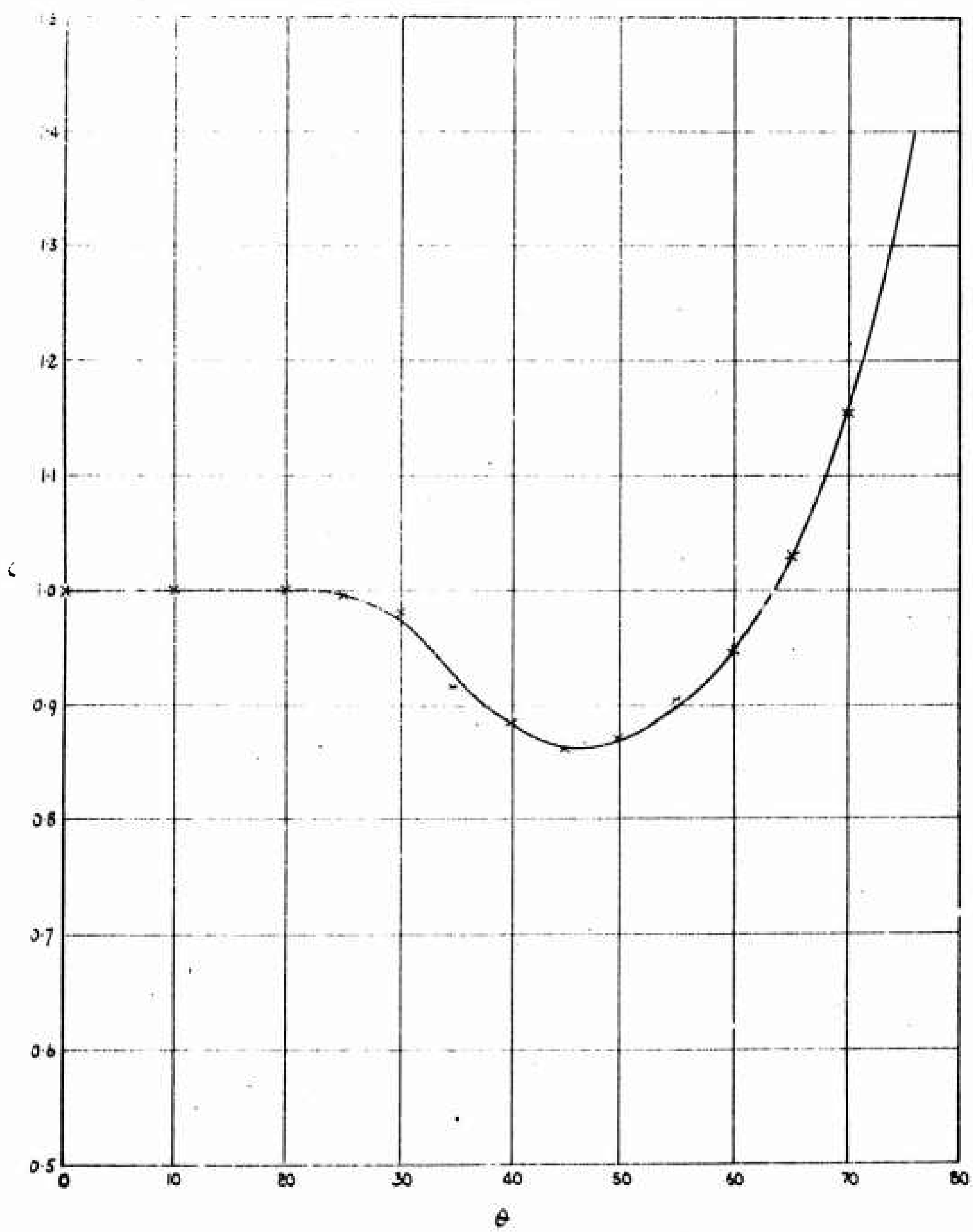
7. In a similar manner using the 17 pdr APCBC values of 'c', required thickness/angle relationships were obtained for the Russian 85 m/m APBC and the 122 m/m APCBC. (See Figs. F11 and F12).

8. As a matter of interest a graph was constructed for 'C' against 'θ', from the values of 'c' given in Fig. 1 and using known values of 'C_N'; and a comparison made with the graph of 'C' given in F.V.D.D. Report No. M9/... (See Figs. F3 and F4). It will be noted that the variations between the two graphs are small, the larger differences lying between 45° and 50°.

c′ FOR 77%m & 17 PDR. APCBC.

(also used for the Russian 85% APCBC & 122% APCBC
the U.S. 75% APC & German 75%)

$$c' = \left[\frac{C_N}{C_G}\right]^{\cdot 7}$$



Appx. F.
Fig. F 2.

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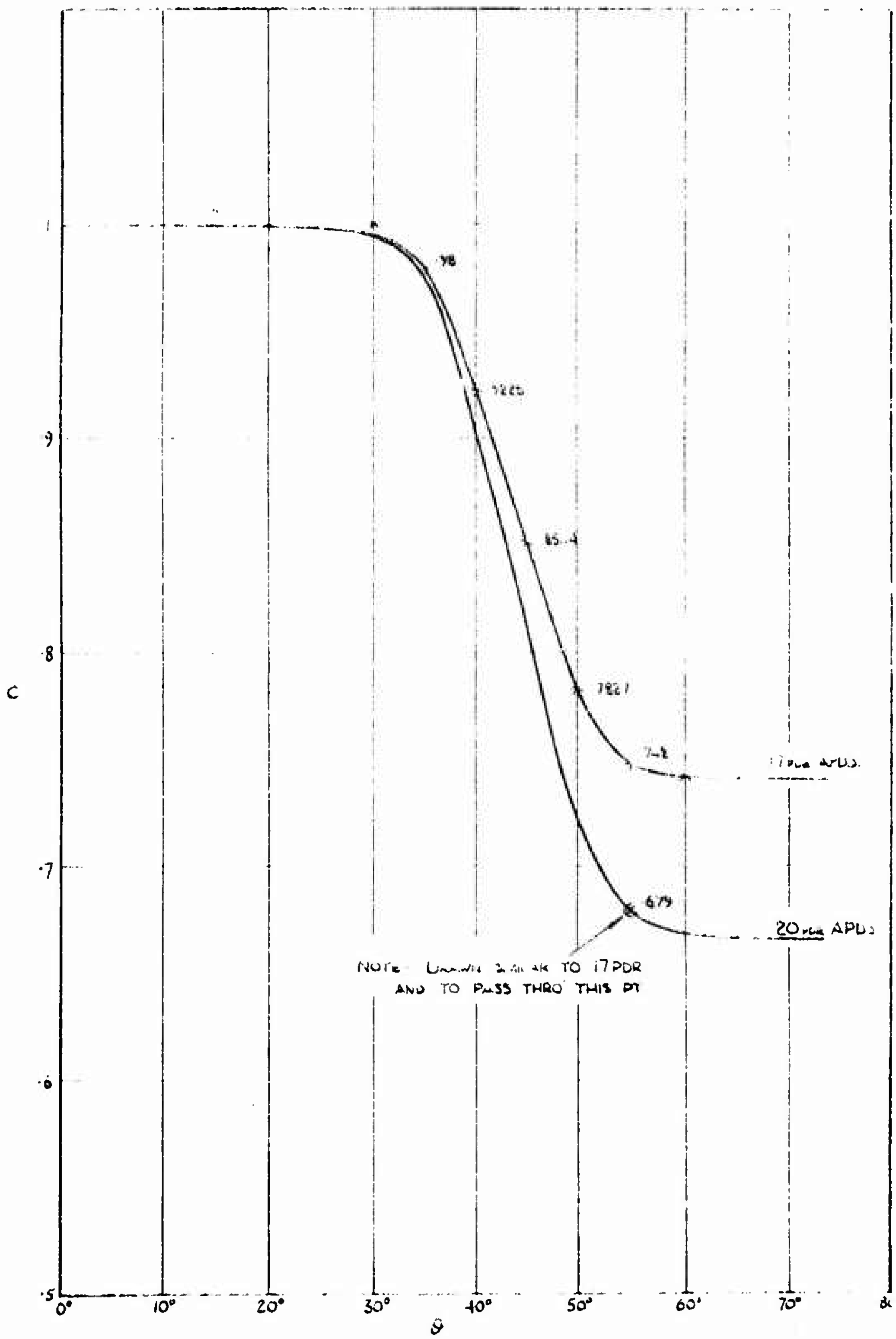
C′ FOR 17 PDR APDS & 20 PDR APDS Mk 1

$$C = \left[\frac{C_N}{C_\theta}\right]^{\cdot 7}$$



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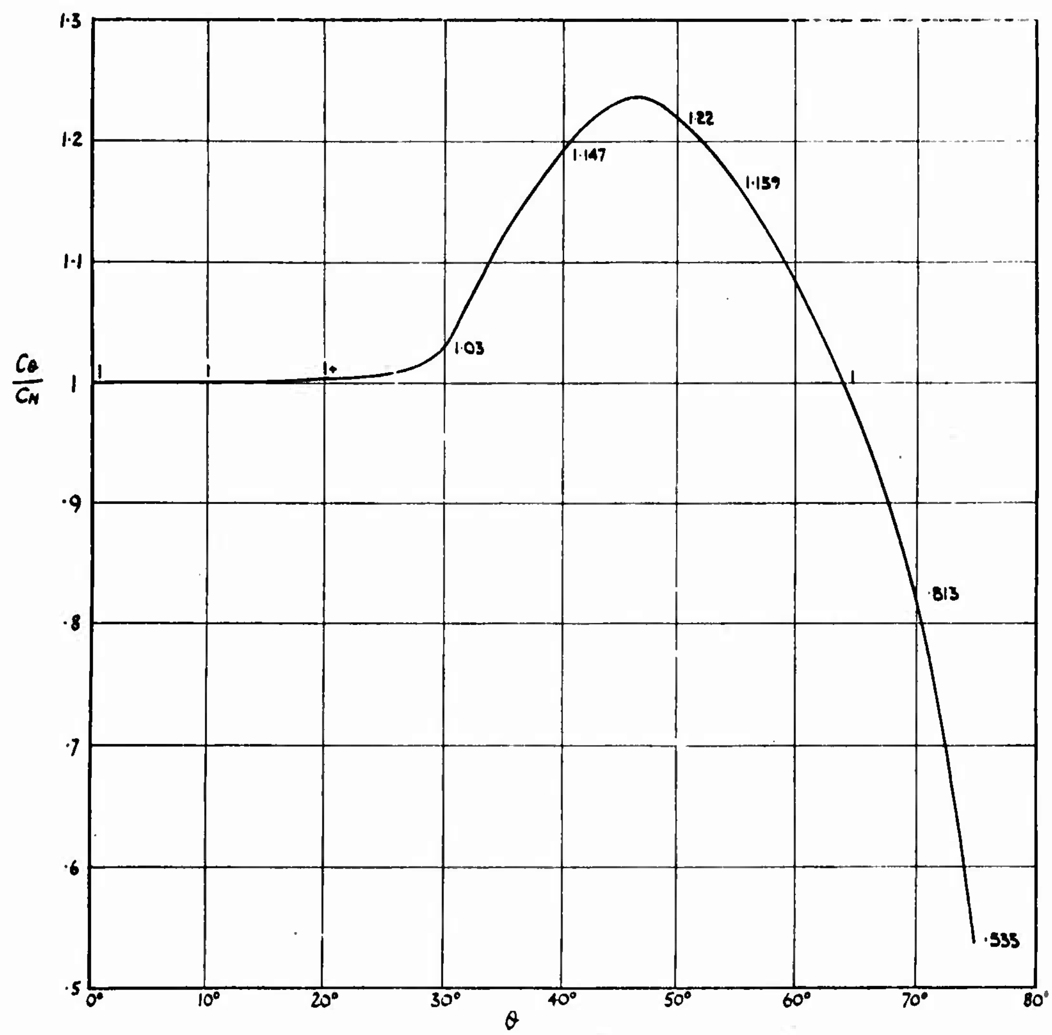
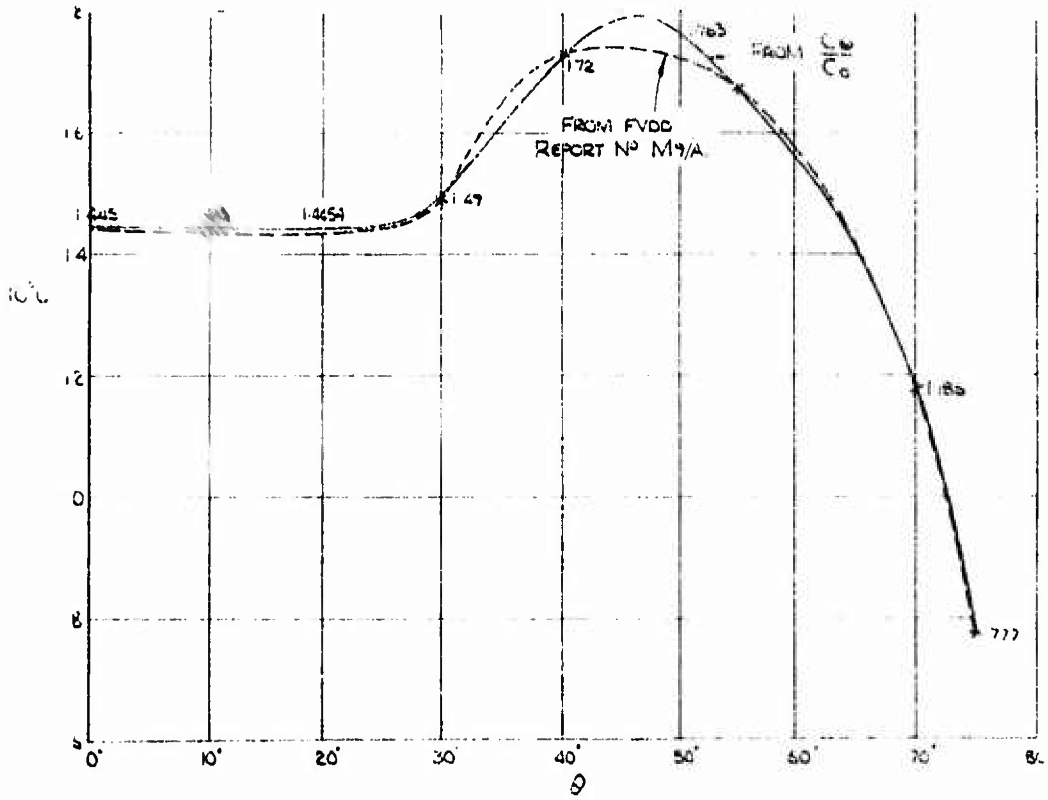
$\frac{C_\theta}{C_N}$ FOR 77mm & 17 PDR APCBC.



APPX. F.
FIG. F 4

C FOR 77% & 17 PDR APCBC

$C_N = 1{\cdot}445 \times 10^6$



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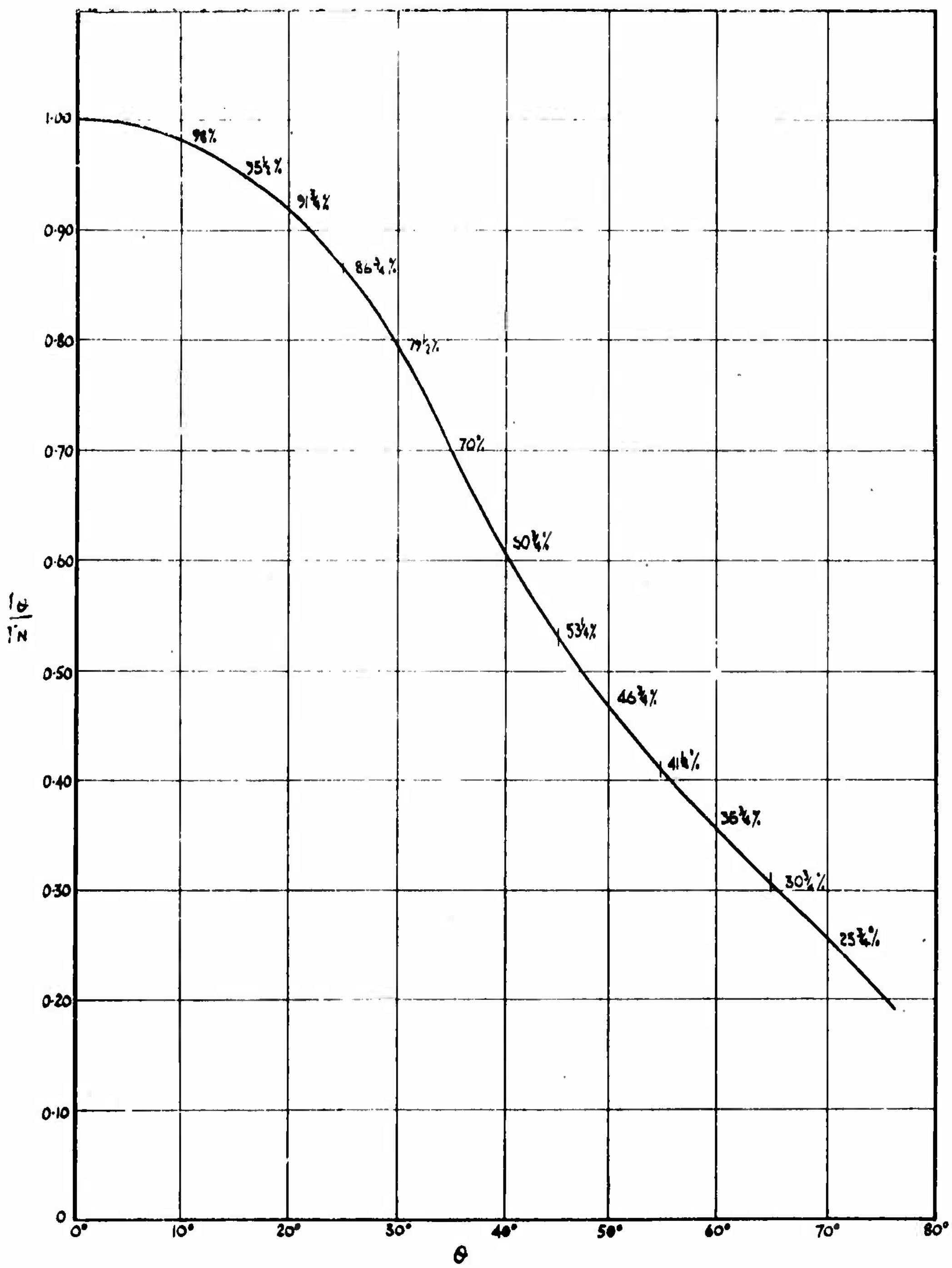
APPX. F.
FIG. F 5.

77% & 17 PDR. APCBC.

(also used for the 85% APBC & 122% APCBC the U.S 75% APC & German 75%)



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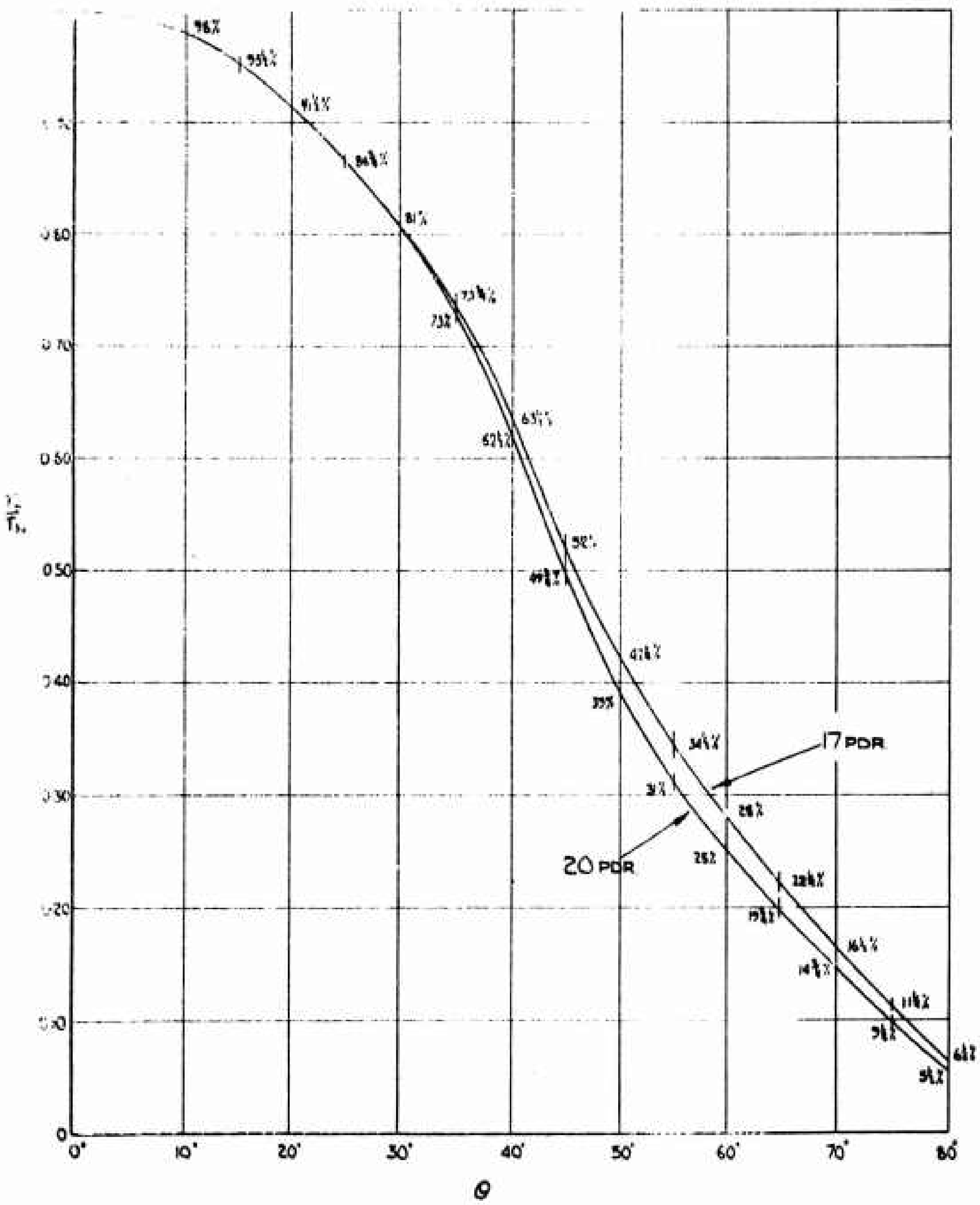
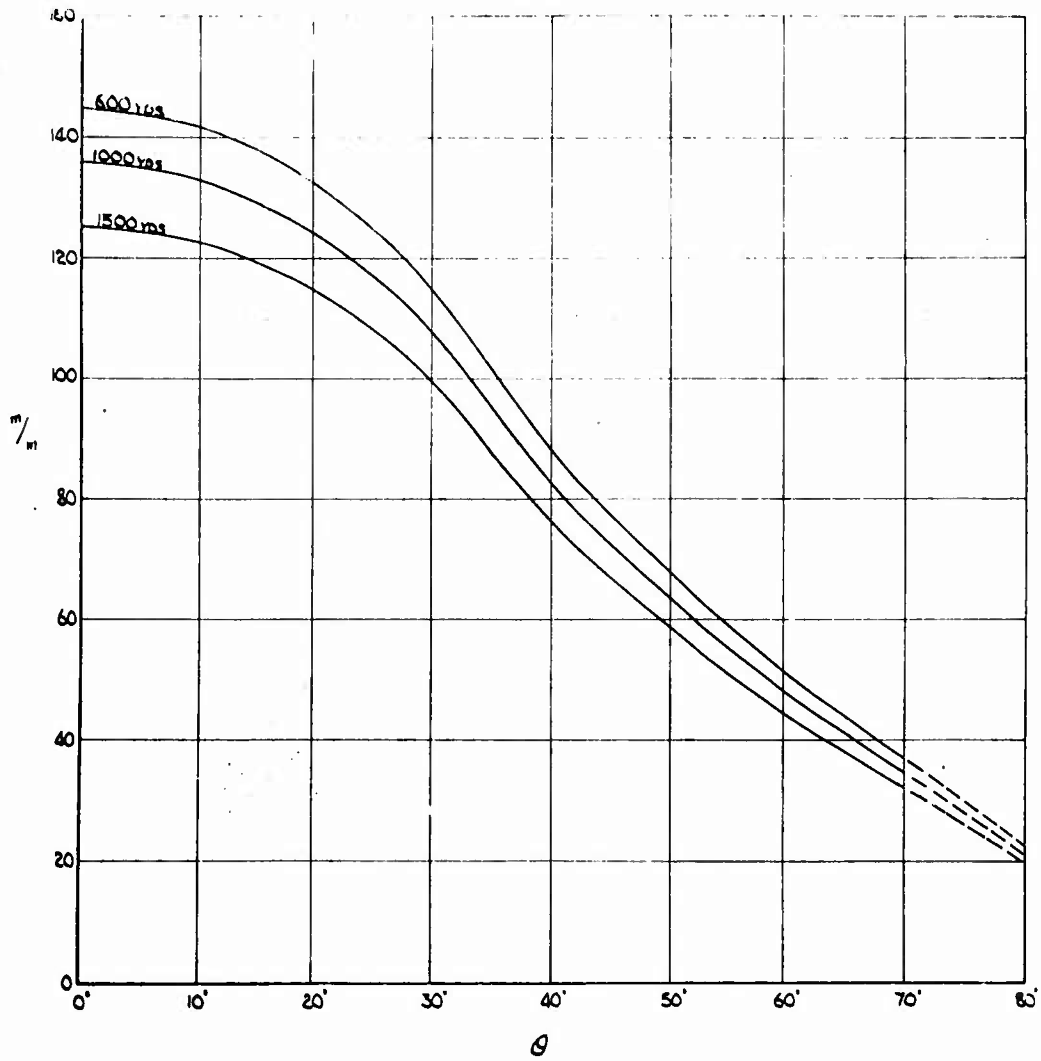
APPX. F
FIG. F 6.

17 PDR APDS & 20 PDR APDS. MK. 1.



APPX. F.
FIG. F 7.

77 m/m APCBC.



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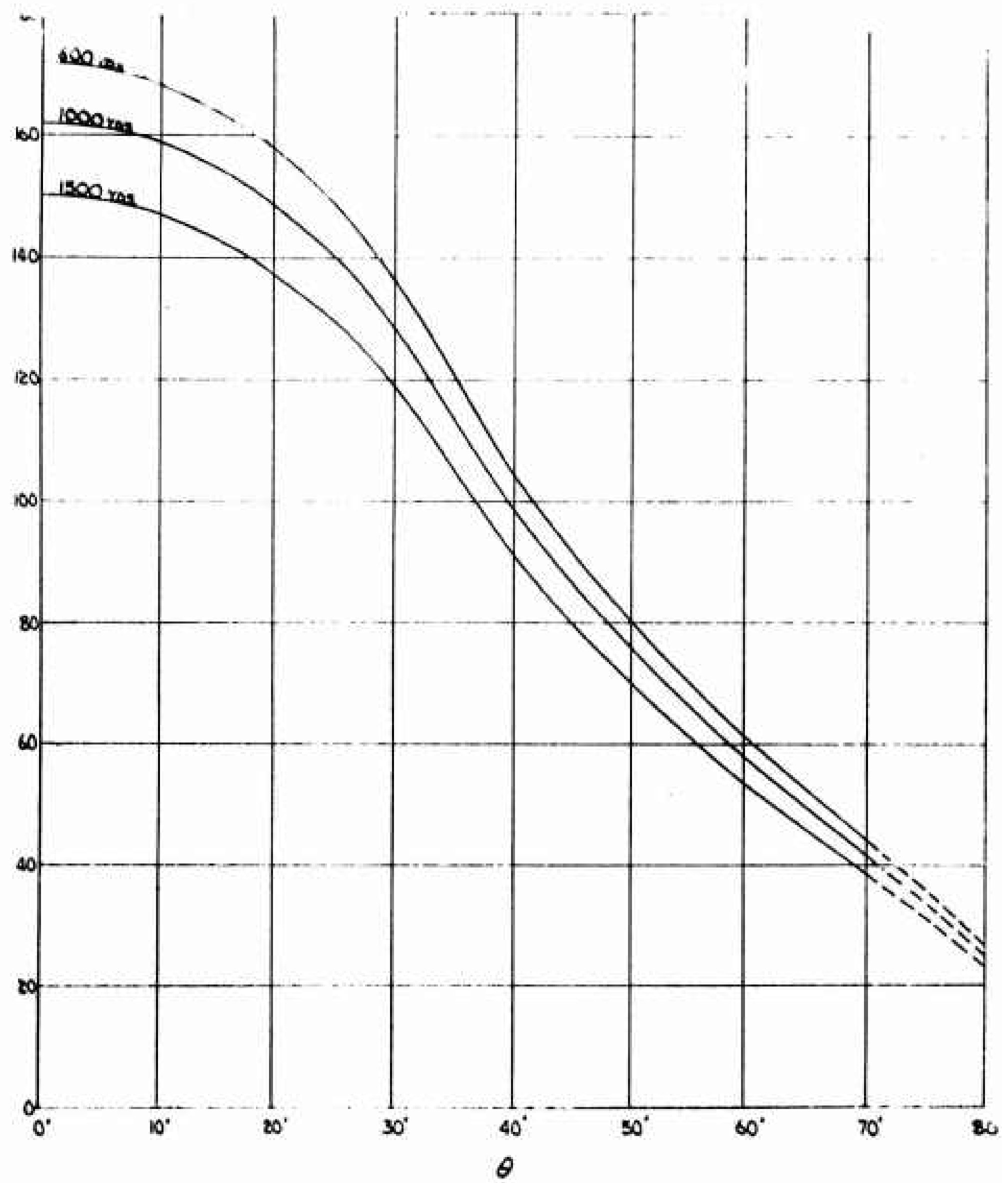
APPX F.

FIG. F 8.

17 PDR. APCBC.



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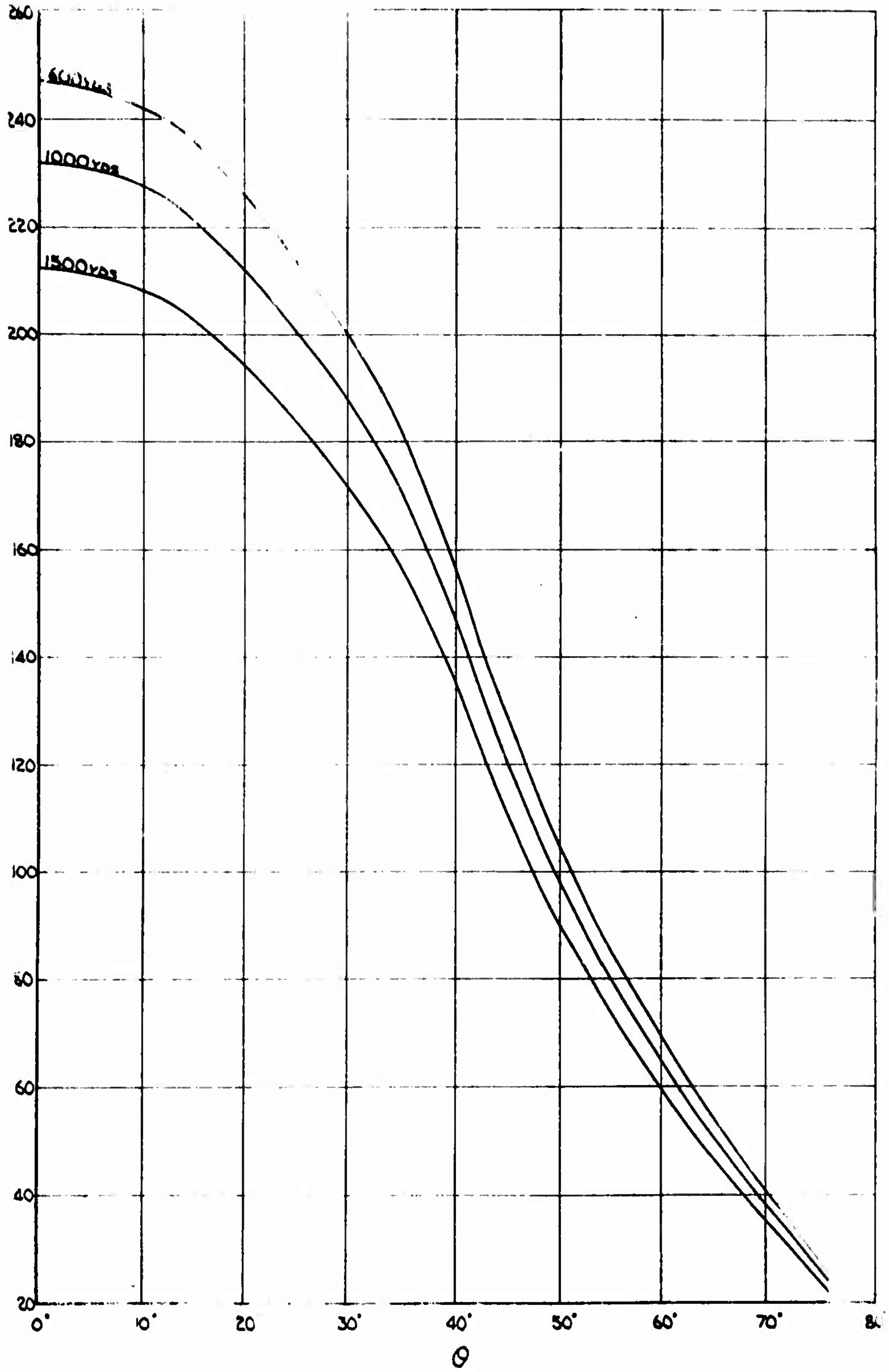
17 pdr. APDS.



Appx I
Fig I 10

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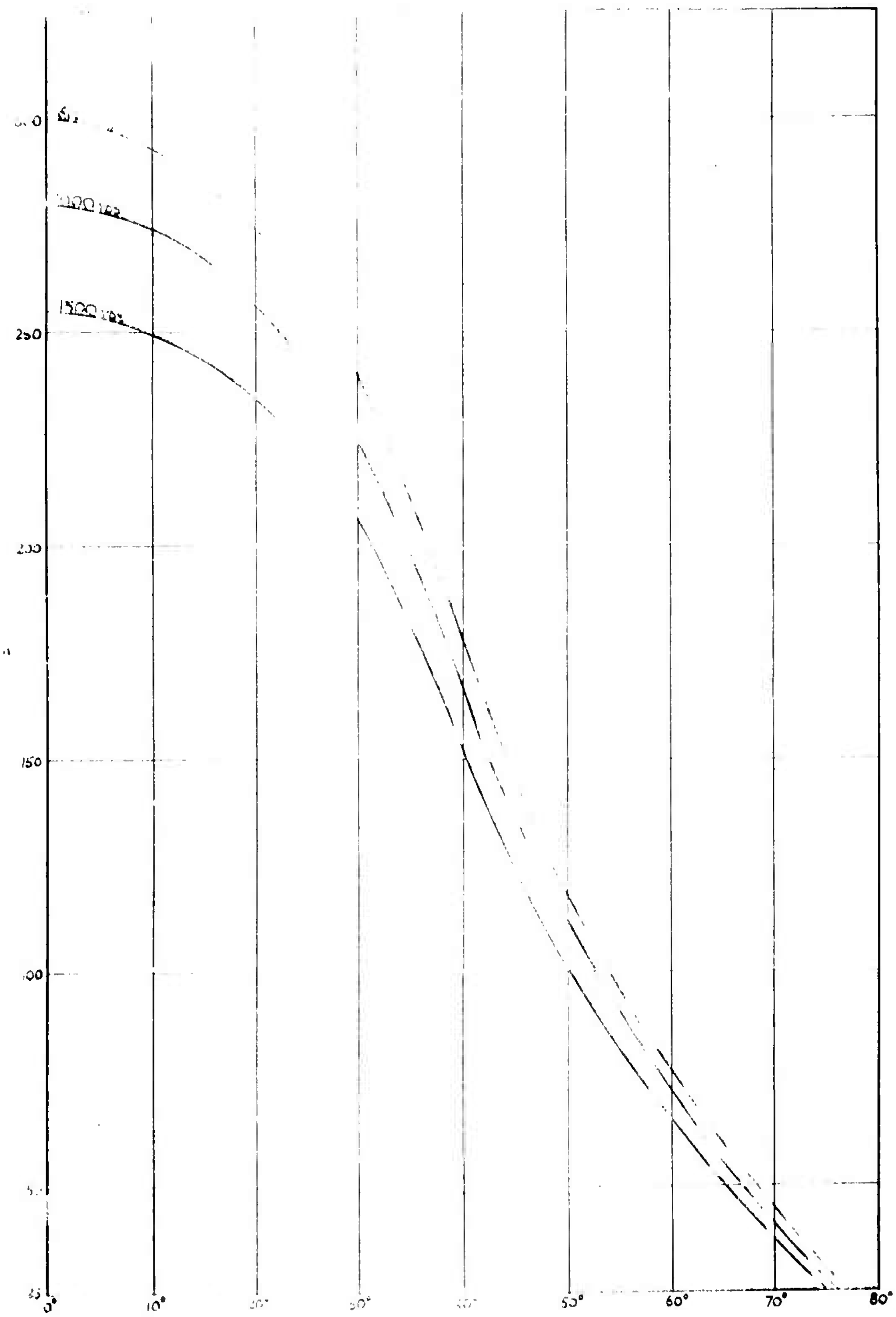

APPX. F.
FIG. F11.

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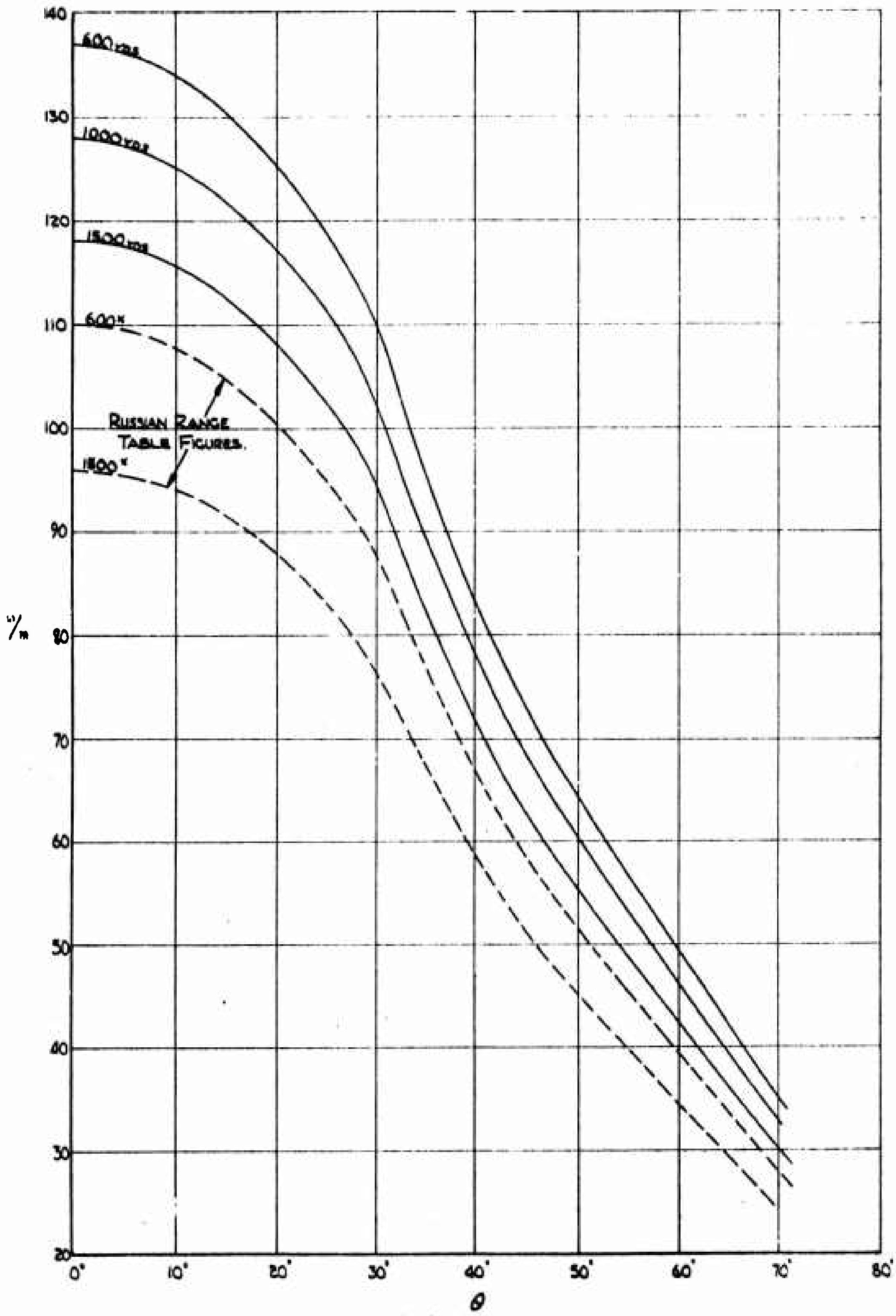
RUSSIAN 85% APBC.

(DERIVED FROM 17PDR. APCBC.)

NB: Ordnance Board Figures for C_N used.
(Russian figures indicated in chain)



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APPX F
FIG. F 12

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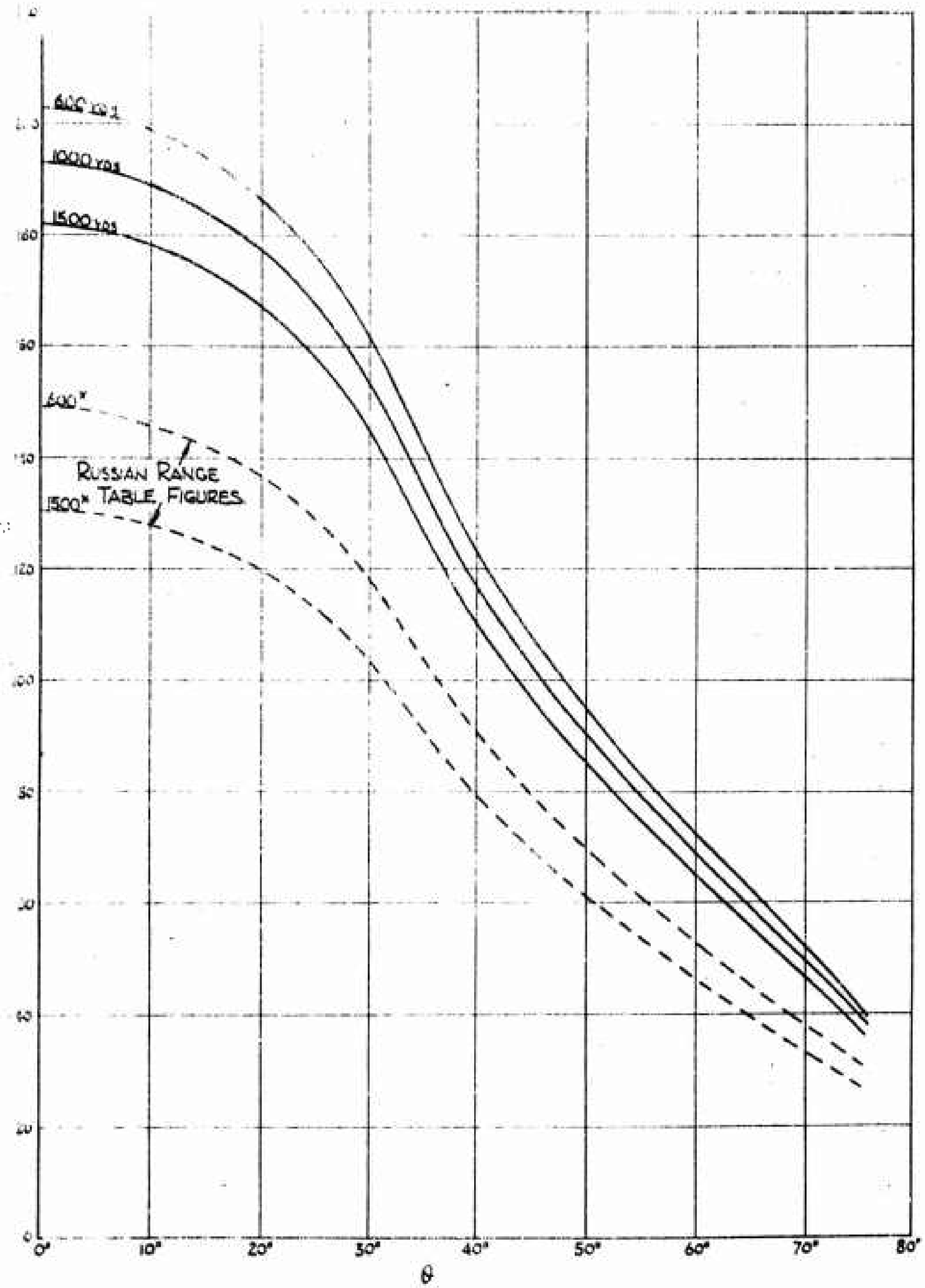
RUSSIAN 122 m/m APCBC.

(DERIVED FROM 17 PDR. APCBC.)

N.B. Ordnance Board Figures for C_N used
(Russian Figures indicated in chain)



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Appendix G

Accuracy of Guns in Tanks

1. The inaccuracies which lead to a shot fired from a gun not passing through the point at which the gun is aimed by means of the sight incorporated in the gun mounting are as follows:-

i. Round to round dispersion of the gun.

ii. Occasion to occasion variation in jump.

iii. Error in boresighting the gun during zeroing of the sight and gun.

iv. Laying error between aiming point of sight and target.

v. Mechanical errors between gun, mounting and sight.

vi. Error due to the size of the interval of adjustment of sight graticule.

The mean jump of the gun is eliminated by zeroing the sight and gun and any personal error of the gunner is eliminated at the same time, provided that the same man lays the gun for zeroing and for effective fire. Reports indicate that even when different men zero and lay the gun for effective fire the difference in personal errors is negligible.

2. If the standard deviations of the above errors are denoted as follows:-

i. σ_g = round to round dispersion

ii. σ_j = occasion to occasion variation in jump

iii. σ_b = boresighting error

iv. σ_1 = laying error

v. σ_m = mechanical errors and sight movement

vi. a = actual T and E clicker adjustment interval

then the manner in which these errors are introduced during the "shooting in" or "zeroing" of the gun and the effective first round are as detailed in subsequent paragraphs. It is assumed that the warmer/cleaner rounds have been fired previously and that 5 rounds are used for zeroing.

3. Then the error introduced during the initial boresighting is due to the accuracy of the boresighting equipment (σ_b).

4. When firing a zeroing round the errors introduced are due to the dispersion of the gun (σ_g), the layer (σ_1), and the mechanical errors (σ_m) i.e. the error is $\sqrt{\sigma_g^2 + \sigma_1^2 + \sigma_m^2}$; but if 5 rounds are used to determine the mean point of impact (m.p.i.), then the error is reduced by a factor of $\sqrt{5}$ and the error becomes $\sqrt{\frac{\sigma_g^2 + \sigma_1^2 + \sigma_m^2}{5}}$. This error is therefore included with the boresighting error to give a total error of $\sqrt{\sigma_b^2 + 0.2\sigma_g^2 + 0.2\sigma_1^2 + 0.2\sigma_m^2}$.

5. The sight is then finally laid onto the target hull thus introducing a further laying error (σ_1), hence a total error at this stage of $\sqrt{\sigma_b^2 + 0.2\sigma_g^2 + 1.2\sigma_1^2 + 0.2\sigma_m^2}$.

6. The adjustment of the sight graticule onto the m.p.i. of the zeroing rounds can be carried out only with that accuracy permitted by the fineness of the adjusting interval, the error of which is measured by $\frac{a}{\sqrt{12}}$ (see Note G1 attached to this Appendix). This adjustment also introduces another laying error (σ_1). Thus the total error is now $\sqrt{\sigma_b^2 + 0.2\sigma_g^2 + 2.2\sigma_1^2 + \frac{a^2}{12} + 0.2\sigma_m^2}$ which represents the "Zeroing Error", and it is assumed that zeroing is always carried out prior to battle and the gun enters battle with a total error given by the Zeroing Error.

7. The additional errors, excepting range estimation, that are introduced with the first effective round are due to the probable deviation of the m.p.i. from its mean position i.e. occasion to occasion variation in jump (σ_j), together with the dispersion of the gun (σ_g) and the laying error for that round (σ_1). A further error which can be considered a residual error due to slight mechanical imperfections causing small relative movements between sight, mounting and gun (σ_m) has also to be accounted for at this point, giving a Round Error of $\sqrt{\sigma_j^2 + \sigma_g^2 + \sigma_1^2 + \sigma_m^2}$.

8. Thus the total error of the first effective round due to the Zeroing Error, the Round Error and the Range Error is

$$\sqrt{3.2\sigma_1^2 + 1.2\sigma_g^2 + \sigma_b^2 + \sigma_j^2 + 1.2\sigma_m^2 + \frac{a^2}{12} + \sigma_r^2}$$ (see Fig G1).

9. The values given in Table G1 of this Appendix for the various errors have been obtained from the published data on British guns and their trials; where figures are obtainable on the Russian equipments from Intelligence sources these have been used, otherwise the equivalent British figures have been inserted.

a. σ_g and σ_j are peculiar to the particular guns.

b. σ_b has been obtained for the latest boresighting instrument, and the same figures used for the Russian guns.

c. σ_1 depends upon the magnification of the sighting telescope. No variation has been made to account for stress and strain of battle which might alter this figure.

d. σ_m was determined as a residual error from an overall figure for an equipment after all the other incidental errors had been accounted for; the same value has been maintained for all equipments both British and Russian. Note:- This error affects only the elevation and does not appear in the line or traverse error.

c. 'a' is the degree or interval of adjustment provided by the T and A knobs of the respective sighting telescopes or periscopes for moving the sight graticule.

10. Table G1 of this Appendix lists the individual errors for all equipments and gives the overall probable Error: in addition the range errors obtained in Appendix D have been listed for inclusion with the elevation error to obtain total standard deviations for the various equipments at the three desired ranges. (Range error not affecting the line or traverse error).

Note:- G1:- Sight Graticule Adjustment Interval.

A step adjustment with an interval of magnitude 'a' provides a uniform or rectangular distribution over that interval. Thus if 'y' is distributed in a rectangular distribution between $-\frac{a}{2}$ and $+\frac{a}{2}$,

Then Variance $(y) = E\ (y^2)$

$$= \int_{-\frac{a}{2}}^{\frac{a}{2}} \frac{1}{a} y^2 dy.$$

$$= \left[\frac{y^3}{3a}\right]_{-\frac{a}{2}}^{\frac{a}{2}}$$

$$= \frac{a^2}{12}$$

If we now consider an normal distribution of 'x' with variance σ^2 and mean 'm'; then the combined distribution of x and y, say z is given by

$$\text{Variance } (z) = \text{Variance } (x) + \text{Variance } (y)$$

$$= \sigma^2 + \frac{a^2}{12}$$

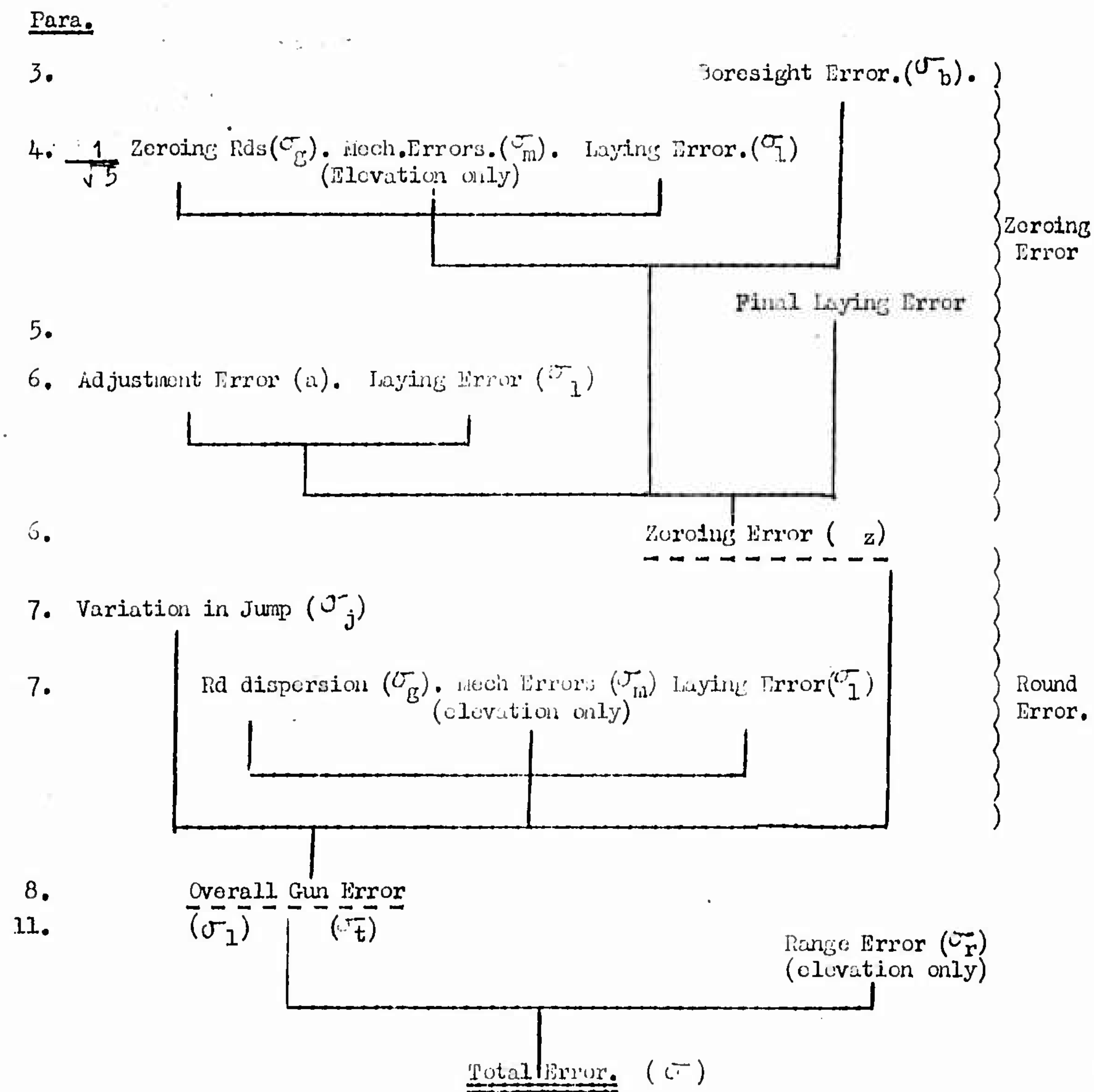
$$\text{and Mean } (z) = \text{Mean } (x) + \text{Mean } (y)$$

$$= m.$$

Thus the square of the error introduced by the T and A adjustment interval is of a value $\frac{a^2}{12}$ which can be summed with the square of the standard deviations of other errors which are distributed normally. The resulting combined distribution is of course not quite normal: the departure from normality depending upon the relative values of 'a' and 'σ'.

Fig. G.1.

Errors affecting Accuracy



$$\sqrt{1.2\sigma_g^2 + \sigma_j^2 + 3.2\sigma_l^2 + \sigma_b^2 + \frac{a^2}{12} + 1.2\sigma_m^2 + \sigma_r^2}$$

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Appx G.

Table G1(a)

Centurion 20 pdr:- Errors in mins. at Gun:-

m.v. = 4500 f.s. APDS Mk.I C_o = 1.

x 6 Telescope. Rate of fire 12/rds/min.

	Elevation	Traverse
m.d. gun	.7'	.9'
m.d. jump	.3'	0
m.d. lay	.13'	.13'
σ_g	.875	1.125
σ_j	.375	0
σ_l	.162	.162
σ_b	.27	.27
a	1	1 (1' adjust)
$1.2\sigma_g^2$	.920	1.525
σ_j^2	.141	0
$3.2\sigma_l^2$	.083	.083
σ_b^2	.073	.073
$a^2/12$	.083	.083
$1.2\sigma_m^2$	.439	–
Sum of Squares	1.739	1.764
σ	1.32'	1.326'
90% zone	4.35'	4.4'

Range Errors:- (on Vert target)

	600^x	1000^x	1500^x
Visual Error (250r)	150^x	250^x	375^x
Rf Error. ($15r^2$)	5.4^x	15^x	33.75^x
Angle of strike	6'	11'	17'
tan angle	.00175	.00321	.00495

Error in ft on Target and in mins at gun:-

V.	.8 ft (1.54')	2.4 ft (2.77')	5.6 ft (4.3')
Rf.	.03 ft (.058')	.15ft (.173')	.5 ft (.384')

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Table G1(b)

Comet 77 m/m:- Errors in mins at Gun.

m.v. = 2575 APCBC C_o = 3.

= 3400 APDS C_o = 1.

x 3 Telescope. Rate of fire 12 rds per min.

	APCBC		APDS	
	Elevation	Traverse	Elevation	Traverse
m.d. gun	.6'	.6'	1.2'	1.1'
m.d. jump	.6'	.7'	1.3'	1.0'
m.d. lay	.25'	.25'	.25'	.25'
σ_g	.75'	.75	1.5	1.375
σ_j	.75	.875	1.625	1.25
σ_l	.31	.31	.31	.31
σ_b	.27	.27	.27	.27
a (1' adjust)	1	1	1	1
$1.2\sigma_g^2$	.677	.675	2.7	2.275
σ_j^2	.564	.766	2.65	1.570
$3.2\sigma_l^2$	.307	.307	.307	.307
σ_b^2	.073	.073	.073	.073
$a^2/12$	.083	.083	.083	.083
$1.2\sigma_m^2$	.439	-	.439	-
Sum of Squares	2.143	1.904	6.252	4.308
σ	1.463'	1.38	2.5'	2.08
90% zone	4.83'	4.55'	8.26'	6.85'

Range Errors:- (on Vert target)

	600^x	1000^x	1500^x
APCBC:-			
Angle of strike	18'	31'	49'
tan angle	.00524	.00902	.01425
V.	2.4 ft (4.61')	6.8 ft (7.85')	16 ft (12.3')
Rf.	.09 ft (.173')	.4 ft (.461')	1.5 ft (1.15')
APDS:-			
Angle of strike	9'	17'	28'
tan angle	.00262	.00495	.00814
V.	1.18 ft (2.27')	3.71 ft (4.28')	9.17 ft (7.05')
Rf.	.0425 ft (.0817')	.223 ft (.257')	.825 ft (.634')

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Table G1(c)

J.S.3. 122 $^{m}/_{m}$:- Errors in mins at Gun

m.v. = 2562 f.s. APCBC C_o = 4.

x 4 hinged telescope: Rate of fire 3 rds per min.

Assume same accuracy as 17 pdr APCBC and same mech.errors.

	Elevation	Traverse	
m.d. gun	.7'	.9'	(as for 17 pdr)
m.d. jump	.6'	.8'	(" " ")
m.d. lay	.2'	.2'	(for x 4 tel)
σ_g	.875	1.125	
σ_j	.75	1.0	
σ_l	.25	.25	
σ_b	.27	.27	(as for UK & US)
a	3.375	3.375	(1 mil adjust)
$1.2\sigma_g^2$	.920	1.525	
σ_j^2	.563	1.0	
$3.2\sigma_l^2$	.200	.200	
σ_b^2	.073	.073	
$a^2/12$	.946	.946	
$1.2\sigma_m^2$	.439	-	(as for UK & US)
Sum of Squares	3.141	3.744	
σ	1.77'	1.937'	
90% zone	5.85'	6.4'	

Later:- Range tables give σ_g 1.0' and 1.0' i.e. same as mean of above.

$\therefore \sigma$ 1.85' 1.85'

Range Errors:- obtained from graph deduced from 77 $^{m}/_{m}$ APCBC (same m.v.) later confirmed from Russian Range Tables.

	600^x	1000^x	1500^x
V.	2.3 ft (4.42')	6.3 ft (7.27')	14.3 ft (11.0')
Rf.	.09 ft (.173')	.4 ft (.461')	1.4 ft (1.075')

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Appx G.

Table G1(d)

T.34 85 m/m:- Errors in mins at Gun.

m.v. = 2600 f.s. AP. C_o = 1.66. APBC C_o = 3.0

x 2.5 hinged telescope. Rate of fire 7-8 rds. per min.

For AP:-	Elevation	Traverse	
m.d. gun	1.0'	1.0'	
m.d. jump	.6'	.8'	(as for 17 pdr)
m.d. lay	.25'	.25'	(for x 2.5 tel)
σ_g	1.25	1.25	
σ_j	.75	1.0	
σ_l	.32	.32	
σ_b	.27	.27	(as for UK & US)
a	3.375	3.375	(1 mil adjust)
$1.2\sigma_g^2$	1.875	1.875	
σ_j^2	.563	1.0	
$3.2\sigma_l^2$	.328	.328	
σ_b^2	.073	.073	
$a^2/12$	.946	.946	
$1.2\sigma_m^2$	.439	-	(as for UK & US)
Sum of Squares	4.224	4.222	
$\therefore\ \sigma$	2.056'	2.055'	
90% zone	6.8'	6.8'	

For APBC:- take σ_g = 1.0' and 1.0' (as for 122 m/m)

	Elevation	Traverse
$\therefore\ \sigma$	1.882'	1.882'
90% zone	6.2'	6.2'

Range Errors:- taken the same as 77 m/m APCBC (same C_o and m.v.)

	600^x	1000^x	1500^x
V.	2.4 ft. (4.61')	6.8 ft. (7.85')	16 ft. (12.3')
Rf.	.09 ft. (.173')	.4 ft. (.461')	15 ft. (1.15')

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Appendix H

Plate Dimensions and Vulnerable Areas of British and Russian Tanks.

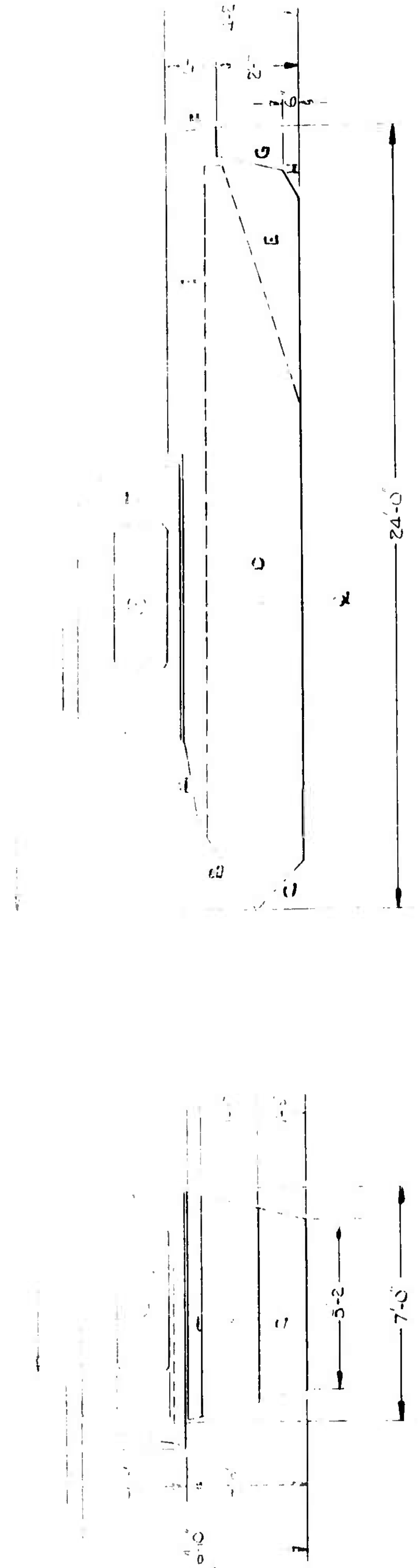
1. The overall and individual armour plate dimensions of the turrets and hulls of the Centurion Mk. 3, Comet, J.S.3 and T34/85 are given in Figs. H1 to H4 of this Appendix.

2. The resulting plate areas presented by each tank at intervals of 15° around the tank are listed in Tables H1 to H4, together with the angle of attack of each plate at each aspect. Indicated in the tables are also those plates which are vulnerable to attack by the guns and shot specified at the head of each table at the ranges of 600 yds., 1000 yds. and 1500 yds., these results being obtained from the perforation graphs in Appendix F.

3. In Fig. H5 a graphical representation is given of the variation in the vulnerable areas presented by Comet to 85 m/m APBC attack at the two ranges of 600 yds. and 1500 yds. Whereas in Fig. H6 the changes in the vulnerable areas presented by J.S.3. to both 17 pdr APCBC and 20 pdr APDS Mk. 1 attack at 1000 yds. are illustrated.

Appx. H.

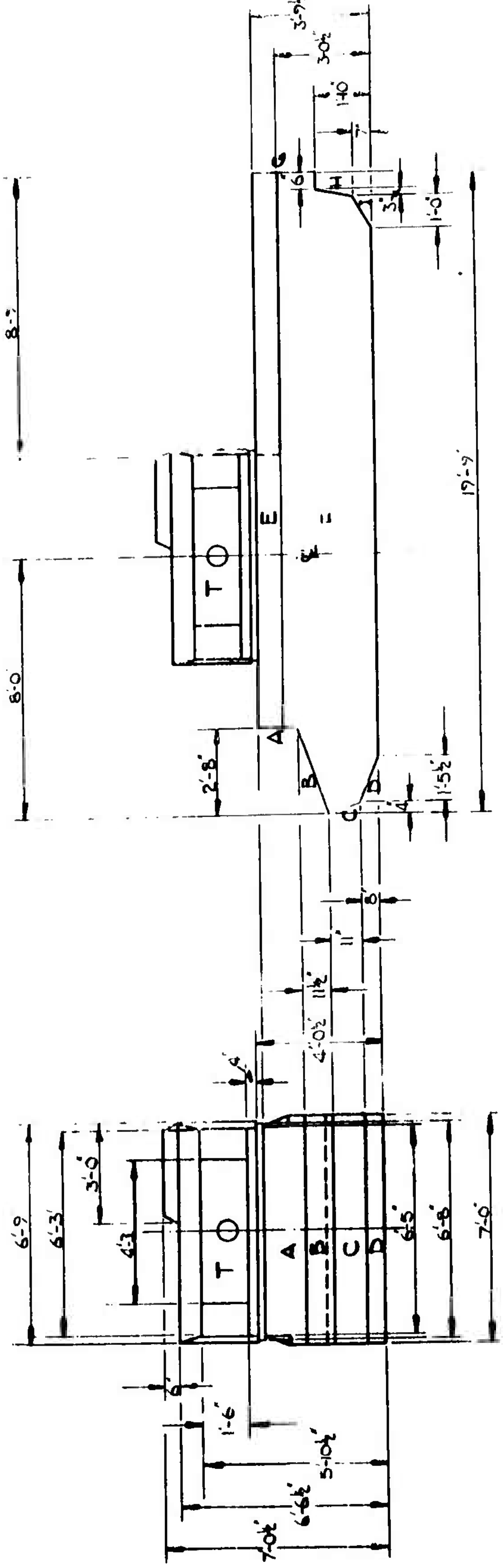
Fig. H 1.



Centurion 3. Plate Diagram

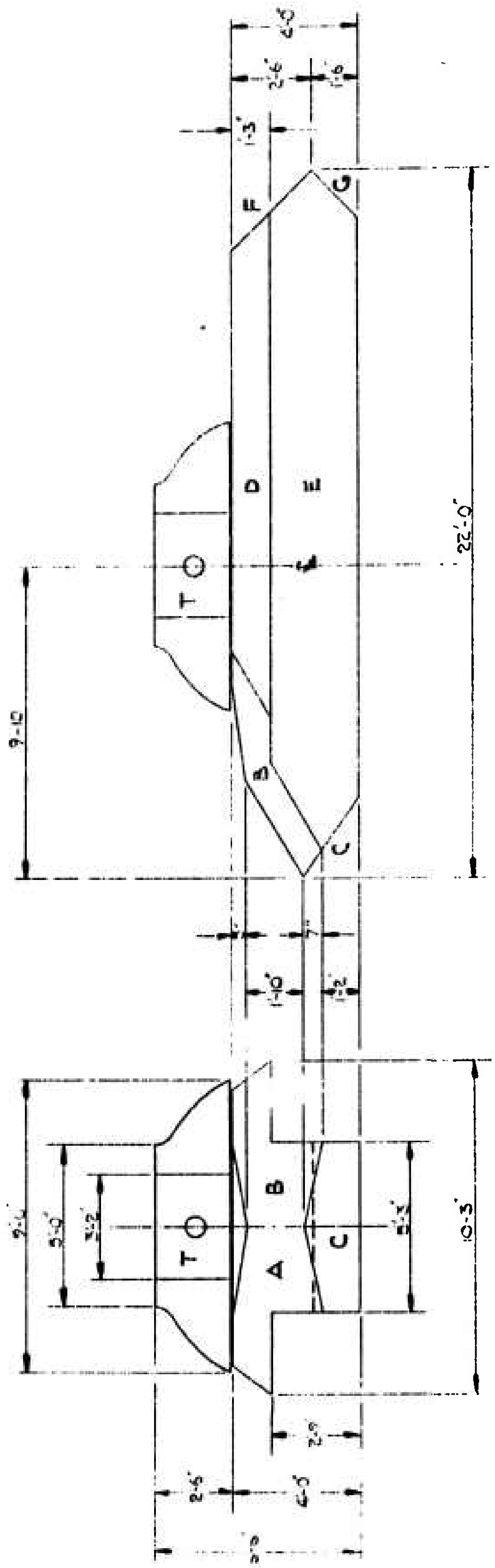
Appx. H.
Fig. H 2.

COMET. PLATE DIAGRAM.

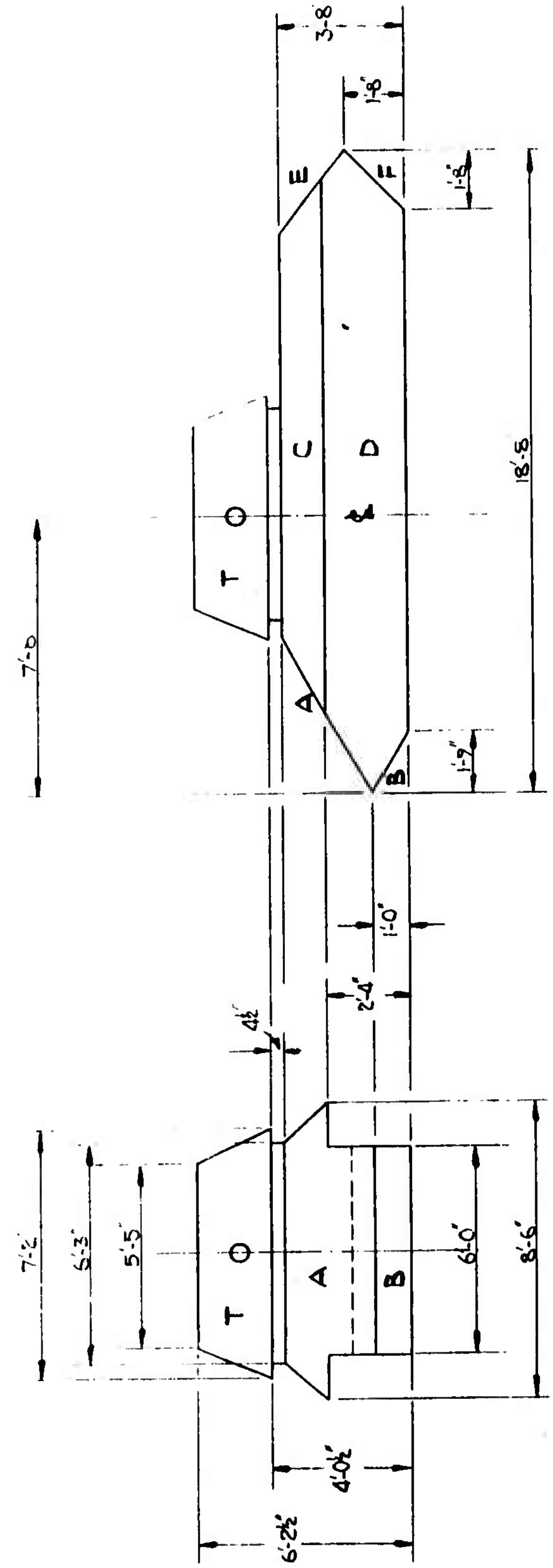


APPX. H.
FIG. H3.

J.S. 3 PLATE DIAGRAM.



Appx. H.
Fig. H4



T 34-85. Plate Diagram.

VULNERABLE PLATES OF CENTURION [illegible]

Aspect	Range in 100 x	Plate A 29mm at 80° – Area in sq.ft. & Angle of Attack	Plate A 88/85/122	Plate B 76 mm at 55° – Area in sq.ft. & Angle of Attack	Plate B 88/85/122	Plate C 76 mm at 45° – Area in sq.ft. & Angle of Attack	Plate C 88/85/122	Plate D 51 + 6 mm at 1[illegible]° – Area in sq.ft. & Angle of Attack	Plate D 88/85/122	Plate E 51 mm at 12° – Area in sq.ft. & Angle of Attack	Plate E 88/85/122	Plate F 38 mm at 7° – Area in sq.ft. & Angle of Attack	Plate F 88/85/122	Plate G 38 mm at 12° – Area in sq.ft. & Angle of Attack	Plate G 88/85/122	Plate H 20 mm at 60° – Area in sq.ft. & Angle of Attack	Plate H 88/85/122	Turret 152 mm (25.75 sq.ft.) – Vulnerable Area sq.ft.	Turret 88/85/122	Total Vulnerable Area 88	Total Vulnerable Area 85	Total Vulnerable Area 122
0°	6	1.25 80°		11.9 55°	V V	8.85 45°	V V											11.0	V	20.75	-	31.75
	10				V V		V V												V	20.75	-	31.75
	15				V		V V												V	20.7[illegible]	-	19.85
15°	6	1.21		11.5 56°	V V	8.54 47°	V V	13.5 75°		7.28 75°								11.0	V	20.04	-	31.04
	10				V V		V V												V	20.04	-	31.04
	15				V		V V												V	20.04	-	19.54
30°	6	1.08		10.3 60°		7.66 52°	V V	26.1 61°	V V	14.1 61°	V V							11.0	V	47.86	-	58.86
	10						V V		V V		V V								V	47.86	-	58.86
	15						V V		V V		V V								V	47.86	-	58.86
45°	6	0.89		8.42 66°		6.25 60°	V	36.9 46°	V V	19.9 46°	V V V							11.0	V	60.35	56.80	67.80
	10								V V V		V V V								V	56.80	56.80	67.80
	15								V V V		V V V								V	56.80	56.80	67.80
60°	6	0.63		5.95 73°		4.43 69°		45.2 32°	V V V	24.3 32°	V V V							11.0	V	69.50	69.50	80.50
	10								V V V		V V V								V	69.50	69.50	80.50
	15								V V V		V V V								V	69.50	69.50	80.50
75°	6	0.32		3.88		2.29		50.4 20°	V V V	27.1 20°	V V V							11.0	V	77.50	77.50	88.50
	10								V V V		V V V								V	77.50	77.50	88.50
	15								V V V		V V V								V	77.50	77.50	88.50
90°	6							[illegible].2 12°	V V V	28.1 12°	V V V							11.0	V	80.30	80.30	91.30
	10								V V V		V V V								V	80.30	80.30	91.30
	15								V V V		V V V								V	80.30	80.30	91.30
105°	6							50.4 20°	V V V	27.1 20°	V V V	2.72 75°		5.07 75°		0.686		11.0	V	77.50	77.50	88.50
	10								V V V		V V V								V	77.50	77.50	88.50
	15								V V V		V V V								V	77.50	77.50	88.50
120°	6							45.2 [illegible]	V V V	24.3 32°	V V V	5.25 60°	V V V	5.93 61°	V V V	1.33 76°		11.0	V	80.68	80.68	91.68
	10								V V V		V V V		V V V						V	80.68	80.68	91.68
	15								V V V		V V V		V V V						V	80.68	80.68	91.68
135°	6							36.9 46°	V V V	19.9 46°	V V V	7.43 45°	V V V	8.39 46°	V V V	1.87 69°	V V V	11.0	V	74.49	74.49	85.49
	10								V V V		V V V		V V V		V V V		V V V		V	74.49	74.49	85.49
	15								V V V		V V V		V V V		V V V		V V V		V	74.49	74.49	85.49
150°	6							26.1 61°	V V	14.1 61°	V V	9.1 31°	V V V	1[illegible].3	V V V	2.29 64°	V V V	11.0	V	61.89	21.69	72.89
	10								V V		V V		V V V		V V V		V V V		V	61.89	21.69	72.89
	15								V V		V V		V V V		V V V		V V V		V	61.89	21.69	72.89
165°	6							13.5 75°		7.20 75°		10.15 17°	V V V	11.[illegible]5 2[illegible]	V V V	2.56 61°	V V V	11.0	V	24.16	24.16	35.16
	10												V V V		V V V		V V V		V	24.16	24.16	35.16
	15												V V V		V V V		V V V		V	24.16	24.16	35.16
180°	6											10.5 7°	V V V	11.85 1[illegible]°	V V V	2.65 60°	V V V	11.0	V	25.0	25.0	36.0
	10												V V V		V V V		V V V		V	25.0	25.0	36.0
	15												V V V		V V V		V V V		V	25.0	25.0	36.0

VULNERABLE PLATES OF [illegible]

Aspect	Range in 100 x	Plate A 76 mm (+ 64 mm) – Area in sq.ft. & Angle of Attack	Plate A 85/122	Plate B 32 mm at 70° – Area in sq.ft. & Angle of Attack	Plate B 85/122	Plate C 64 mm at 20° – Area in sq.ft. & Angle of Attack	Plate C 85/122	Plate D 25 mm at 65° – Area in sq.ft. & Angle of Attack	Plate D 85/122	Plate E 46 mm A (49 mm + 25 at 30°) – Area in sq.ft. & Angle of Attack	Plate E 85/122	Plate F 43 mm – Area in sq.ft. & Angle of Attack	Plate F 85/122	Plate G 45 mm – Area in sq.ft. & Angle of Attack	Plate G 85/122	Plate H 32 mm at 12° – Area in sq.ft. & Angle of Attack	Plate H 85/122	Plate I 20 mm at 60° – Area in sq.ft. & Angle of Attack	Plate I 85/122	Turret 102 mm (20.1 sq.ft.) – Vulnerable Area sq.ft.	Turret 85/122	Total Vulnerable Area 85	Total Vulnerable Area 122
0°	6	8.75 0°	V V	6.71 70°	V V	6.42 20°	V V	4.67 65°	V V											9.38	V V	35.92	35.92
	10		V V		V V		V V		V V												V V	35.92	35.92
	15		V V		V		V V		V V												V V	29.21	35.92
15°	6	8.27 15°	V V	6.48 71°	V	6.20 29°	V V	4.51 66°	V V	5.32 75°		14.18 75°								9.38	V V	28.36	34.84
	10		V V		V		V V		V V												V V	28.36	34.84
	15		V V		V		V V		V V												V V	28.36	34.84
30°	6	7.41 30°	V V	5.81 73°	V	5.56 36°	V V	4.03 69°	V V	6.41 60°	V V	27.35 60°	V V							9.38	V V	60.14	65.95
	10		V V		V		V V		V V		V V		V V								V V	60.14	65.95
	15		V V		V		V V		V V		V		V								V V	26.38	65.95
45°	6	6.05 45°	V	4.74 76°	V	4.53 49°	V V	3.30 73°	V V	9.07 45°	V V	38.70 45°	V V							9.38	V V	64.98	75.77
	10		V		V		V		V V		V V		V V								V V	60.45	75.77
	15		V		V		V		V V		V V		V V								V V	60.45	75.77
60°	6	4.28 60°		3.35		3.21 62°	V	2.33 78°		11.30 30°	V V	47.40 30°	V V							9.38	V V	68.08	71.29
	10										V V		V V								V V	68.08	68.08
	15										V V		V V								V V	68.08	68.08
75°	6	2.22 75°		1.74		1.66 76°		1.21		12.79 15°	V V	52.80 15°	V V							9.38	V V	74.97	74.97
	10										V V		V V								V V	74.97	74.97
	15										V V		V V								V V	74.97	74.97
90°	6									13.41 0°	V V	54.70 0°	V V							9.38	V V	77.48	77.48
	10										V V		V V								V V	77.48	77.48
	15										V V		V V								V V	77.48	77.48
105°	6									12.95 15°	V V	52.80 15°	V V	3.14 75°		2.43 75°		1.06		9.38	V V	75.13	75.13
	10										V V		V V								V V	75.13	75.13
	15										V V		V V								V V	75.13	75.13
120°	6									11.60 30°	V V	47.40 30°	V V	6.06 60°	V V	4.69 61°	V V	2.04 76°	V V	9.38	V V	81.17	81.17
	10										V V		V V		V V		V V		V V		V V	81.17	81.17
	15										V V		V V		V		V V		V V		V V	75.11	81.17
135°	6									9.52 45°	V V	38.70 45°	V V	8.58 45°	V V	6.62 46°	V V	2.88 69°	V V	9.38	V V	75.68	75.68
	10										V V		V V		V V		V V		V V		V V	75.68	75.68
	15										V V		V V		V V		V V		V V		V V	75.68	75.68
150°	6									6.70 60°	V V	27.35 60°	V V	10.56 30°	V V	8.32 32°	V V	3.53 64°	V V	9.38	V V	65.84	65.84
	10										V V		V V		V V		V V		V V		V V	65.84	65.84
	15										V		V		V V		V V		V V		V V	31.79	65.84
165°	6									3.48 75°		14.18 75°		11.92 15°	V V	9.46 19°	V V	3.94 61°	V V	9.38	V V	34.70	34.70
	10														V V		V V		V V		V V	34.70	34.70
	15														V V		V V		V V		V V	34.70	34.70
180°	6													12.5 0°	V V	9.958 12°	V V	4.083 60°	V V	9.38	V V	35.9[illegible]	35.9[illegible]
	10														V V		V V		V V		V V	3[illegible].92	35.9[illegible]
	15														V V		V V		V V		V V	35.92	35.9[illegible]

UNCLASSIFIED

VULNERABLE PLATES OF J.S.3.

Aspect	Range in 100x	Plate A 110 mm at 55°: Area in sq.ft. & Angle of Attack	Plate A: 17 pdr APCBC / 77 mm APCBC / 20 pdr APDS	Plate B 120 mm at 55°: Area & Angle	Plate B: 17 pdr / 77 mm / 20 pdr	Plate C [illegible] mm at 55°: Area & Angle	Plate C: 17 pdr / 77 mm / 20 pdr	Plate D [illegible] at 3[illegible]: Area & Angle	Plate D: 17 pdr / 77 mm / 20 pdr	Plate E 90 mm: Area & Angle	Plate E: 17 pdr / 77 mm / 20 pdr	Plate F 60 mm at 45°: Area & Angle	Plate F: 17 pdr / 77 mm / 20 pdr	Plate G: Area & Angle	Plate G: 17 pdr / 77 mm / 20 pdr	Turret 200 mm (18.7 sq.ft.): Vulnerable Area sq.ft.	Turret: 17 pdr / 77 mm / 20 pdr	Total Vulnerable Area: 17 pdr APCBC	77 mm APCBC	20 pdr APDS
0°	6	6.9		8.45		[illegible]											V	-	-	5.0
	10	55°		60°		[illegible]										5.0	V	-	-	5.0
	15																V	-	-	5.0
15°	6	[illegible]		[illegible]						[illegible]							V	-	-	5.0
	10	5[illegible]°		66°		5[illegible]		[illegible]		75°						5.0	V	-	-	5.0
	15																V	-	-	5.0
30°	6	[illegible]		[illegible]		9.76		8.16		26.13							V	-	-	5.0
	10	60°		73°		55°		67°		60°						5.0	V	-	-	5.0
	15																V	-	-	5.0
45°	6	4.68		2.53		9.42		12.67	V	36.95	V V						V	49.62	-	54.62
	10	66°				56°		66°		45°	V					5.0	V	-	-	41.95
	15										V						V	-	-	41.95
60°	6	3.45				8.45		15.52	V	45.26	V V V						V	45.26	45.26	65.78
	10	73°				60°		[illegible]	V	30°	V V V					5.0	V	45.26	45.26	65.78
	15								V		V V V						V	45.26	45.26	65.78
75°	6	1.79				6.9		[illegible]	V V	50.48	V V V						V	67.79	50.48	72.79
	10					66°		[illegible]	V V	15°	V V V					5.0	V	[illegible].79	50.48	72.79
	15								V V		V V V						V	[illegible].79	50.48	72.79
90°	6					4.68		17.52	V V V	52.26	V V V						V	70.18	70.18	75.18
	10					73°		57°	V V V	0°	V V V					5.0	V	70.18	70.18	75.18
	15								V V		V V V						V	70.18	52.26	75.18
105°	6					2.53		17.31	V V	50.48	V V V	4.44		1.98			V	67.79	50.48	72.79
	10							40°	V V	15°	V V V	76°		70°		5.0	V	67.79	50.48	72.79
	15								V V		V V V						V	67.79	50.48	72.79
120°	6							15.52	V	45.26	V V V	8.50		3.83			V	45.26	45.26	65.78
	10							[illegible]	V	30°	V V V	63°		69°		5.0	V	45.26	45.26	65.78
	15								V		V V						V	45.26	45.26	65.78
135°	5							1[illegible].67	V	36.95	V V	12.13	V V	5.41	V V		V	54.49	-	72.16
	10							5[illegible]°		45°	V	60°	V	60°	V	5.0	V	-	-	59.49
	15										V		V		V		V	-	-	59.49
150°	6							8.96		26.1[illegible]		14.65	V V V	6.63	V V V		V	21.48	21.48	26.48
	10							67°		[illegible]		52°	V V	52°	V V	5.0	V	21.48	-	26.48
	15												V V		V V		V	21.48	-	26.48
165°	6							[illegible]		13.53		16.57	V V V	7.34	V V V		V	23.91	23.91	28.91
	10							79°		75°		47°	V V V	47°	V V V	5.0	V	23.91	23.91	28.91
	15												V V V		V V V		V	23.91	23.91	28.91
180°	6											17.15	V V V	7.65	V V V		V	24.8	24.8	29.8
	10											45°	V V V	45°	V V V	5.0	V	24.8	24.8	29.8
	15												V V V		V V V		V	24.8	24.8	29.8

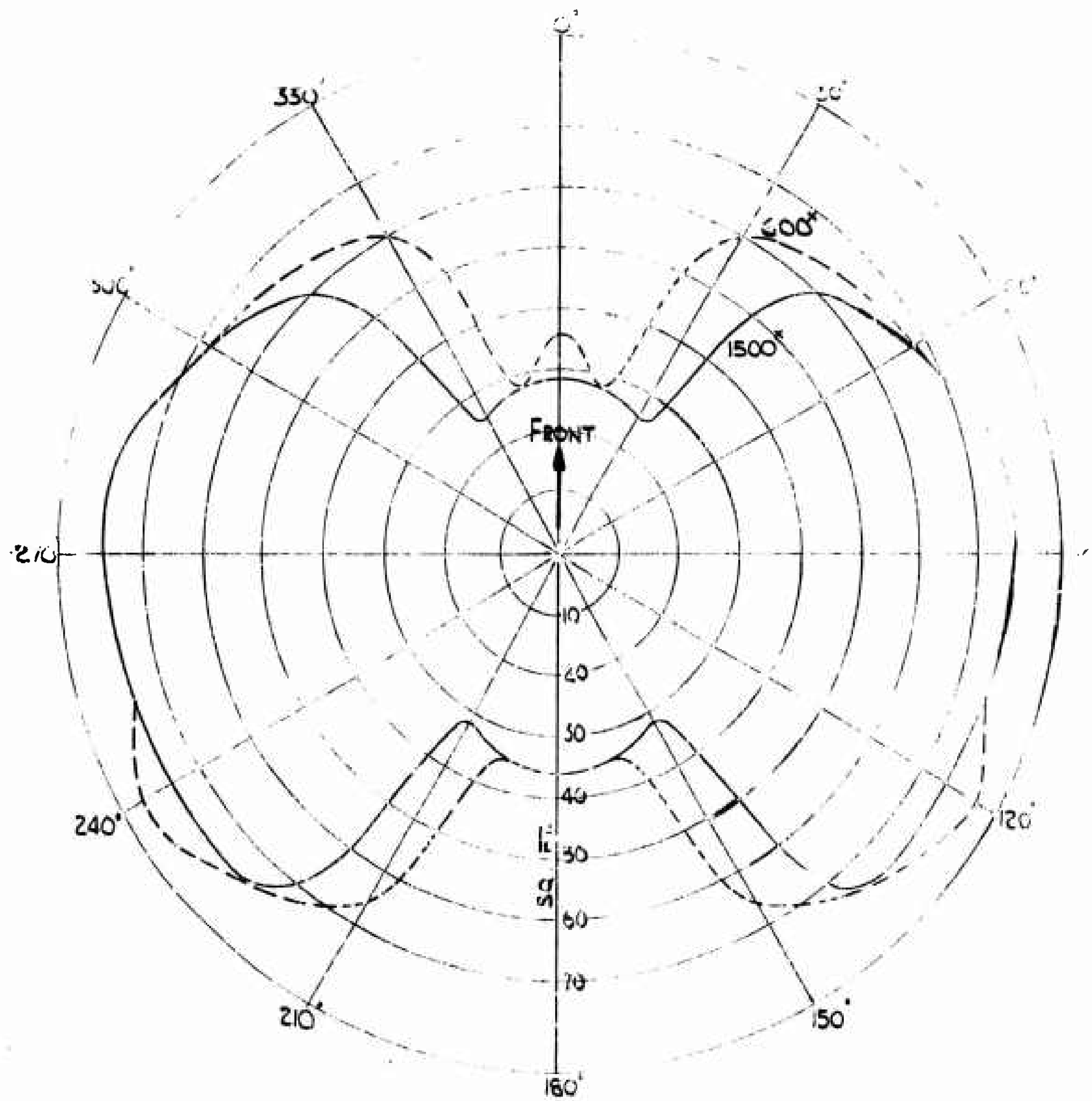
VULNERABLE PLATES OF T34/85

Aspect	Range in 100x	Plate A 47 mm at 60°: Area in sq.ft. & Angle of Attack	Plate A: 17 pdr APCBC / 77 mm APCBC / 20 pdr APDS	Plate B 47 mm at 60°: Area & Angle	Plate B: 17 pdr / 77 mm / 20 pdr	Plate C 45 mm at 40°: Area & Angle	Plate C: 17 pdr / 77 mm / 20 pdr	Plate D 47 mm Vertical: Area & Angle	Plate D: 17 pdr / 77 mm / 20 pdr	Plate E 45 mm at 50°: Area & Angle	Plate E: 17 pdr / 77 mm / 20 pdr	Plate F 45 mm at 45°: Area & Angle	Plate F: 17 pdr / 77 mm / 20 pdr	Turret 90-100 mm (17.6 sq.ft.): Vulnerable Area sq.ft.	Turret: 17 pdr / 77 mm / 20 pdr	Total Vulnerable Area: 17 pdr APCBC	77 mm APCBC	20 pdr APDS
0°	6	17.5	V V V	5.92	V V V										V V V	26.17	25.85	27.67
	10	60°	V V V	60°	V V V										V V V	26.17	25.85	27.67
	15		V V		V V									*	V V V	26.17	-	27.67
15°	6	16.9	V V V	5.72	V V V	4.67		10.24							V V V	25.37	25.05	26.87
	10	61°	V V	61°	V V			75°							V V V	25.37	-	26.87
	15		V V		V V									*	V V V	25.37	-	26.87
30°	6	15.13	V V	5.12	V V	9.0	V V	19.73	V V V						V V V	51.73	22.16	53.23
	10	64°	V V	64°	V V	68°	V V	60°	V V V						V V V	51.73	22.16	53.23
	15		V V		V V				V V					*	V V V	42.73	-	44.23
45°	6	12.38	V V	4.19	V V	12.73	V V V	27.95	V V V						V V V	60	43.11	61.50
	10						V V V		V V V						V V V	43.43	43.11	44.93
	15	69°		69°		57°	V V V		V V V					*	V V V	43.43	43.11	44.93
60°	6	8.75		2.96		15.57	V V V	34.15	V V V						V V V	52.47	52.15	53.97
	10	76°		76°			V V V		V V V						V V V	52.47	52.15	53.97
	15					49°	V V V	30°	V V V					*	V V V	52.47	52.15	53.97
75°	6	4.53		1.53		17.4	V V V	38.15	V V V						V V V	58.3	57.98	[illegible].8
	10					42°	V V V	15°	V V V						V V V	[illegible]	[illegible]	[illegible].8
	15						V V V		V V V					*	V V V	[illegible]	[illegible]	[illegible].8
90°	6					18.0	V V V	39.46	V V V						V V V	60.21	59.89	61.71
	10					40°	V V V	0°	V V V						V V V	60.21	59.89	61.71
	15						V V V		V V V					*	V V V	60.21	59.89	61.71
105°	6					17.4	V V V	38.15	V V V	5.51		2.55			V V V	58.3	57.98	[illegible].8
	10					42°	V V V	15°	V V V						V V V	58.3	57.98	59.8
	15						V V V		V V V					*	V V V	58.3	57.98	59.8
120°	6					15.57	V V V	34.15	V V V	6.78		4.95	V V		V V V	57.40	52.15	58.90
	10					49°	V V V	30°	V V V	71°		69°			V V V	52.47	52.15	53.97
	15						V V V		V V V					*	V V V	52.47	52.15	53.97
135°	6					12.73	V V V	27.95	V V V	9.50	V V V	6.97	V V V		V V V	59.9[illegible]	59.66	61.48
	10					57°	V V V	45°	V V V	63°	V V	60°	V V V		V V V	59.98	[illegible].08	61.48
	15						V V V		V V V		V V		V V	*	V V V	59.98	[illegible].11	61.48
150°	6					9.0	V V	19.73	V V V	11.72	V V V	8.52	V V V		V V V	51.72	44.4	53.22
	10					6°	V V	60°	V V V	56°	V V V	52°	V V V		V V V	51.72	42.4	53.22
	15						V V		V V V		V V V		V V V	*	V V V	42.72	[illegible].67	44.22
165°	6					4.67		10.24		13.1	V V V	9.53	V V V		V V V	25.38	25.06	26.88
	10							75°		5°	V V V	47°	V V V		V V V	25.38	25.06	26.88
	16										V V V		V V V	*	V V V	25.38	25.06	26.88
180°	6									13.56	V V V	9.86	V V V		V V V	26.17	25.85	2[illegible].67
	10									50°	V V V	45°	V V V		V V V	26.17	25.85	27.67
	16										V V V		V V V	*	V V V	26.17	25.85	27.67

* Vulnerable Area of Turret depends upon gun firing at it:-

GUN	VUL AREA
17 pdr.	3.75 sq.ft.
77 mm.	3.43 sq.ft.
20 pdr.	4.25 sq.ft.

PRESENTED VULNERABLE AREAS



Cover v 80%
AT 600 & 1500

Appx. H.
Fig. H 6.

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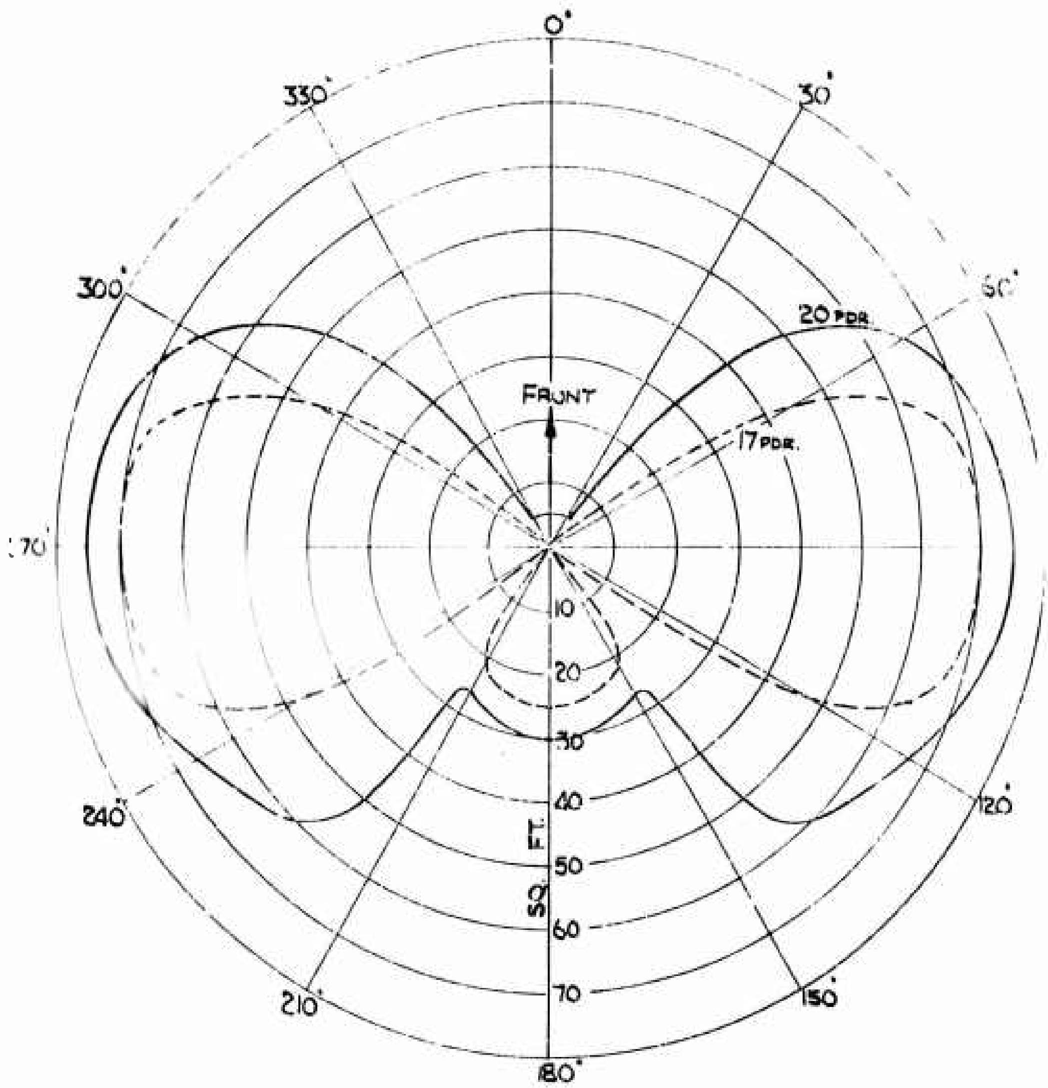
Presented Vulnerable Areas.



J.S. 3. v 17 PDR. APCBC & 20 PDR. APDS Mk. I.
AT 1000 YDS.

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Appendix J

Diagrams of Vulnerability and Probability
of Defeat of Tanks at 1000 yds.

1. In this Appendix the values of P_V and S_V, as calculated by the method described in Appendix "H" for each aspect of the various tanks, are listed and the 1000 yds range results plotted as polar diagrams.

2. The quantity P_V for each aspect is termed the Vulnerability of the tank to a given attack, and is the chance of the attack hitting a vulnerable area of the tank at each aspect.

3. When the quantity P_V is multiplied by the value of the particular d.p.v. for that aspect the quantity S_V is obtained, which is termed the Probability of the tank being defeated by a given attack. In all cases S_V is calculated for both Whittaker's d.p.v. and the "Elliptical" d.p.v.; S_{1V} indicating the use of Whittaker's d.p.v. and S_{4V} the use of the "Elliptical" d.p.v.

4. Tables J1 to J8 of this Appendix give the values of P_V, S_{1V} and S_{4V} at the three ranges 600 yds, 1000 yds and 1500 yds and for the two aiming points centre of hull and centre of vulnerable area, for the Centurion Mk. 3 under attack by the J.S.3, the Comet under attack by the T 34/85 and vice versa.

5. Figure J1 of this Appendix shows the envelopes of the two d.p.vs Whittaker's and "Elliptical" for vectorial values at 15° intervals (vide Appendix E Fig. E2). Figures J2 to J16 are the polar and vectorial diagrams of the values of P_V, S_{1V} and S_{4V} for 1000 yds range at intervals of 15°.

6. It is interesting to note that where the tank is more or less uniformly vulnerable to the attack at all aspects, then the form of the probability of defeat is primarily controlled by the form of the d.p.v. Whereas in those cases where some aspects of the tank are invulnerable or much less vulnerable to the attack, then the form of the vulnerability predominates in the final shape of the probability of defeat.

Table J1

Centurion Mk. 3 attacked by 122 mm APCBC (J.S.3)

(1) (Aiming Point Centre of Hull)

Range / Aspect	P_v 600x	P_v 1000x	P_v 1500x	S_{1v} 600x	S_{1v} 1000x	S_{1v} 1500x	S_{4v} 600x	S_{4v} 1000x	S_{4v} 1500x
0°	.947	.709	.237	.108	.080	.026	.184	.138	.046
15°	.386	.377	.176	.044	.043	.020	.058	.056	.026
30°	.955	.788	.545	.098	.081	.056	.084	.069	.048
45°	.954	.786	.547	.055	.045	.032	.050	.041	.028
60°	.954	.783	.551	.036	.030	.021	.031	.026	.018
75°	.954	.780	.548	.029	.024	.017	.021	.017	.012
90°	.954	.779	.546	.027	.022	.015	.014	.011	.008
105°	.954	.780	.547	.023	.018	.013	.011	.009	.007
120°	.954	.782	.551	.018	.015	.010	.009	.007	.005
135°	.954	.786	.555	.013	.011	.008	.007	.006	.004
150°	.955	.790	.560	.009	.007	.005	.006	.005	.004
165°	.637	.497	.355	.003	.002	.002	.004	.003	.002
180°	.953	.751	.469	.002	+	+	.006	.004	.002

(2) (Aiming Point Vulnerable Area)

Range / Aspect	P_v 600x	P_v 1000x	P_v 1500x	S_{1v} 600x	S_{1v} 1000x	S_{1v} 1500x	S_{4v} 600x	S_{4v} 1000x	S_{4v} 1500x
0°	.947	.709	.212	.108	.080	.024	.184	.138	.042
15°	.943	.681	.191	.107	.077	.022	.140	.101	.028
30°	.955	.793	.557	.098	.082	.057	.084	.070	.049
45°	.955	.792	.562	.056	.046	.033	.050	.041	.029
60°	.955	.793	.565	.037	.030	.022	.032	.026	.019
75°	.954	.788	.558	.029	.024	.017	.021	.017	.012
90°	.954	.779	.546	.027	.022	.015	.014	.012	.008
105°	.954	.789	.559	.023	.019	.013	.011	.009	.007
120°	.954	.784	.553	.018	.015	.010	.009	.007	.005
135°	.954	.786	.555	.013	.011	.008	.007	.006	.004
150°	.954	.790	.560	.009	.007	.005	.006	.005	.004
165°	.951	.729	.441	.004	.003	.002	.006	.004	.003
180°	.953	.751	.469	.002	+	+	.006	.004	.002

\+ These values are less than .0005.

Table J2

Centurion Mk. 3 attacked by 85 mm. APBC (T34/85)

(1) (Aiming Point Centre of Hull)

Range / Aspect	P_v			S_{1v}			S_{4v}		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	-	-	-	-	-	-	-	-	-
15°	-	-	-	-	-	-	-	-	-
30°	-	-	-	-	-	-	-	-	-
45°	.937	.716	.442	.054	.042	.026	.049	.037	.023
60°	.937	.716	.447	.036	.027	.017	.031	.024	.015
75°	.937	.716	.447	.029	.022	.014	.021	.016	.010
90°	.937	.716	.447	.026	.020	.012	.014	.011	.007
105°	.937	.716	.447	.022	.017	.011	.011	.009	.005
120°	.937	.716	.447	.018	.014	.008	.008	.006	.004
135°	.937	.716	.447	.013	.010	.006	.007	.005	.003
150°	.005	.044	.068	+	+	.001	+	+	+
165°	.638	.437	.254	.003	.002	.001	.004	.003	.002
180°	.936	.690	.374	.002	+	+	.006	.004	.002

(2) (Aiming Point Vulnerable Area)

Range / Aspect	P_v			S_{1v}			S_{4v}		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	-	-	-	-	-	-	-	-	-
15°	-	-	-	-	-	-	-	-	-
30°	-	-	-	-	-	-	-	-	-
45°	.937	.716	.447	.054	.042	.026	.049	.037	.023
60°	.937	.716	.447	.036	.027	.017	.031	.024	.015
75°	.937	.716	.447	.029	.022	.014	.021	.016	.010
90°	.937	.716	.447	.026	.020	.012	.014	.011	.007
105°	.937	.716	.447	.022	.017	.011	.011	.009	.005
120°	.937	.716	.447	.018	.014	.008	.008	.006	.004
135°	.937	.716	.447	.013	.010	.006	.007	.005	.003
150°	.934	.666	.345	.009	.006	.003	.006	.004	.002
165°	.936	.685	.367	.004	.003	.002	.006	.004	.002
180°	.936	.690	.374	.002	+	+	.006	.004	.002

\- denotes zero

\+ These values are less than .0005.

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Table J3

Comet attacked by 122 mm APCBC (J.S.3)

(1) (Aiming Point Centre of Hull)

	P_v			S_{1v}			S_{4v}		
Range / Aspect	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	.961	.769	.475	.108	.088	.054	.186	.150	.092
15°	.804	.595	.391	.091	.068	.044	.120	.089	.058
30°	.962	.805	.564	.099	.083	.058	.085	.071	.050
45°	.962	.804	.564	.056	.047	.033	.050	.042	.029
60°	.961	.802	.556	.037	.031	.021	.032	.026	.018
75°	.961	.800	.559	.030	.025	.017	.021	.018	.012
90°	.961	.800	.559	.027	.022	.016	.014	.012	.008
105°	.961	.801	.559	.023	.019	.013	.012	.010	.007
120°	.961	.802	.562	.018	.015	.011	.009	.007	.005
135°	.962	.804	.564	.014	.011	.008	.007	.006	.004
150°	.962	.805	.564	.009	.008	.005	.006	.005	.004
165°	.796	.590	.388	.004	.003	.002	.005	.004	.002
180°	.961	.769	.475	.002	+	+	.006	.004	.002

(2) (Aiming Point Vulnerable Area)

	P_v			S_{1v}			S_{4v}		
Range / Aspect	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	.961	.769	.475	.108	.088	.054	.186	.150	.092
15°	.960	.752	.454	.109	.085	.052	.143	.112	.068
30°	.962	.805	.564	.099	.083	.058	.085	.071	.050
45°	.962	.804	.564	.056	.047	.033	.050	.042	.029
60°	.962	.807	.567	.037	.031	.022	.032	.027	.019
75°	.962	.806	.567	.030	.025	.017	.021	.018	.012
90°	.961	.800	.558	.027	.022	.016	.014	.012	.008
105°	.962	.806	.567	.023	.019	.013	.011	.010	.007
120°	.962	.802	.562	.018	.015	.011	.009	.007	.005
135°	.962	.804	.564	.014	.011	.008	.007	.006	.004
150°	.962	.805	.564	.009	.008	.005	.006	.005	.004
165°	.959	.751	.453	.005	.004	.002	.006	.005	.003
180°	.961	.769	.475	.002	+	+	.006	.004	.002

\+ These values are less than .0005.

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Table J4

Comet attacked by 85 mm APBC (T34/85)

(1) (Aiming Point Centre of Hull)

Range / Aspect	P_v 600ˣ	P_v 1000ˣ	P_v 1500ˣ	S_{1v} 600ˣ	S_{1v} 1000ˣ	S_{1v} 1500ˣ	S_{4v} 600ˣ	S_{4v} 100ˣ	S_{4v} 1500ˣ
0°	.950	.766	.374	.108	.086	.042	.184	.148	.072
15°	.497	.433	.307	.056	.049	.035	.074	.065	.046
30°	.950	.787	.178	.098	.081	.018	.084	.069	.016
45°	.950	.784	.531	.055	.046	.031	.049	.041	.028
60°	.950	.783	.537	.036	.030	.021	.031	.026	.018
75°	.950	.782	.538	.029	.024	.017	.021	.017	.012
90°	.950	.781	.537	.026	.022	.015	.014	.012	.008
105°	.950	.782	.538	.022	.019	.013	.011	.009	.006
120°	.950	.784	.540	.018	.015	.010	.009	.007	.005
135°	.950	.786	.543	.013	.011	.008	.007	.006	.004
150°	.950	.788	.206	.009	.007	.002	.006	.005	.001
165°	.808	.593	.387	.004	.003	.002	.005	.004	.002
180°	.950	.766	.478	.002	+	+	.006	.004	.002

(2) (Aiming Point Vulnerable Area)

Range / Aspect	P_v 600ˣ	P_v 1000ˣ	P_v 1500ˣ	S_{1v} 600ˣ	S_{1v} 1000ˣ	S_{1v} 1500ˣ	S_{4v} 600ˣ	S_{4v} 1000ˣ	S_{4v} 1500ˣ
0°	.950	.737	.374	.108	.084	.042	.184	.142	.072
15°	.582	.539	.354	.066	.061	.040	.087	.080	.053
30°	.950	.790	.351	.098	.081	.036	.084	.069	.031
45°	.950	.790	.546	.055	.046	.032	.049	.041	.028
60°	.950	.790	.548	.036	.030	.021	.031	.026	.018
75°	.950	.788	.547	.029	.024	.017	.021	.017	.012
90°	.950	.781	.537	.026	.022	.015	.014	.012	.008
105°	.950	.788	.546	.023	.019	.013	.011	.009	.007
120°	.950	.784	.540	.018	.015	.010	.009	.007	.005
135°	.950	.786	.543	.013	.011	.008	.007	.006	.004
150°	.950	.788	.441	.009	.007	.004	.006	.005	.003
165°	.950	.749	.455	.005	.004	.002	.006	.004	.003
180°	.950	.766	.478	.006	+	+	.006	.004	.002

\+ These values are less than .0005.

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Table J5

J.S.3. attacked by 20 pdr APDS Mk. 1 (Centurion 3)

(1) (Aiming Point Centre of Hull)

Range / Aspect	Pv			S_{1v}			S_{4v}		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	+	.019	.053	+	.002	.006	+	.004	.010
15°	+	.016	.048	+	.002	.005	+	.002	.007
30°	+	.011	.039	+	.001	.004	+	.001	.003
45°	.996	.704	.548	.058	.041	.032	.052	.037	.029
60°	.996	.918	.745	.038	.035	.029	.033	.030	.025
75°	.996	.917	.740	.031	.028	.023	.022	.020	.016
90°	.996	.916	.738	.028	.026	.021	.015	.014	.011
105°	.996	.917	.740	.024	.022	.018	.012	.011	.009
120°	.996	.918	.745	.019	.017	.014	.009	.008	.007
135°	.996	.704	.550	.014	.010	.008	.007	.005	.004
150°	.007	.076	.157	+	.001	.001	+	+	.001
165°	.849	.688	.527	.004	.003	.003	.005	.004	.003
180°	.997	.927	.725	.002	+	+	.006	.006	.004

(2) (Aiming Point Vulnerable Area)

Range / Aspect	Pv			S_{1v}			S_{4v}		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	.792	.438	.222	.090	.050	.026	.154	.086	.044
15°	.792	.440	.222	.090	.050	.025	.118	.066	.033
30°	.792	.440	.222	.082	.045	.023	.070	.039	.020
45°	.997	.765	.575	.058	.044	.033	.052	.040	.030
60°	.997	.918	.770	.038	.035	.030	.033	.030	.025
75°	.996	.916	.758	.031	.028	.023	.022	.020	.017
90°	.996	.916	.746	.028	.026	.021	.015	.014	.011
105°	.996	.917	.758	.024	.022	.018	.012	.011	.009
120°	.997	.918	.770	.019	.017	.015	.009	.008	.007
135°	.996	.765	.575	.014	.011	.008	.007	.006	.004
150°	.996	.896	.639	.009	.008	.006	.006	.006	.004
165°	.996	.907	.704	.005	.004	.003	.006	.005	.004
180°	.997	.927	.726	.002	.002	+	.006	.006	.004

\+ These values are less than .0005.

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Table J6.

J.S.3. attacked by 77 mm APCBC (Comet)

(1) (Aiming Point Centre of Hull)

Range / Aspect	P_v 600ˣ	P_v 1000ˣ	P_v 1500ˣ	S_{1v} 600ˣ	S_{1v} 1000ˣ	S_{1v} 1500ˣ	S_{4v} 600ˣ	S_{4v} 1000ˣ	S_{4v} 1500ˣ
0°	-	-	-	-	-	-	-	-	-
15°	-	-	-	-	-	-	-	-	-
30°	-	-	-	-	-	-	-	-	-
45°	-	-	-	-	-	-	-	-	-
60°	.829	.636	.383	.032	.024	.015	.027	.021	.013
75°	.829	.636	.383	.025	.020	.012	.018	.014	.008
90°	.990	.856	.383	.028	.024	.011	.015	.013	.006
105°	.829	.636	.383	.020	.015	.009	.010	.008	.005
120°	.829	.636	.383	.016	.012	.007	.007	.006	.003
135°	-	-	-	-	-	-	-	-	-
150°	.009	-	-	+	-	-	+	-	-
165°	.834	.622	.356	.004	.003	.002	.005	.004	.002
180°	.990	.847	.498	.002	.002	+	.006	.006	.002

(2) (Aiming Point Vulnerable Area)

Range / Aspect	P_v 600ˣ	P_v 1000ˣ	P_v 1500ˣ	S_{1v} 600ˣ	S_{1v} 1000ˣ	S_{1v} 1500ˣ	S_{4v} 600ˣ	S_{4v} 1000ˣ	S_{4v} 1500ˣ
0°	-	-	-	-	-	-	-	-	-
15°	-	-	-	-	-	-	-	-	-
30°	-	-	-	-	-	-	-	-	-
45°	-	-	-	-	-	-	-	-	-
60°	.829	.636	.383	.032	.024	.015	.027	.021	.013
75°	.829	.636	.383	.025	.020	.012	.018	.014	.008
90°	.990	.856	.383	.028	.024	.011	.015	.013	.006
105°	.829	.636	.383	.020	.015	.009	.010	.008	.005
120°	.829	.636	.383	.016	.012	.007	.007	.006	.003
135°	-	-	-	-	-	-	-	-	-
1500°	.990	-	-	.009	-	-	.006	-	-
165°	.990	.845	.492	.005	.004	.002	.006	.005	.003
180°	.990	.847	.498	.002	.002	+	.006	.006	.002

\- Denotes zero

\+ These values are less than .0005.

Table J7

T34/85 attacked by 20 pdr APDS Mk I. (Centurion 3)

(1) (Aiming Point Centre of Hull)

Range / Aspect	P_v 600x	P_v 1000x	P_v 1500x	S_{1v} 600x	S_{1v} 1000x	S_{1v} 1500x	S_{4v} 600x	S_{4v} 1000x	S_{4v} 1500x
0°	.993	.903	.690	.112	.102	.078	.192	.176	.134
15°	.929	.747	.547	.106	.085	.062	.138	.111	.082
30°	.993	.905	.726	.102	.093	.075	.087	.080	.064
45°	.993	.900	.708	.058	.052	.041	.052	.047	.037
60°	.993	.900	.724	.038	.034	.028	.033	.030	.024
75°	.992	.899	[illegible]	.030	.028	.022	.022	.020	.016
90°	.992	[illegible]	.722	.028	.025	.020	.015	.013	.011
105°	.992	[illegible]	.722	.023	.021	.017	.012	.011	.009
120°	.993	.900	.724	.019	.017	.014	.009	.008	.007
135°	.993	.902	.728	.014	.013	.010	.007	.007	.005
150°	.993	.905	.726	.009	.009	.007	.006	.006	.005
165°	.930	.747	.547	.004	.004	.003	.006	.004	.003
180°	.993	.903	.690	.002	.002	+	.006	.006	.004

(2) (Aiming Point Vulnerable Area)

Range / Aspect	P_v 600x	P_v 1000x	P_v 1500x	S_{1v} 600x	S_{1v} 1000x	S_{1v} 1500x	S_{4v} 600x	S_{4v} 1000x	S_{4v} 1500x
0°	.993	.903	.690	.112	.102	.028	.192	.176	.134
15°	.992	.889	.668	.113	.101	.076	.148	.132	.100
30°	.993	.905	.730	.102	.093	.075	.087	.080	.064
45°	.993	.899	.725	.058	.052	.042	.052	.047	.038
60°	.993	.907	.733	.038	.035	.028	.033	.030	.024
75°	.993	.906	.733	.030	.028	.022	.022	.020	.016
90°	.992	.898	.722	.028	.025	.020	.015	.013	.011
105°	.993	.906	.733	.024	.021	.017	.012	.011	.009
120°	.993	.907	.733	.019	.017	.014	.009	.008	.007
135°	.993	.902	.728	.014	.013	.010	.007	.007	.005
150°	.993	.905	.730	.009	.009	.007	.006	.006	.005
165°	.992	.889	.666	.005	.004	.003	.006	.005	.004
180°	.993	.903	.690	.002	.002	+	.006	.006	.004

\+ These values are less than .0005

Table J8

T34/85 attacked by 77 mm. APCBC (Comet)

(1) (Aiming Point Centre of Hull)

Range / Aspect	Pv			S1v			S4v		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	.983	.830	.038	.112	.094	.004	.190	.160	.008
15°	.912	.016	.037	.104	.002	.004	.136	.002	.006
30°	.728	.529	.036	.075	.053	.004	.064	.047	.003
45°	.983	.830	.523	.057	.047	.030	.051	.043	.027
60°	.982	.831	.537	.038	.031	.021	.032	.027	.018
75°	.982	.830	.536	.030	.025	.016	.022	.018	.012
90°	.982	.830	.536	.027	.023	.015	.015	.012	.008
105°	.982	.830	.536	.023	.020	.013	.012	.010	.006
120°	.982	.831	.537	.019	.016	.010	.009	.007	.005
135°	.983	.830	.523	.014	.011	.007	.007	.006	.004
150°	.780	.666	.167	.007	.006	.002	.005	.004	.001
165°	.912	.680	.401	.004	.003	.002	.005	.004	.002
180°	.983	.830	.506	.002	.002	+	.006	.004	.004

(2) (Aiming Point Vulnerable Area)

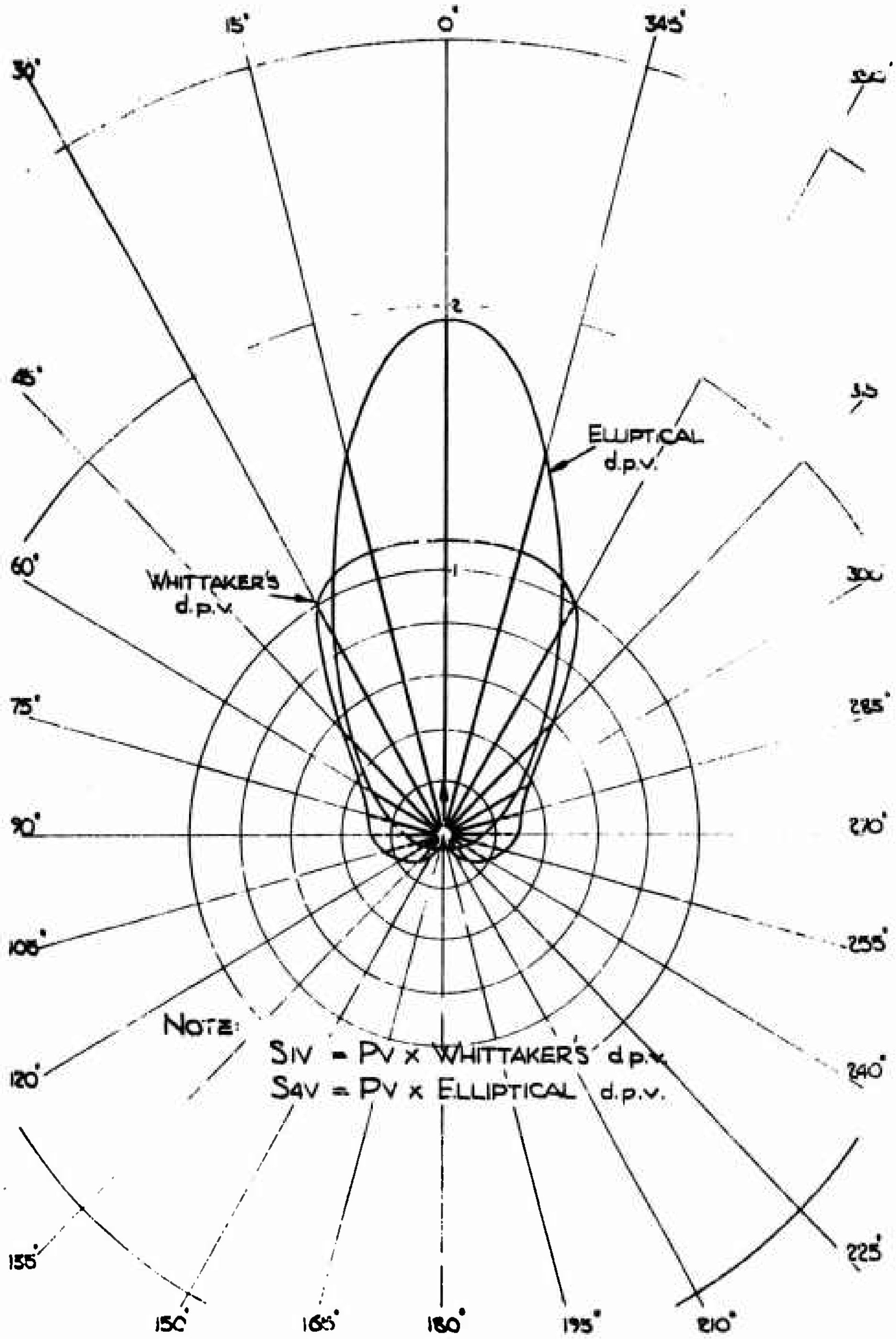
Range / Aspect	Pv			S1v			S4v		
	600x	1000x	1500x	600x	1000x	1500x	600x	1000x	1500x
0°	.983	.830	.038	.112	.094	.004	.190	.160	.008
15°	.982	.008	.026	.112	.001	.003	.146	.001	.004
30°	.732	.560	.025	.076	.058	.003	.064	.049	.002
45°	.982	.831	.536	.057	.048	.031	.051	.043	.028
60°	.983	.835	.544	.038	.032	.021	.032	.028	.018
75°	.983	.835	.543	.030	.026	.017	.022	.018	.012
90°	.982	.830	.536	.027	.023	.015	.015	.012	.008
105°	.983	.835	.543	.023	.020	.013	.012	.010	.007
120°	.983	.835	.544	.019	.016	.010	.009	.008	.005
135°	.982	.877	.536	.014	.012	.008	.007	.007	.004
150°	.982	.815	.468	.009	.008	.004	.006	.005	.003
165°	.982	.819	.489	.005	.004	.002	.006	.005	.003
180°	.983	.830	.506	.002	.002	+	.006	.004	.004

\+ These values are less than .0005.

Appx. J.
Fig. J. 1.

DPVs.

AT 15° INTERVALS
(vide Appendix E. Fig. E2.)



Appx. J.
Fig. J2.

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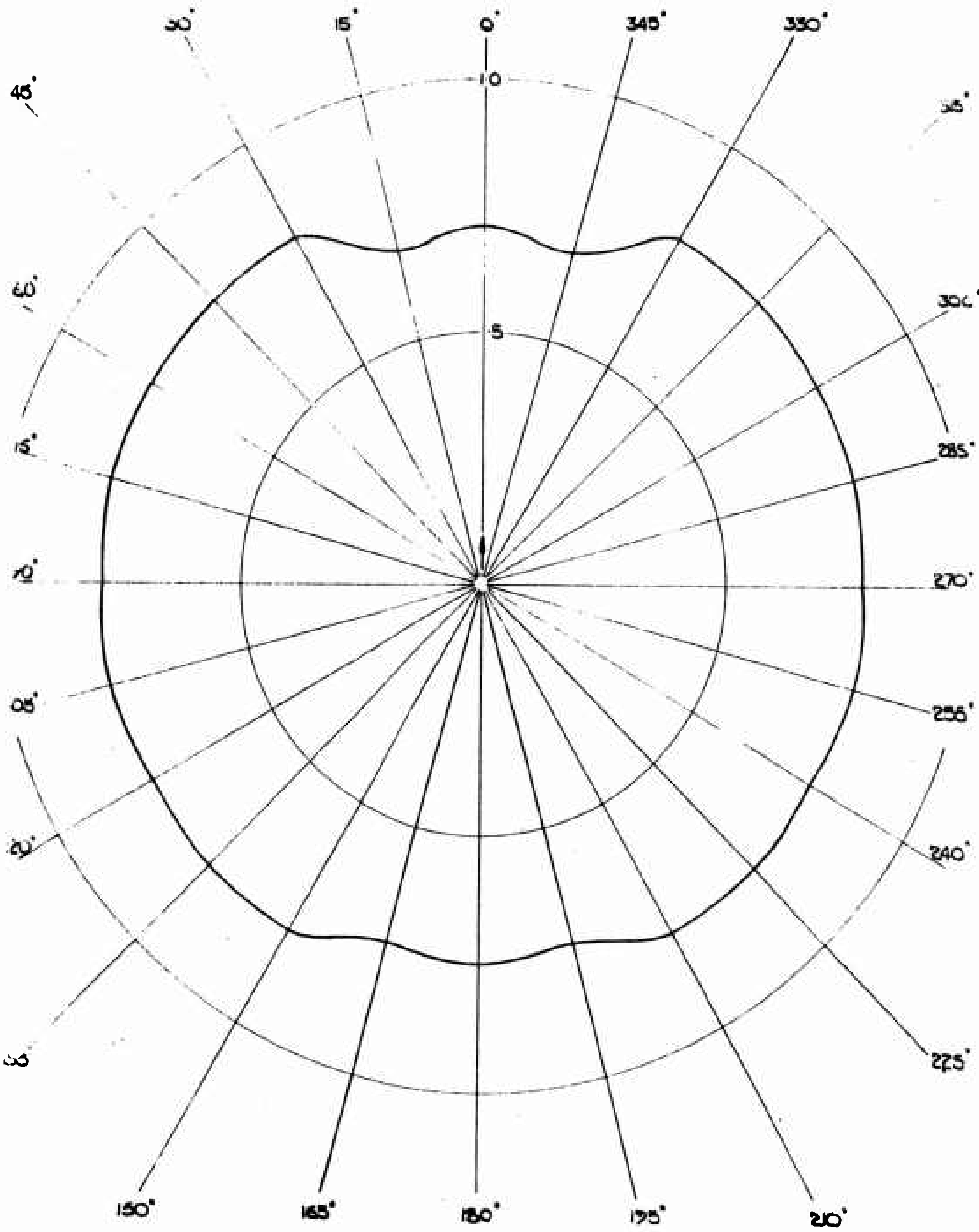
Vulnerability of Centurion 3 to attack by 122mm. (JS 3)

(Aiming Point Vulnerable Area.)

(Range 1000 yds.)

Polar Diagram of Pv (Vulnerability.)



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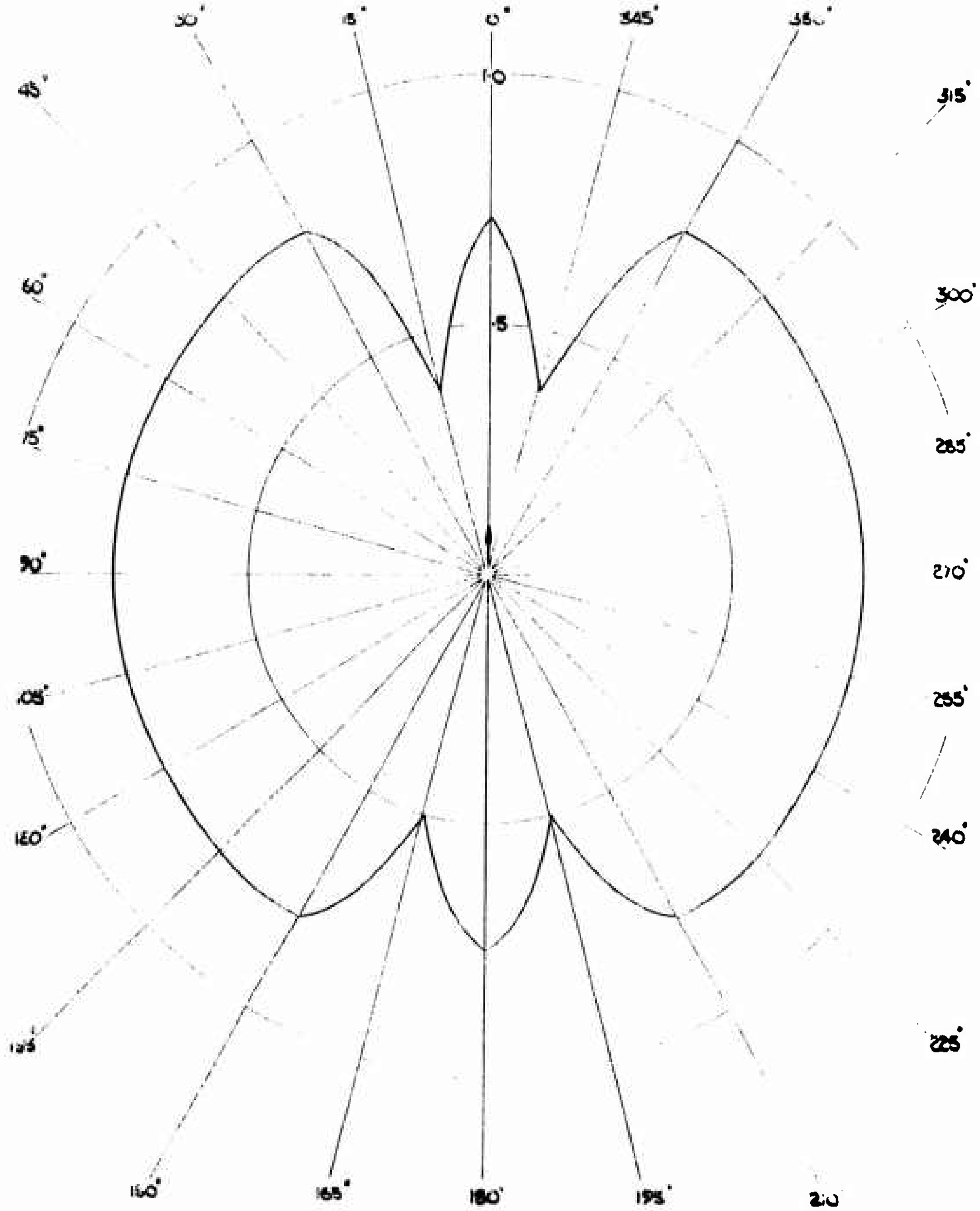
VULNERABILITY OF CENTURION 3 TO ATTACK BY 122mm (JS 3)
(AIMING POINT CENTRE OF HULL)
(Range 1000 yds)

POLAR DIAGRAM OF PV (VULNERABILITY)



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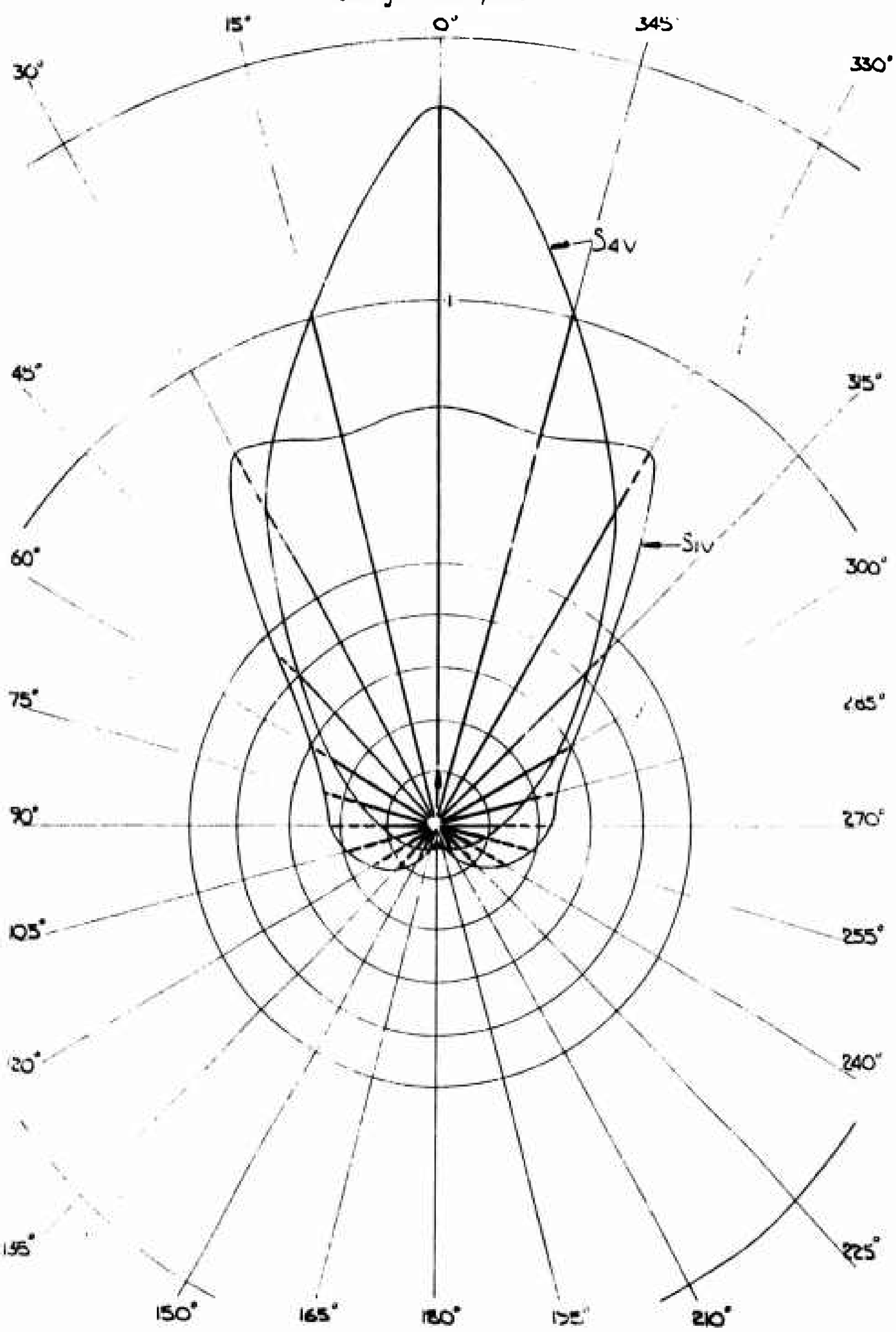
Appx. J.

Fig. J 4

Probability of Centurion 3 being defeated by 122mm (JS3)

(Aiming Point Vulnerable Area)

(Range 1000 yds.)



Vector Diagram of Sv (Probability)

Sv = Pv. x d.p.v.

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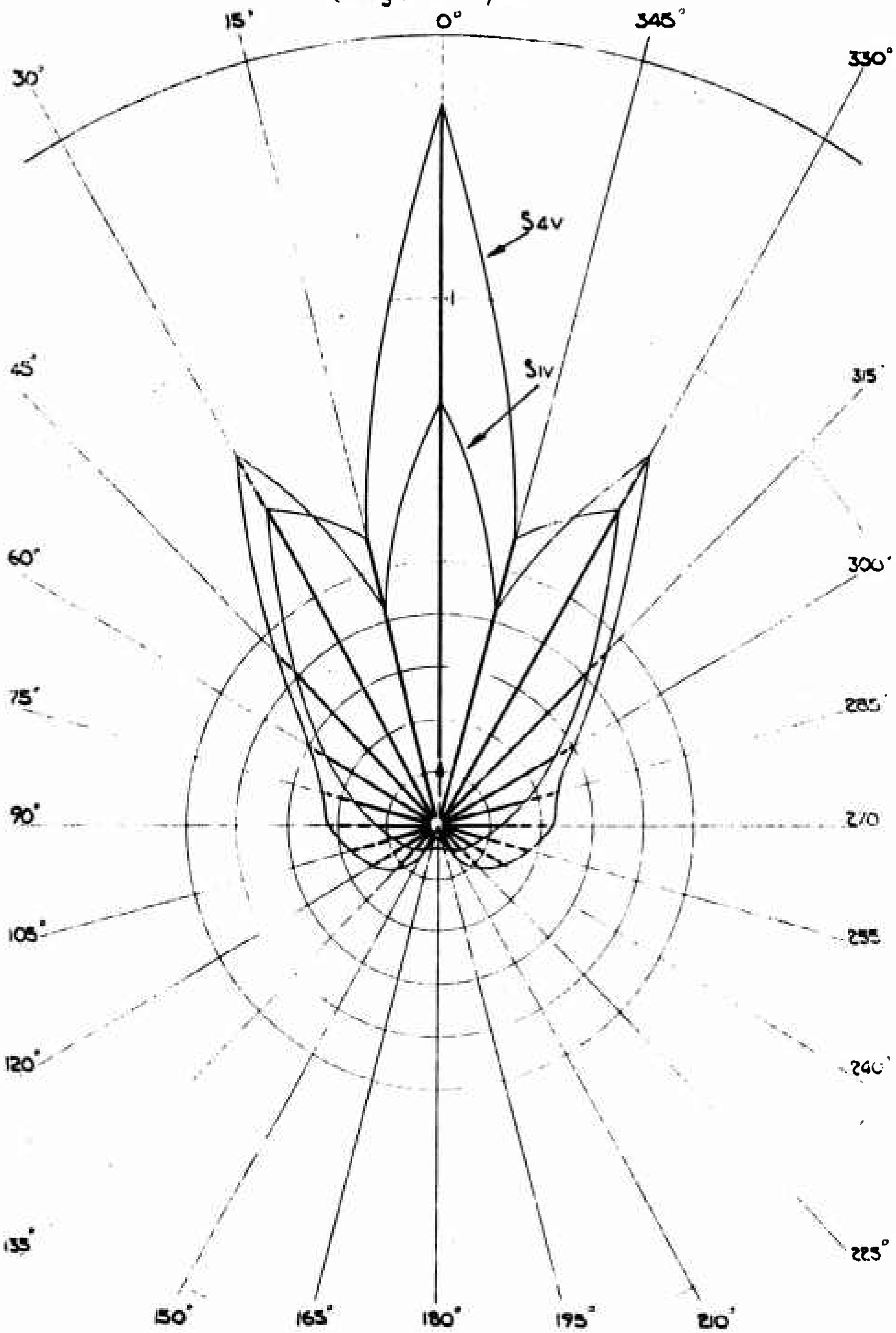
PROBABILITY OF CENTURION 3 BEING DEFEATED BY 122mm (JS 3)
AIMING POINT: CENTRE OF HULL.
(Range 1000 yds.)



VECTOR DIAGRAM OF SV (PROBABILITY)
(SV = PV x d.p.v)

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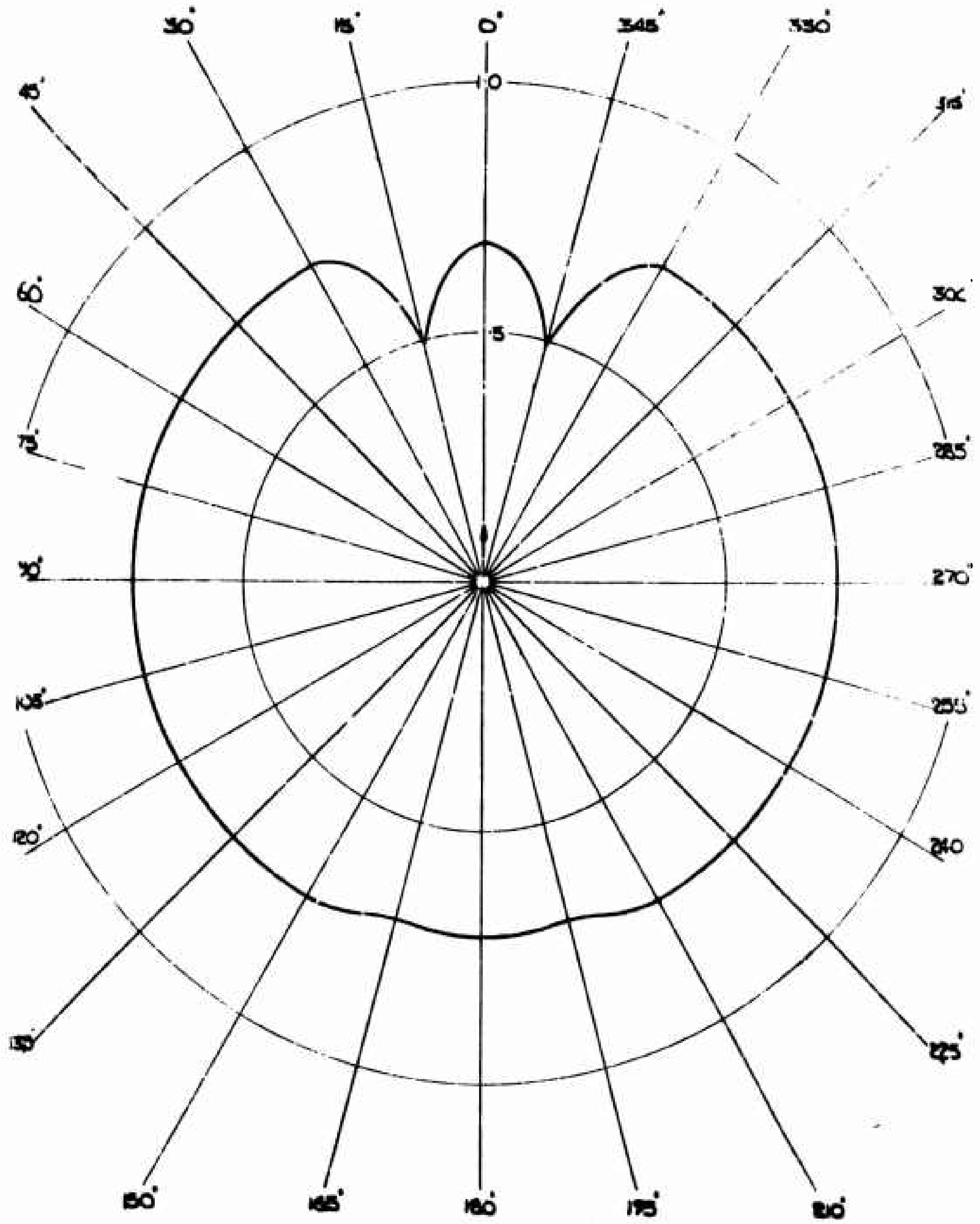
VULNERABILITY OF COMET TO ATTACK BY 85 mm. APBC (T 34/58)

(AIMING POINT VULNERABLE AREA)

(Range 1000 yds)

POLAR DIAGRAM OF Pv (VULNERABILITY)



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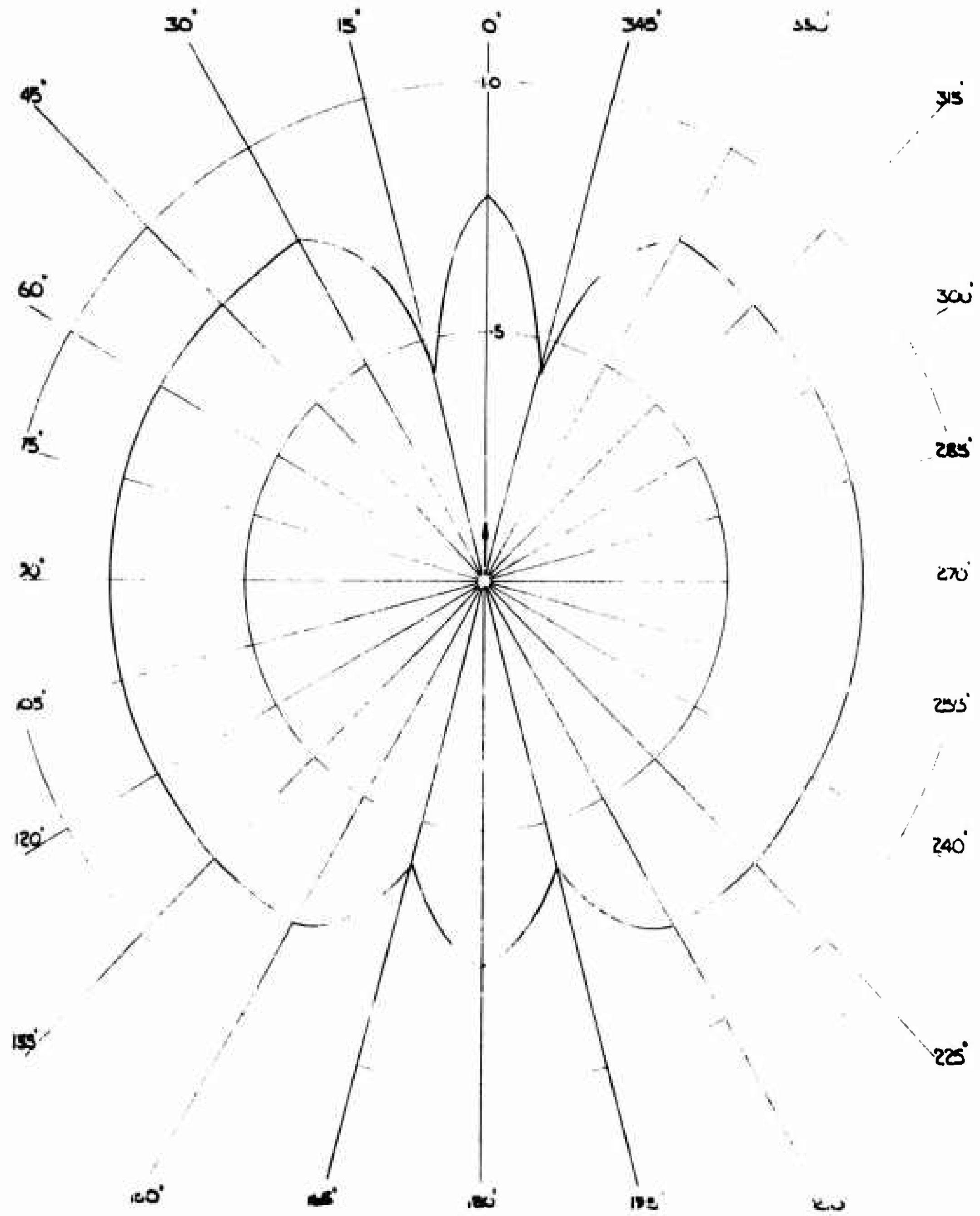
APPX J.
FIG. J 7.

VULNERABILITY OF COMET TO ATTACK BY 85 mm APBC (T34/85)
(AIMING POINT CENTRE OF HULL)
(Range 1000 yds)

POLAR DIAGRAM OF PV (VULNERABILITY)



Appx. J.

Fig. J. 8.

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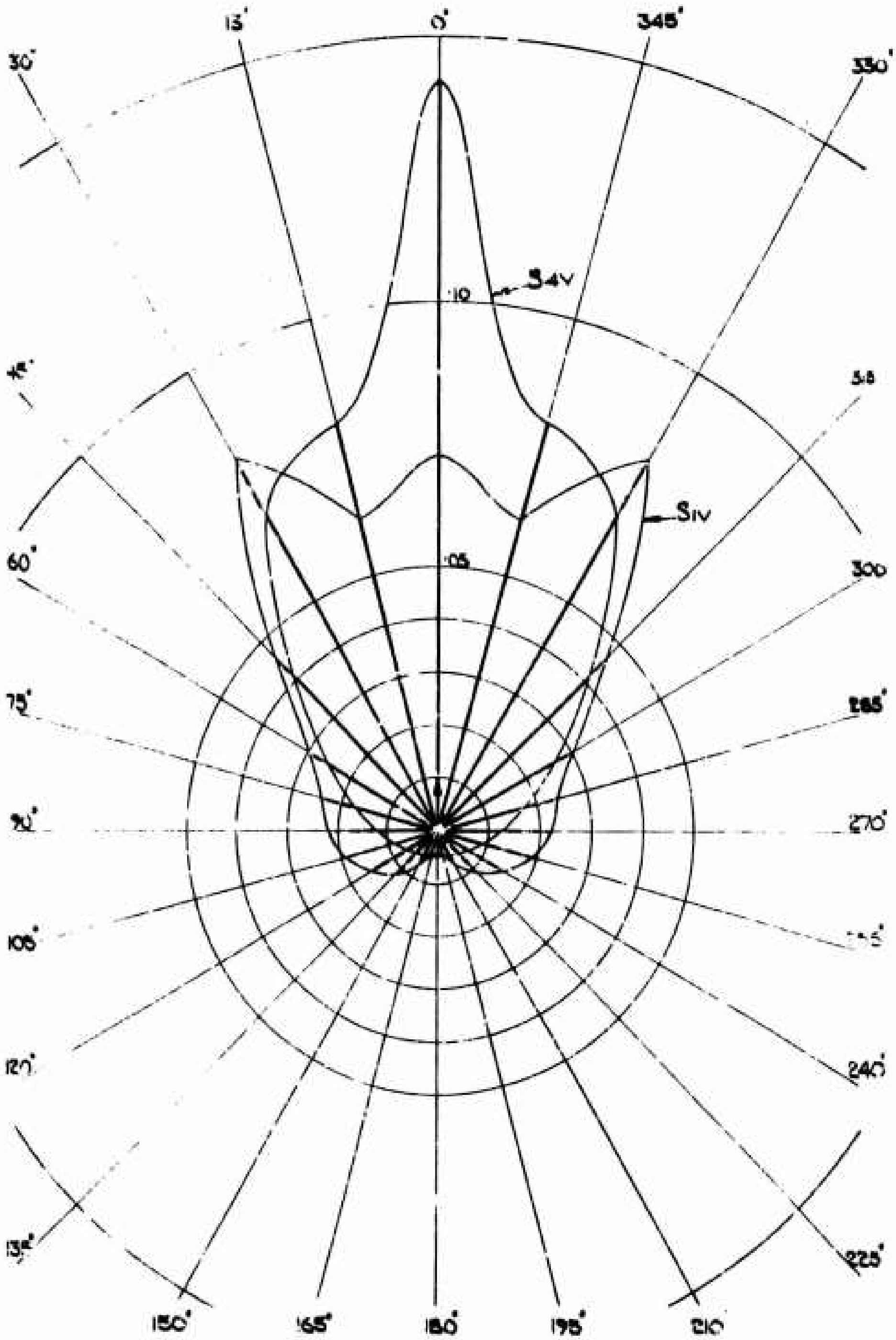
PROBABILITY OF COMET BEING DEFEATED BY 85mm APBC (T34/58)

(AIMING POINT VULNERABLE AREA)

(Range 1000 yds.)



VECTOR DIAGRAM OF SV (PROBABILITY)

SV = PV x d.p.v.

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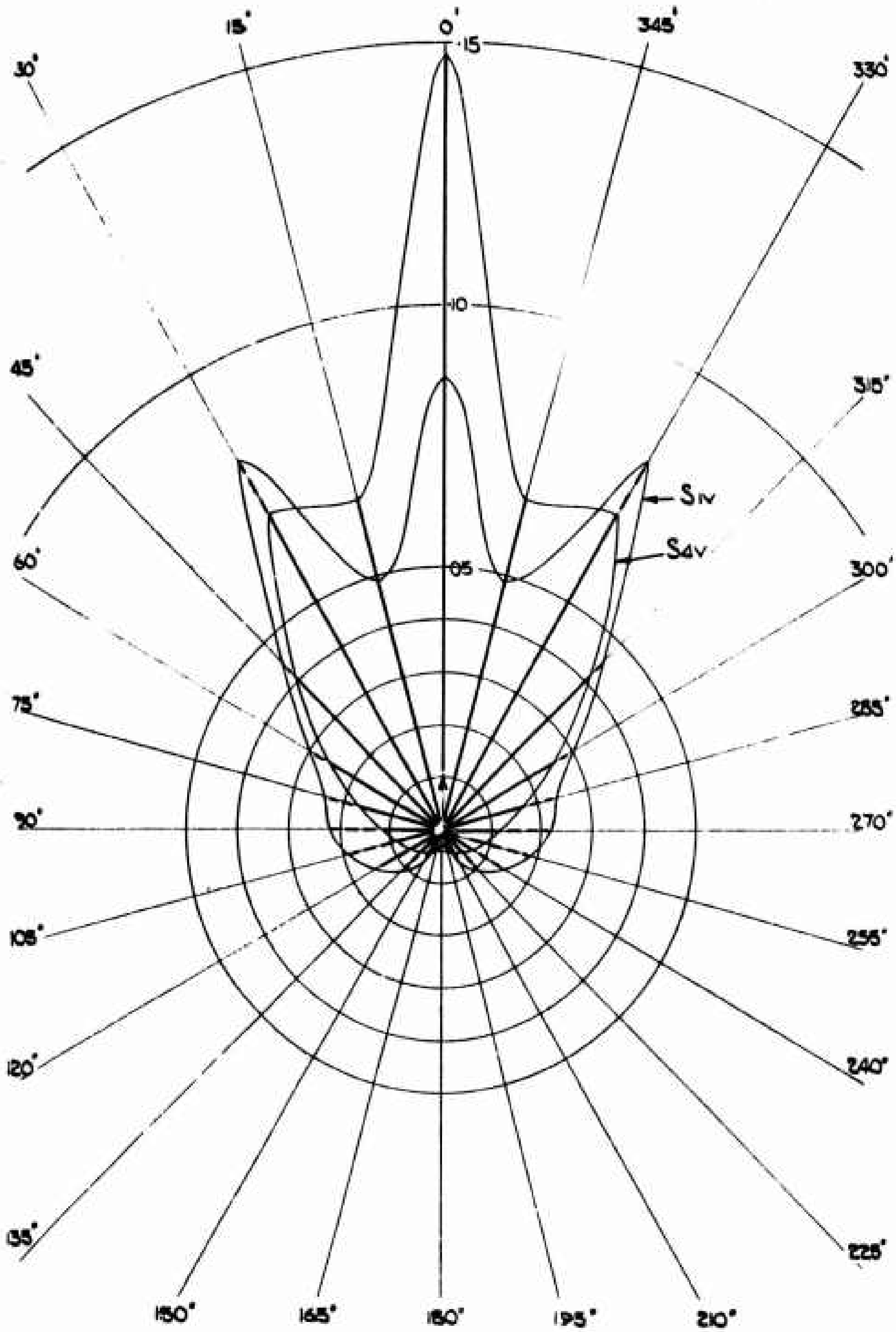
PROBABILITY OF COMET BEING DEFEATED BY 85mm. APBC (T34/58)

(AIMING POINT CENTRE OF HULL.)

(Range 1000 yds)



VECTOR DIAGRAM OF SV (PROBABILITY)

$S_V = P_V \times d.p.v.$

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APPX J

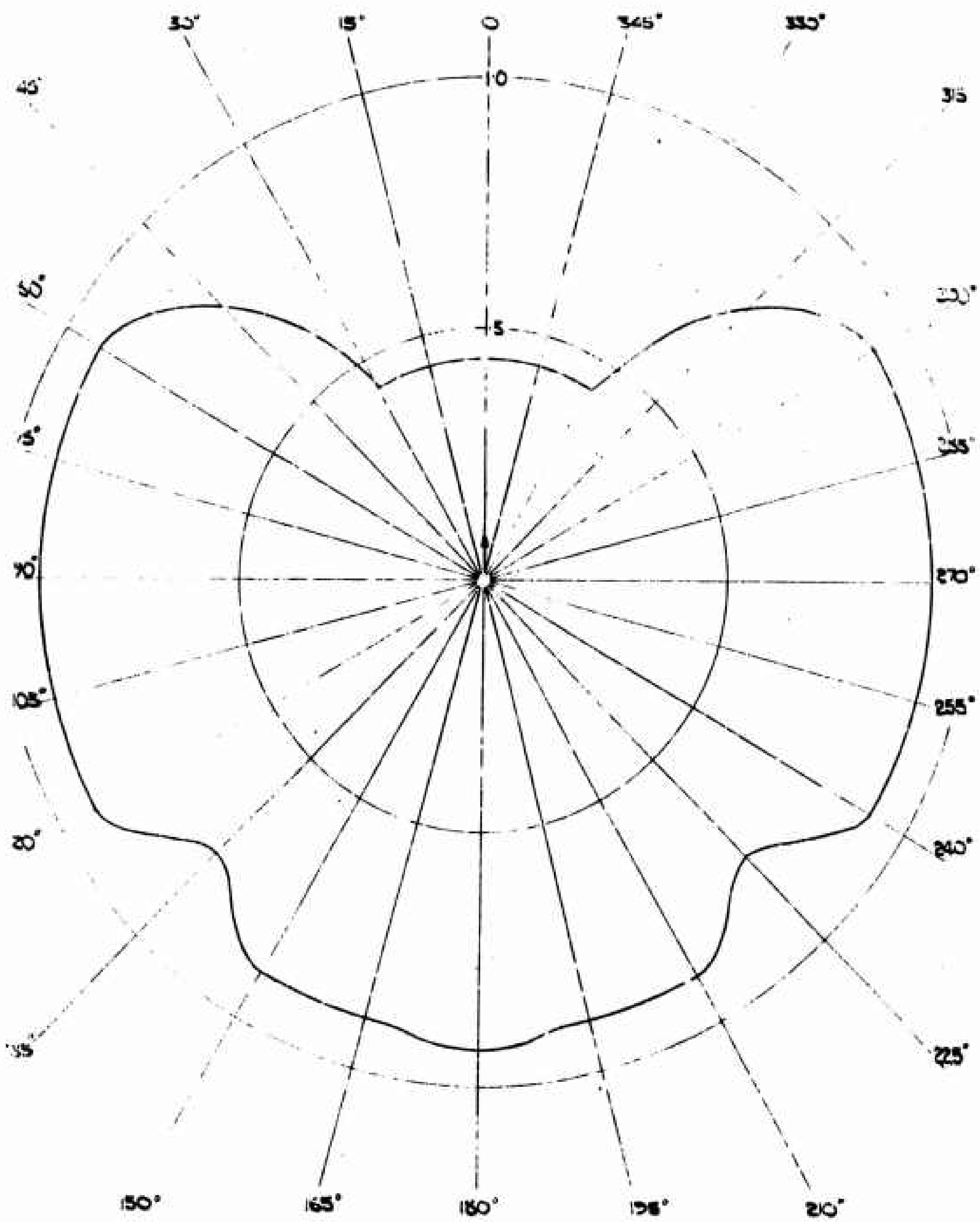
FIG. J 10

VULNERABILITY OF JS 3 TO ATTACK BY 20 PDR. APDS (CONT'S)

(AIMING POINT VULNERABLE AREA.)

(Range 1000 yds.)

POLAR DIAGRAM OF PV (VULNERABILITY)



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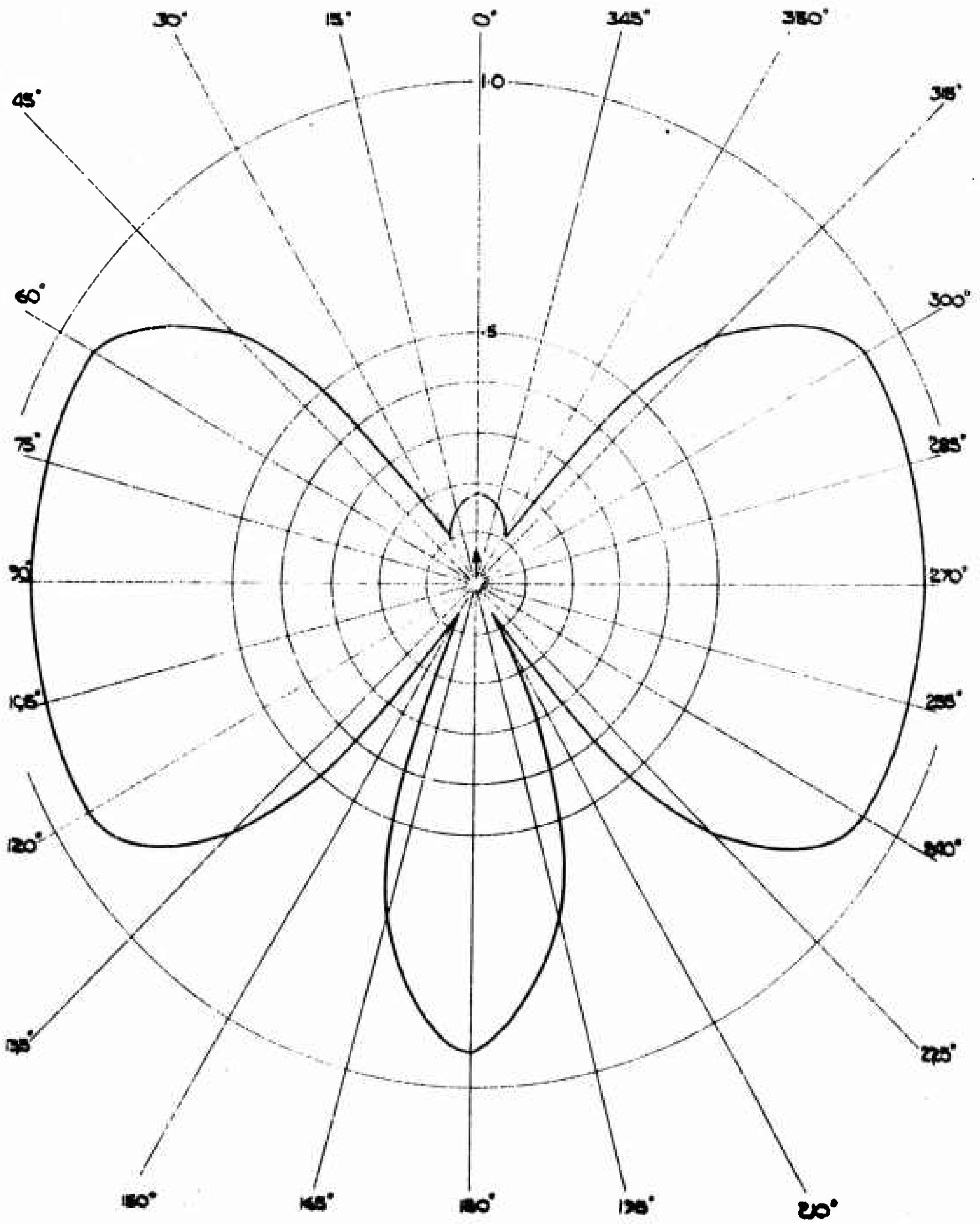
VULNERABILITY OF JS 3 TO ATTACK BY 20 PDR APDS (CENT 3)

(AIMING PT. :— CENTRE OF HULL)

(Range 1000 yds.)

POLAR DIAGRAM OF PV (VULNERABILITY) AT 15° INTERVALS.



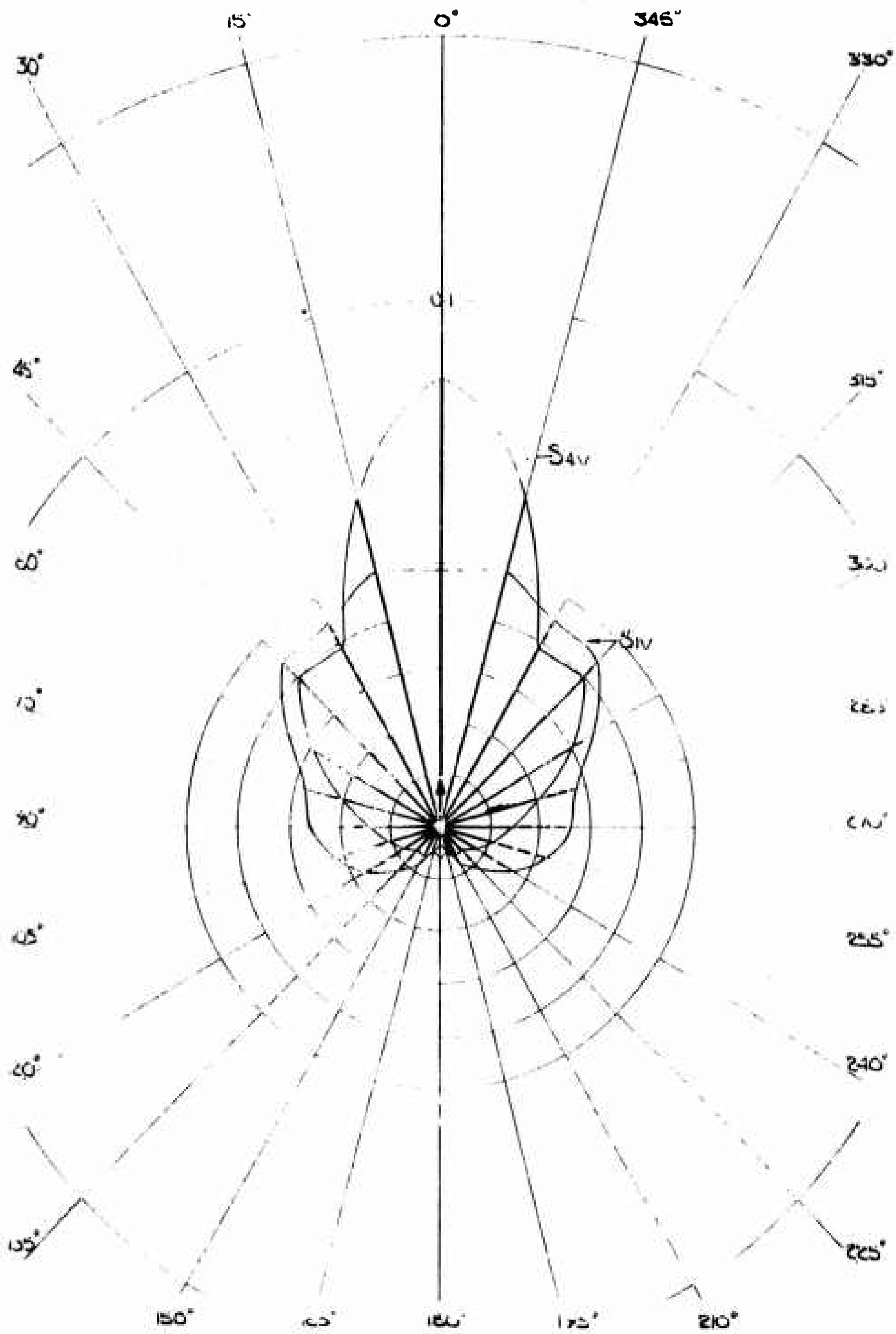
Appx J.

Fig J 12.

PROBABILITY OF IS 3 BEING DEFEATED BY 20 PDR APDS (CENT. 3)

(AIMING POINT VULNERABLE AREA)

(Range 1000 yds)



VECTOR DIAGRAM OF SV (PROBABILITY)

$Sv = Pv \times d.p.v.$

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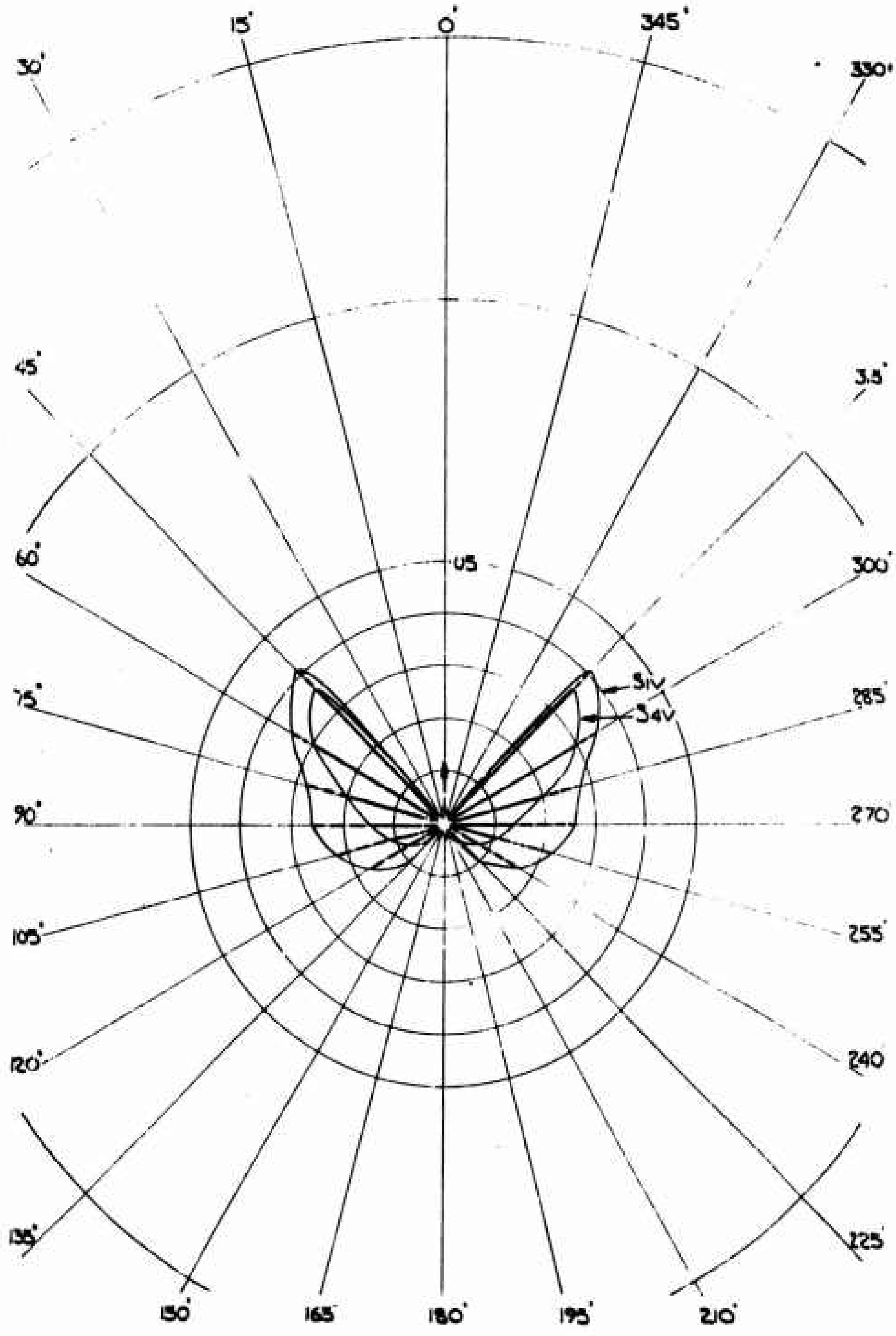
Appx. J.
Fig. J13.

PROBABILITY OF JS 3 BEING DEFEATED BY 20 PDR. APDS (CENT. 3)
(AIMING POINT CENTRE OF HULL)
(Range 1000 yds.)



VECTOR DIAGRAM OF SV (PROBABILITY)
(SV = PV x d.p.v.)

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Appx J.

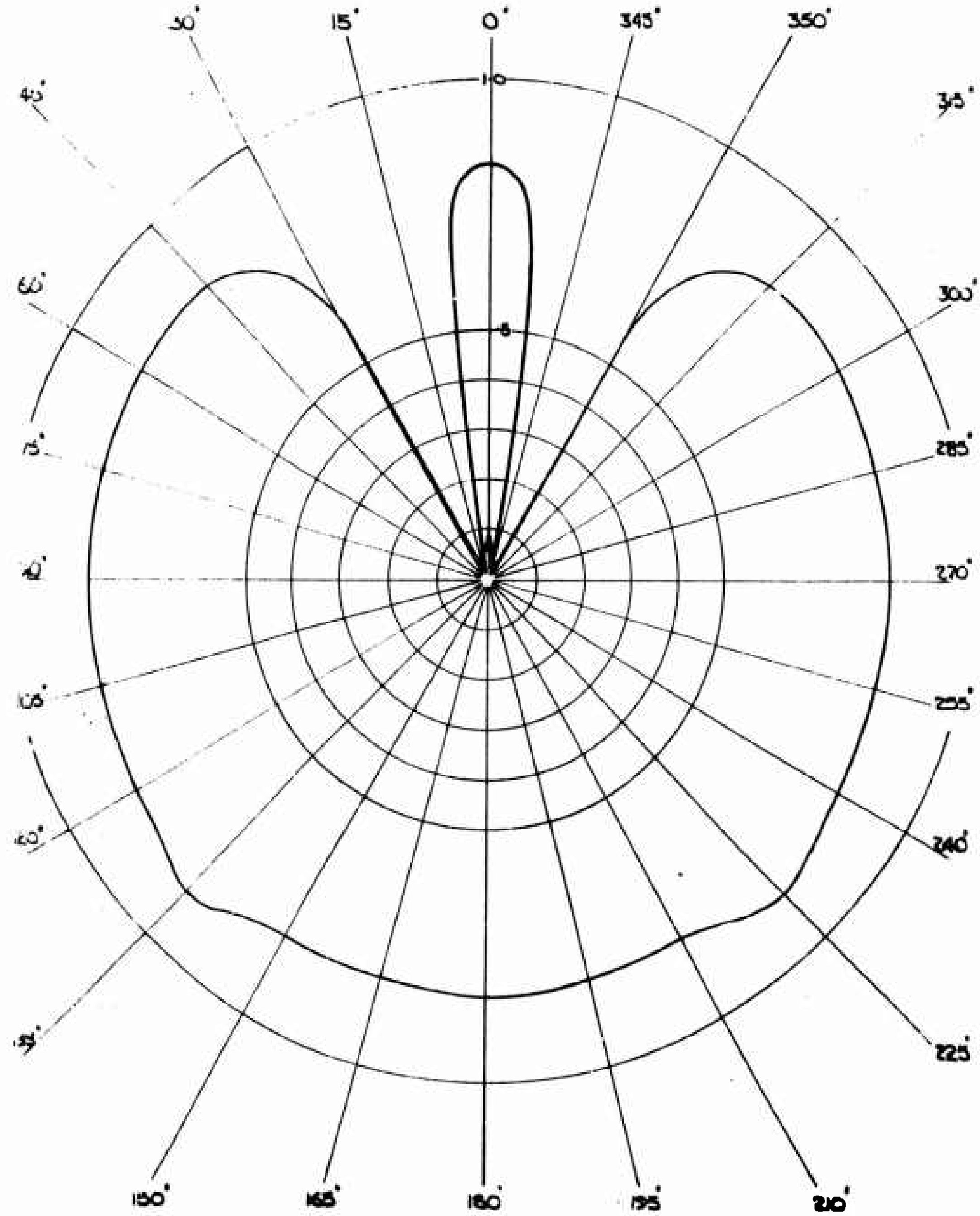
Fig. J 14.

Vulnerability of T34/58 to Attack by 77mm. APCBC (Comet)

(Aiming Point Vulnerable Area)

(Range 1000 yds.)

Polar Diagram of Pv (Vulnerability)



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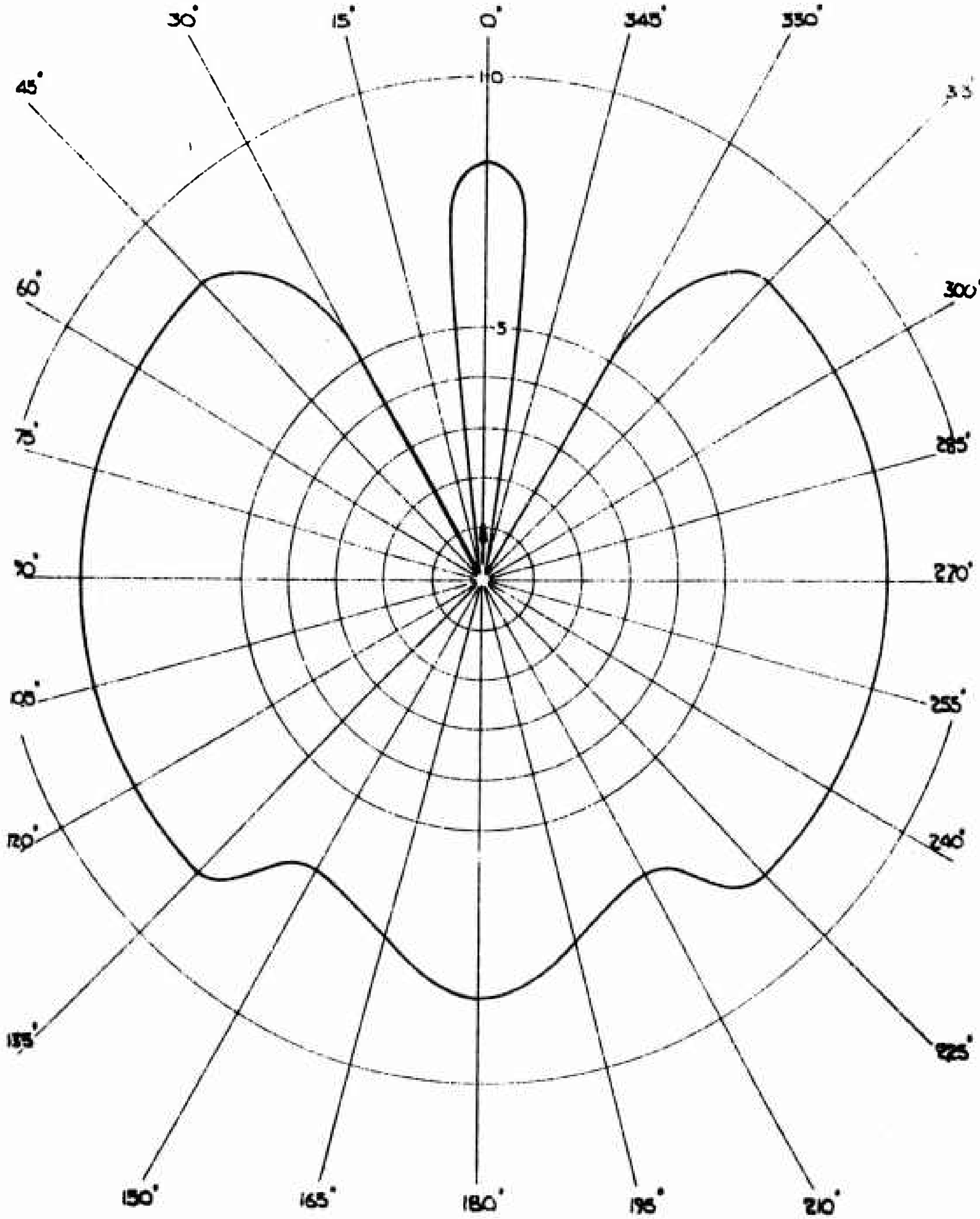
Appx J.
Fig J 15.

VULNERABILITY OF T34/85 TO ATTACK BY 77mm APCBC (COMET)
(AIMING POINT CENTRE OF HULL.
(Range 1000 yds.)

POLAR DIAGRAM OF PV (VULNERABILITY)



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Appx. J.
Fig. J 16.

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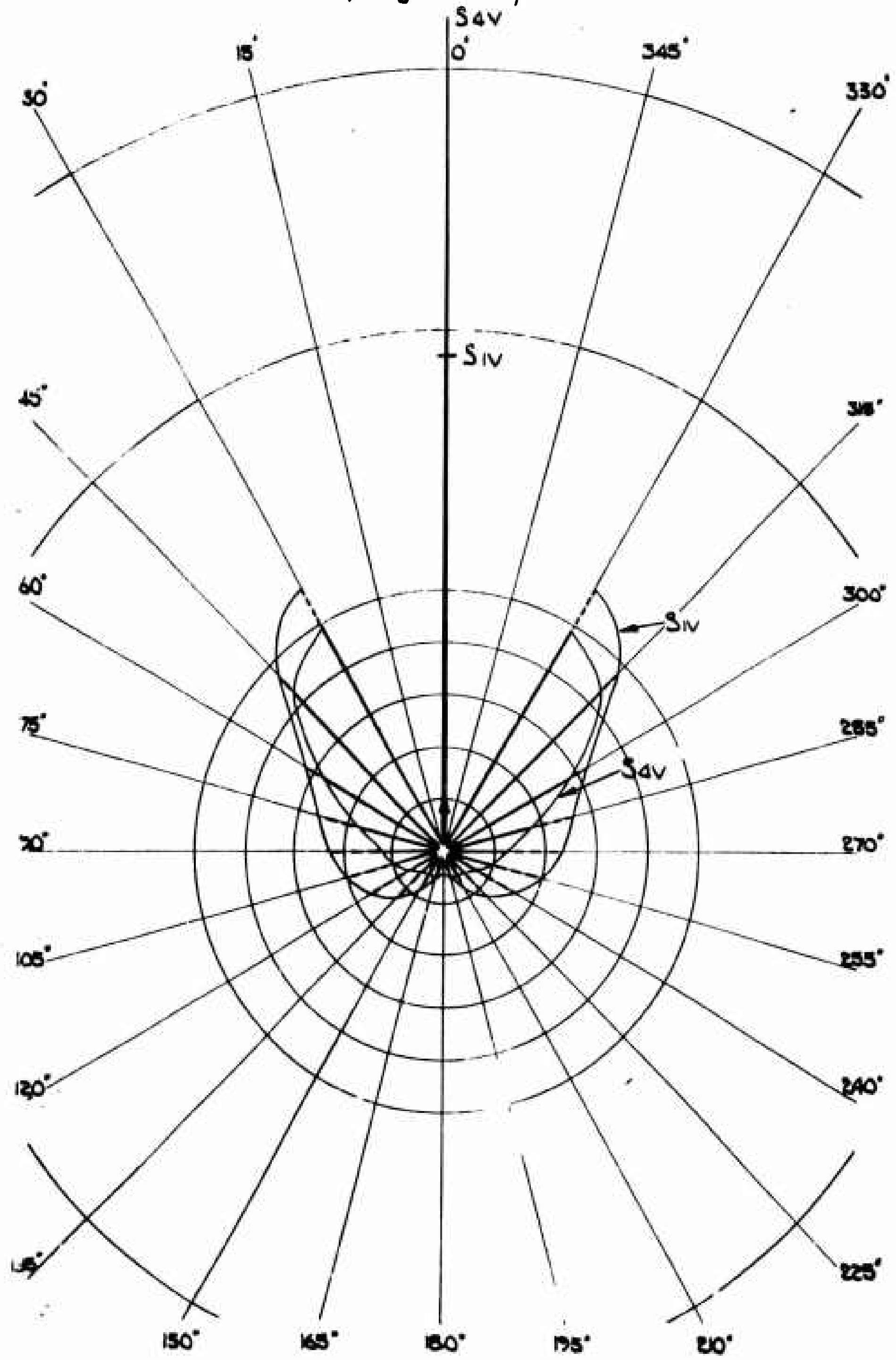
PROBABILITY OF T34/58 BEING DEFEATED BY 77mm. APCBC (COMET)

(AIMING POINT VULNERABLE AREA.)

(Range 1000 yds.)



VECTOR DIAGRAM OF SV (PROBABILITY)

SV = PV x d.p.v.

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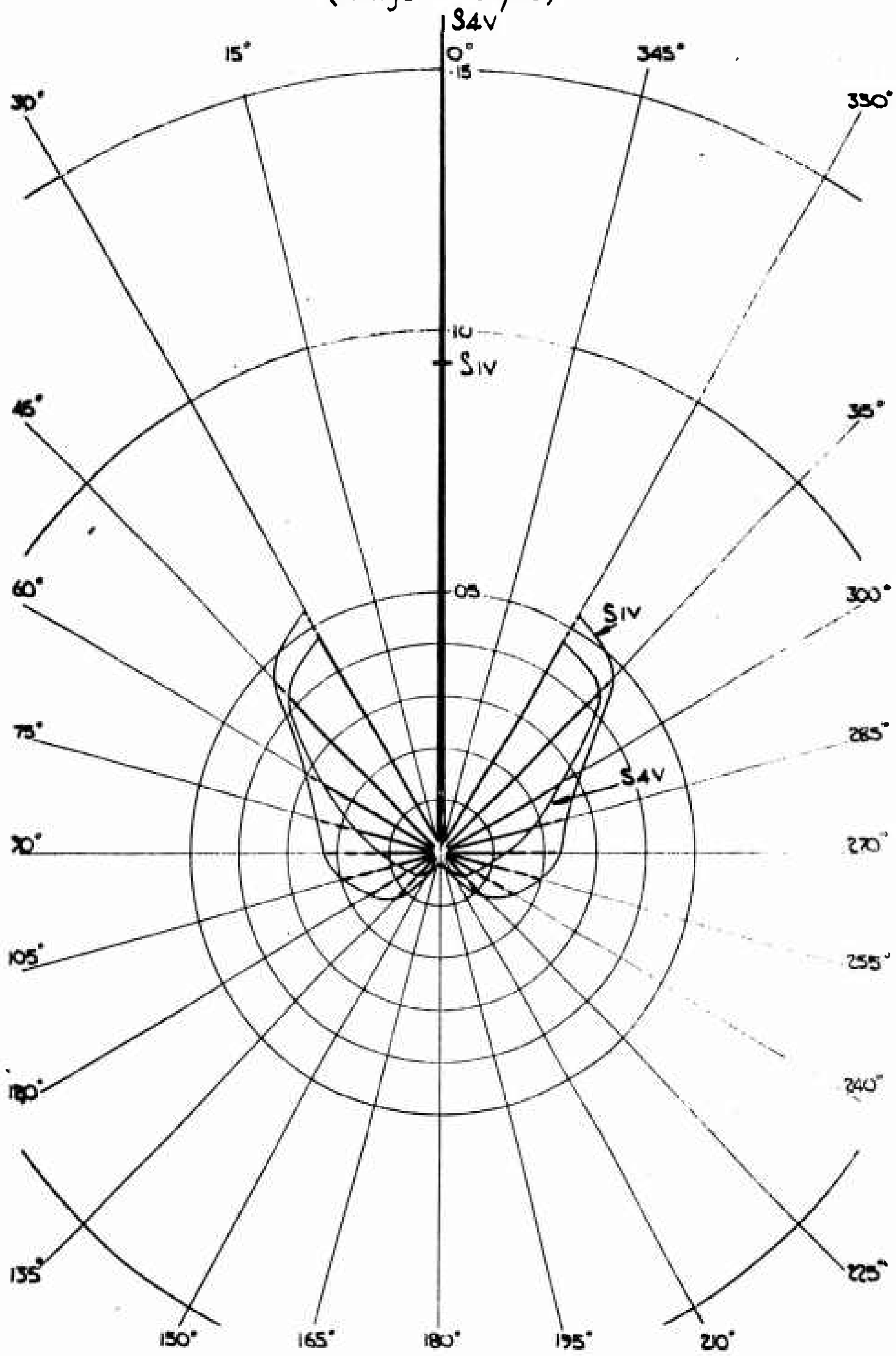
Probability of T34/85 being defeated by 77mm APCBC (Comet)

(Aiming Point Centre of Hull)

(Range 1000 yds.)



Vector Diagram of Sv (Probability)
(Sv = Pv x d.p.v.)

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Distribution

S.A./A.C.	12
D.M.O.	1
D.Plans	1
D.E.I.P.	1
D.M.I.	1
D.G.M.T.	2
Military College of Science	1
R.A.C. Centre	1
S.T.T.	1
D.W.D.	1
D.S.D.	1
D.R.A.C.	2
W.O. Library	2
Ministry of Defence	
D.R.P.C.	35
Sir Frederick Brundrett	1
Director of Operational Research, Admiralty	1
Scientific Adviser to the Air Ministry	1
Ministry of Supply	
P.O.B.	1
D.G.F.V.	1
D.F.V.(A)	1
F.V.D.E.	2
T.P.A.3/T.I.B.	3
Supt. Applied Ballistics	1
Defence Research Liaison Canada	6
Australian Army Staff	4
New Zealand Military Headquarters	4
British Joint Services Mission, Washington	6
Senior U.S. Standardisation Representative (G.S.(W)4)	8

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