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FURTHER STUDIES OF THE
DESIGN OF GUIDED WEAPON WARHEADS,
WITH A DESCRIPTION OF A NOMOGRAPHIC METHOD OF CALCULATING LETHALITY

by

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MASE-AM 11 July 1975

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June, 1951

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Further studies of the design of guided weapon warheads, with a description of a nomographic method of calculating lethality

by

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R.A.E. Ref. GW/S.100/10/26

SUMMARY

The nomogram described in this report has proved itself in regular use over a period of some months, particularly because it presents a number of the standard results employed in lethality assessment in a form at once readily accessible and suitable for application to a wide range of calculations; results obtained from it have led to the following conclusions:-

(1) The optimum fragment mass to attack the crew and engines of a heavy bomber aircraft is $\frac{1}{4}$ oz, unless it is certain that the crew is not protected by armour when smaller sizes, possibly as small as $^1/_{32}$ oz, would be better.

(2) It would be profitable to attack light-cased H.E. bombs within the aircraft using $\frac{1}{4}$ oz fragments having an initial velocity of 8000 ft/sec.

(3) If the warhead were filled with Torpex rather than T.N.T. there would be a saving in total weight of 10% or possibly more. For R.D.X./T.N.T., 60/40, the corresponding saving would be about 5%.

(4) For $\frac{1}{4}$ oz fragments double wire-winding does not seem to be a practicable method of fragment control within the range of warhead dimensions considered, but for a warhead designed to attack moderately soft targets controlled to give $^1/_{16}$ oz fragments the method might be used with advantage.

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1 Introduction

An earlier report[1] described a theoretical method of calculating the survival chance of a typical aircraft, exposed to the fragmentation of a cylindrical guided missile warhead, under certain assumptions of which the chief were:-

(i) that the warhead is detonated by a proximity fuze characterized by a constant looking angle of 70°, and

(ii) that the vulnerable components of the aircraft may reasonably be supposed spherically symmetrical and concentrated at the same point in space.

The theory was applied to assess the probability of survival under conditions defined by particular values of certain parameters such as fragment mass, total warhead weight, charge/case weight ratio, fuze burst range and height of attack: the criteria for destruction of the whole aircraft were taken to be:-

(i) lethal damage to at least two of the four engines, or

(ii) injury to the two pilots sufficient to incapacitate both, or

(iii) at heights greater than 43,000 ft only, the penetration of the pressure cabin transparencies.

The usefulness of the results in Ref.1 was limited, to some extent, by the arbitrary ranges of values chosen for the parameters and it was recognized, as the computation proceeded, not only that it would be necessary to enlarge the scope of the original work but also that the potential application of the method might be widened if the fundamental results were presented graphically as a nomogram. The results of such additional work are published in this note and the opportunity has been taken of presenting the nomogram at the same time: its use makes additions and subtractions the only arithmetic processes requisite in the calculation of the survival chance, thus facilitating greatly the task of the average computer.

It is not necessary to repeat the essential theory, which was developed fully in Ref.1, and the notes that follow will be devoted to details of the new work; this comprises methods of calculating:-

(i) the survival chance of a thin cased H.E. bomb as a distinct subtarget,

(ii) the effect on the total survival chance of substituting explosive fillings other than T.N.T. in the guided missile warhead,

(iii) the use of annular charges in the guided missile warhead, and

(iv) the use of wire winding as a method of fragment control.

The construction of the nomogram and the method of use, step by step, may be deduced from Table V, and the specimen work-sheet, Table VI.

There are, in addition, a number of changes of a detailed nature to be recorded but two restrictions must still be accepted: firstly it has not been possible to consider more than two fragment shapes (as distinct from sizes), the large increase in the number of graphs required for further cases being considered unreasonable, and, in consequence, calculations can be performed only for fragments controlled to cubes or 2:2:1 parallelopipeds; secondly the results still apply to cylindrical warheads only. Certain restrictions were placed on warhead dimensions in the earlier work[1] which have been accepted here, namely that the length should not exceed 24 ins, approximately, and that the diameter should be between 4 ins and 20 ins.

In all calculations relating to the H.E. bomb the bomb filling was assumed to be T.N.T.; the warhead was also supposed to be filled with T.N.T. except in a few instances where the filling is mentioned by name. Most of the results refer to explicit miss distances and it must be remembered, when comparing these with others referred to R.M.S. miss distances, that the lethalities may appear to differ considerably: some indication of the effect of these different methods of presentation may be obtained by comparing figures 2.06(a) and 2.06(b).

2 The fundamental theory: changes and additions to the earlier theory

2.1 The wider range of parameters

It is a notable advantage of the nomographic method that several parameters appearing as arbitrary constants in any given calculation enter only at the final stage. Among these are the mean vulnerable areas of the various subtargets and it has been decided to make use of this property by revising the figures originally used* to accord more closely with the most recent experimental results[2,3]: (in particular it seems that the compressor is the only component of a jet engine which can be assumed to contribute effectively to the vulnerability for British category C damage and, even so, fragments whose mass is $\frac{1}{8}$ oz or less do no damage). Similarly it would be a simple matter to change the penetration criteria. This increased flexibility, in conjunction with a change in the main computing scheme (to be described below) such that survival chances are calculated for each subtarget individually, makes it possible to use the nomogram to assess the vulnerability of a number of aircraft types.

The graphs have been prepared in such a way that engagements at any altitude up to 60,000 ft may be considered; two minor improvements in the construction of the statistical model permit variation in the proportion of the warhead case assumed to break into fragments of the desired size (previously fixed at $\frac{3}{4}$) and also the use of the true distribution function of fragment presented area, $g(a_i)$, rather than a linear approximation.

2.2 The survival chance of individual subtargets

It is convenient to be able to assess the contributions to the total destruction chance of each separate subtarget and, since the individual chances are readily combined to give the total, a small modification has been made in the computing process in order to determine them. It follows immediately from the theory already described** that, if the probability of destroying at least h of a set of k identical components, each presenting an area A, be denoted by $P(h:k)$, then

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* Ref.1, P.12. Revised figures appear in Table I of this note.

** Ref.1, Section 8.

$$P(2:4) = 1 - 4e^{-\frac{3nA}{\Omega r^2}} + 3e^{-\frac{4nA}{\Omega r^2}} \qquad (2.21)$$

$$P(2:2) = 1 - 2e^{-\frac{nA}{\Omega r^2}} + e^{-\frac{2nA}{\Omega r^2}} \qquad (2.22)$$

$$P(1:1) = 1 - e^{-\frac{nA}{\Omega r^2}} \qquad (2.23)$$

where n represents here the number of effective fragments and the notation is, otherwise, that previously used.

In the case of a four-engined aircraft the quantities $P(2:4)$, $P(2:2)$ and $P(1:1)$ represent, respectively, the chances of destroying more than two of the four engines, of disabling each of the two pilots and of penetrating the transparencies (or exploding the bomb); but, if a two engined aircraft controlled by one pilot only were under consideration, then the probabilities of causing lethal damage to the engines and crew would be $P(1:2)$ and $P(1:1)$ respectively.

Defining the total chance of destruction by P then, for a four-engined aircraft,

$$(1 - P) = (1 - P_e(2:4))\,(1 - P_c(2:2))\,(1 - P_t(1:1))\,(1 - P_b(1:1)) \qquad (2.24)$$

Here the subscripts e, c, t and b, referring respectively to the engines, pilots, transparencies and bomb load, have been introduced to eliminate all chance of ambiguity.

2.3 <u>The bomb load as a subtarget</u>

Although there remains a measure of disagreement as to the best method of assessing the chance of exploding a high explosive bomb by fragment impact it is thought that, under the conditions envisaged - that is, in the instance of a light cased bomb - an energy criterion is more nearly representative of actual conditions than a penetration criterion. That employed in the nomogram is based upon the results of K.S. Jones[4] and may be written,

$$\begin{aligned} &\text{if } \tfrac{1}{2}mV^2 \leqslant 2.6.10^6 \text{ then } P_d = 0 \\ &\text{if } \tfrac{1}{2}mV^2 \geqslant 5.0.10^6 \text{ then } P_d = 1 \qquad (2.31) \\ &\text{if } 2.6.10^6 < \tfrac{1}{2}mV^2 < 5.0.10^6 \text{ then } P_d = \frac{\tfrac{1}{2}mV^2 - 2.6.10^6}{2.4.10^6} \end{aligned}$$

where P_d = the probability of detonation

m = fragment mass (oz)

V = velocity at which the fragment strikes the bomb case (ft/sec)

This is believed to be a good approximation if the bomb case is less than $\frac{1}{2}$ in. thick and for fragment masses of $\frac{1}{4}$ oz or greater.

In general the fragment must penetrate one of the bomb doors before it strikes the bomb. As yet no satisfactory relation between the fragment velocities before and after penetration of a thin plate has received general acceptance and it has been decided, therefore, as an approximation to define the loss in velocity by the loss in momentum supposed equal to the minimum required to penetrate a bomb door consisting of a dural plate, 0.056 ins thick.

The chance of destroying the bomb load, P_b, is then expressed by the relation,

$$P_b = P_d \cdot P_h \tag{2.32}$$

where P_h = chance of the fragment striking the bomb load which has presented area A_b

$$= 1 - e^{-\frac{nAb}{\Omega r^2}} \tag{2.23}$$

2.4 The effect of changing the H.E. filling of the warhead

The assumption was made in the earlier calculations[1] that the missile would be charged with T.N.T. However, the use of more powerful explosives will make it possible to achieve a higher lethality for the same warhead weight and the nomogram has been constructed in a manner which allows this effect to be evaluated. The only important difference in method occurs in the calculation of initial fragment velocity. A considerable amount of field work has been done to establish a connection between fragment velocity and charge/case weight ratio and the relation previously employed* is thought to be a satisfactory representation provided that the length/diameter ratio of the warhead is fairly large (see 2.7): moreover, it has been shown that, to a reasonable degree of approximation, the velocities generated by any two explosives in cylindrical warheads of the same charge/case weight ratio are, themselves, in a constant ratio. Applying the latter conclusion, it follows that fragment velocities due to any explosive other than T.N.T. are found by multiplying the corresponding T.N.T. velocities by a constant factor, λ, say. Values of λ for a number of explosives are listed in Table III[5,6]. It is assumed, of course, that in fixing or calculating the charge/case weight ratio due account is taken of the change in density of the filling.

2.5 Annular warheads

The general theory has been applied to examine the effect of an annular hollow charge on warhead performance and the reasons which might justify the design of such a charge have been enumerated**. The computing process is identical to that employed for a solid warhead except that

* Ref.1 P.16 and Fig.7.

** Ref.1 Section 10.

a value must be assigned to one more parameter, namely, the internal radius of the annulus; but the relation between fragment velocity and charge/case weight ratio must be revised and, having regard to the very small amount of evidence in support of existing theories, it is thought that the hollow charge relation previously used is a satisfactory approximation*, subject to the proviso that the annular internal radius should not be less than one quarter of the external radius. It is pertinent to note that the weight of the material lining the annulus or of any substance within the annulus is neglected in reckoning the charge/case weight ratio.

2.6 Methods of fragmentation control

Complementary to the grooved charge method of fragmentation control are a number of methods depending on the use of notched wire, rings, cast pellets, punched holes or the use of spot hardened steel in the manufacture of the warhead case. A series of experiments is in progress in the United States with the object of determining the percentage of the case weight which can be converted to controlled fragments and the results so far available in this country show that although the punched hole and spot hardening methods are disappointing percentages of the order of 80% may be obtained using rings[7,8,9]. The only modifications to be observed in the computing process as defined previously[1] are,

(i) the use of the appropriate factor f defining the proportion of fragmenting metal converted to controlled fragments,

(ii) the inclusion of the weight of any liner with the weight of metal in calculating the charge/case weight ratio, and

(iii) the possibility of using cubical fragments even when the fragment mass is less than $\frac{1}{2}$ oz.

The nomogram is so constructed as to permit these modifications. If, however, it were required to study any fragment shape, other than the cube and the 2 x 2 x 1 rectangular parallelopiped which has its larger face parallel to the warhead surface, certain modifications would become necessary whose extent can be ascertained by inspection of the formulae given in Table V. For want of better information the curves for initial fragment velocity previously used have been assumed valid, remaining unmodified by the method of obtaining fragmentation control.

2.7 The initial fragment velocity theory for a short warhead

At the present time interest is increasing ~~the~~ in the design of warheads which have small values (≤ 1) of the length/diameter ratio. The relations between initial fragment velocity and charge/case weight ratio used in previous work[1] and illustrated in this note in figures 1.091 and 1.092 were intended to apply to long cylindrical warheads; experimental evidence which has become available recently[7,10] suggests that the velocities have been over-estimated whenever the length of the warhead was less than (approximately) twice its diameter.

The new information is contained in the results of two series of experiments recently completed in the U.S., one at the Ballistic Research Laboratories where a trial warhead was designed in such a way that the detonation wave was almost flat as it passed through the short warhead** and a second, which may be considered more realistic, at the

* Ref.1, Fig.90.

** Ref.7, Fig. 6.

Naval Proving Ground, where the initiation of the warhead was arranged to occur close to that section of the case where the fragments whose velocities were to be measured originated, so simulating more accurately the conditions likely to be encountered in practice. The results of both have been used to compute curves of the quantities γ_1, and γ_2, defined as, respectively, the ratios of the true initial velocity, according to the two sets of experimental data, to that initial velocity predicted by the long cylinder theory: γ is, of course, a function of the length/diameter ratio which tends to unity as that ratio increases. Graphs of γ_1 and γ_2 appear in figure 1.093.

In some of the calculations pertaining to this note the correction factor based on the B.R.L. data was applied and the use of γ_1 is to be understood wherever reference is made in subsequent paragraphs to the effect of the length/diameter ratio. The N.P.G. data were not available when the work was carried out, but the curve based on them is included as being more likely to represent the actual conditions during the detonation of a short warhead: but it should be emphasized that both curves are likely to be revised as more data become available.

3 Results and conclusions

3.1 The effects of fragment mass on the vulnerability of individual components

It is of considerable interest to know the magnitude of the relative contributions of individual subtargets or groups of subtargets to the probability of destruction of the whole aircraft and the manner in which they vary with the mass of the striking fragment. Typical curves are presented in figures 2.01 and 2.02 corresponding to a warhead weight of 150 lb at a miss distance of 90 ft. In figure 2.02, which refers to high altitude attack, the chances of incapacitating the pilots calculated under two sets of conditions, either allowing the possibility of an explosive decompression following the shattering of the cabin transparencies or not, are both shown.

In view of the steep rise in the pilot vulnerability curve corresponding to the lower fragment weight, and, therefore, to a higher fragment density, it has been thought wise to illustrate the effect of armour: it has been assumed that the pilots are completely encased within a layer of dural, $\frac{3}{8}$" thick, although clearly such an arrangement is not possible in practice. The pilots having been armoured thus the engines remain as the most vulnerable component (neglecting the bomb load which will be considered in greater detail in the next section) and it is fair to conclude that the fragment weight should be of the order of $\frac{1}{4}$ oz, the optimum against the engines and sufficient to give at least some chance of incapacitating the pilots even when they are moderately armoured.

3.2 H.E. bomb vulnerability

It is evident that the survival chance of the aircraft must diminish considerably when it carries a light-cased H.E. bomb. The method of assessing bomb vulnerability having been described in a previous section it remains to illustrate its effect, but first this point must be made: the conditions of fragment strike best suited to detonate the bomb and to destroy the other components here considered are unlike and it follows that the warhead design may be influenced by the strategic decision as to how far it is desirable that the defences should be particularly effective against aircraft carrying light-cased H.E. bombs.

It has been found that the best solid warhead of given weight to attack an aircraft (whose bomb load is neglected) is that giving the greatest fragment density, namely, the longest permissible, under the restrictions on length and diameter already noted, which has been that with the lowest charge/case weight ratio in the range of parameters so far considered[1]. The chance of detonating the bomb improves, however, as the charge/case weight ratio is increased, due to the higher striking velocity, and in most of the cases studied there has been a tendency for the optimum to be raised above the minimum defined by the lower limit of 4 ins imposed on the external diameter of the case: the extent is illustrated in figure 2.04. As the ratio is increased beyond this optimum the reduction in fragment velocity associated with small values of the warhead length/diameter ratio is sufficient to cause the total chance of detonation to diminish rapidly. Although these conclusions suggest that the differences between warheads intended to attack aircraft carrying and not carrying H.E. bombs might be considerable the results discussed below show that, in the range of parameters considered, they are in fact usually small.

Figures 2.01, 2.02 and 2.03, illustrating the effect of the variation of fragment mass on the lethalities of the bomb alone and of the whole aircraft, indicate that a fragment mass of $\frac{1}{4}$ oz is likely to be the most generally useful and, accordingly, most of the results that follow refer to solid warheads controlled to give $\frac{1}{4}$ oz (2:2:1) fragments (it being assumed that 75% of the metal in the warhead sides is converted into controlled fragments). It may also be concluded that fragments weighing 1/16 oz or less are incapable of damaging the bomb and it appears that the method of optimizing the charge/case weight ratio has little effect, particularly at high altitude. This impression is confirmed by figures 2.05 and 2.06, graphs of probability of destruction against miss distance, which are also intended to show what increase in the probabilities of destruction is to be expected when the aircraft carries a load of thin-cased H.E. bombs. By comparing these two graphs an estimate may be made of the importance of the value attached to the solid angle Ω defining the fragment zone. That appropriate to figure 2.05 is the 'optimum' in the sense of Ref.1 (that is to say it is such that the detected point always lies within the fragment beam whatever the directions of flight of the missile and target aircraft) and varies with the conditions of attack*. When the magnitude of the target is taken into account, however, the constant value of 4 steradians used in preparing figure 2.06, is probably more correct. The effects on the weight of the warhead of assessing the bomb load as vulnerable and of the two methods of optimizing the charge/case weight ratio may be estimated from figure 2.07 while the order of difference in the probability of destruction due to the use of the constant Ω rather than the variable Ω may be determined from figure 2.08.

3.3 The comparative lethalities of warheads with various explosive fillings/

The substitution of an explosive more powerful than T.N.T. serves to

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* The optimum value of Ω so defined will hereafter be referred to briefly as the variable Ω and the term fixed Ω will be assumed to imply a constant value of 4 steradians.

/ In the numerical work relevant to this section no account was taken of the reduction in fragment velocity due to small values of the warhead length/diameter ratio (cf. section 2.7). It should be noticed, also, that the values of the charge/case weight ratios used were the optima for T.N.T. filled warheads; in order to maintain the same values of the total warhead weight the dimensions of warheads filled with other explosives necessarily had to be different and, consequently, the limitations set out in Ref.1, namely $\ell \leq 24"$ and $2" \leq R \leq 10"$, have not been strictly observed in all instances.

increase the initial fragment velocity at a given charge/case weight ratio (in the manner described in section 2.4). Under the fuze matching conditions implied by the use of the variable Ω , as previously defined in this note and in Ref.1, the probability of destruction is increased as a result of the greater fragment velocity and the narrower permissible fragment zone but for a fixed Ω the former factor only contributes: the curves in figure 2.09 confirm that the increase is greater when Ω is variable but it must be repeated that the results based on variable Ω seriously over-estimate the advantage to be gained against a target of finite size.

Some saving in weight might thus be achieved by the use of a more powerful explosive and it is shown in figure 2.10 that the amount is sensibly independent of miss distance, of the altitude of attack and of the level of the probability of destruction when the weight of the T.N.T. filled warhead is 150 lb; however, figure 2.11 suggests that for other warhead weights the probability level does affect the percentage of weight saved. Figure 2.12 shows the proportional saving in warhead weight and increase in miss distance permissible to attain a given lethality level: the effects of varying the three parameters, warhead weight, miss distance and target altitude are so small that the curves plotted may be taken to represent all values in the ranges $100 \text{ lb} \leqslant W \leqslant 250 \text{ lb}$, $0 \leqslant S \leqslant 90$ ft and $h = 15{,}000$ ft or $50{,}000$ ft but they are not valid for fragment masses other than $\frac{1}{4}$ oz.

3.4 The optimum internal radius of a hollow cylindrical warhead controlled to give $\frac{1}{4}$ oz fragments

The calculations here described were intended to supplement an earlier study[1], which was restricted to $\frac{1}{2}$ oz fragments, and to demonstrate an important change in the order of the optimum annulus due to the inclusion of an H.E. bomb load as a vulnerable component. Figures 2.13 and 2.14, from which the optima may be deduced, show the probabilities of destruction of the aircraft without bomb load and of the bomb load alone, to be expected at miss distances of 45 and 95 feet and at altitudes of 15,000 and 50,000 feet: in preparing them it was necessary, at small values of the annular radius, to compromise between the two initial fragment velocity theories appropriate to hollow and solid charges. None of the warheads represented has a length/diameter ratio as low as unity and no allowance has been made for the fall-off in velocity associated with small values of that ratio. In figure 2.5 the probability of destruction of the aircraft and bomb as a single target are shown for the same values of other parameters.

It is obvious that the optimum size of the annulus depends primarily on whether or not the bomb is considered vulnerable. It is believed that the situation represented by these figures is close to the truth, despite any doubt as to the general reliability of the detonation criterion; this is so, not only because the assumption that the bomb has a thin case reduces the relative importance of the alternative penetration criterion, but also because the fragment mass here considered is of the same order as those occurring most frequently in penetration trials, a circumstance which heightens confidence in the energy criterion in this particular instance. It may be accepted, therefore, within the limits implied by the choice of parameters in this study, that the warhead design should depend fundamentally on the tactical use of the weapon envisaged: if the design is intended to be particularly effective against H.E. bomb carrying aircraft then the annulus should be small or, perhaps, non-existent, whereas if the weapon is to be used against all bomber aircraft a large annulus is likely to prove most satisfactory in the long run.

3.5 <u>The practicability of double-layer wire-winding as a method of fragment control in a short range guided missile</u>

The success of a double-layer wire-wound warhead must depend on the ability of the designer to provide fragments which are, at one and the same time, both sufficiently large and sufficiently fast to cause lethal damage. If the weapon and corresponding warhead should both be small the fact that fragment mass and velocity are interdependent is likely to cause some difficulty: for the case thickness depends directly on the fragment size and itself implies a minimum radius and length/diameter ratio in order to satisfy the velocity requirement. If the warhead defined by these minima is larger than that which can be installed no double wire-wound warhead can satisfy the conditions; otherwise the designer has a certain degree of choice.

A study has been made of a 200 lb solid warhead in order to compare the single and double wire-winding methods of controlling fragments to a mass of $\frac{1}{4}$ oz. The case thickness of the double wire-wound warhead is, of course, twice that of the single, and the warhead is of such a size for the argument outlined in the previous paragraph to apply, under the conditions stated: consequently the single is in this case decidedly the better (the H.E. bomb being completely invulnerable to the double wire-wound warhead, indeed) and the extent of its superiority is shown in figure 2.6. It has been considered instructive to present in the same figure corresponding curves for $^1/16$ oz fragments; in this case the indications are that under certain conditions the double wire-wound warhead is the better.

3.6 <u>Conclusions and Summary</u>

The nomogram described in this report has proved itself in regular use over a period of some months, particularly because it presents a number of the standard results employed in lethality assessment in a form at once readily accessible and suitable for application to a wide range of calculations; results obtained from it have led to the following conclusions:-

(1) The optimum fragment mass to attack the crew and engines of a heavy bomber aircraft is $\frac{1}{4}$ oz, unless it is certain that the crew is not protected by armour when smaller sizes, possibly as small as $^1/32$ oz, would be better.

(2) It would be profitable to attack light-cased H.E. bombs within the aircraft using $\frac{1}{4}$ oz fragments having an initial velocity of 8000 ft/sec.

(3) If the warhead were filled with Torpex rather than T.N.T. there would be a saving in total weight of 10% or possibly more; for R.D.X./T.N.T., 60/40, the corresponding saving would be about 5%.

(4) For $\frac{1}{4}$ oz fragments double wire-winding does not seem to be a practicable method of fragment control within the range of warhead dimensions considered, but for a warhead designed to attack moderately soft targets controlled to give $^1/16$ oz fragments the method might be used with advantage.

4 <u>Acknowledgement</u>

The authors wish to acknowledge the assistance of the computing staff of Assessment Division in performing the preliminary computation and in preparing the graphs of the nomogram.

REFERENCES

No.	Title, etc.
1	Report of the R.A.E. Project Group on medium-range anti-aircraft guided missiles, Appendix VI. R.A.E. Report No. G.W.6.
2	A.A. Lethality Committee Paper No.27.
3	A.A. Lethality Committee Paper No.31.
4	Vulnerability of warheads to single fragments. B.R.L.691.
5	A.R.D. Explosives Report, 124/44.
6	A.D.E. Report, 8/48.
7	Aircraft vulnerability and weapon lethality developments in the U.S.A. Report on a visit during November and December 1949. Report No. G.W.7, Mech.Eng.15.
8	Controlled fragmentation trials of 5" Ex-6 HVAR Heads. N.P.G.263.
9	First partial report on fragmentation tests of warheads for guided missiles. N.P.G.375.
10	First partial report on fragment velocity law programme. First partial report on fragmentation tests of experimental warheads with small length/diameter ratios. N.P.G.339.

Attached

Appendix
Tables I to VI
Drgs GW/P/2632-2682

Advance Distribution

M.O.S.		R.A.E.	
Chief Scientist		Director	
Chief Executive (GW)		DD(E)	
CS(A)		DD(A)	
PDSR(A)		RPD	
DGTD(A)		Aero Dept	
DGWRD	Action copy +10	Arm Dept	2
DMARD		ME Dept	2
DMXRD		Library	
DG of A			
GWAB (Dr. Knight)			
TPA3/TIB	175		

APPENDIX

A list of the parameters used in the nomogram together with a brief discussion of the extent to which they may be varied

The following parameters are implicit in the graphs and cannot be varied:-

V_M/V_T = ratio, (missile velocity)/(target aircraft velocity) = 2.0

α = the fuze looking-angle = 70^o

ρ_m = the density of mild steel = 0.28399 lb/cu. in

C_h = the atmospheric retardation constant at altitude h = $0.005564\ \rho_h/\rho_o$

Similarly the energy criterion of H.E. bomb detonation and the criterion to determine the residual velocity of a fragment which has penetrated the bomb doors are invariable.

The following quantities may be chosen to suit any condition of engagement, within reasonable limits:-

f = proportion of fragmenting metal converted into controlled fragments

h = height of attack

k_o/k = ratio, (thickness of liner)/(thickness of warhead case)

m = fragment mass

r = distance of burst from target

t = ratio, (end plate thickness)/(case thickness, k)

z = ratio, (density of H.E. filling)/(density of T.N.T.)

C/W = ratio, (charge weight)/(weight of case, excluding end plates but including liner)

R_A = radius of annulus

W = total weight of warhead (excluding any material filling the central annulus)

λ = ratio, (fragment velocity due to H.E. filling)/(fragment velocity due to T.N.T.)

ρ_L = density of liner

Also the fragments may be cubes or (2x2x1) parallelopipeds, whose greatest faces lie in the surface of the case, and it is possible to examine the effect of a single or double wire-winding. The quantities λ, z depend on the type of H.E. filling considered.

However most of these restrictions only apply to certain graphs: for example the value of the ratio V_M/V_T quoted is only employed in the calculation of Ω according to the 'optimum' method of Ref.1. The reader is referred to the equations and remarks in Table V for detailed information.

TABLE I

Values of A_j, the mean presented area (sq.ft) of the j^{th} subtarget, and of $\log_{10} A_j$: also of the penetration constants and thicknesses for each subtarget

Fragment Mass (oz) \ Component		Pilot Part shielded by Dural	Pilot Part shielded by Perspex	Engine	Transparencies h < 43000	Transparencies h ≥ 43000	Bomb
$\frac{1}{2}$	No.	1.9	0.9	2.4	0	5.0	15.0
	log	0.2788	-0.0458	0.3802	$-\infty$	0.6990	1.1761
$\frac{1}{4}$	No.	1.7	0.8	1.44	0	5.0	15.0
	log	0.2304	-0.0969	0.1584	$-\infty$	0.6990	1.1761
$\frac{1}{8}$	No.	1.4	0.7	0	0	5.0	15.0
	log	0.1461	-0.1549	$-\infty$	$-\infty$	0.6990	1.1761
< 1/16	No.	1.3	0.6	0	0	5.0	15.0
	log	0.1139	-0.2218	$-\infty$	$-\infty$	0.6990	1.1761
K_j		700,8000*	700,1800*	6000	1800		
p_j		0.7,0.06	0.7,0.5	0.31	0.5		
$K_j \cdot p_j$		970	1390	1860	900		
$\log(K_j \cdot p_j)$		2.9868	3.1430	3.2695	2.9542		

* The criterion for incapacitating a pilot is equivalent to that for the penetration of 0.7 ins of wood: the pilot is shielded partly by 0.06 ins dural plates and partly by the cabin transparencies, here supposed perspex, 0.5 ins thick. If the transparencies are included as a vulnerable component that part of the pilot shielded by them must be neglected in the pilot lethality assessment. In the calculations relating to armoured pilots (section 3.1) the value of $K_j p_j$ must be increased by the quantity 0.315 x 8000 to correspond to the greater thickness of dural: thus

$K_j p_j = 3490$ $\quad$ $\log K_j p_j = 3.5428$ $\quad$ (dural shielding)

$K_j p_j = 3910$ $\quad$ $\log K_j p_j = 3.5922$ $\quad$ (perspex shielding)

TABLE II

Values of k, the thickness of the warhead case (in), and of $\log_{10}k$: also of the fragment parameters y_1, y_2 and y_3*

	Fragment mass (oz) \ Dimensions of fragment		$k \times k \times k$	$\frac{k}{2} \times \frac{k}{2} \times \frac{k}{2}$	$2k \times 2k \times k$
Values of k	$\frac{1}{2}$	No.	0.4792	0.9584	0.3019
		log	-0.3195	-0.0184	-0.5201
	$\frac{1}{4}$	No.	0.3803	0.7607	0.2396
		log	-0.4199	-0.1188	-0.6205
	$\frac{1}{8}$	No.	0.3019	0.6038	0.1902
		log	-0.5201	-0.2191	-0.7208
	1/16	No.	0.2396	0.4792	0.1509
		log	-0.6205	-0.3195	-0.8213
	1/32	No.	0.1902	0.3803	0.1198
		log	-0.7208	-0.4199	-0.9216
	1/64	No.	0.1509	0.3019	0.0951
		log	-0.8213	-0.5201	-1.0218
Values of parameters	y_1	No.	2.0	16.0	0.5
		log	0.3010	1.2041	-0.3010
	y_2	No.	1.5	3.0	1.0
		log	0.1761	0.4771	0
	y_3	No.	1.0	0.5	4.0
		log	0	-0.3010	0.6021

* The quantities y_1, y_2 and y_3 are parameters introduced to reduce the number of dimensions in certain graphs and are defined as follows:-

$$y_1 = 2k^3 \rho_m/m$$

$$y_2 = \bar{a}k \rho_m/m$$

$$y_3 = m/k \rho_m \delta^2$$

TABLE III

Values of λ and z

H.E. charge	λ	z
Amatol	0.87	1.0
T.N.T.	1.0	1.0
RDX/TNT 60/40	1.1	1.0449
Torpex	1.2	1.1089

λ = ratio, (fragment velocity due to H.E.filling)/(fragment velocity due to T.N.T.)

z = ratio, (density of H.E. filling)/(density of T.N.T.)

ρ_c = density of T.N.T. = 0.05624 lb/cu.in.

TABLE IV

Notation

Symbol	Meaning	Units
a_i	presented area of fragment at the instant of impact	sq.in
$a_{i_{crit}}$	maximum value of a_i for which penetration is possible	sq.in
$\bar{a}$	mean presented area of fragment	sq.in
b	(as suffix) appropriate to the H.E. bomb	
c	(as suffix) appropriate to the pilots	
c_h	atmospheric retardation factor at altitude h	
d	(as suffix) appropriate to dural bomb doors	
e	(as suffix) appropriate to the engines	
f	properties of fragmenting metal converted into controlled fragments	
$g(a_i)$	distribution function of a_i	
h	altitude of attack	ft
k	thickness of warhead case	in
k_o	thickness of liner	in
ℓ	length of warhead (excluding end-plates)	in
m	fragment mass	oz
n	number of controlled fragments produced	
$p,(p_j)$	thickness of the (j^{th}) subtarget	in
r	distance of burst from target	ft
t	ratio, (end plate thickness)/(case thickness, k)	
t	(as suffix) appropriate to the cabin transparencies	
y_1	$2k^3 \rho_m/m$) parameters, functions of fragment shape, tabulated in Table II	
y_2	$\bar{a}k \rho_m/m$)	
y_3	$m/k \rho_m \delta^2$)	
z	ratio, (density of H.E. filling)/(density of T.N.T.)	
$A,(A_j)$	mean presented vulnerable area (of the j^{th} subtarget) tabulated in Table I	sq.ft
B	$\log_{10} (n/\Omega r^2)$	
C/W	ratio, (charge weight)/(weight of case, excluding end plates but including liner)	
E	kinetic energy of fragment	ft/oz/sec dynamic units

Symbol	Meaning	Units
$I(I_j)$	factor diminishing $A,(A_j)$, to account for the number of fragments failing to penetrate (the j^{th} subtarget) at range r	
$K(K_j)$	penetration constant (for the j^{th} subtarget)	
L/D	warhead length/diameter ratio	
P	probability of destroying the target aircraft, as a whole	
P_d	probability of detonating the H.E. bomb, given a fragment strike	
P_h	probability of a fragment striking the H.E. bomb	
P(h:k)	probability of destroying at least h of a set of k identical subtargets	
P_j	probability of causing lethal damage to the j^{th} subtarget	
Q	survival chance of the target aircraft, as a whole	
Q(h:k)	1 - P(h:k)	
Q_j	survival chance of the j^{th} subtarget	
R	external radius of the warhead	in
R_A	radius of annulus	in
V_M	missile velocity	ft/sec
V_o	initial static fragment velocity	ft/sec
V_r	residual fragment velocity after penetration of dural skin	ft/sec
V_S	striking velocity of fragment	ft/sec
V_T	velocity of the target aircraft	ft/sec
W	total warhead weight (excluding that of any material within the central annulus)	lb
W_C	weight of charge	lb
W_E	weight of the two end plates	lb
W_L	weight of liner.	lb
W_m	weight of side walls	lb
W_1	$(W - W_E)/k^3$	
W_2	$\left(1 + \frac{C}{W}\right)\left(\frac{W_M + W_L}{\ell k^2}\right) = \frac{W_e + W_m + W_L}{\ell k^2}$	

Symbol	Meaning	Units
Y	$2\pi t\, \rho_m (R/k)^2$	
Y_A	$2\pi t\, \rho_m (R_A/k)^2$	
Z	$\log_{10}\{Kp\, a_i\, \rho_m/m\, V_o\}$	
α	the fuze looking-angle	degrees
β	static fragmentation angle of throw	degrees
γ	ratio (V_o, experimental)/(V_o, predicted)	
δ	length of the shortest edge of a fragment	in
λ	ratio, (fragment velocity due to H.E. filling)/(fragment velocity due to T.N.T.)	
μ	$a_{i_{crit}}/k^2$	
ρ_c	density of warhead charge	lb/cu.in
ρ_h	density of atmosphere at altitude h	lb/cu.ft
$\rho,(\rho_j)$	expected number of strikes penetrating (the j^{th} subtarget)	
ρ_L	density of the liner	lb/cu.in
ρ_m	density of the metal case	lb/cu.in
Ω	solid angle defining the fragmentation zone	solid radians

TABLE V

A summary of the graphs in the nomogram

A. Graphs to find the dimensions of the warhead and the number of effective fragments

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.01	$^{x}/k$	x		k	-	Values of k from Table II
1.02	$\frac{C}{W} \cdot \frac{1}{z}$	$\frac{C}{W}$		z	-	Values of z from Table III
1.031	$\log(^{R}/k)$	$\frac{C}{W} \cdot \frac{1}{z}$	$\frac{R}{k} = 1 + \frac{k_o}{k} + \frac{C}{W}\left(\frac{\rho_m}{\rho_c} + \frac{\rho_L}{\rho_c} \cdot \frac{k_o}{k}\right) + \left[\left(\frac{R_A}{k}\right)^2 + \frac{C}{W}\left\{\frac{\rho_m}{\rho_c}\left(1 + 2\frac{k_o}{k}\right) + \frac{\rho_L}{\rho_c}\left(\frac{k_o}{k}\right)^2\right\} + \left(\frac{C}{W}\right)^2 \left\{\frac{\rho_m}{\rho_c} + \frac{\rho_L}{\rho_c} \cdot \frac{k_o}{k}\right\}^2\right]^{\frac{1}{2}}$	R_A/k	$k_o/k = 0$	All the figures 1.03 are correct only for the particular value of $\rho_m = 0.28399$ lb/cu.in
1.0321	"	"	"	"	$k_o/k = 0.3$ $\rho_L = 0$	These two graphs representing warheads which could not, in fact, exist, are provided to facilitate interpolation for intermediate values of ρ_L
1.0322	"	"	"	"	$k_o/k = 0.6$ $\rho_L = 0$	
1.0331	"	"	"	"	$k_o/k = 0.3$ $\rho_L = 0.096$	The density is that of aluminium
1.0332	"	"	"	"	$k_o/k = 0.6$ $\rho_L = 0.096$	"

TABLE V (Contd.)

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.04	$W_m/\ell k^2$	R/k	$\frac{W_m}{\ell k^2} = \pi \rho_m \left(2\frac{R}{k} - 1\right)$	-	-	Correct only when $\rho_m = 0.28399$ lb/cu.in
1.051) 1.052)	$W_L/\ell k^2$	R/k	$\frac{W_L}{\ell k^2} = \pi \rho_L \frac{k_o}{k} \left\{2\left(\frac{R}{k} - 1\right) - \frac{k_o}{k}\right\}$	ρ_L, $\frac{k_o}{k}$	-	Correct only when $\rho_m = 0.28399$ lb/cu.in
1.06	W_2	$\frac{(W_m + W_L)}{\ell k^2}$	$W_2 = \left(1 + \frac{C}{W}\right) \frac{(W_m + W_L)}{\ell k^2}$	$\frac{C}{W}$		
			$= \frac{W_c}{\ell k^2} + \frac{W_m + W_L}{\ell k^2}$			
1.071) 1.072) 1.073)	Y	R/k	$Y = 2\pi t\, \rho_m \left(\frac{R}{k}\right)^2$	t		Hence Y and Y_A: $Y - Y_A = W_E/k^3$ $W_1 = \frac{W - W_E}{k^3}$ correct only when $\rho_m = 0.28399$ lb/cu.in
1.081) 1.082)	W/k^3	W		k		Values of k from Table II

Then $$n = \frac{32\pi \rho_m f R k \ell}{m} = \pi f \frac{R}{k} y_1 \cdot \frac{W_1}{W_2}$$

and n may be found using logarithms (figure 1.18). Also

$$\log \ell = \log W_1 - \log W_2 + \log k$$

TABLE V (Contd.)

B. Graphs to evaluate the fragment cone and effective vulnerable areas

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.091	V_o $\log V_o$	C/W		λ		For solid charges. Values of λ from Table III
1.092	"	"		"		For annular charges. Values of λ from Table III
1.093	Υ $\log \Upsilon$	L/D				
1.10	$\log \Omega$	$y_2 \cdot \frac{r}{k}$	$\Omega = 2\pi(X_m - X_M)$ where $X_i = \frac{V_M + \overline{V}\cos\beta_i}{\{V_M^2 + \overline{V}^2 + 2V_M\overline{V}\cos\beta_i\}^{\frac{1}{2}}}$ $\overline{V}\sin(\beta_M - \alpha) = V_M \sin\alpha + V_T$ $\overline{V}\sin(\beta_m - \alpha) = V_M \sin\alpha - V_T$ $\overline{V} = V_o c_h \frac{\overline{a}r}{m} \Big/ (e^{c_h \frac{\overline{a}r}{m}} - 1)$	V_o, h		β_M, β_m are the angles defining the limits of the static fragmentation cone. Correct only when $V_M = 2V_T$ and $\alpha = 70^\circ$
1.11	Z	$y_2 \cdot \frac{r}{k}$	$Z = \log\left\{\frac{16\,Kpa_i\,\rho_m}{m V_o}\right\}$ $= \log(16\rho_m) - 0.027144 \frac{c_h}{\rho_m} \cdot y_2 \cdot \frac{r}{k}$	h		Correct only when $\rho_m = 0.28399$ lb/cu.in

TABLE V (Contd.)

B. (Contd.)

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.1211) 1.1212)	$-\log I_j$	$\log \mu$	$I = \int \left\{ 1 - \frac{K^2 p^2}{m^2 V_o^2} a_i^2 e^{2c_h \frac{r\bar{a}}{m}} \right\} g(a_i)\, d\, a_i$			for (1:1:1) fragments; $A_j I_j$ is the effective vulnerable area of the j^{th} subtarget (except the H.E. bomb)
1.1221) 1.1222) 1.1223)	"	"	the integration being over the range of a_i for which $g(a_i)$ exists and the integrand is positive			for (2:2:1) fragments; $A_j I_j$ is the effective vulnerable area of the j^{th} subtarget (except the H.E. bomb)

Then $\rho_j = \frac{n\, A_j\, I_j}{\Omega r^2}$

Hence $\log \rho_j$.

C. The survival chances of individual subtargets (except the bomb)

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.131)) 1.132)	$\log Q$	$\log \rho$	$Q(2:4) = 4e^{-3\rho} - 3e^{-4\rho}$ $Q(2:2) = 2e^{-\rho} - e^{-2\rho}$ $Q(1:1) = e^{-\rho}$			$Q(h:k) = 1 - P(h:k)$ as defined

Then $Q = \prod_j Q(h:k)$

where Q = survival chance of the target aircraft as a whole,

the product being over the whole range of vulnerable subtargets.

TABLE V (Contd.)

D. Graphs relating to the H.E. bomb load only

(The use of an energy criterion for bomb detonation necessitates this different computing schedule)

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.14	V_S	$\log\left(y_2 \cdot \frac{r}{k}\right)$	$V_S = V_o e^{-c_h \frac{\bar{a}r}{m}}$	h, V_o		
1.151	P_d	V_S	$P_d = 0 \quad E \leqslant E_1$	m		(1:1:1) fragments; Correct only when $E_1 = 2.6 \times 10^6$, $E_2 = 5.0 \times 10^6$, $K_d = 8000$, $p_d = 0.056$ ins
1.152	P_d	V_S	$P_d = 1.0 \quad E \geqslant E_2$; $P_d = \frac{\frac{1}{2}m V_r^2 - E_1)}{(E_2 - E_1)} \quad E_1 < E < E_2$	m		(2:2:1) fragments; Correct only when $E_1 = 2.6 \times 10^6$, $E_2 = 5.0 \times 10^6$, $K_d = 8000$, $p_d = 0.056$ ins
			where E = kinetic energy of fragment; $V_r = V_S - K_d \, p_d \frac{\bar{a}}{m}$			
1.16	P_h	$\log\left(\frac{nA_b}{\Omega r^2}\right)$	$P_h = 1 - e^{-\frac{nA_b}{\Omega r^2}}$			
1.171) 1.172)	P_d	P_h	$Q_b = 1 - P_d \cdot P_h$	Q_b		contour diagram for $\log Q_b$

E. Finally, in order to make the nomogram independent of tables of logarithms, a graph of $\log_{10} x$ against x is provided

Figure No.	Ordinate	Abscissa	Equation	Variable parameters	Fixed parameters	Remarks
1.18	log x	x				

Technical Note No. G.W.120

TABLE VI

A computing schedule for the calculation of the survival chance, Q, of a four-engined aircraft*

Conditions of the engagement

h =	50,000	fragment control =	double wire-winding	f =	0.75	H.E. =	RDX/TNT 60/40
r =	100	m =	$\frac{1}{4}$	t =	2	λ =	1.1
		fragment shape =	1:1:1	R_A =	2.5	z =	1.0449
		C/W =	0.88	k_o/k =	0.15		
		W =	500	ρ_L =	0.048		

Computation*	to be evaluated:	value:	obtained from:	Computation*			
1	k	0.7607	Table II	19	log y_1	1.2041	Table II
2	log k	-0.1188	Table II	20	log f	-0.1245	1.18
3	R_A/k	3.28	chart 1.01	21	log n	3.8647	log R/k + log W_1 - log W_2 + log y_1 + log f + 0.4971
4	$C/W \cdot 1/z$	0.842	" 1.02				
5	log R/k	1.088	" 1.03	22	n	7323	1.18
6	R/k	12.2	" 1.18	23	log ℓ	1.092	log W_1 - log W_2 + log k
7	log R	0.969		24	ℓ	12.1	1.18
8	R	9.31	" 1.18	25	log r	2.0	1.18
9	$W_m/\ell k^2$	20.8	" 1.04	26	log y_2	0.4771	Table II
10	$W_L/\ell k^2$	2.6	" 1.05	27	log (y_2 r/k)	2.5959	
11	$(W_L + W_m)/\ell k^2$	23.4		28	y_2 r/k	394.5	1.18
12	W_2	41.0	" 1.06	29	V_o	4420	1.09
13	log W_2	1.613	" 1.18	30	log Ω	0.428	1.10
14	Y	530	" 1.07	31	B	-0.5633	log n - log Ω - 2 log r
15	Y_A	40	" 1.07	32	Z	0.623	1.11
16	W/k^3	1140	" 1.08	33	log y_3	-0.3010	Table II
17	W_1	650	W/k^3 - Y + Y_A	34	log V_o	3.6455	1.18
18	log W_1	2.813	" 1.18	35	log k p μ	3.8487	Z + log k + log y_3 + log V_o

TABLE VI (Contd.)

		Pilot part shielded by Dural	Pilot part shielded by Perspex	Engine	Trans-parencies	
36	log K_p	2.9868	3.1430	3.2695	2.9542	Table I
37	log μ_j	0.8619	0.7057	0.5792	0.8945	log $K_p \mu$ - log K_p
38	log I_j	-0.018	-0.038	-0.075	-0.016	1.12
39	log A_j	0.2304	-0.0969	0.1584	0.6990	Table I
40	log ρ_j	-0.3509	-0.6982	-0.4799	0.1197	B + log I + log A
41	ρ_j	0.446	0.200	———	———	1.18
		Dural	Dural +Persp.			
42	ρ_c	———	0.646	———	———	$\rho_c = \rho_c$ (Dural) + ρ_c (Perspex)
43	log ρ_c	———	-0.190	———	———	1.18
44	log Q_j	-0.060	-0.112	-0.168	-0.574	1.13
45	Q_j	0.871	0.773	0.679	0.277	1.18

H.E. Bomb

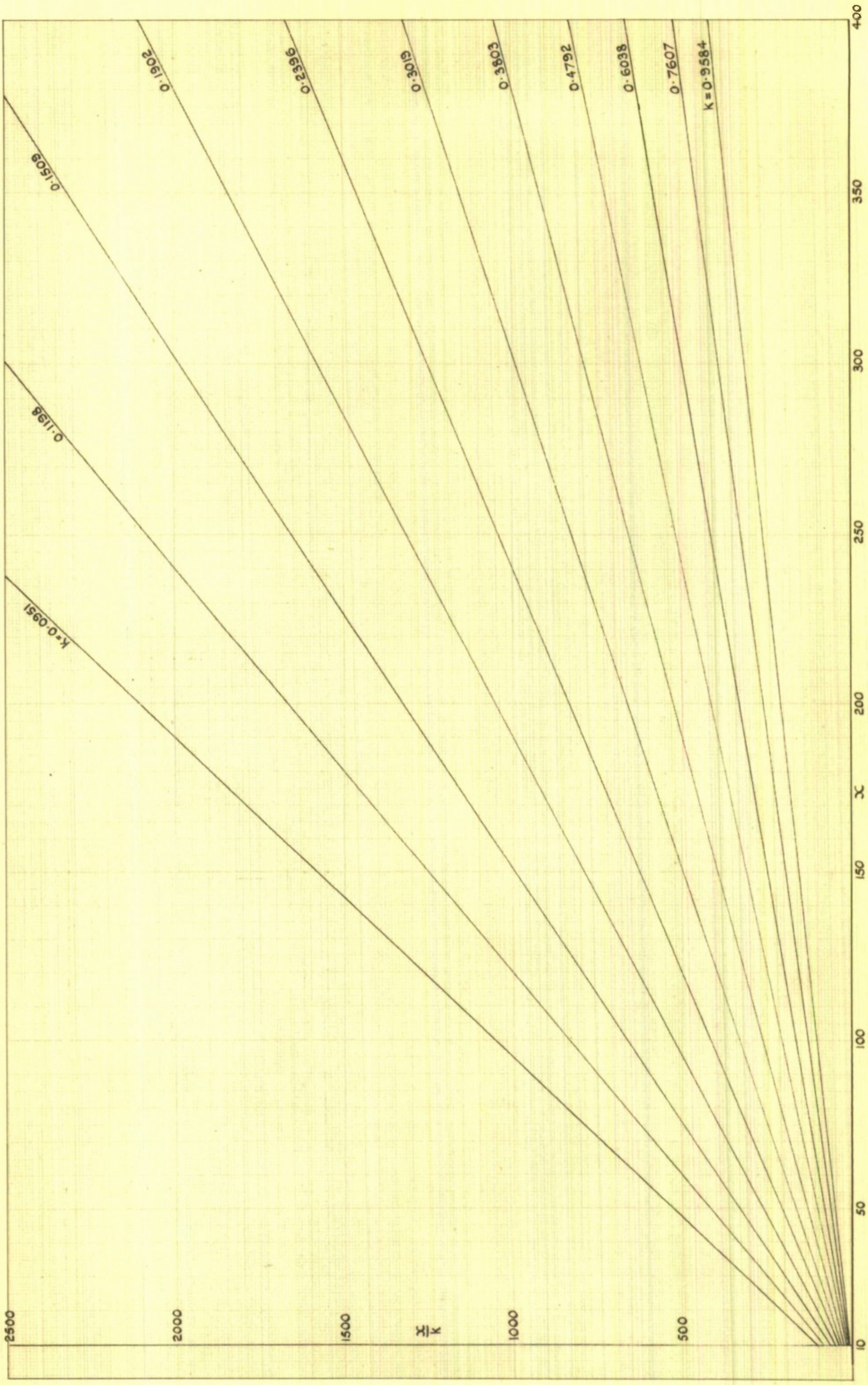
46	V_S	4086	1.14	49	P_h	0.985	1.16
47	P_d	0	1.15	50	log Q_b	0	1.17
48	$\log(nA_B/\Omega r^2)$	0.6238	B + log A_B	51	Q_b	1.0	1.18

	Whole aircraft	Aircraft excluding Bomb	Aircraft excluding Transparencies	Aircraft excluding Bomb and Transparencies	
log Q	-0.914	-0.914	-0.340	-0.340	$\log Q = \sum_j \log Q_j$
Q	0.122	0.122	0.457	0.457	

Q = overall survival chance

* Where a calculating machine is available some modifications of this schedule will probably be considered desirable. No allowance has been made here for the length/diameter ratio effect.

FIG. 1·01.


K=0·0951
0·1198
0·1509
0·1902
0·2396
0·3019
0·3803
0·4792
0·6038
0·7607
K=0·9584
10
50
100
150
200
250
300
350
400
x
500
1000
1500
2000
2500
x/k

GW/P. 2649.

T.N. G.W. 120.

FIG. 1·02

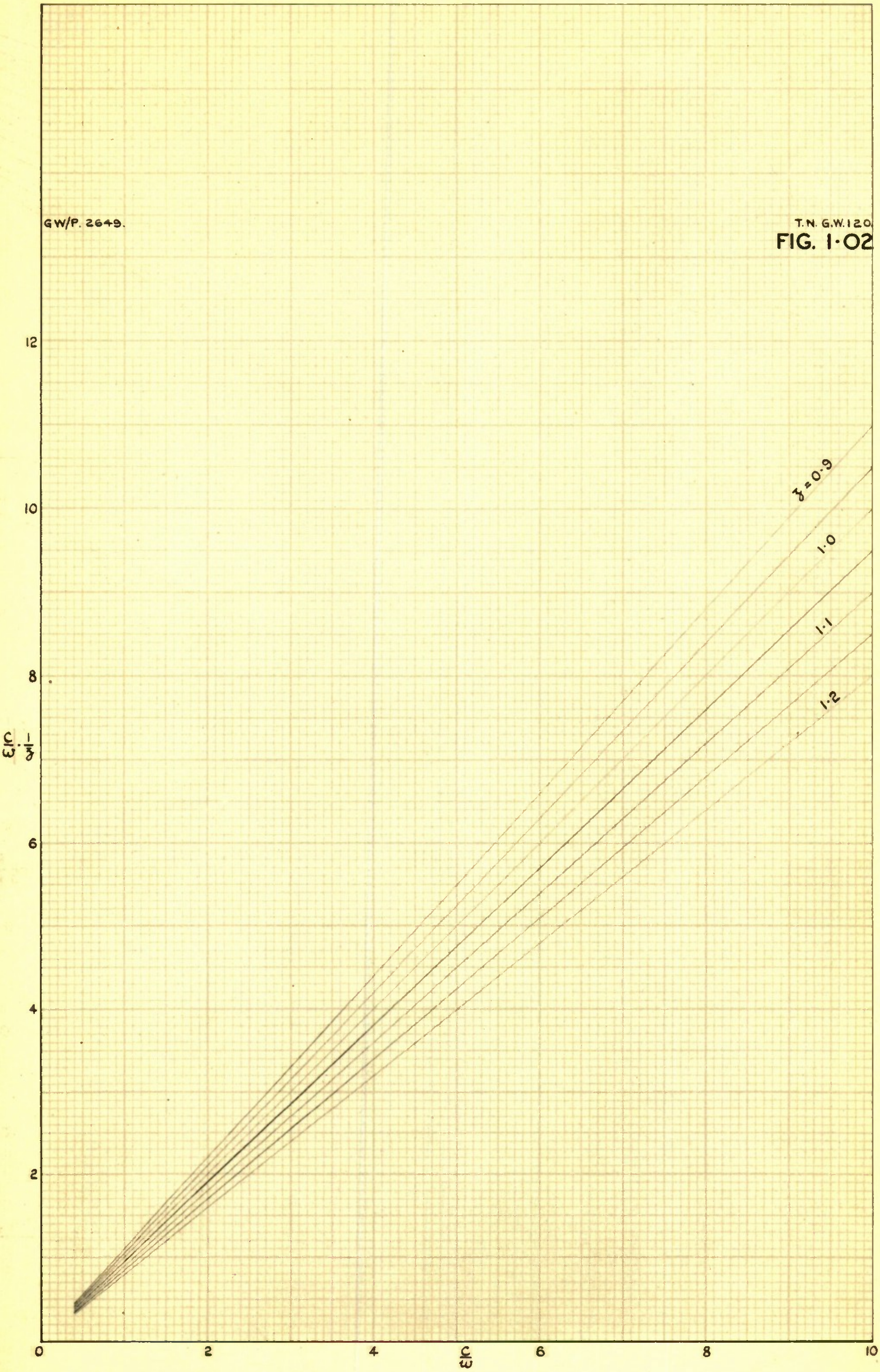


FIG. 1·031

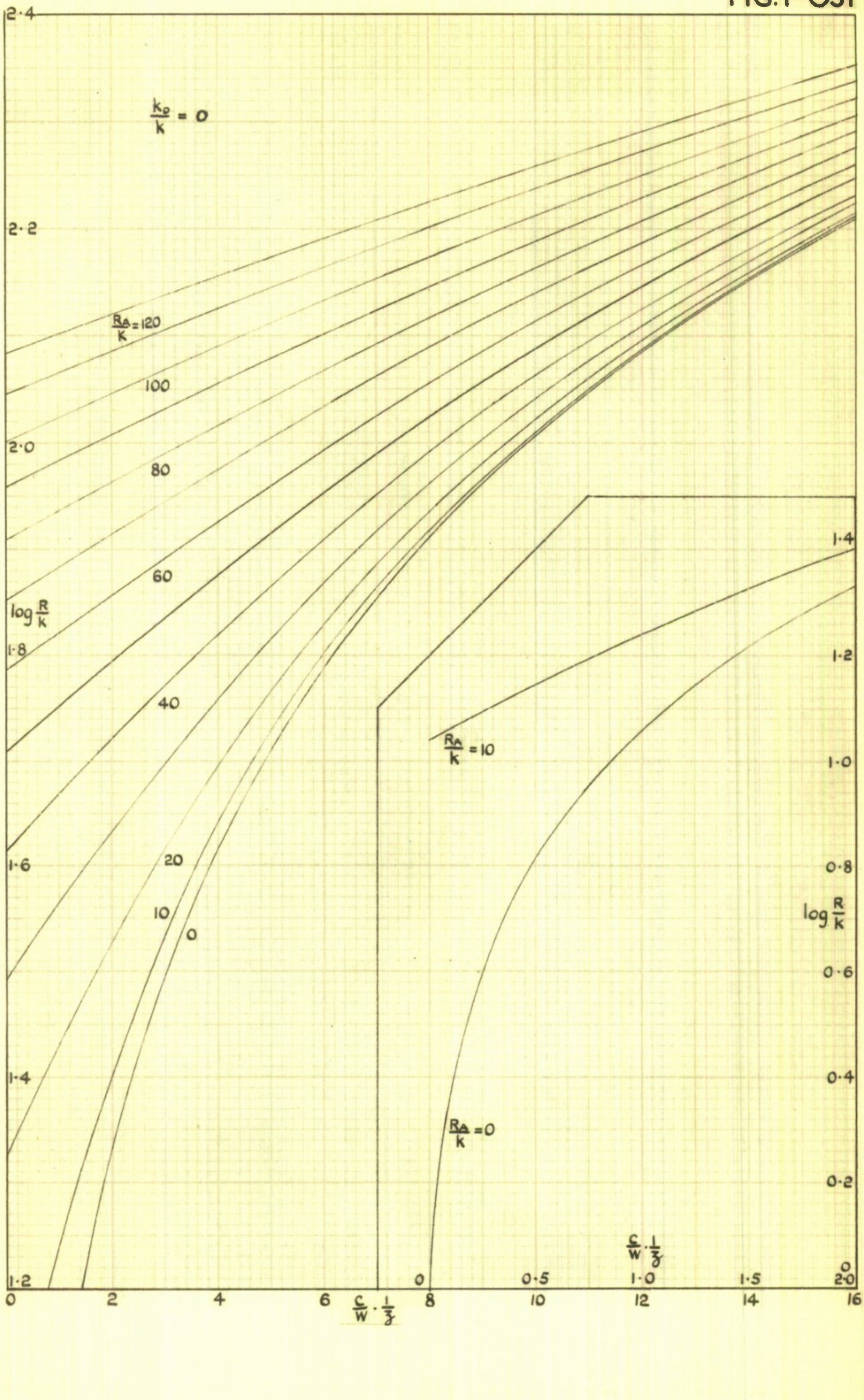

$\frac{k_0}{k} = 0$
$\frac{R_A}{K} = 120$
100
80
60
40
20
10
0
$\frac{R_A}{K} = 10$
$\frac{R_A}{K} = 0$
$\log \frac{R}{k}$
$\frac{c}{W} \cdot \frac{1}{\gamma}$
2·4
2·2
2·0
1·8
1·6
1·4
1·2
0
2
4
6
8
10
12
14
16
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
0·5
1·0
1·5
2·0

FIG. 1·0321.

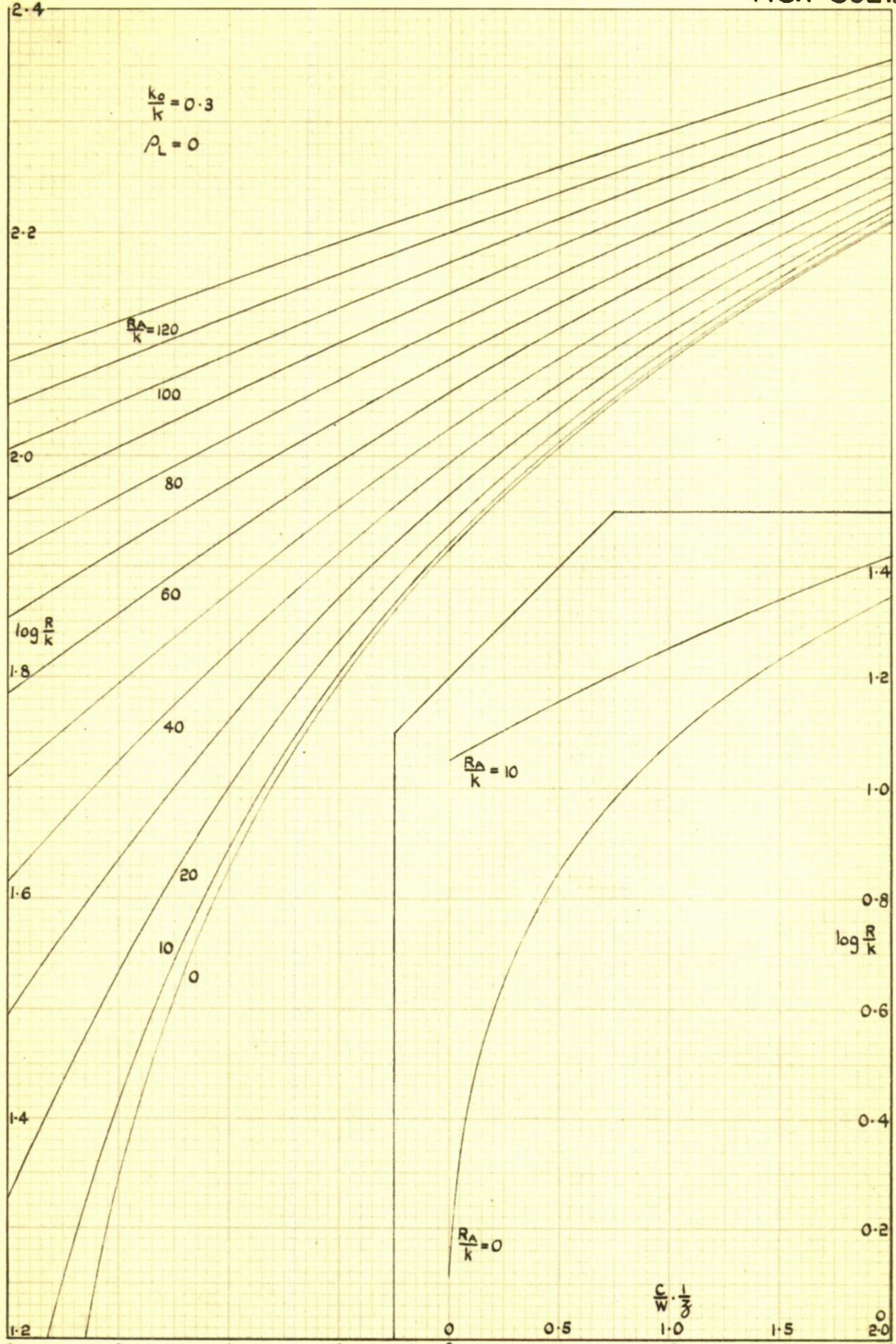

$\frac{k_0}{k} = 0\cdot3$
$\rho_L = 0$
$\frac{R_A}{k} = 120$
100
80
60
40
20
10
0
$\frac{R_A}{k} = 10$
$\frac{R_A}{k} = 0$
$\log \frac{R}{k}$
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
0
2
4
6
8
10
12
14
16
$\frac{C}{W} \cdot \frac{1}{3}$
0
0·5
1·0
1·5
2·0

FIG. 1·0322

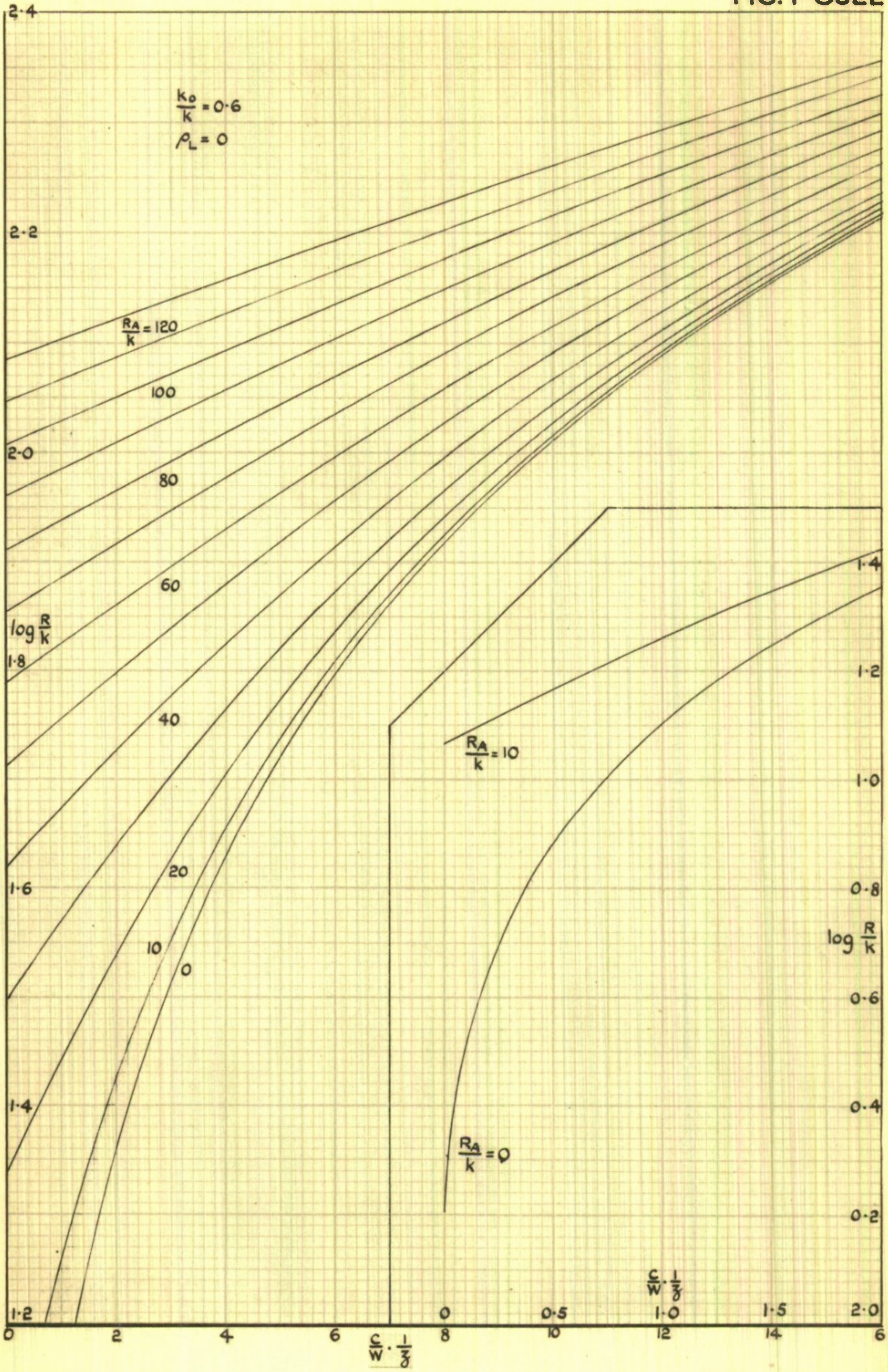

$\frac{k_0}{k} = 0{\cdot}6$
$\rho_L = 0$
$\frac{R_A}{k} = 120$
100
80
60
40
20
10
0
$\log \frac{R}{k}$
2·4
2·2
2·0
1·8
1·6
1·4
1·2
0
2
4
6
8
10
12
14
16
$\frac{C}{W} \cdot \frac{1}{\delta}$
$\frac{R_A}{k} = 10$
$\frac{R_A}{k} = 0$
1·4
1·2
1·0
0·8
0·6
0·4
0·2
2·0
1·5
1·0
0·5
0

FIG. 1·0331.

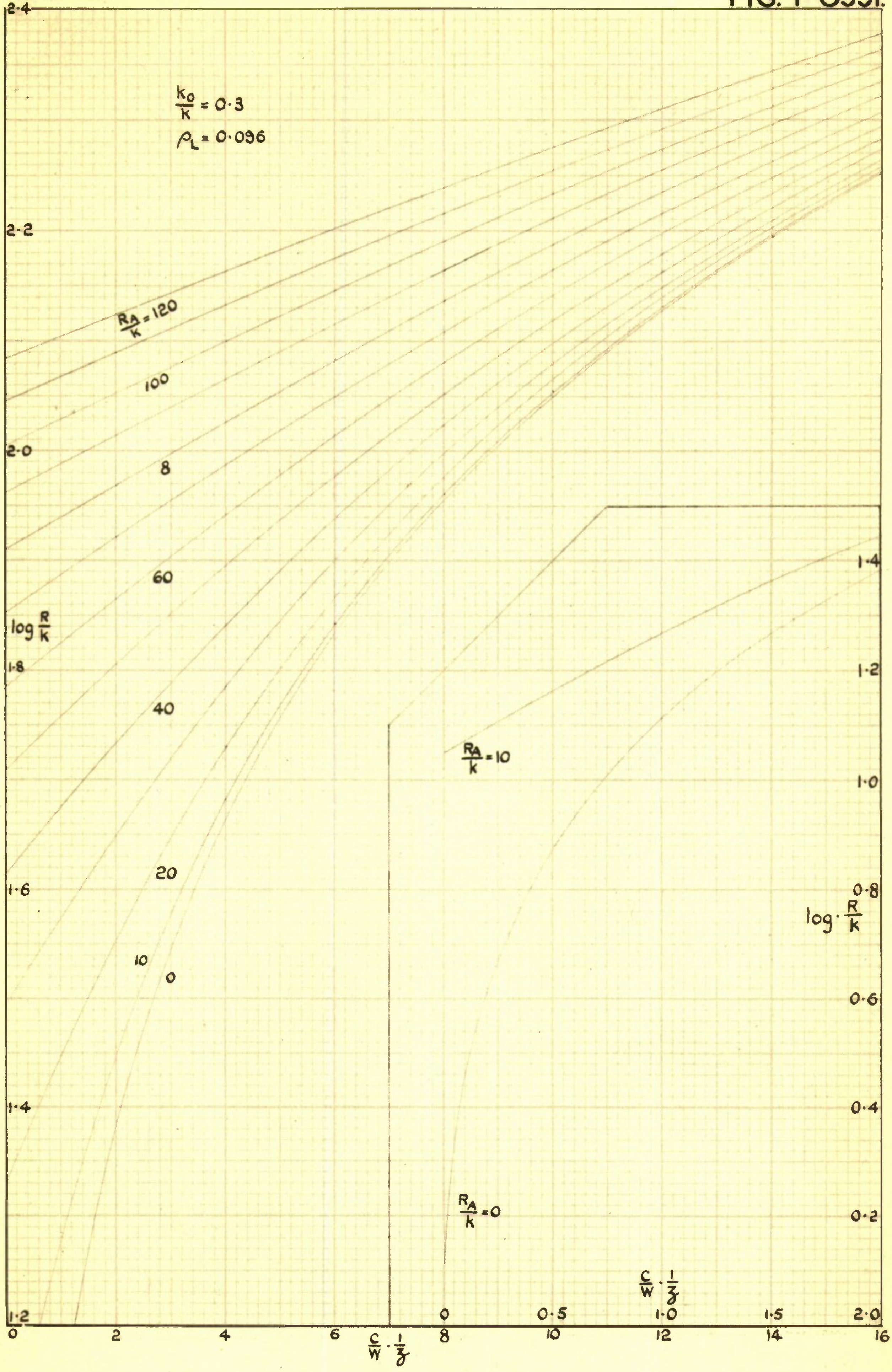

$\frac{k_0}{k} = 0{\cdot}3$
$\rho_L = 0{\cdot}096$
$\frac{R_A}{k} = 120$
100
8
60
40
20
10
0
$\log \frac{R}{k}$
$\frac{R_A}{k} = 10$
$\frac{R_A}{k} = 0$
$\log \cdot \frac{R}{k}$
$\frac{C}{W} \cdot \frac{1}{\gamma}$
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
0·5
1·0
1·5
2·0
0
2
4
6
8
10
12
14
16

FIG. 1·0332.

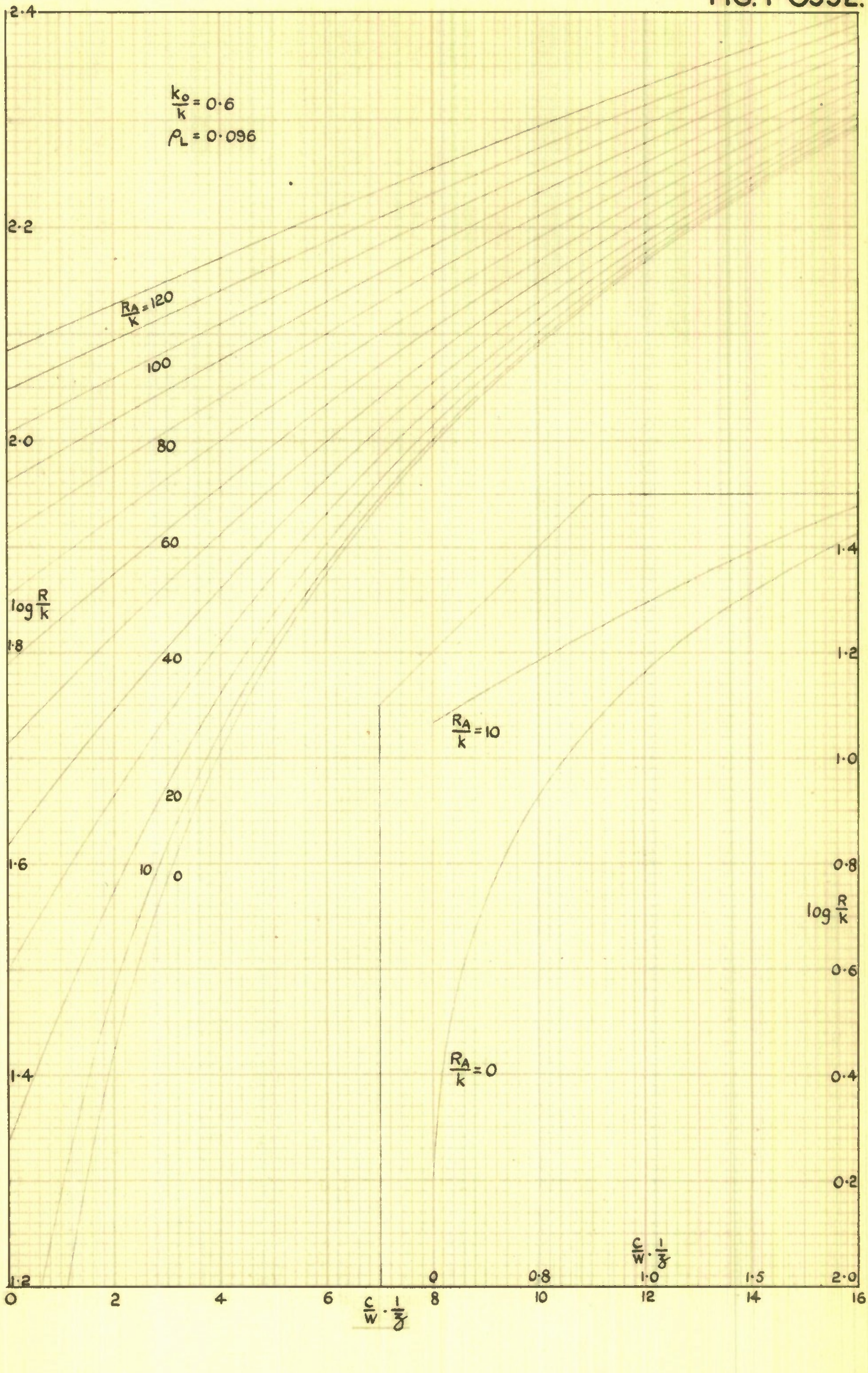

$\frac{k_0}{k} = 0·6$
$\rho_L = 0·096$
$\frac{R_A}{k} = 120$
100
80
60
40
20
10
0
$\log \frac{R}{k}$
$\frac{R_A}{k} = 10$
$\frac{R_A}{k} = 0$
$\frac{c}{w} \cdot \frac{1}{\gamma}$
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
0·8
1·0
1·5
2·0
0
2
4
6
8
10
12
14
16

FIG. 1·04.

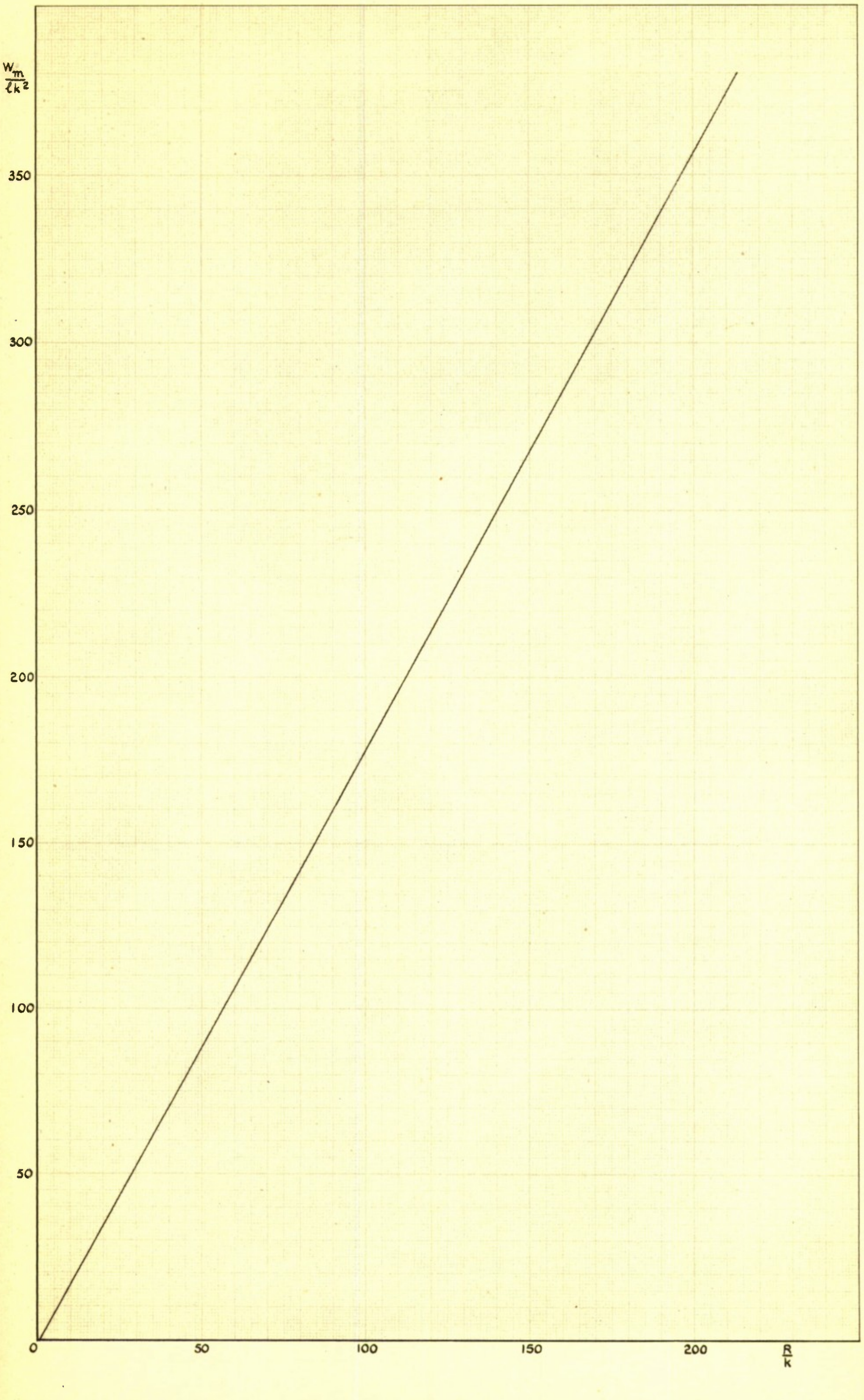


FIG. 1·051.

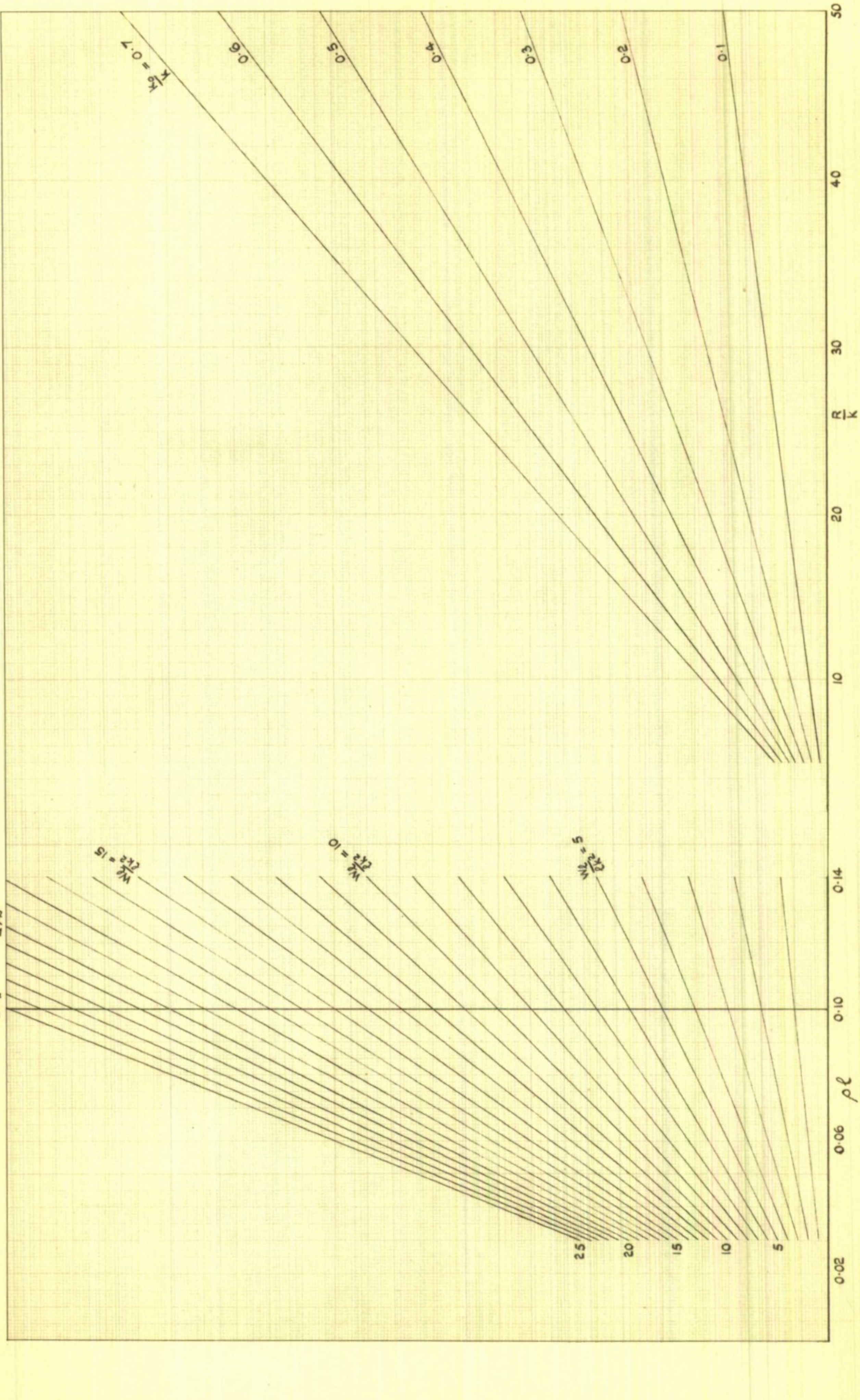
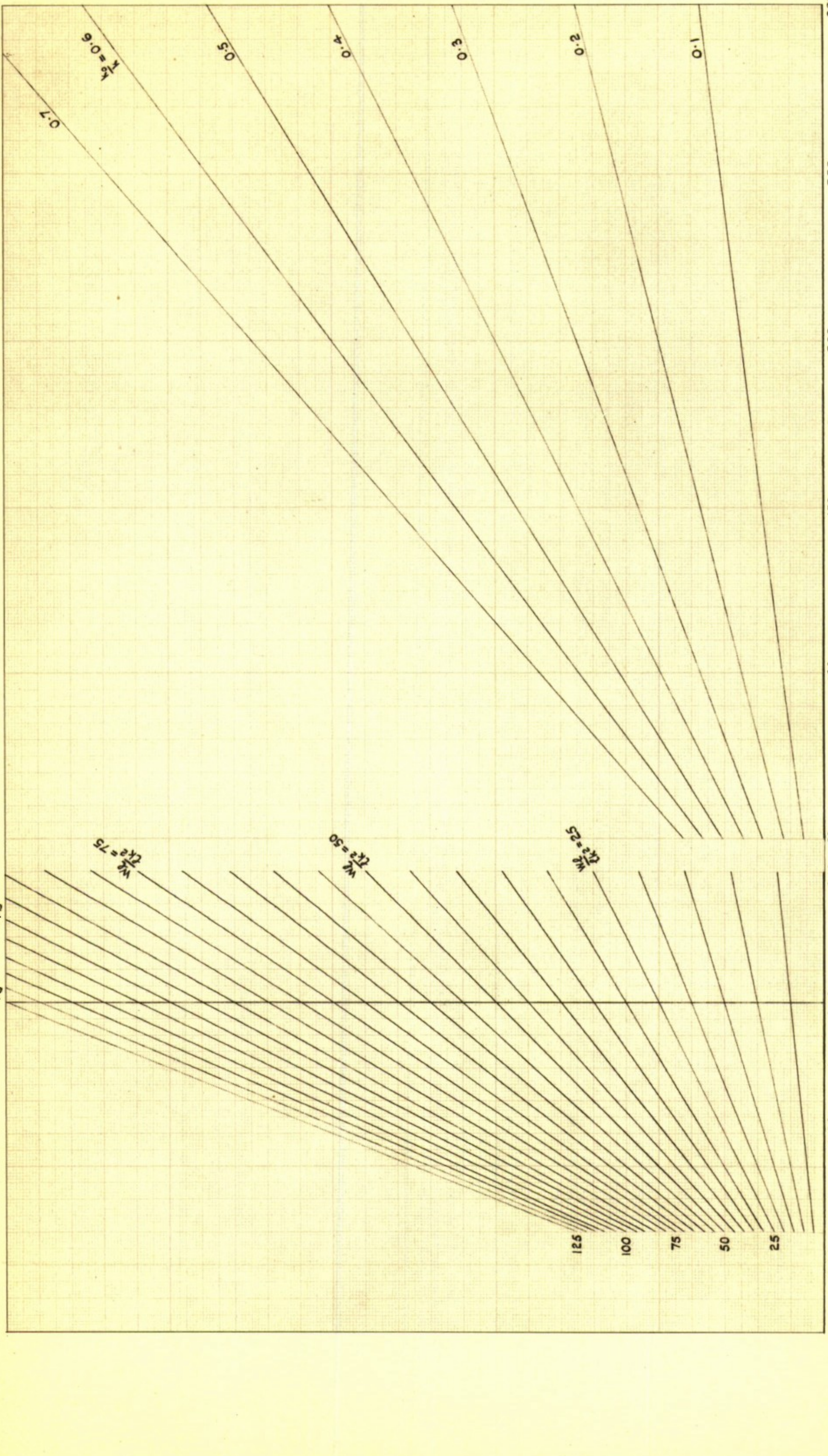


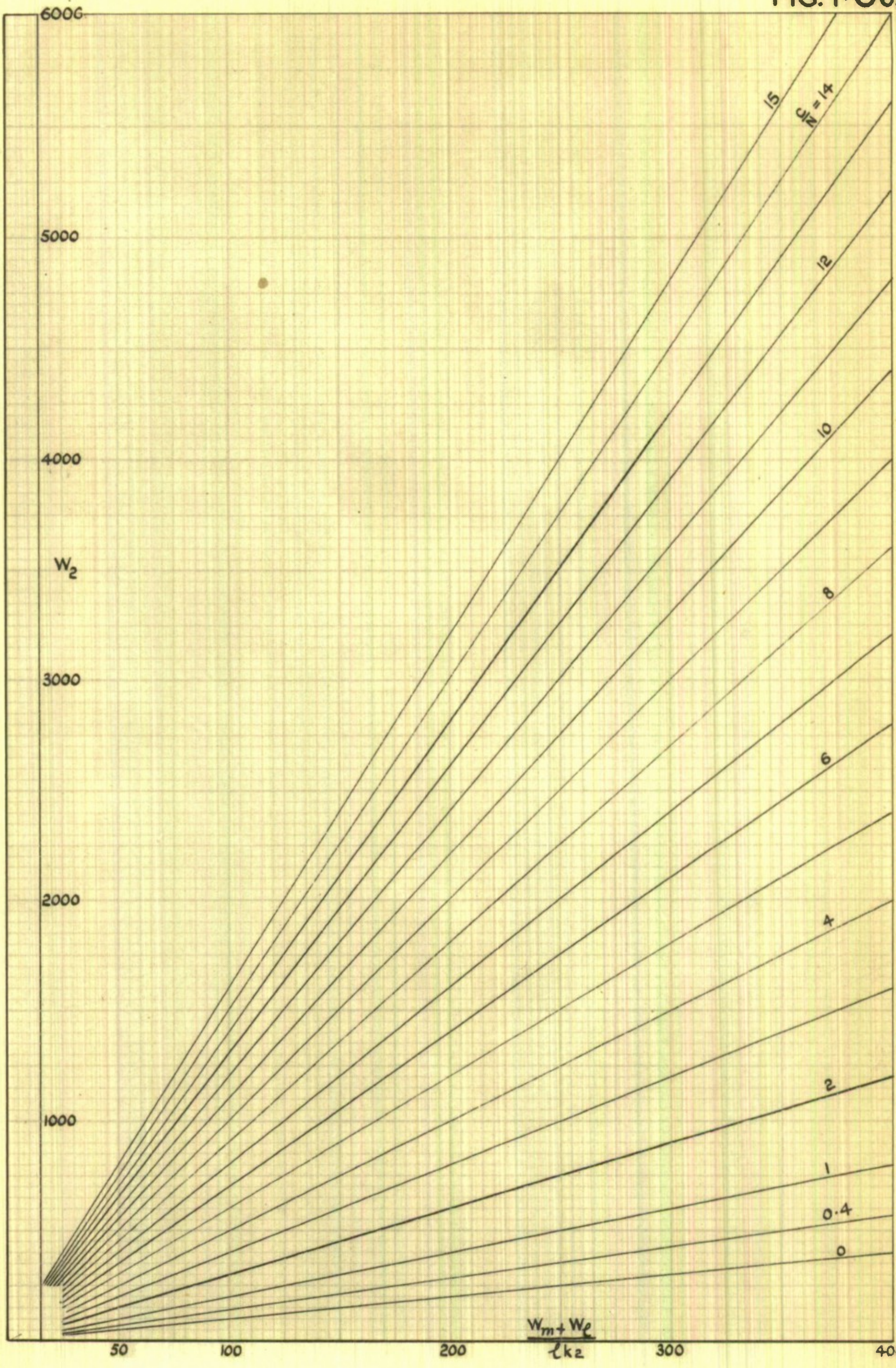
FIG. 1·052.

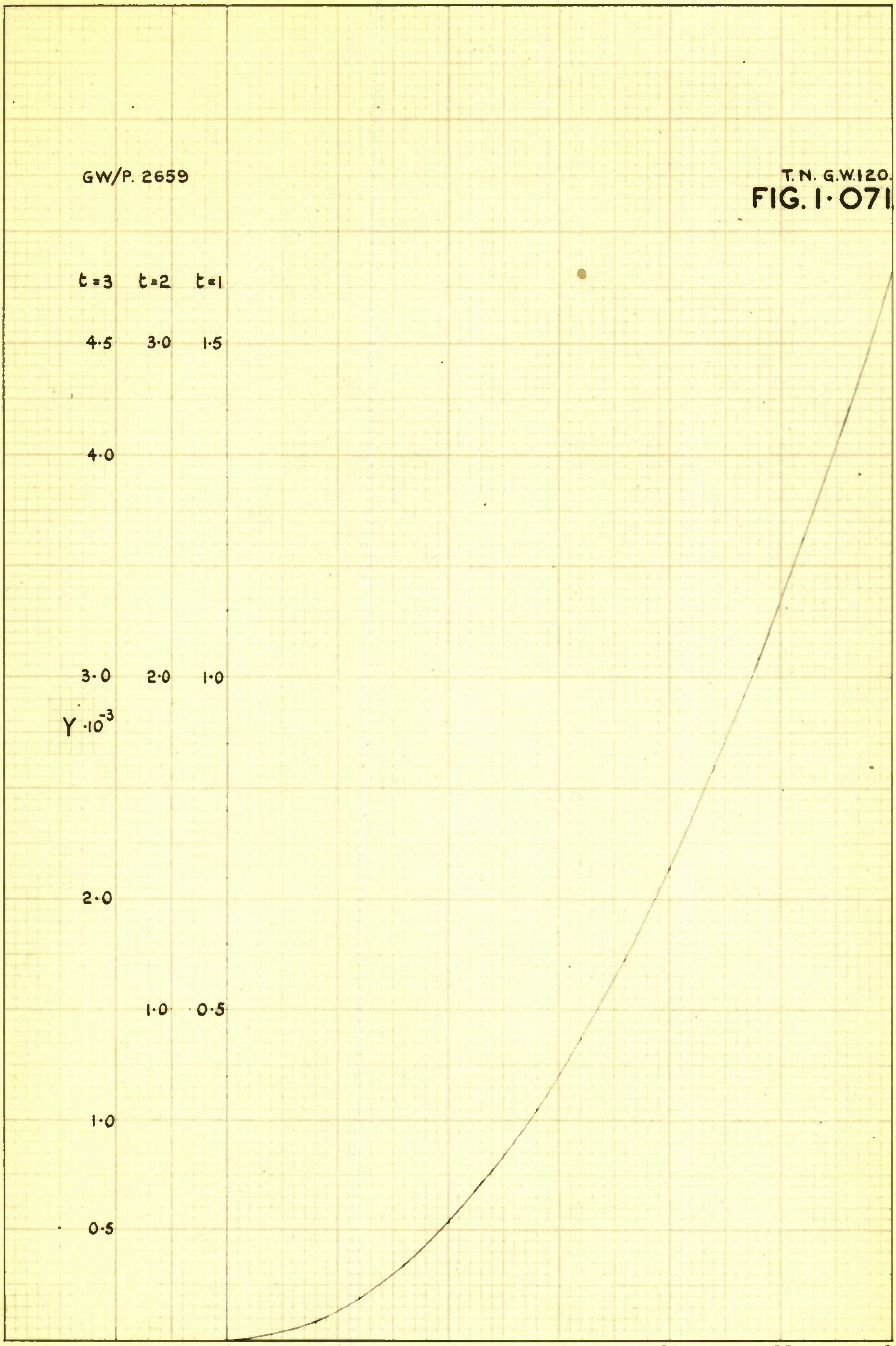

0·1
0·2
0·3
0·4
0·5
0·6
0·7
300
250
200
150
100
50
R/k
0·14
0·10
0·06
0·02
ρℓ
125
100
75
50
25

GW/P. 2658.

T. N. G.W. 120.

FIG. 1·06.




GW/P. 2659
T. N. G.W.120.
FIG. 1·071
t=3
t=2
t=1
4·5
3·0
1·5
4·0
3·0
2·0
1·0
Y·10^-3
2·0
1·0
0·5
1·0
0·5
0
5
10
15
W
20
25
30

GW/P. 2660.

T. N. G.W.120.

FIG. 1·072.

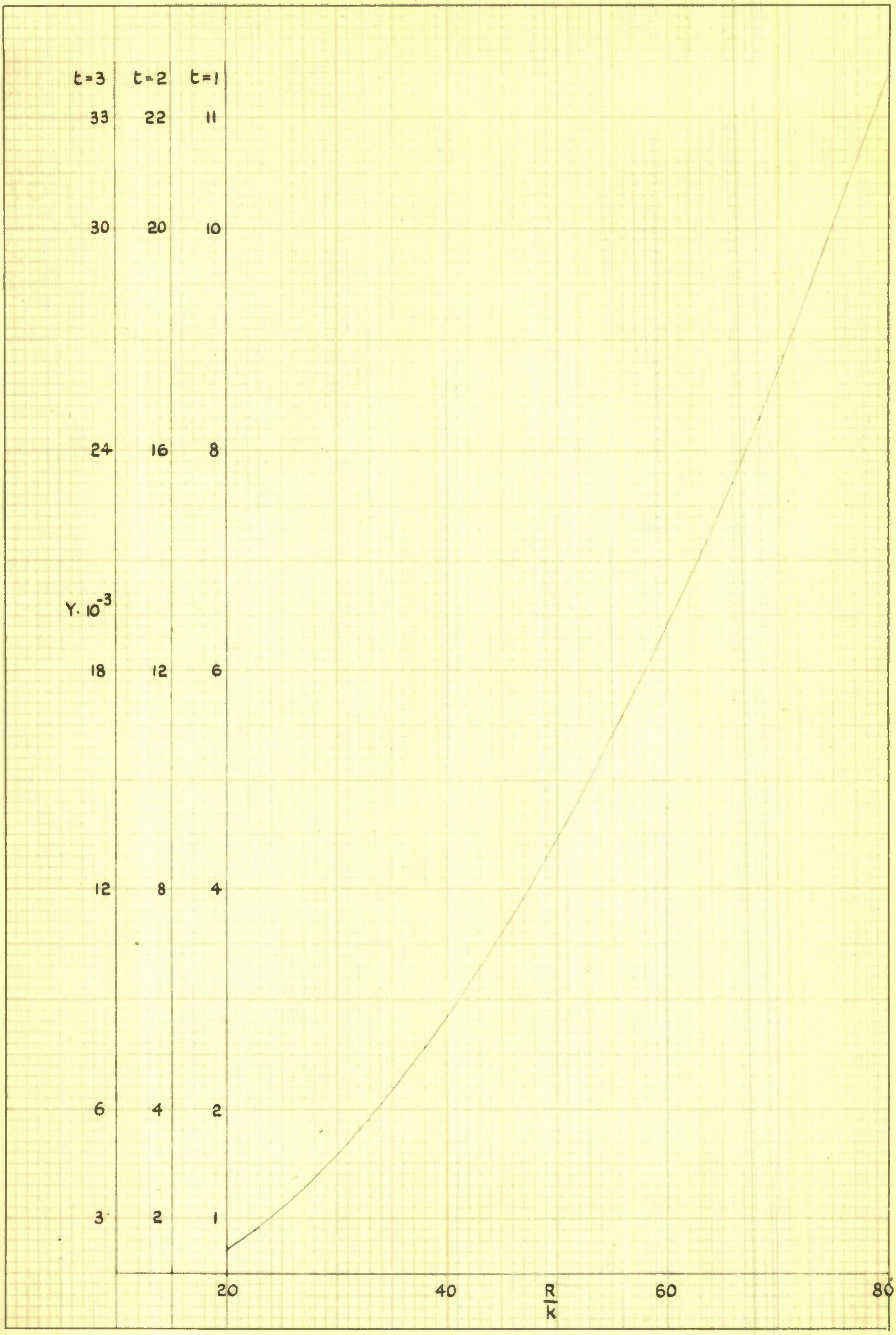
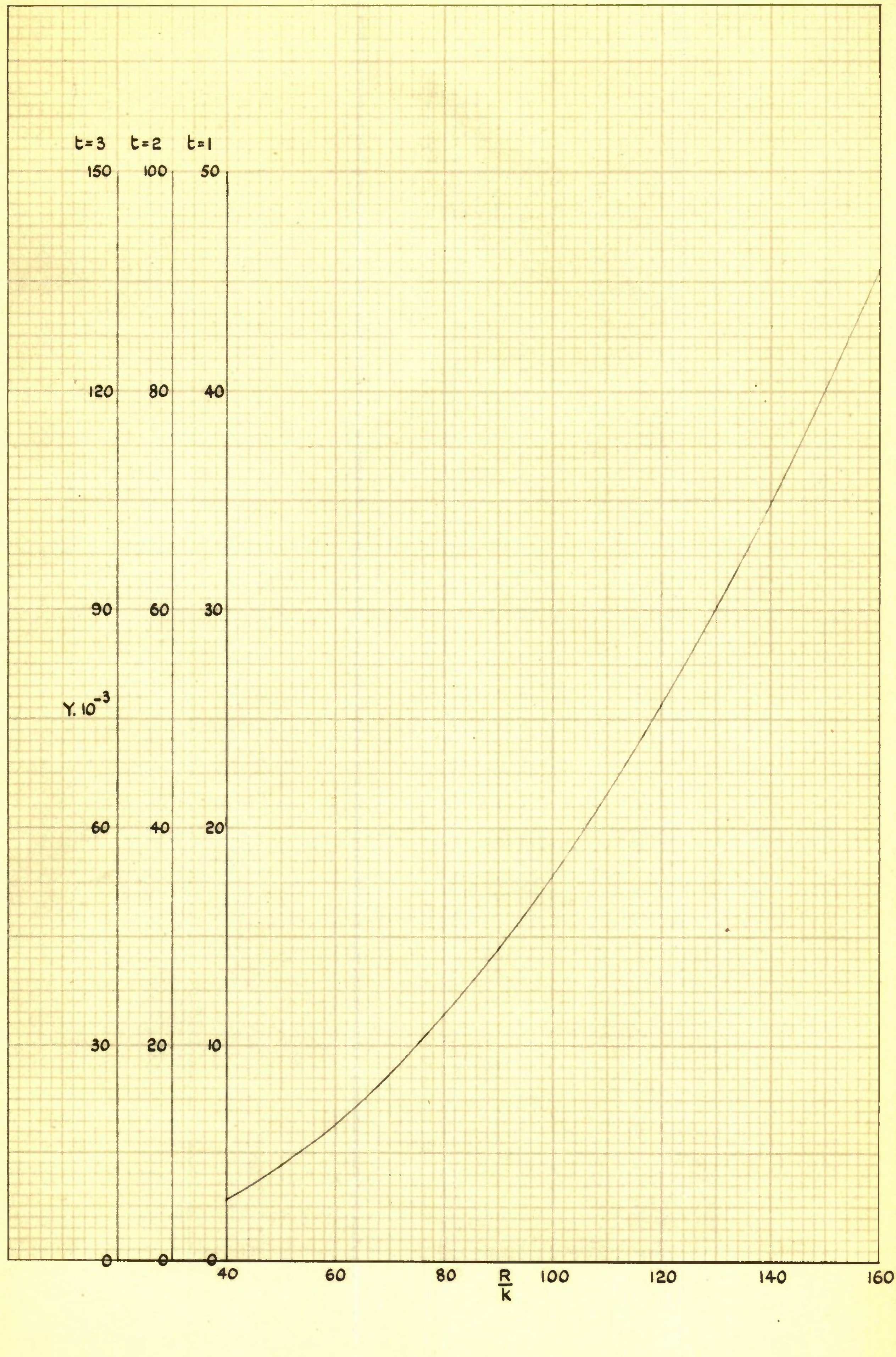


FIG. 1·073


t=3
t=2
t=1
150
100
50
120
80
40
90
60
30
Y. 10^-3
60
40
20
30
20
10
0
0
0
40
60
80
R/k
100
120
140
160

GW/P. 2662.

T.N. G.W. 120.

FIG. 1·081.

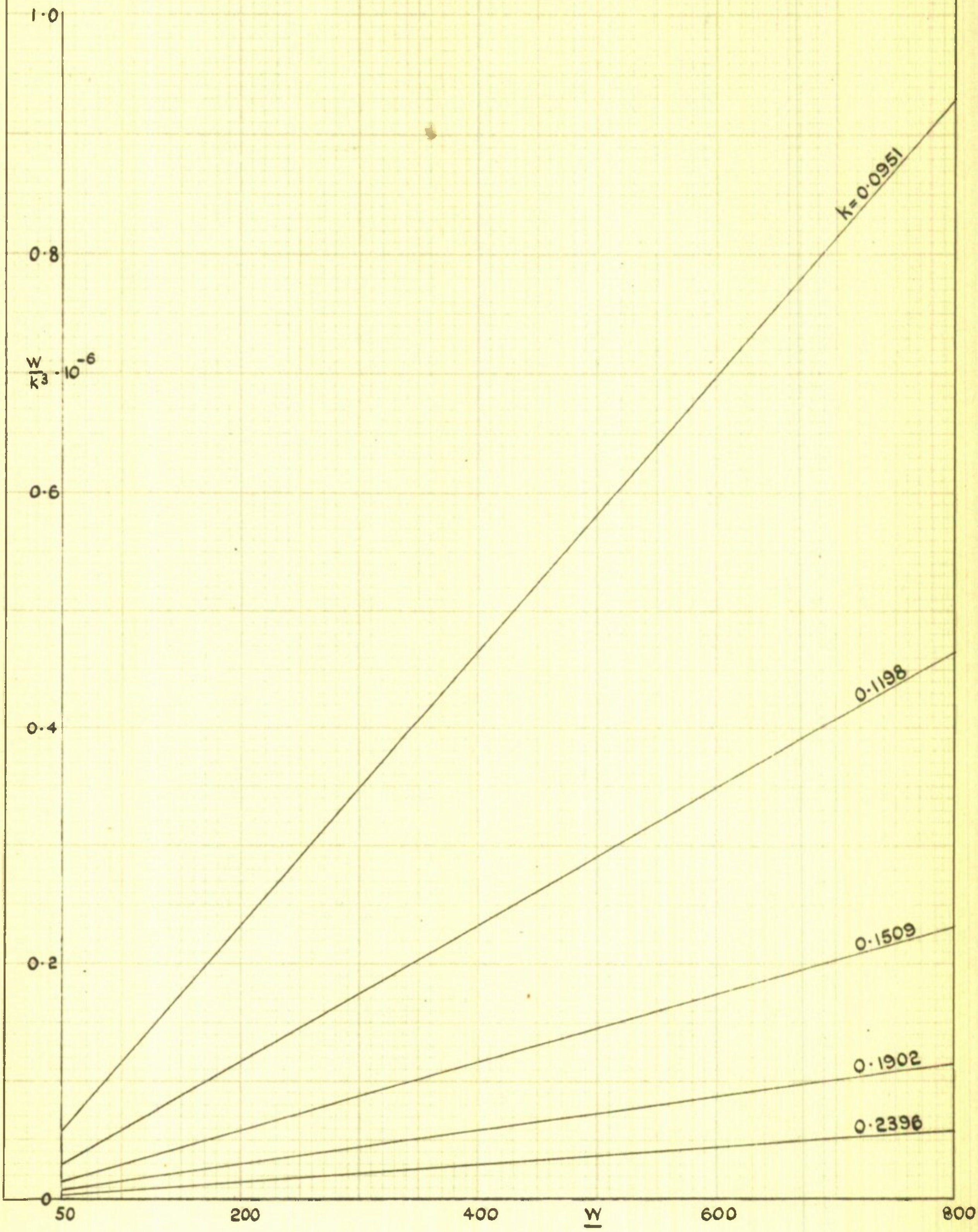


FIG. 1·082.

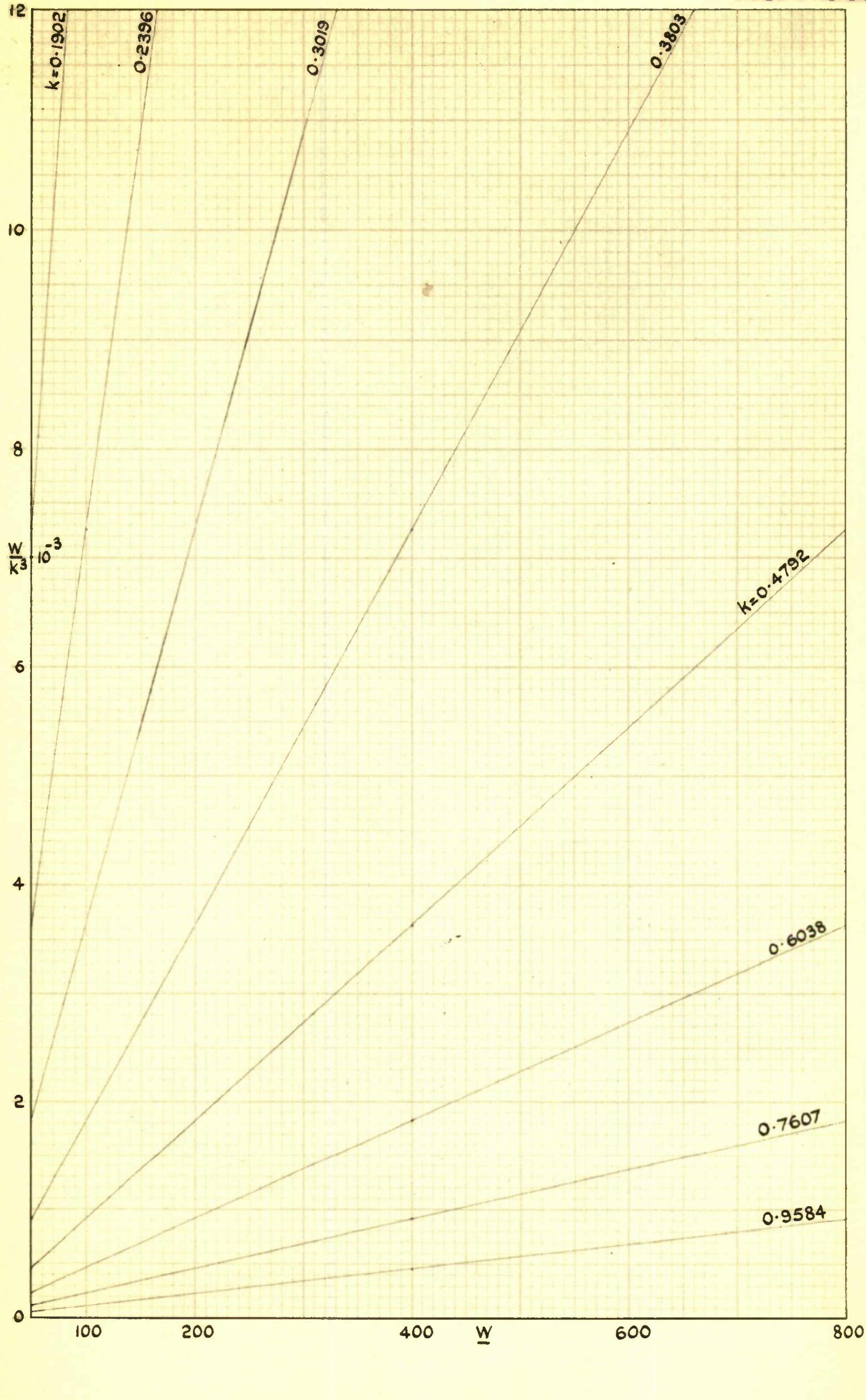
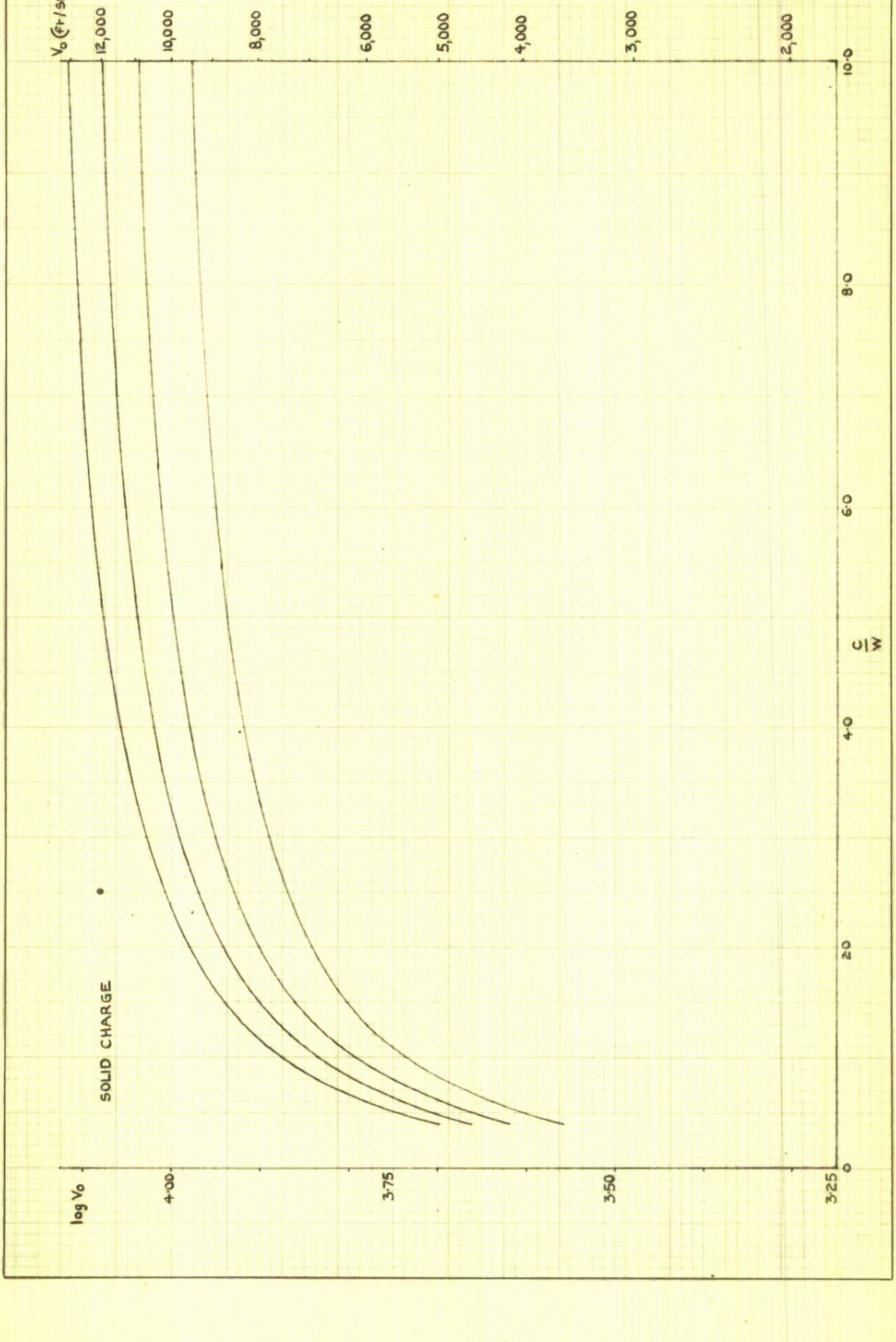

k=0·1902
0·2396
0·3019
0·3803
k=0·4792
0·6038
0·7607
0·9584
W/k³ ·10⁻³
0
2
4
6
8
10
12
100
200
400
W
600
800

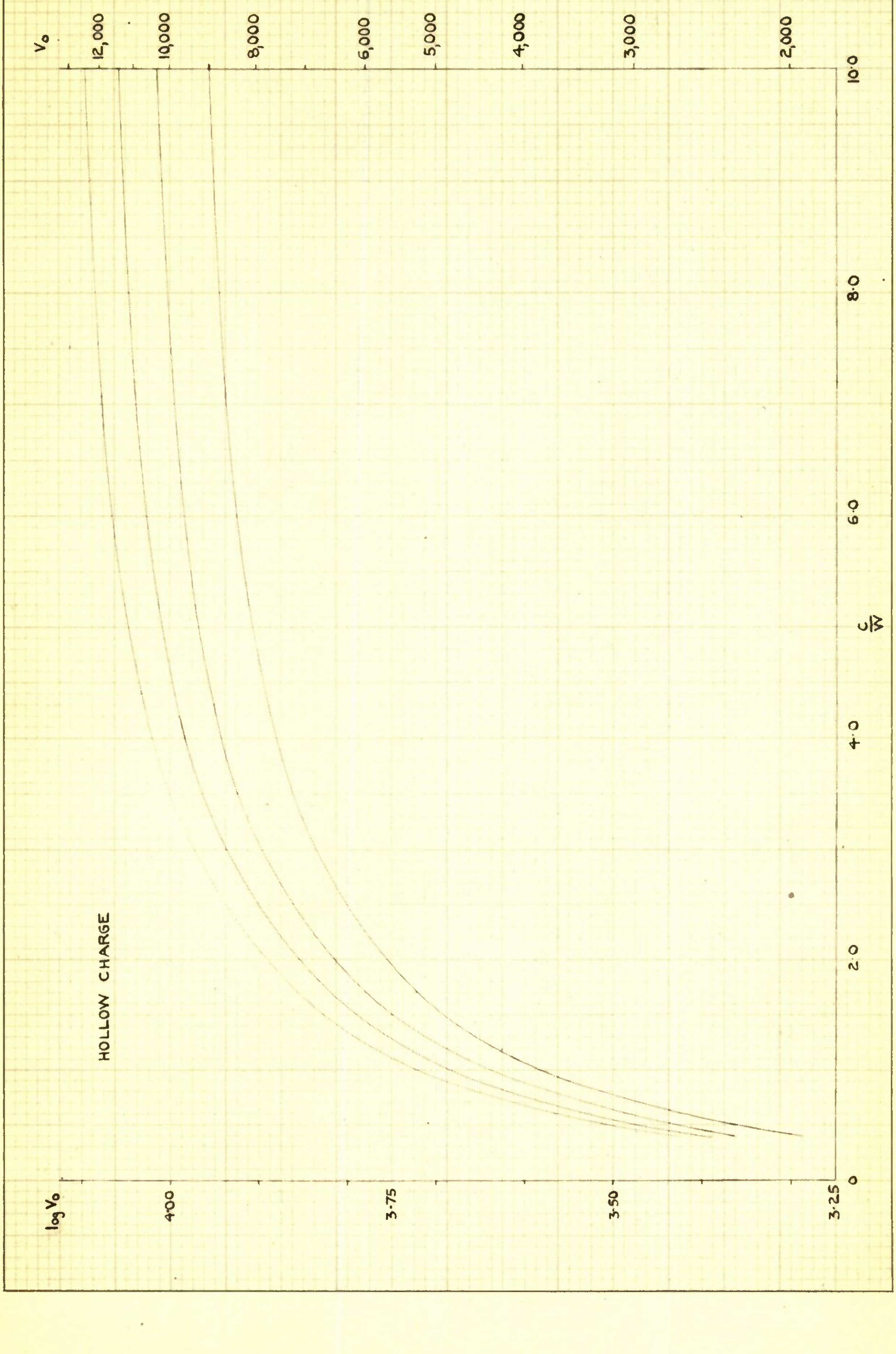
FIG. 1·091


V_o (FT/SEC)
12,000
10,000
8,000
6,000
5,000
4,000
3,000
2,000
log V_o
4·00
3·75
3·50
3·25
0
2·0
4·0
6·0
8·0
10·0
$\frac{C}{W}$
SOLID CHARGE

GW/P. 2665.

T.N.G.W.120.

FIG. 1·092.



GW/P. 2666.

T.N.G.W. 120.

FIG. 1·093.

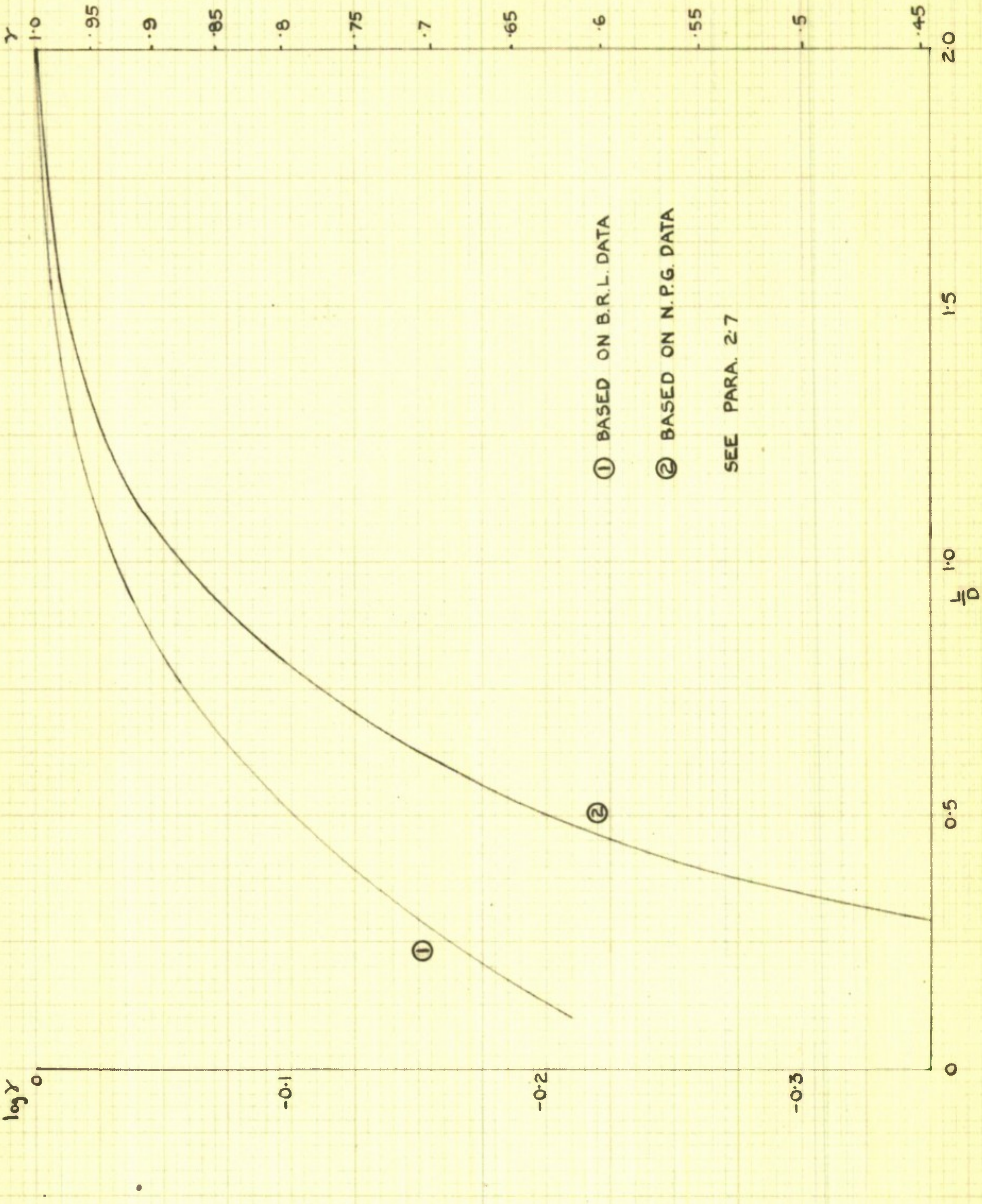
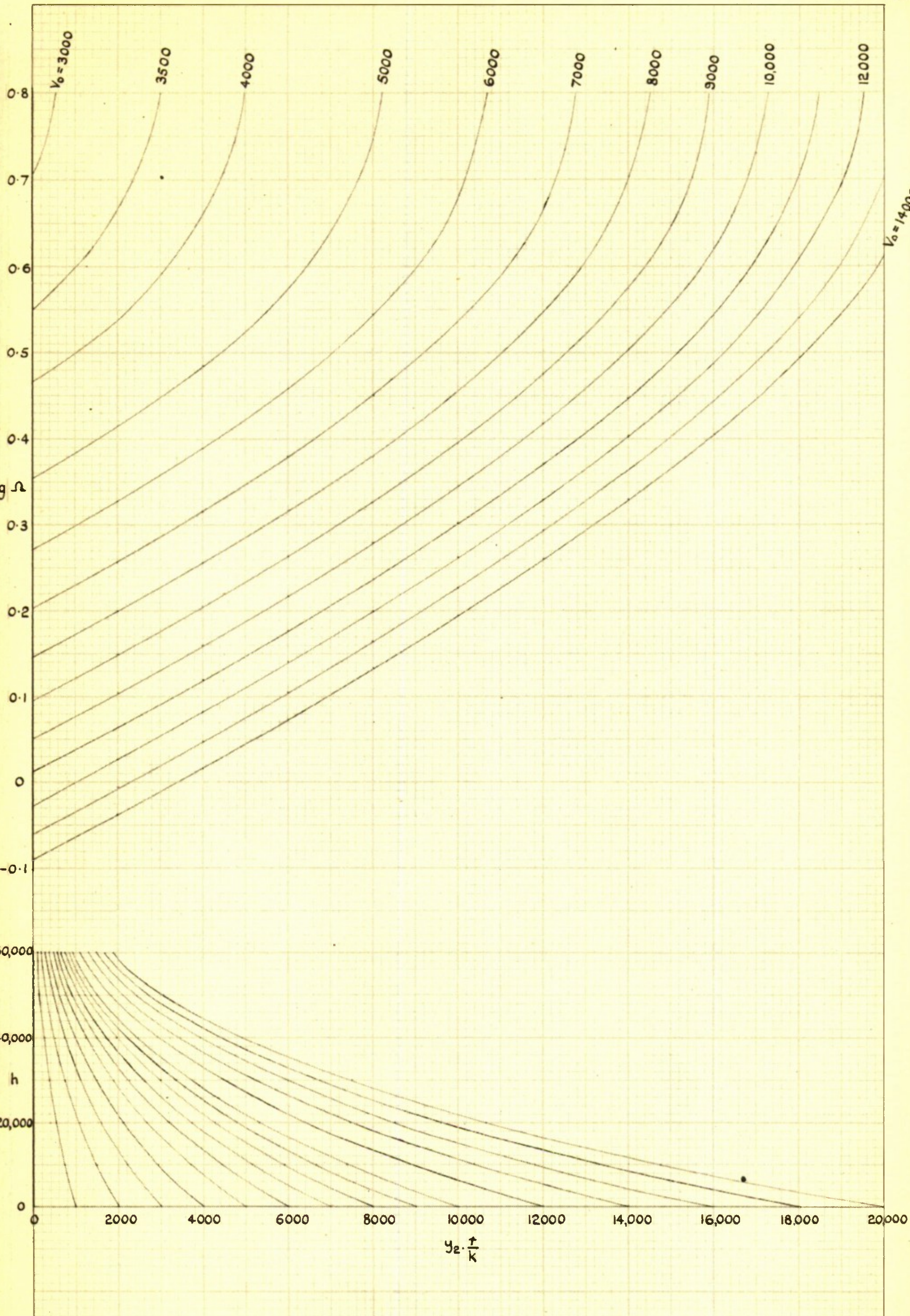


FIG. 1·10.


$V_0 = 3000$
3500
4000
5000
6000
7000
8000
9000
10,000
12,000
$V_0 = 14000$
0·8
0·7
0·6
0·5
0·4
log Ω
0·3
0·2
0·1
0
-0·1
60,000
40,000
h
20,000
0
0
2000
4000
6000
8000
10000
12000
14,000
16,000
18,000
20,000
$y_2 \cdot \frac{t}{k}$

GW/P. 2668.

T.N. G.W.120.

FIG. 1·11

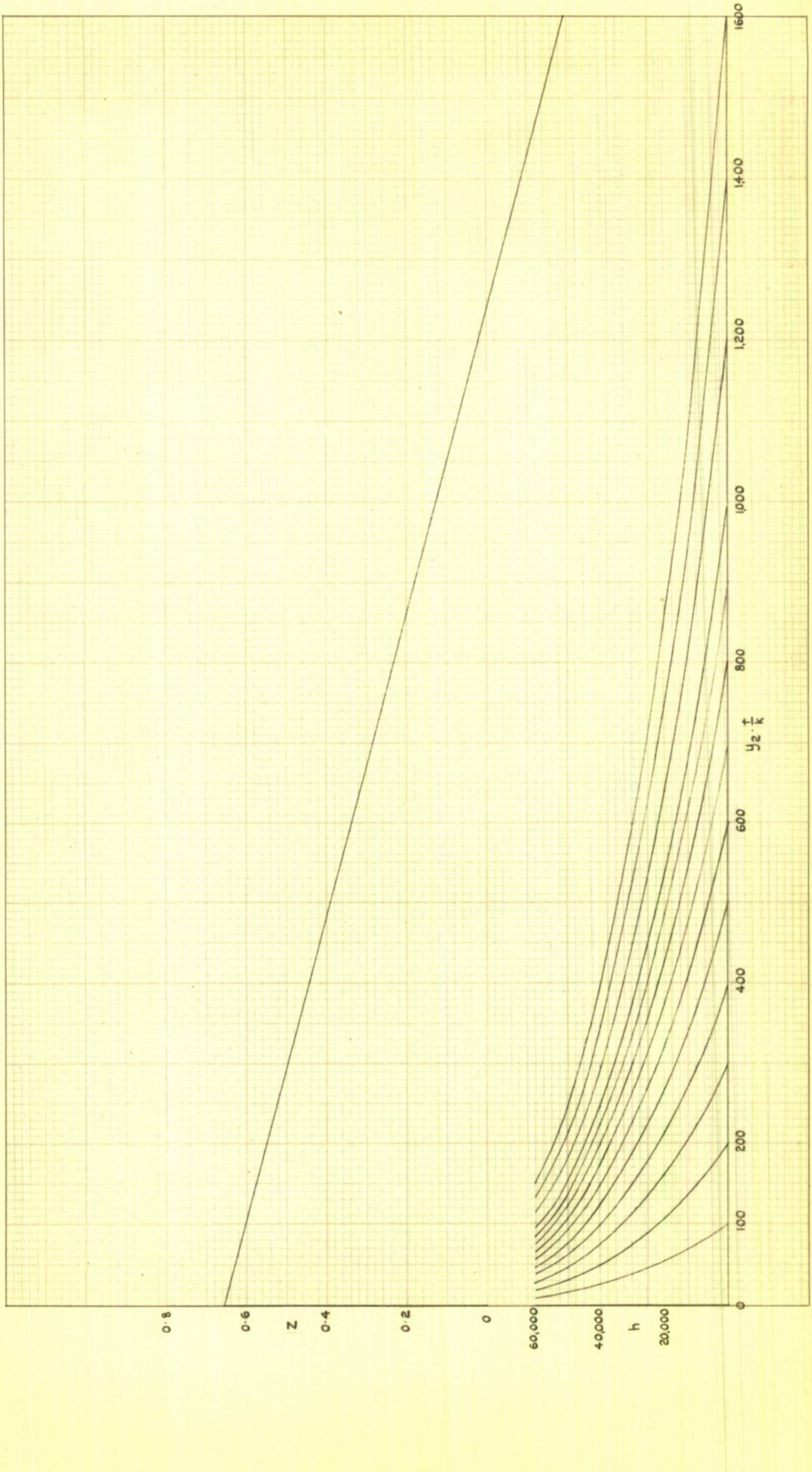
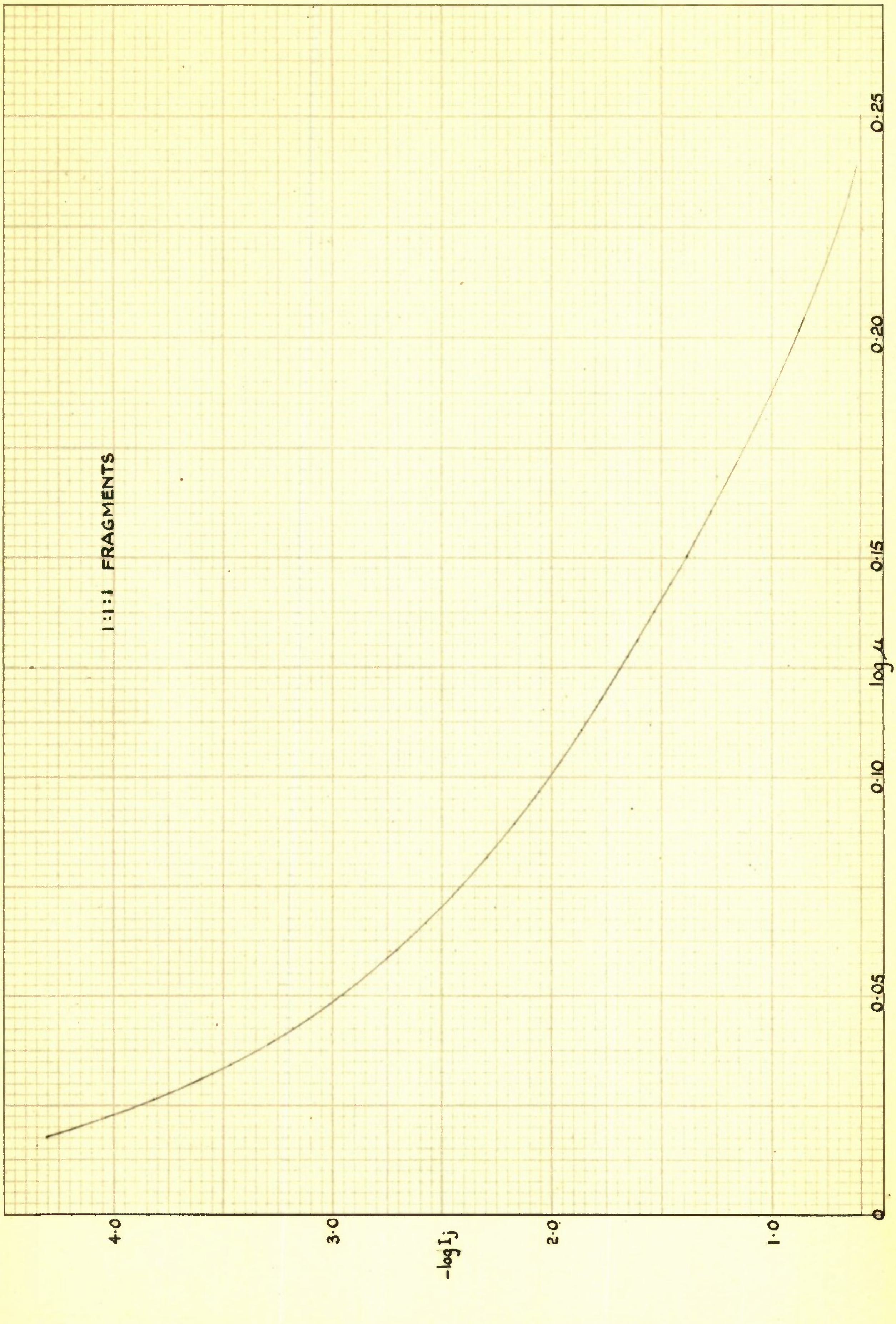


FIG. 1·1211.



GW/P. 2670.

T.N. G.W. 120

FIG. 1·1212

FIG. 1·1221.

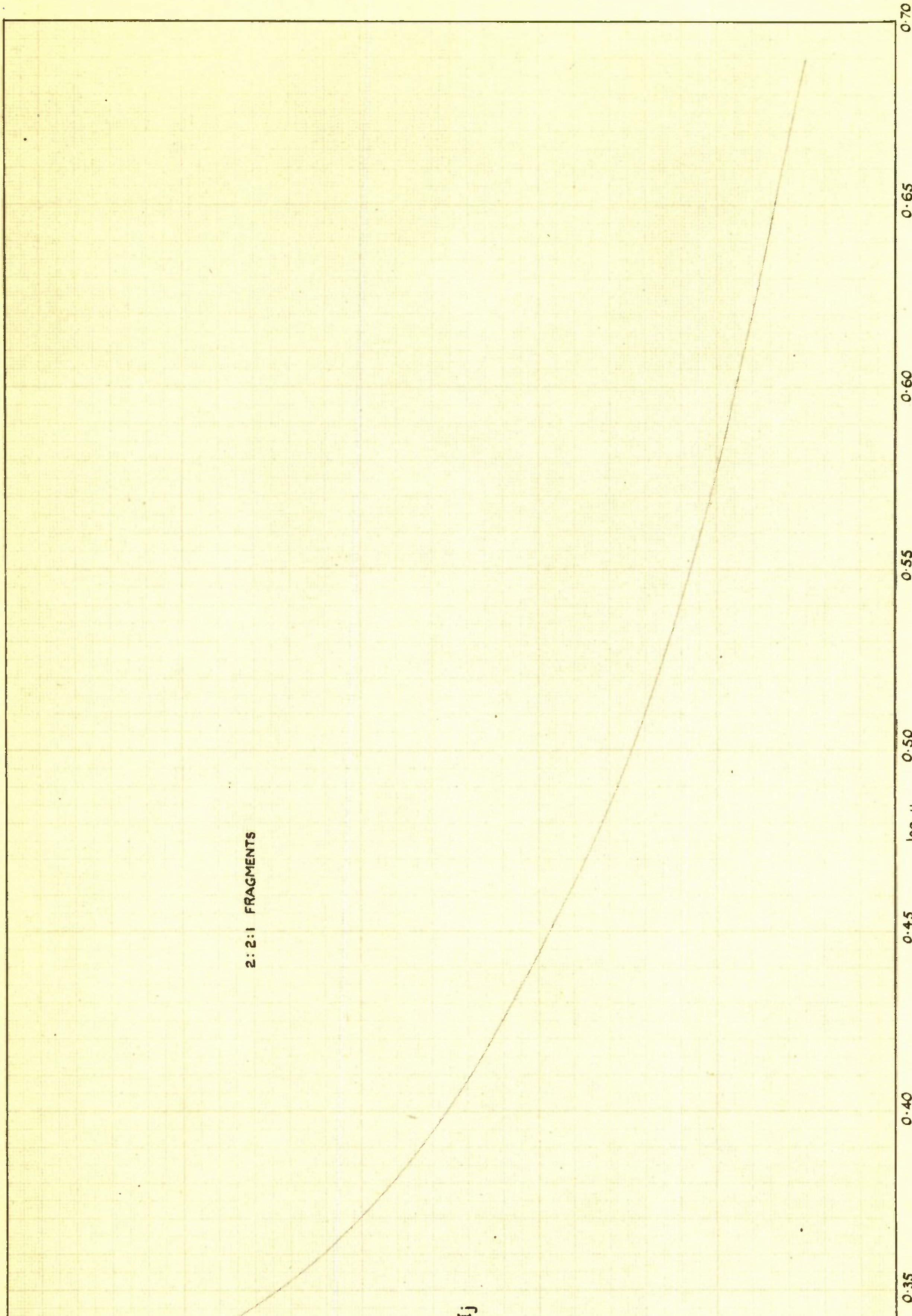

2 : 2 : 1 FRAGMENTS
log μ
0·35
0·40
0·45
0·50
0·55
0·60
0·65
0·70
−log I j
4·0
3·0
2·0
1·0

FIG. 1·1222.

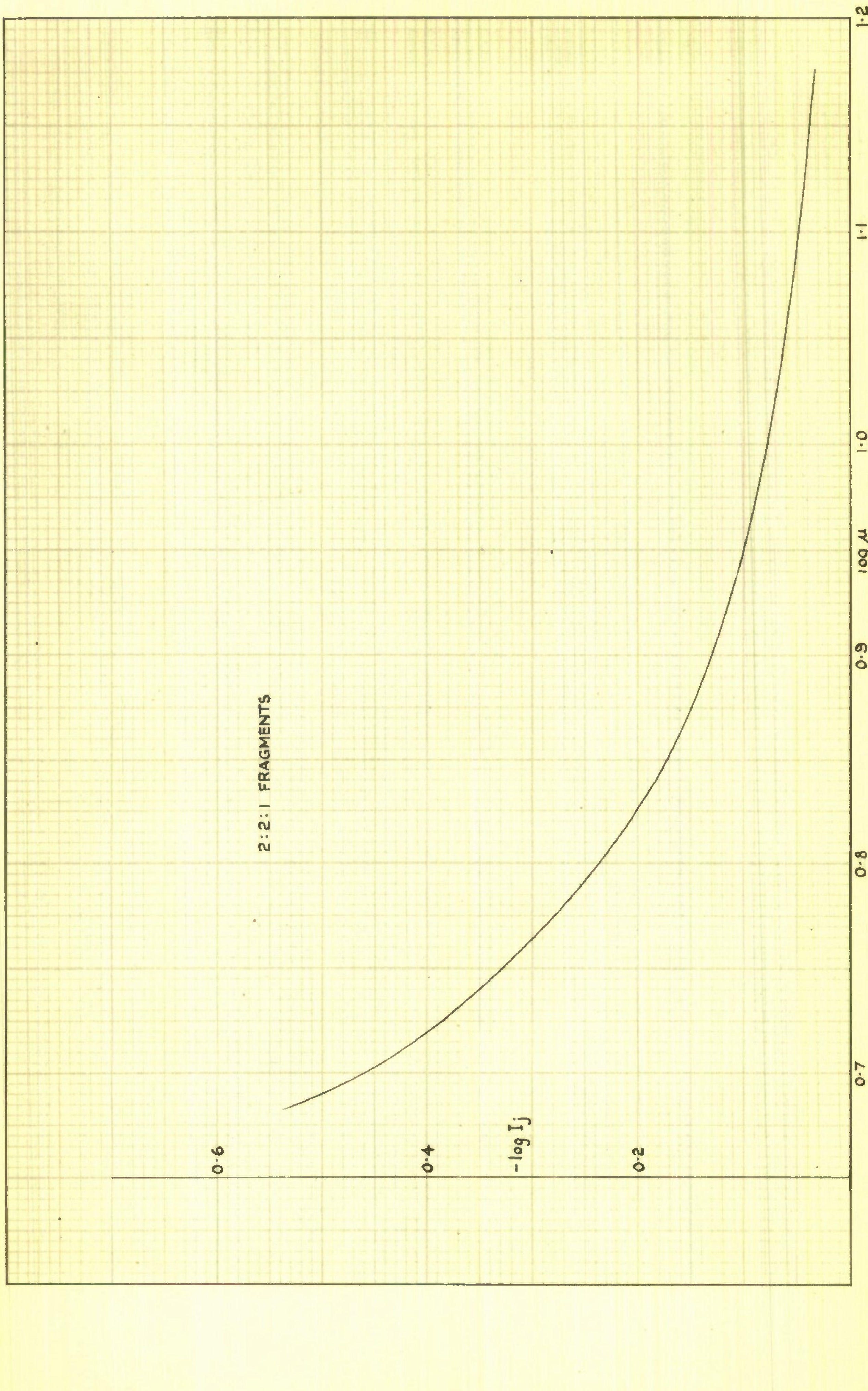
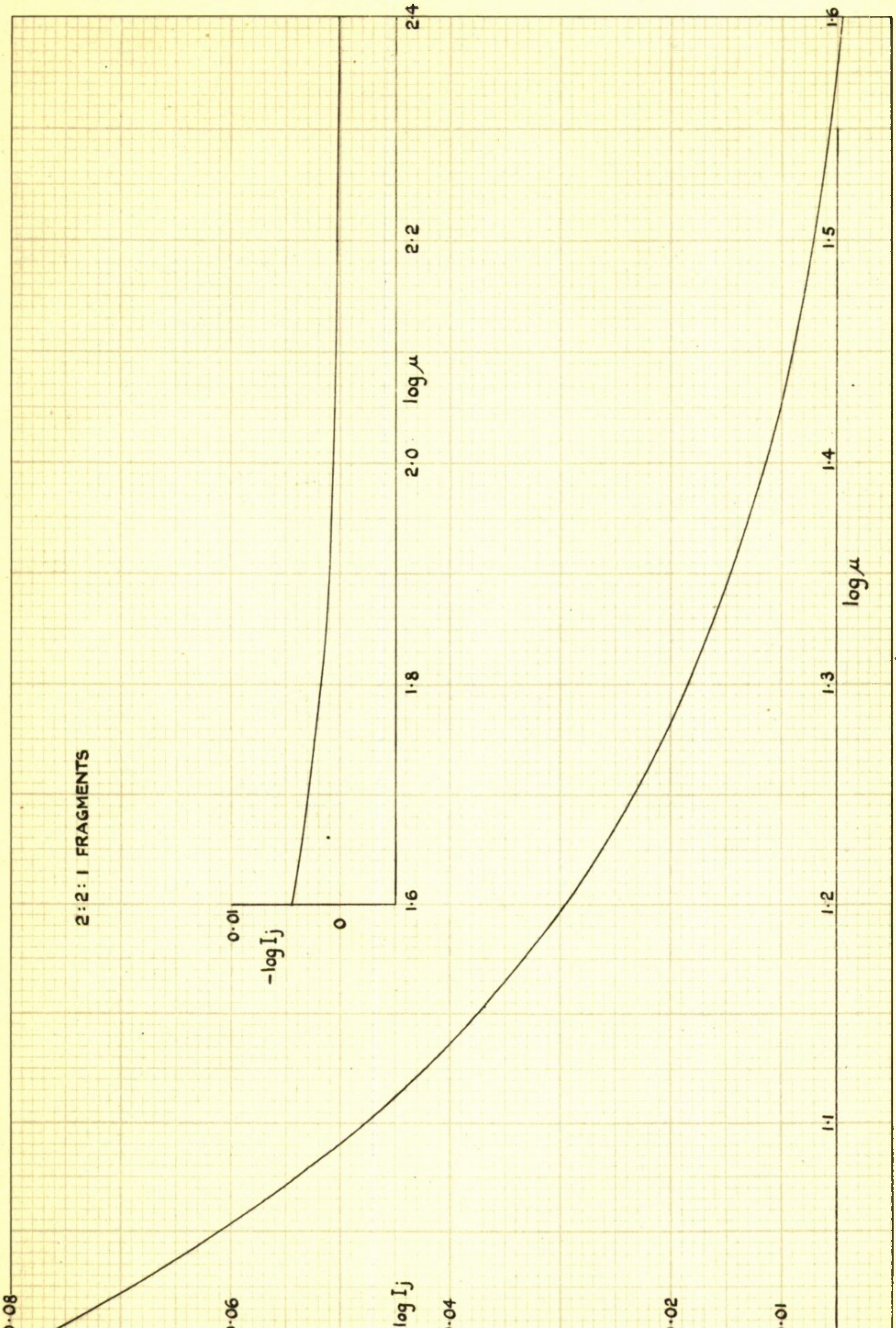


FIG. 1·1223.


2:2:1 FRAGMENTS
-log Ij
log μ
0·08
0·06
0·04
0·02
0·01
1·0
1·1
1·2
1·3
1·4
1·5
1·6
0·01
0
1·6
1·8
2·0
2·2
2·4

GW/P. 2675.

T.N. G.W. 120.

FIG. 1·131.

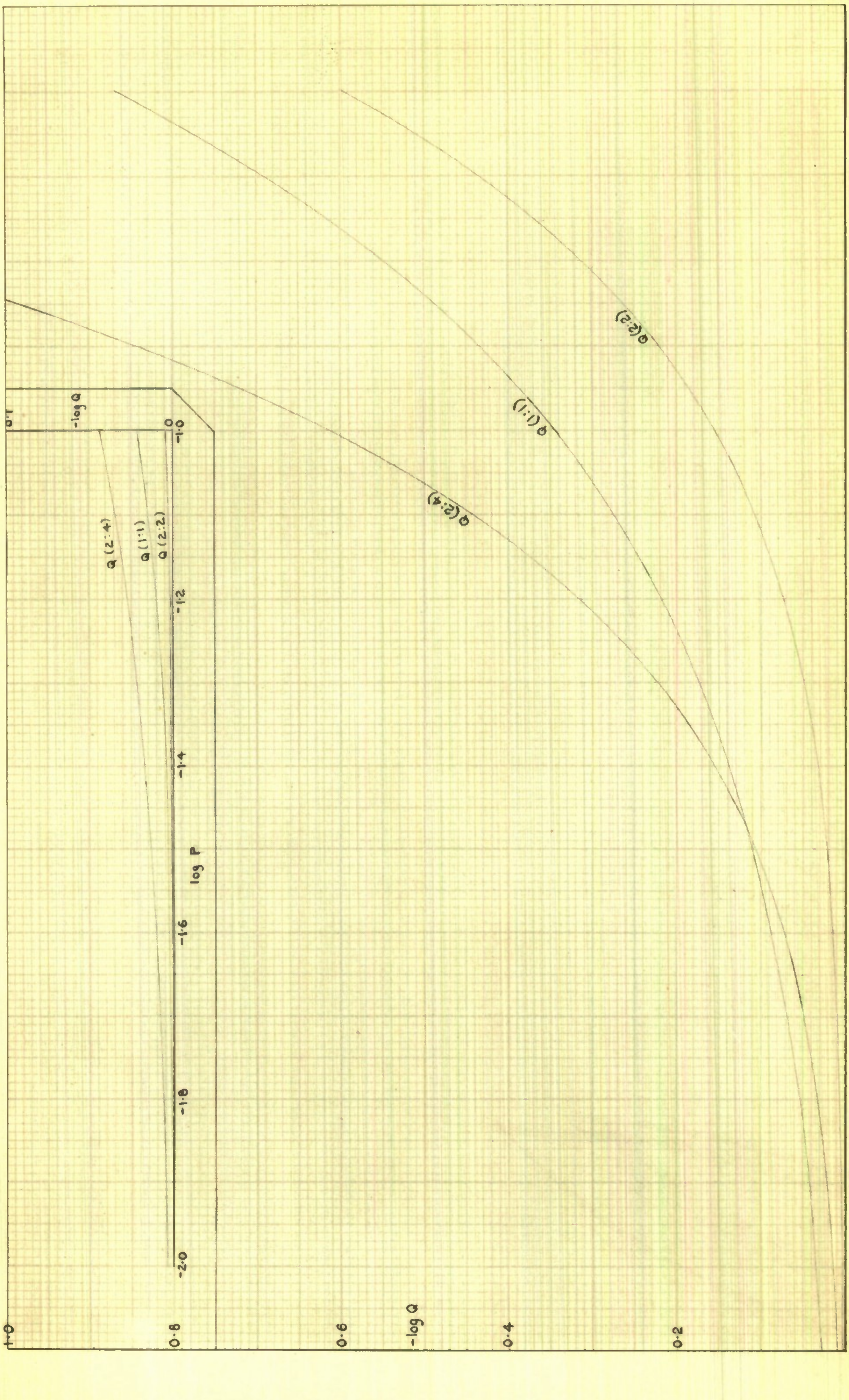
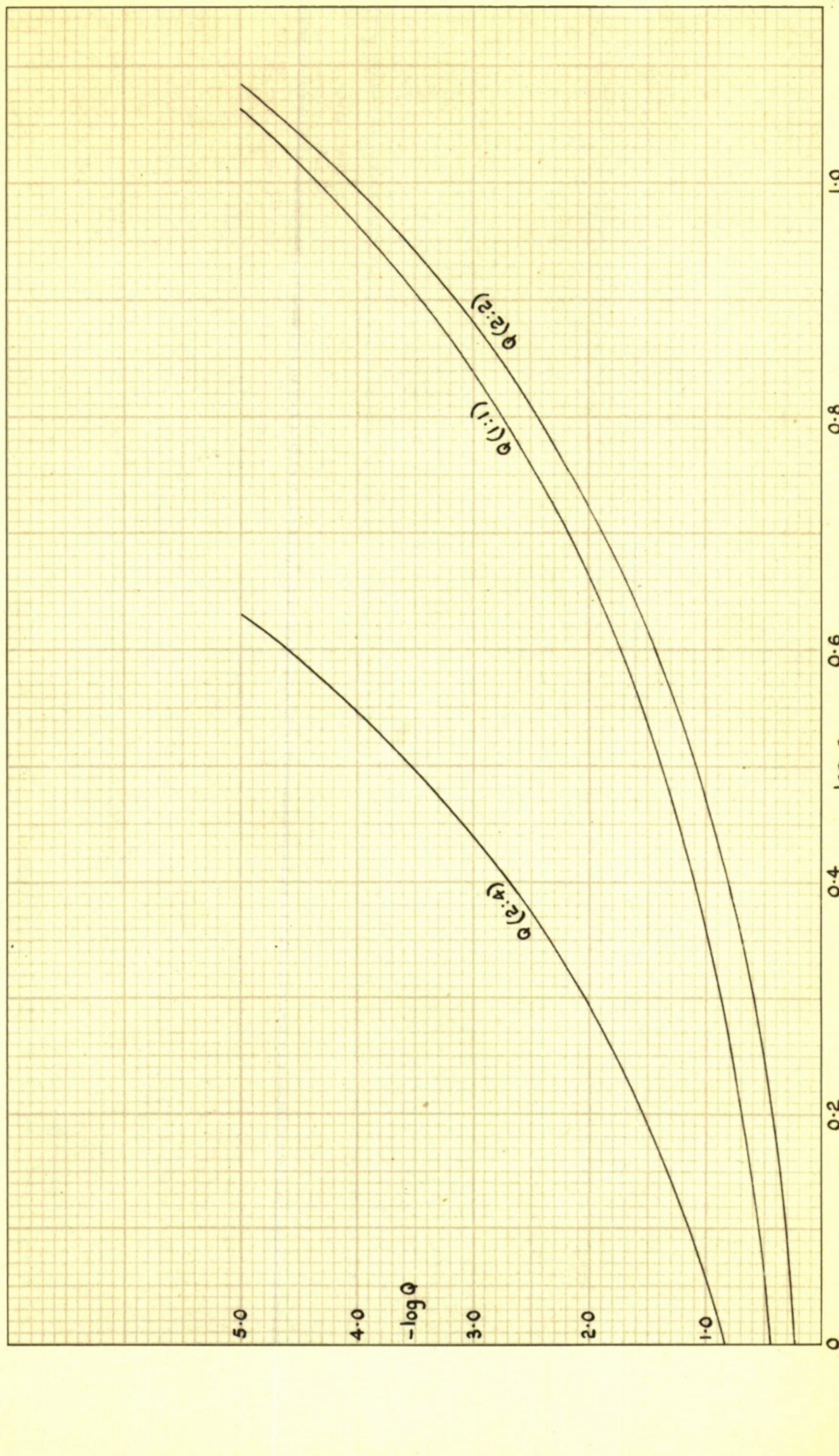


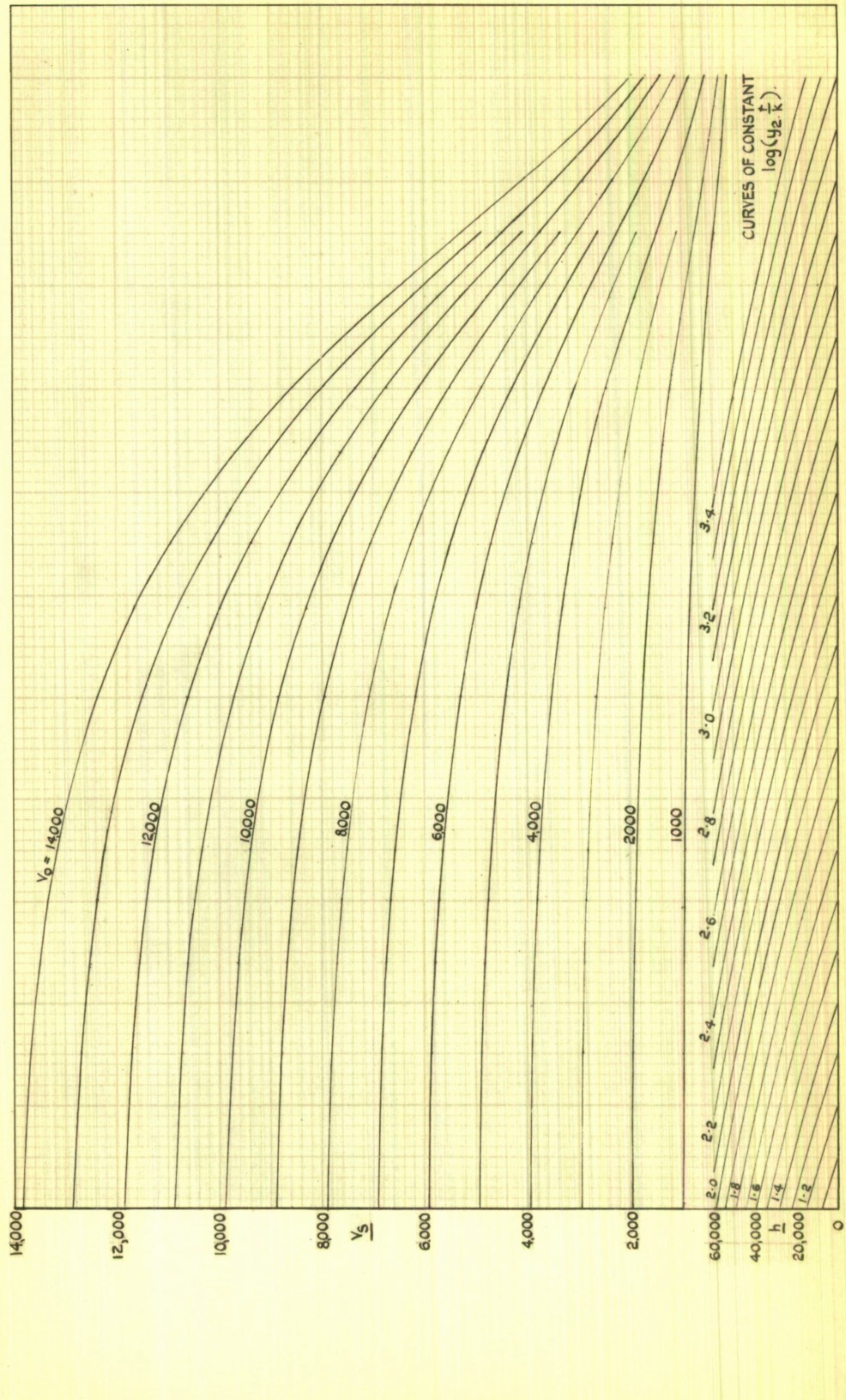
FIG. 1·132.



GW/P. 2676

T.N. G.W.120.

FIG. 1·14.



GW/P. 2677

T.N.G.W.120

FIG. 1·151

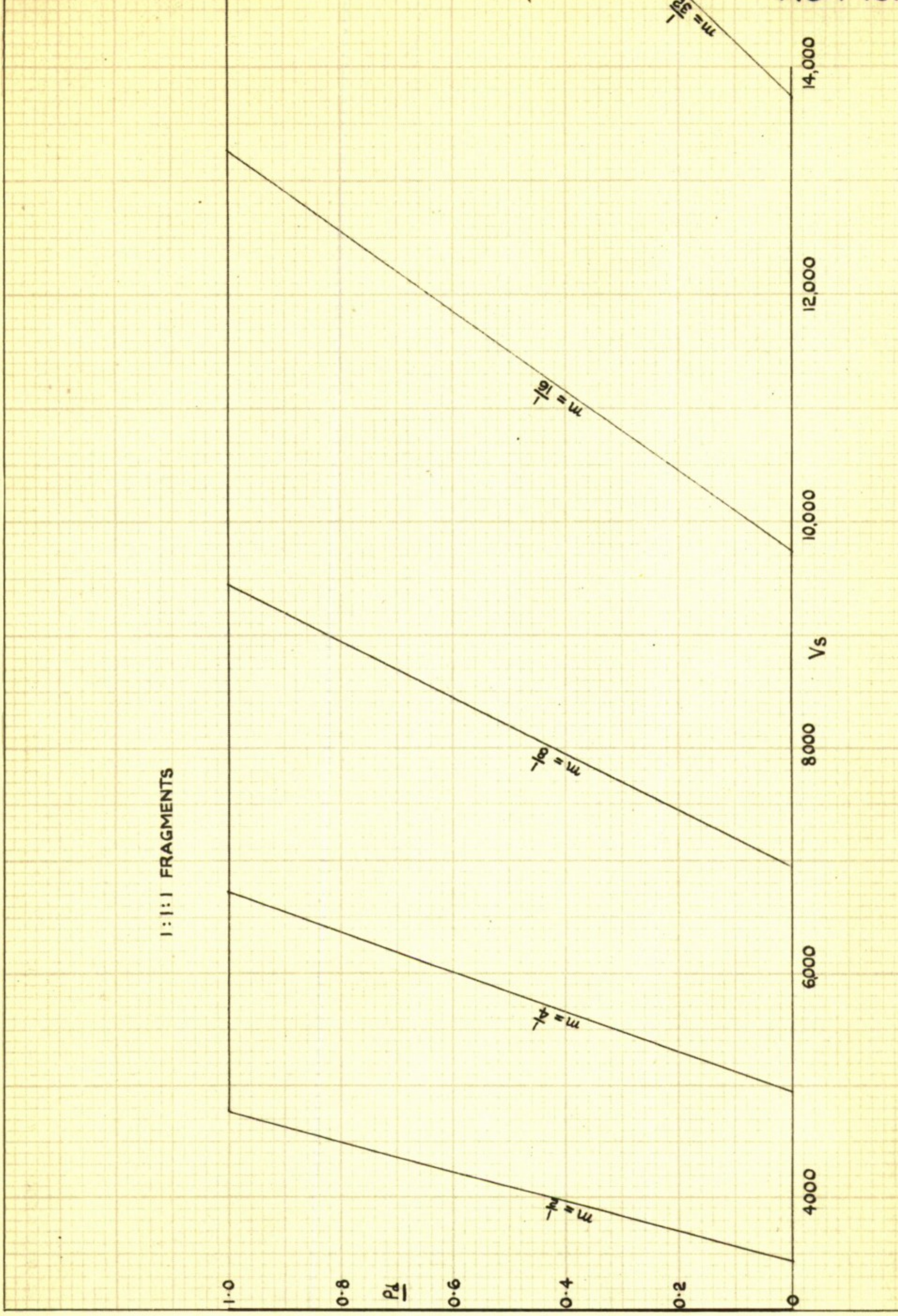
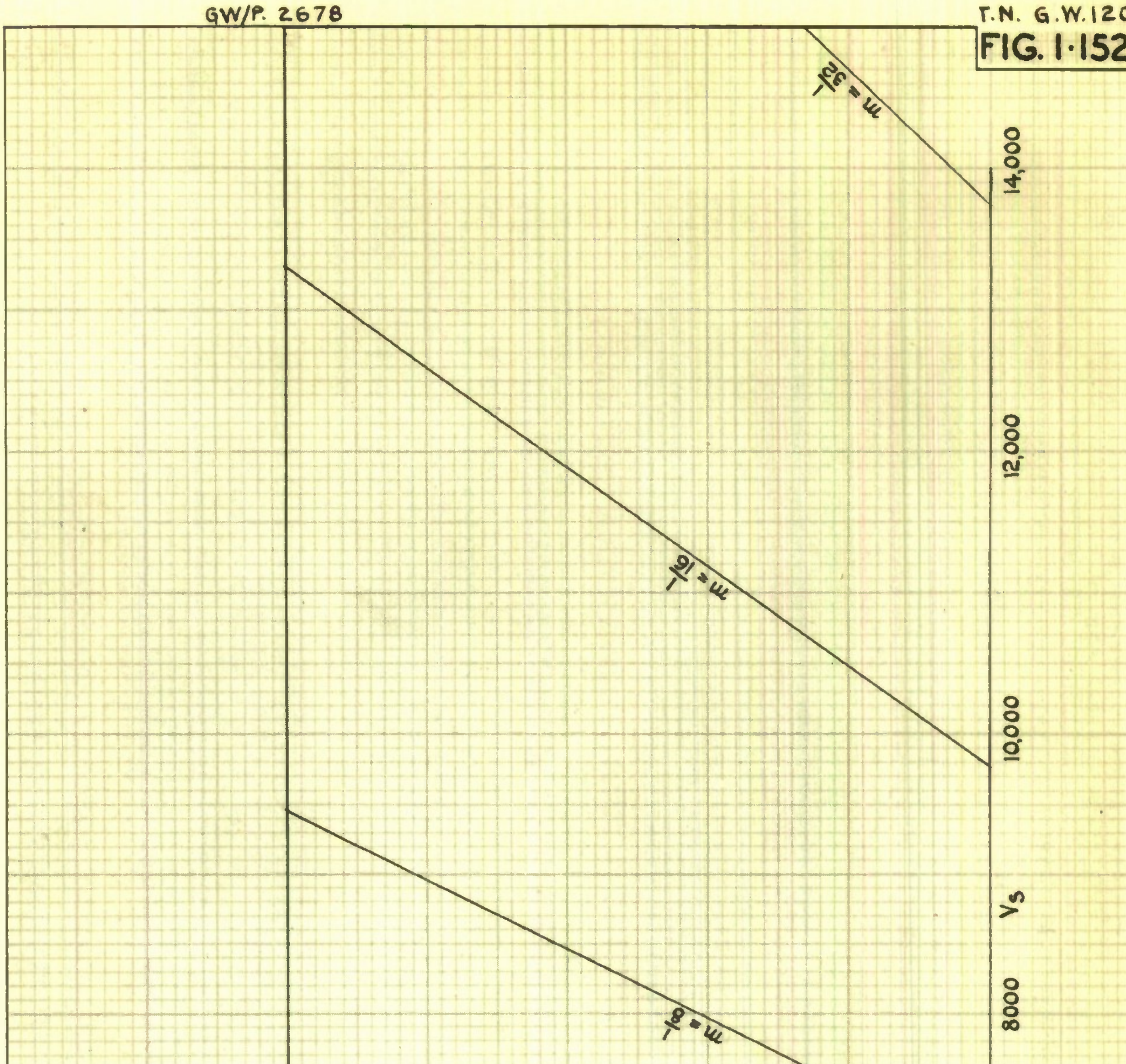
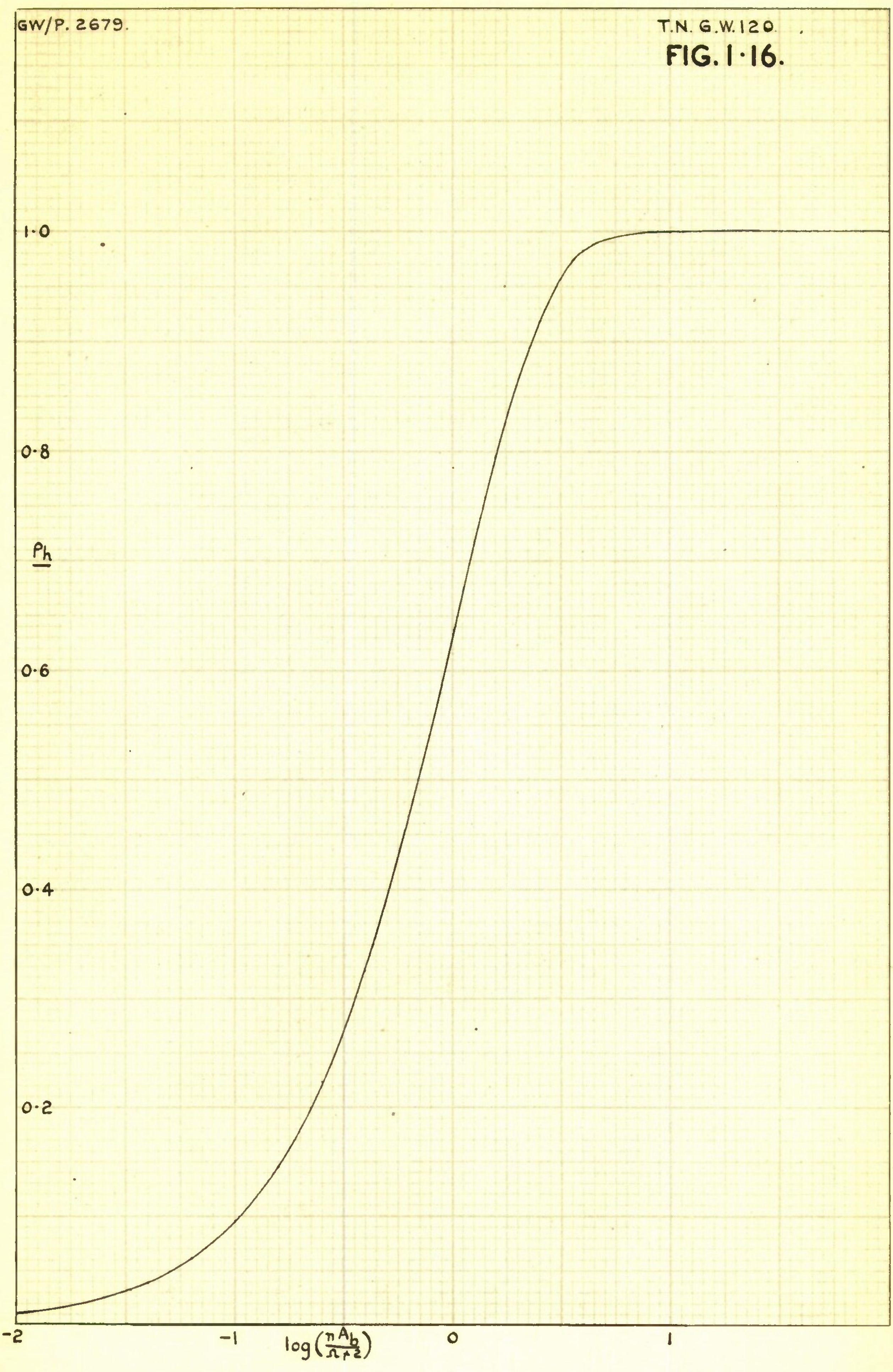


FIG. 1·152.

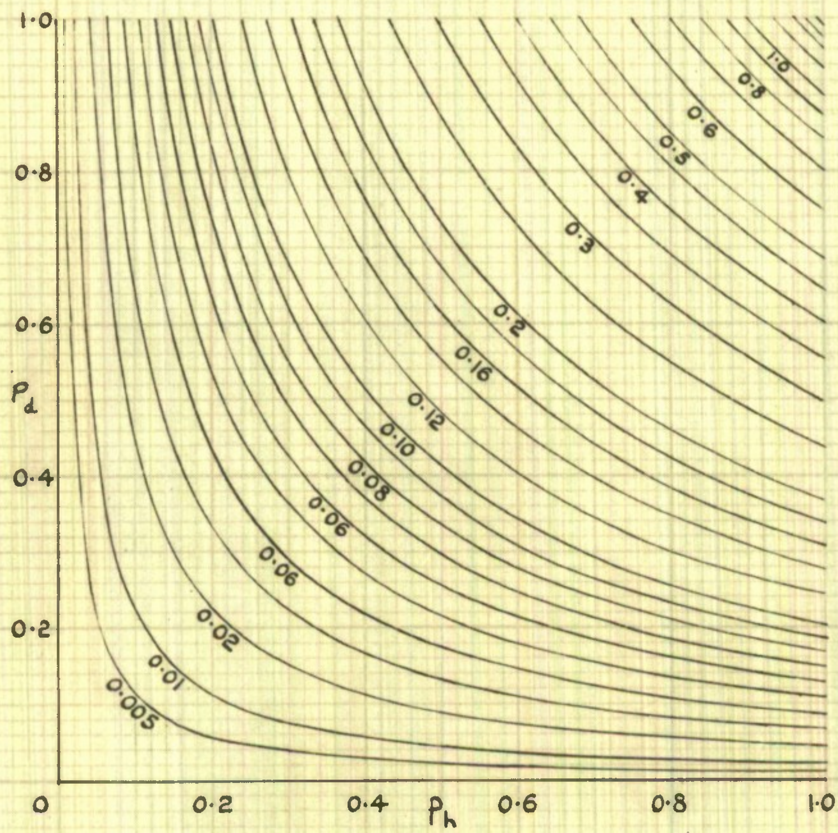

2:2:1 FRAGMENTS
Pd
1·0
0·8
0·6
0·4
0·2
0
Vs
4,000
6,000
8000
10,000
12,000
14,000
m = 1/2
m = 1/4
m = 1/8
m = 1/16
m = 1/32



GW/P. 2679.
T.N. G.W.120.
FIG. 1·16.
1·0
0·8
p_h
0·6
0·4
0·2
-2
-1
0
1
$\log\left(\frac{n A_b}{\Omega r^2}\right)$

FIG. 1·171.

CONTOURS OF $-\log . Q_b$



GW/P. 2681.

T.N. G.W.120.

FIG. 1·172.

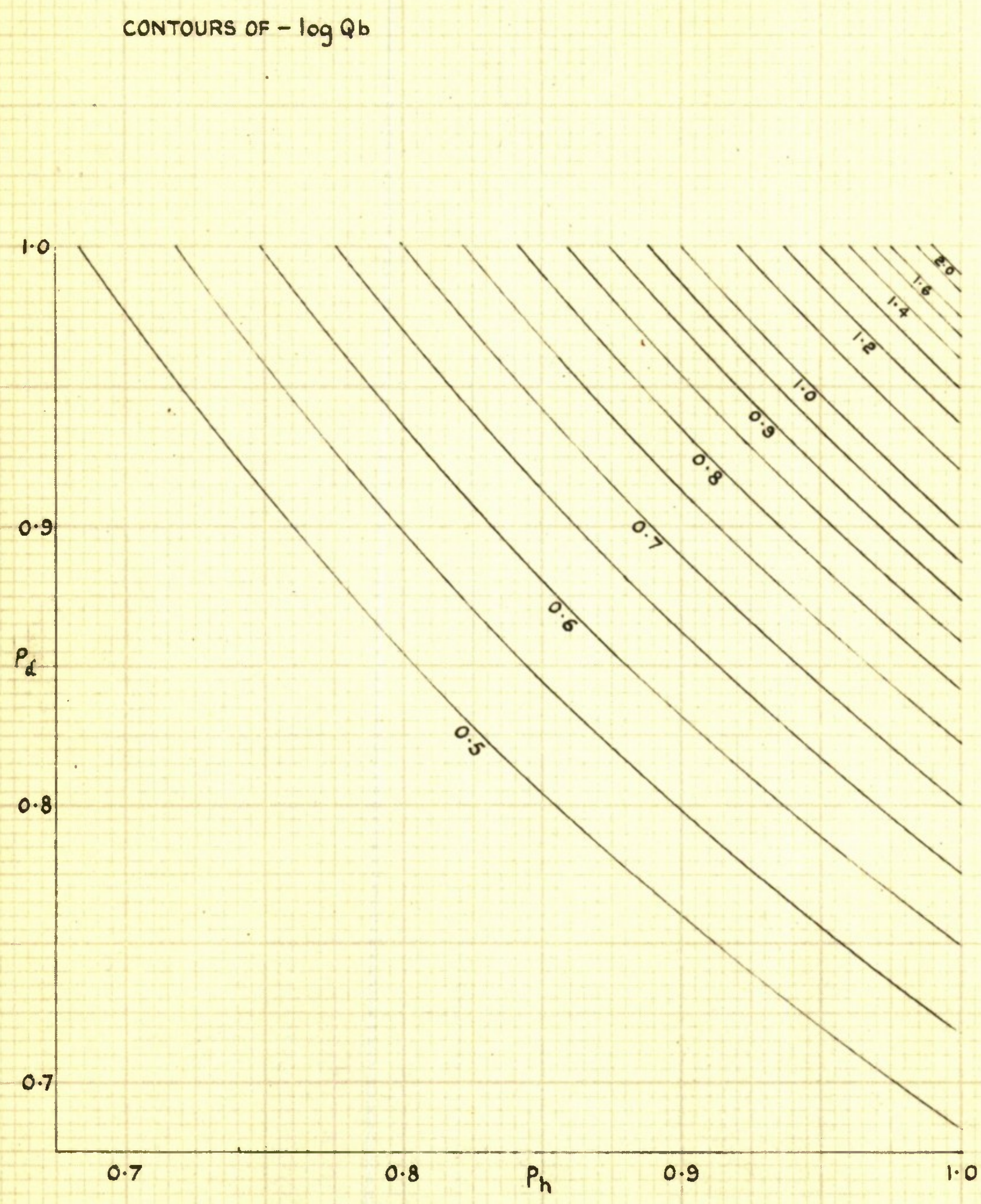
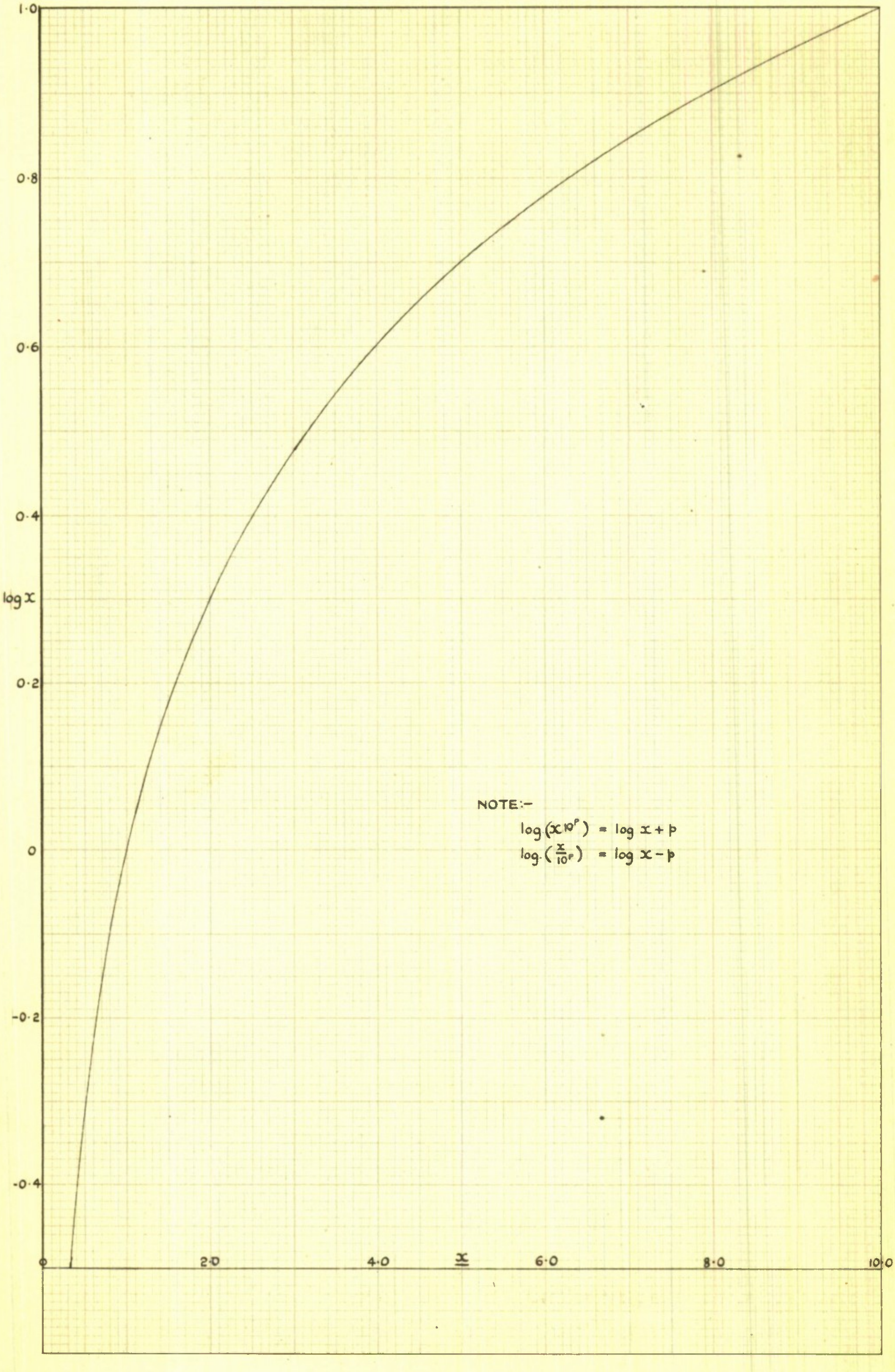


FIG 1·18



1·0
0·8
0·6
0·4
log x
0·2
0
-0·2
-0·4
0
2·0
4·0
x
6·0
8·0
10·0
NOTE:-
$\log(x\,10^{p}) = \log x + p$
$\log\left(\frac{x}{10^{p}}\right) = \log x - p$

FIG 2·01.

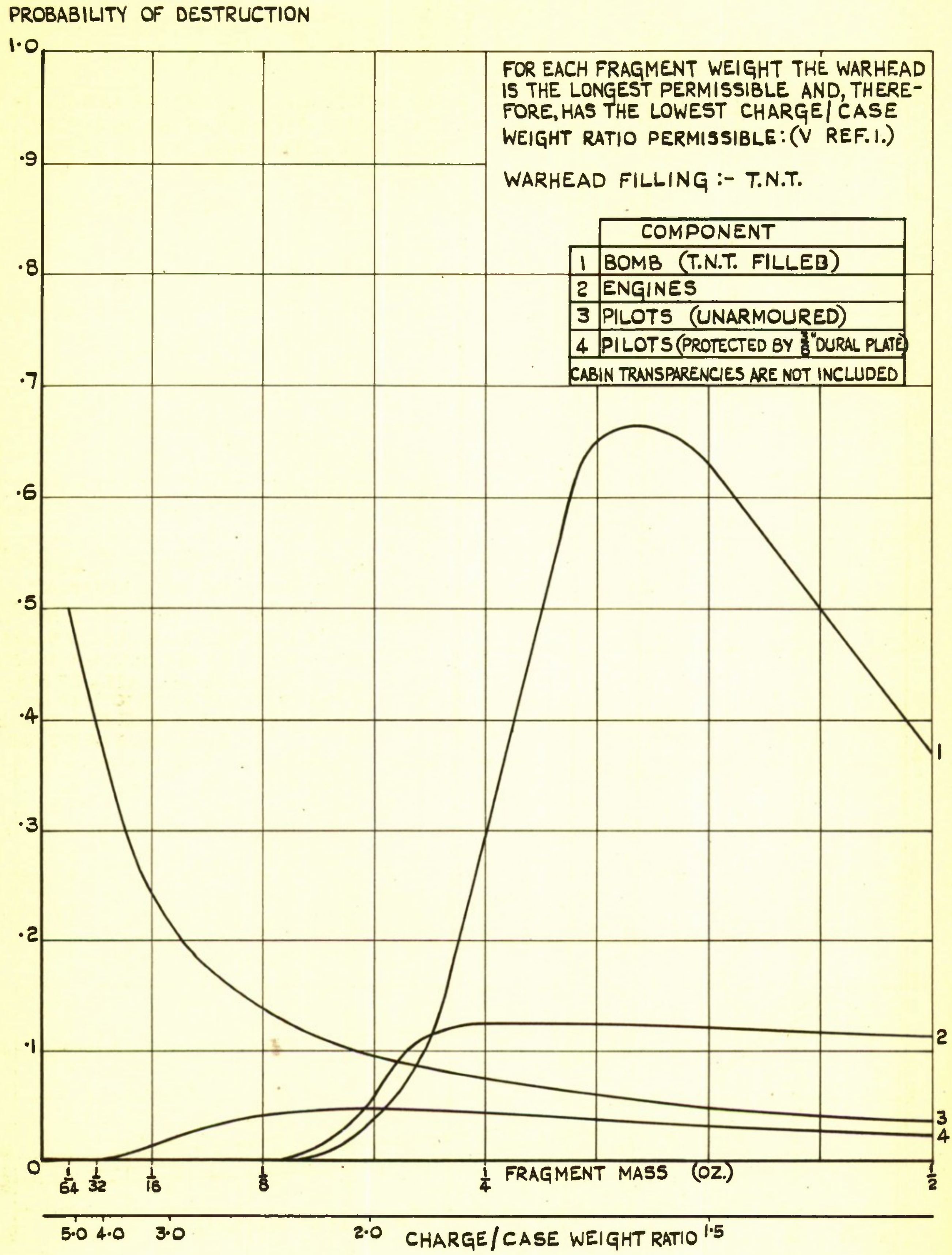


FIG. 2·01. VARIATION OF THE VULNERABILITY OF VARIOUS COMPONENTS WITH THE VALUE TO WHICH FRAGMENT MASS IS CONTROLLED FOR A 150 LB. WARHEAD ON A TRAJECTORY AT A DISTANCE OF 90 FT. FROM THE VULNERABLE AREA OF THE TARGET: TARGET ALTITUDE 15,000 FT.

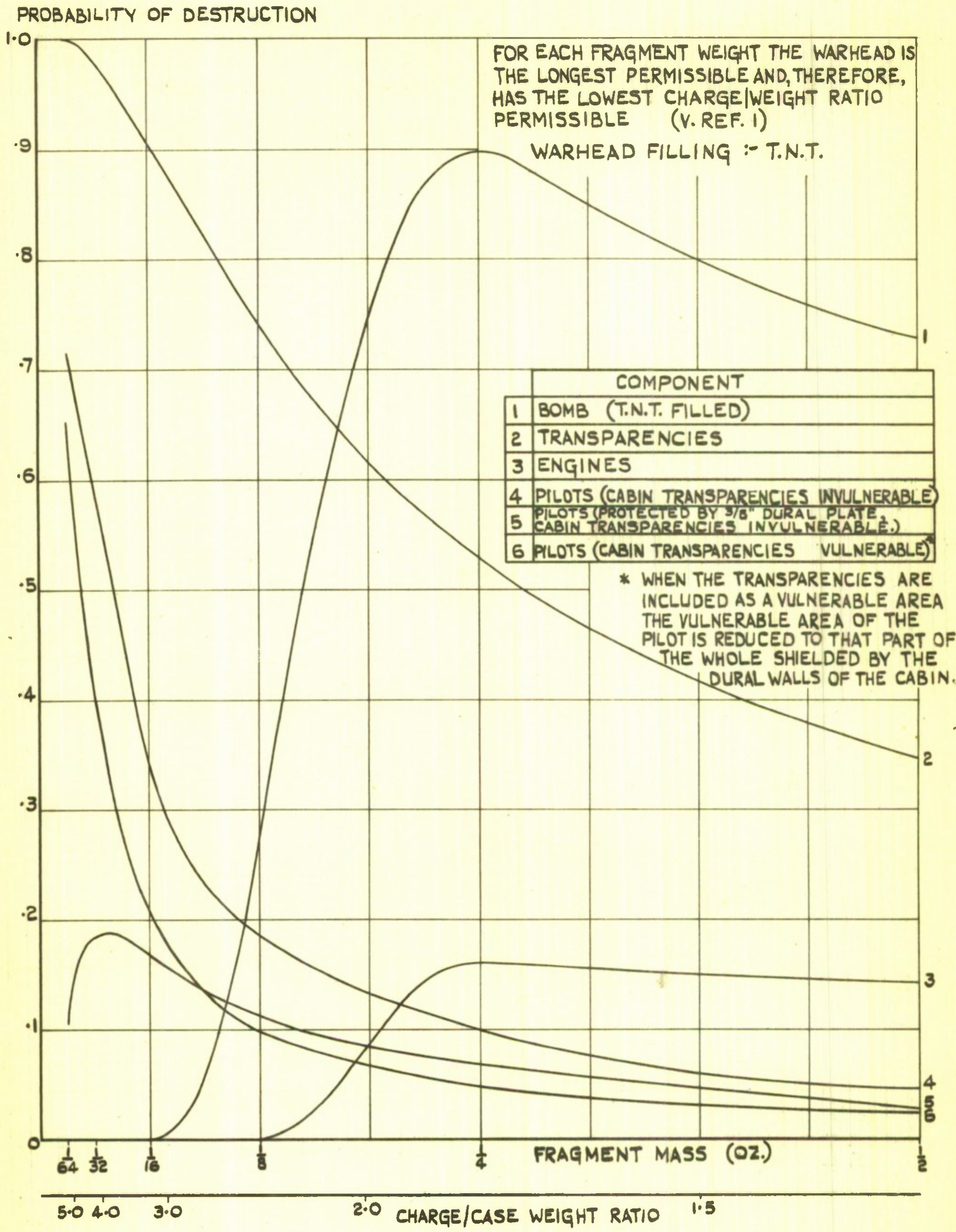


FIG. 2·02. VARIATION OF THE VULNERABILITY OF VARIOUS COMPONENTS WITH THE VALUE TO WHICH FRAGMENT MASS IS CONTROLLED FOR A 150 LB. WARHEAD ON A TRAJECTORY AT A DISTANCE OF 90 FT. FROM THE VULNERABLE AREA OF THE TARGET: TARGET ALTITUDE, 50,000 FT.

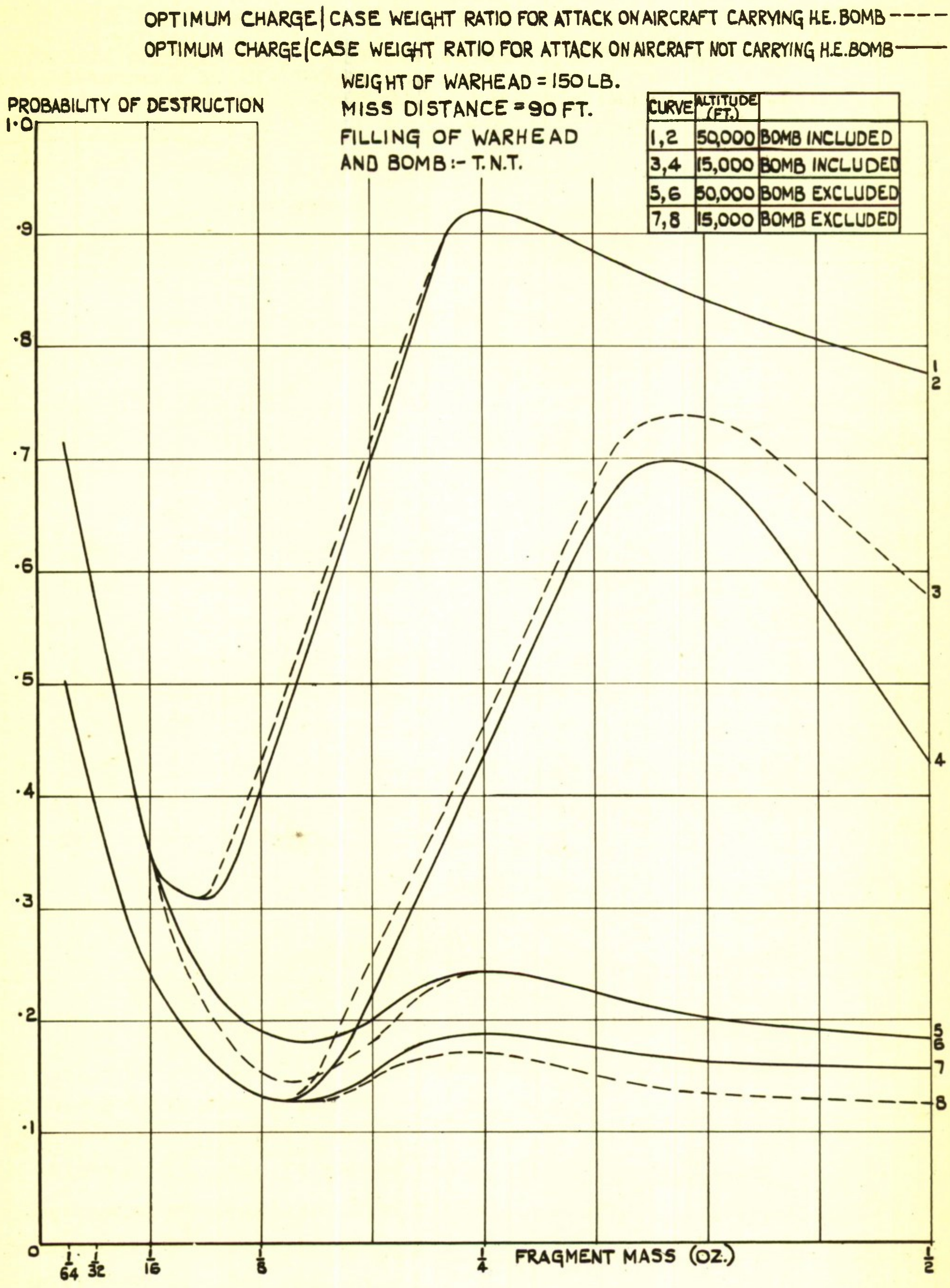
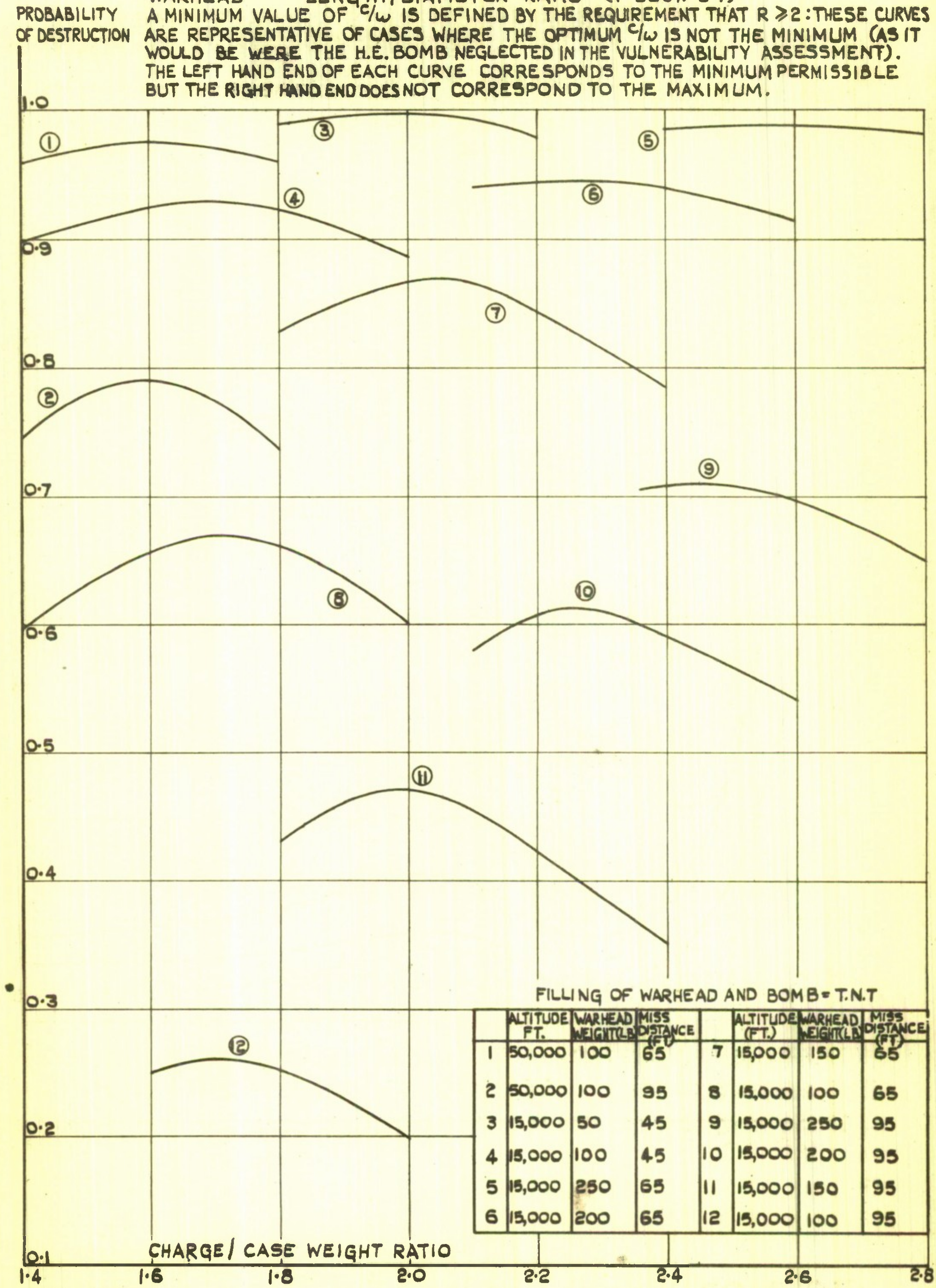


FIG. 2·03. VARIATION OF THE VULNERABILITY OF THE H.E. BOMB WITH THE VALUE TO WHICH FRAGMENT MASS IS CONTROLLED, THE CHARGE/CASE WEIGHT RATIO HAVING BEEN OPTIMISED UNDER EACH OF TWO CONDITIONS, NAMELY THAT THE AIRCRAFT IS AND IS NOT CARRYING AN H.E. BOMB.

FIG. 2·04.

ALLOWANCE HAS BEEN MADE FOR THE EFFECTS OF SMALL VALUES OF THE WARHEAD LENGTH/DIAMETER RATIO (V SECT. 2·7)
A MINIMUM VALUE OF $^{c}/_{w}$ IS DEFINED BY THE REQUIREMENT THAT $R \geqslant 2$: THESE CURVES ARE REPRESENTATIVE OF CASES WHERE THE OPTIMUM $^{c}/_{w}$ IS NOT THE MINIMUM (AS IT WOULD BE WERE THE H.E. BOMB NEGLECTED IN THE VULNERABILITY ASSESSMENT).
THE LEFT HAND END OF EACH CURVE CORRESPONDS TO THE MINIMUM PERMISSIBLE BUT THE RIGHT HAND END DOES NOT CORRESPOND TO THE MAXIMUM.



FILLING OF WARHEAD AND BOMB = T.N.T

	ALTITUDE FT.	WARHEAD WEIGHT(LB)	MISS DISTANCE (FT)		ALTITUDE (FT.)	WARHEAD WEIGHT(LB)	MISS DISTANCE (FT)
1	50,000	100	65	7	15,000	150	65
2	50,000	100	95	8	15,000	100	65
3	15,000	50	45	9	15,000	250	95
4	15,000	100	45	10	15,000	200	95
5	15,000	250	65	11	15,000	150	95
6	15,000	200	65	12	15,000	100	95

FIG. 2·04. OPTIMUM VALUES OF THE CHARGE/CASE WEIGHT RATIO OF WARHEADS OF VARIOUS WEIGHTS, CONTROLLED TO GIVE 1/4 OZ. (2:2:1) FRAGMENTS, AGAINST A TYPICAL FUTURE BOMBER, THE H.E. BOMB LOAD BEING CONSIDERED VULNERABLE.

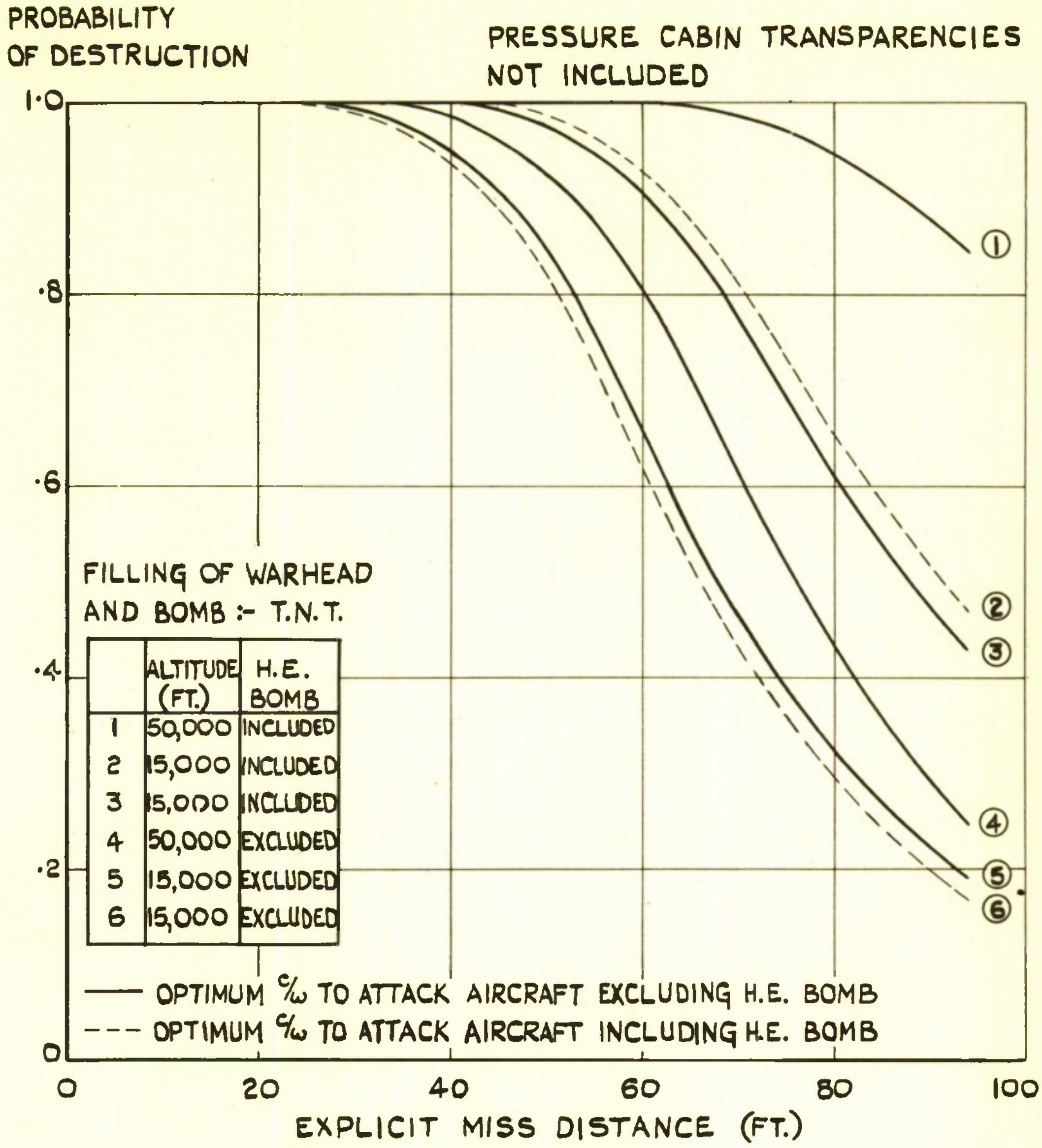


FIG. 2·05. VARIATION OF THE PROBABILITY OF DESTRUCTION WITH EXPLICIT MISS DISTANCE FOR A 150 LB. WARHEAD CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, TO ILLUSTRATE THE EFFECT OF INCLUDING THE H.E. BOMB IN THE VULNERABILITY ASSESSMENT : FRAGMENT CONE DEFINED BY THE VARIABLE ⎍.

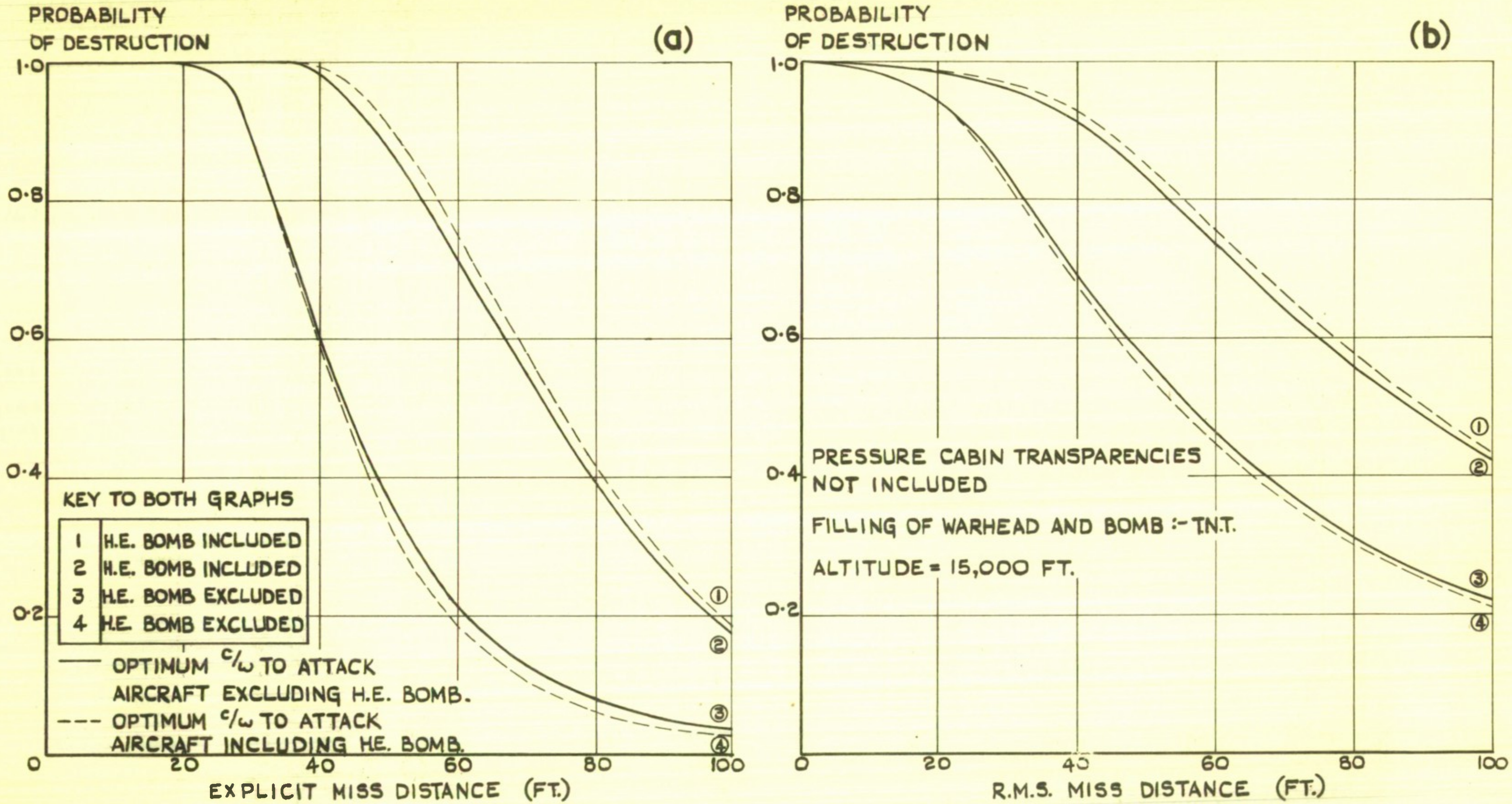
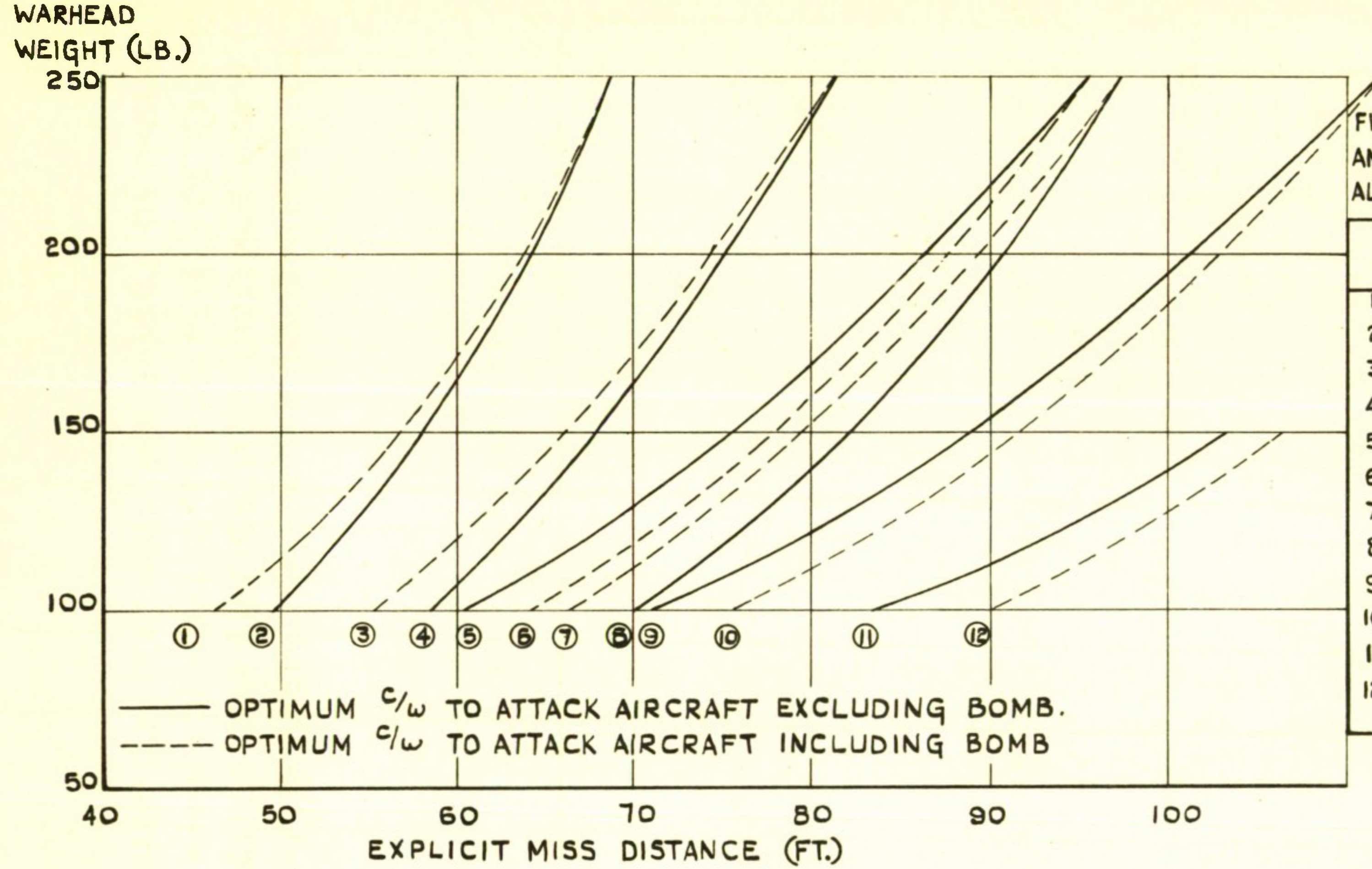


FIG. 2·06. VARIATION OF THE PROBABILITY OF DESTRUCTION WITH BOTH (a) EXPLICIT AND (b) R.M.S. MISS DISTANCE FOR A 150 LB. WARHEAD, CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, TO ILLUSTRATE THE EFFECT OF INCLUDING THE H.E. BOMB IN THE VULNERABILITY ASSESSMENT: FRAGMENT CONE DEFINED BY Ω = 4·0.



FILLING OF WARHEAD AND BOMB :- T.N.T.
ALTITUDE = 15,000 FT.

	PROBALITY OF DESTRUCTION	H.E. BOMB
1	0·7	EXCLUDED
2	0·7	EXCLUDED
3	0·5	EXCLUDED
4	0·5	EXCLUDED
5	0·7	INCLUDED
6	0·7	INCLUDED
7	0·3	EXCLUDED
8	0·3	EXCLUDED
9	0·5	INCLUDED
10	0·5	INCLUDED
11	0·3	INCLUDED
12	0·3	INCLUDED

FIG.2·07. VARIATION OF WARHEAD WEIGHT WITH EXPLICIT MISS DISTANCE FOR A WARHEAD, CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, TO ILLUSTRATE THE EFFECT OF INCLUDING THE H.E. BOMB IN THE VULNERABILITY ASSESSMENT: FRAGMENT CONE DEFINED BY THE VARIABLE Ω.

FIG. 2·08.

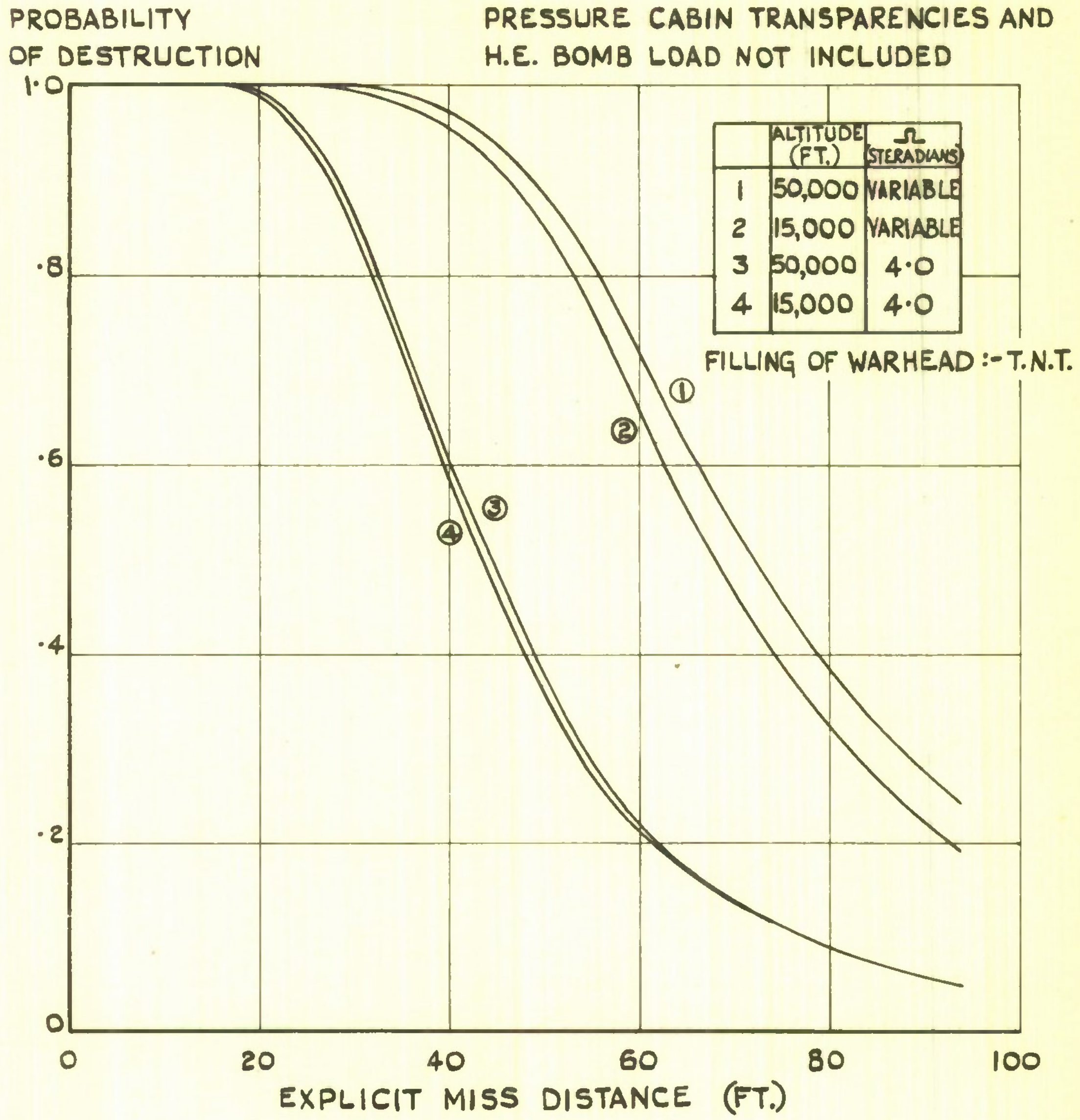
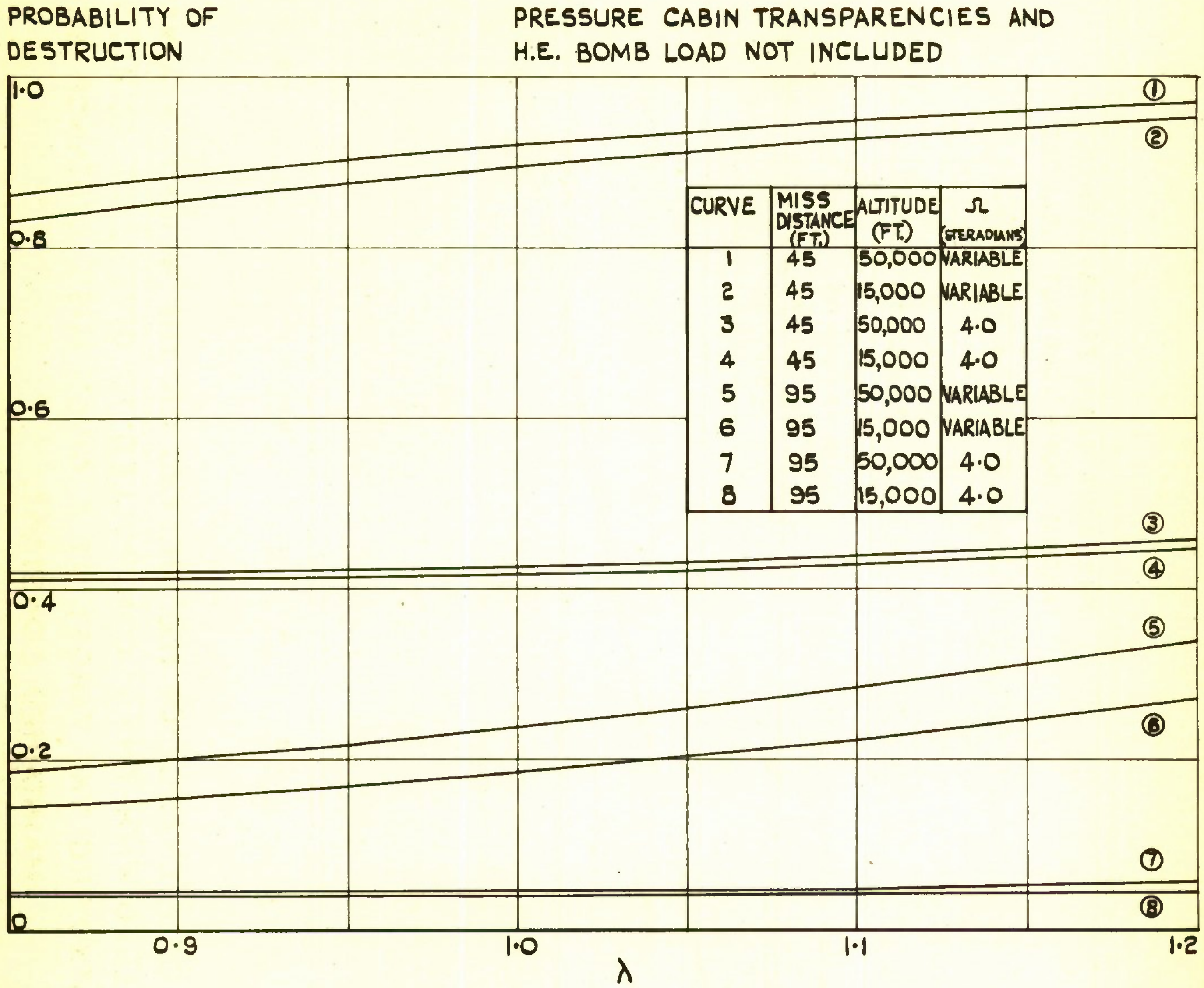
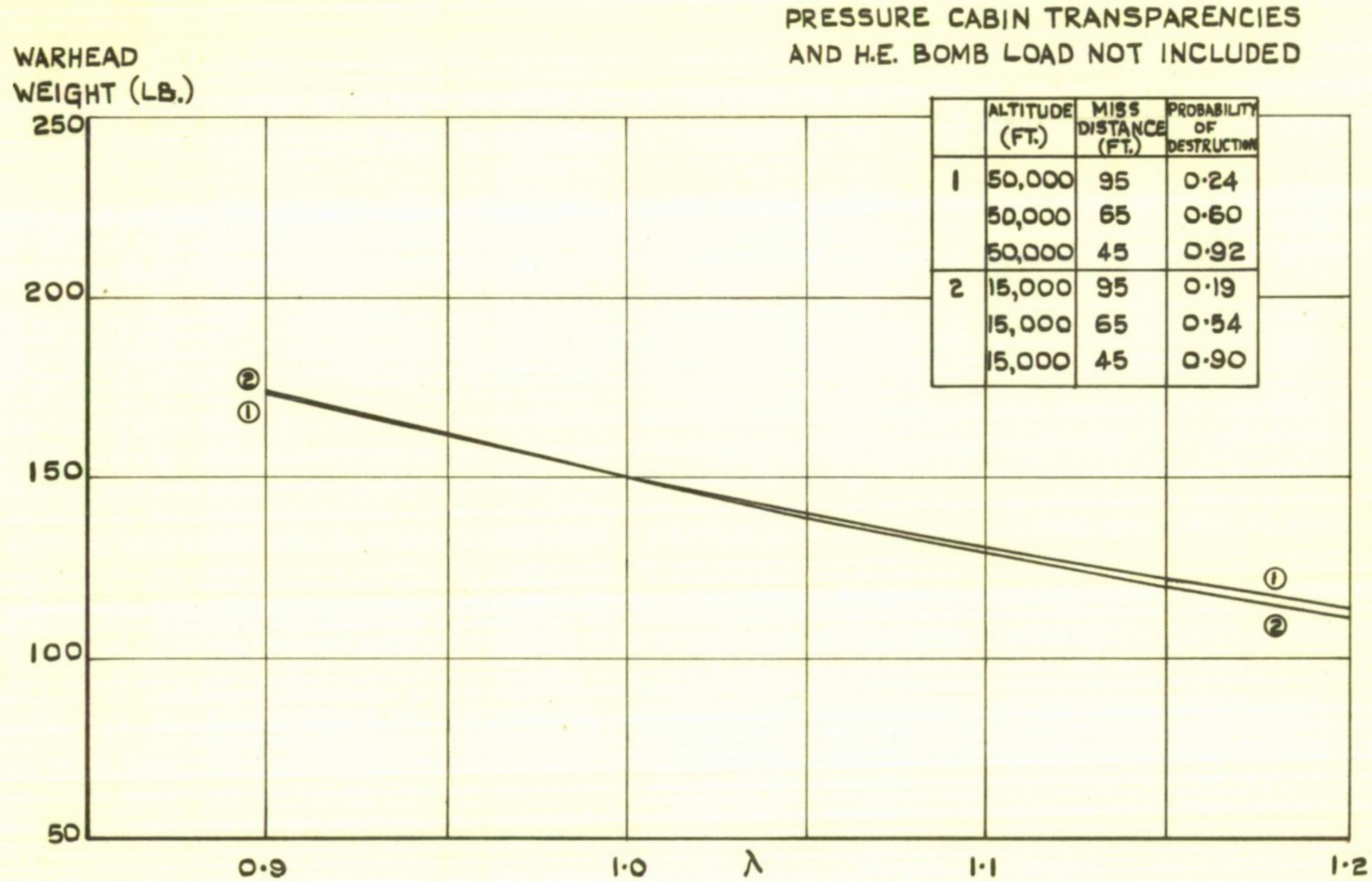


FIG. 2·08. VARIATION OF THE PROBABILITY OF DESTRUCTION WITH EXPLICIT MISS DISTANCE FOR A 150 LB. WARHEAD, CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, TO ILLUSTRATE THE EFFECT OF VARYING Ω.



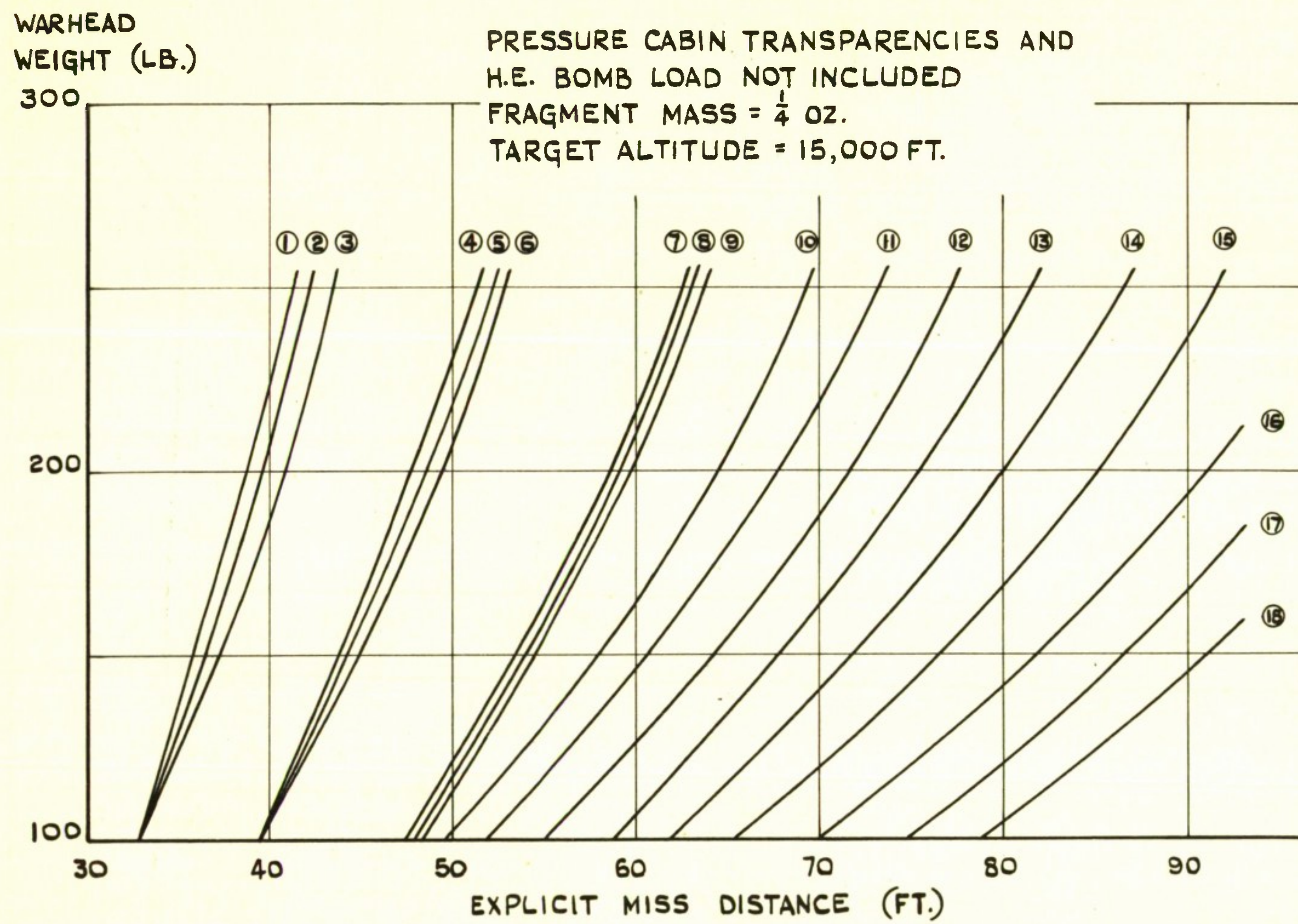
CURVE	MISS DISTANCE (FT.)	ALTITUDE (FT.)	Ω (STERADIANS)
1	45	50,000	VARIABLE
2	45	15,000	VARIABLE
3	45	50,000	4·0
4	45	15,000	4·0
5	95	50,000	VARIABLE
6	95	15,000	VARIABLE
7	95	50,000	4·0
8	95	15,000	4·0

FIG. 2·09. VARIATION OF THE PROBABILITY OF DESTRUCTION WITH THE RATIO $\lambda = \dfrac{\text{FRAGMENT VELOCITY DUE TO H.E. FILLING}}{\text{FRAGMENT VELOCITY DUE TO T.N.T.}}$ FOR A 150 LB. WARHEAD CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS.



	ALTITUDE (FT.)	MISS DISTANCE (FT.)	PROBABILITY OF DESTRUCTION
1	50,000	95	0·24
	50,000	65	0·60
	50,000	45	0·92
2	15,000	95	0·19
	15,000	65	0·54
	15,000	45	0·90

FIG. 2·10. THE EFFECT OF A CHANGE OF H.E. FILLING ON THE WEIGHT OF A WARHEAD (WEIGHING 150 LB. WHEN FILLED WITH T.N.T.) CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, THE PROBABILITY OF DESTROYING THE TARGET AT A GIVEN MISS DISTANCE BEING MAINTAINED CONSTANT.



	λ	Ω STERADIANS	PROBABILITY OF DESTRUCTION
1	1·0	4·0	0·7
2	1·1	4·0	0·7
3	1·2	4·0	0·7
4	1·0	4·0	0·5
5	1·1	4·0	0·5
6	1·2	4·0	0·5
7	1·0	4·0	0·3
8	1·1	4·0	0·3
9	1·2	4·0	0·3
10	1·0	VARIABLE	0·7
11	1·1	VARIABLE	0·7
12	1·2	VARIABLE	0·7
13	1·0	VARIABLE	0·5
14	1·1	VARIABLE	0·5
15	1·2	VARIABLE	0·5
16	1·0	VARIABLE	0·3
17	1·1	VARIABLE	0·3
18	1·2	VARIABLE	0·3

FIG.2·11. THE EFFECT OF CHANGING THE H.E. FILLING ON THE VARIATION OF WARHEAD WEIGHT WITH EXPLICIT MISS DISTANCE FOR CERTAIN CONSTANT PROBABILITIES OF DESTRUCTION.

FIG. 2·12.

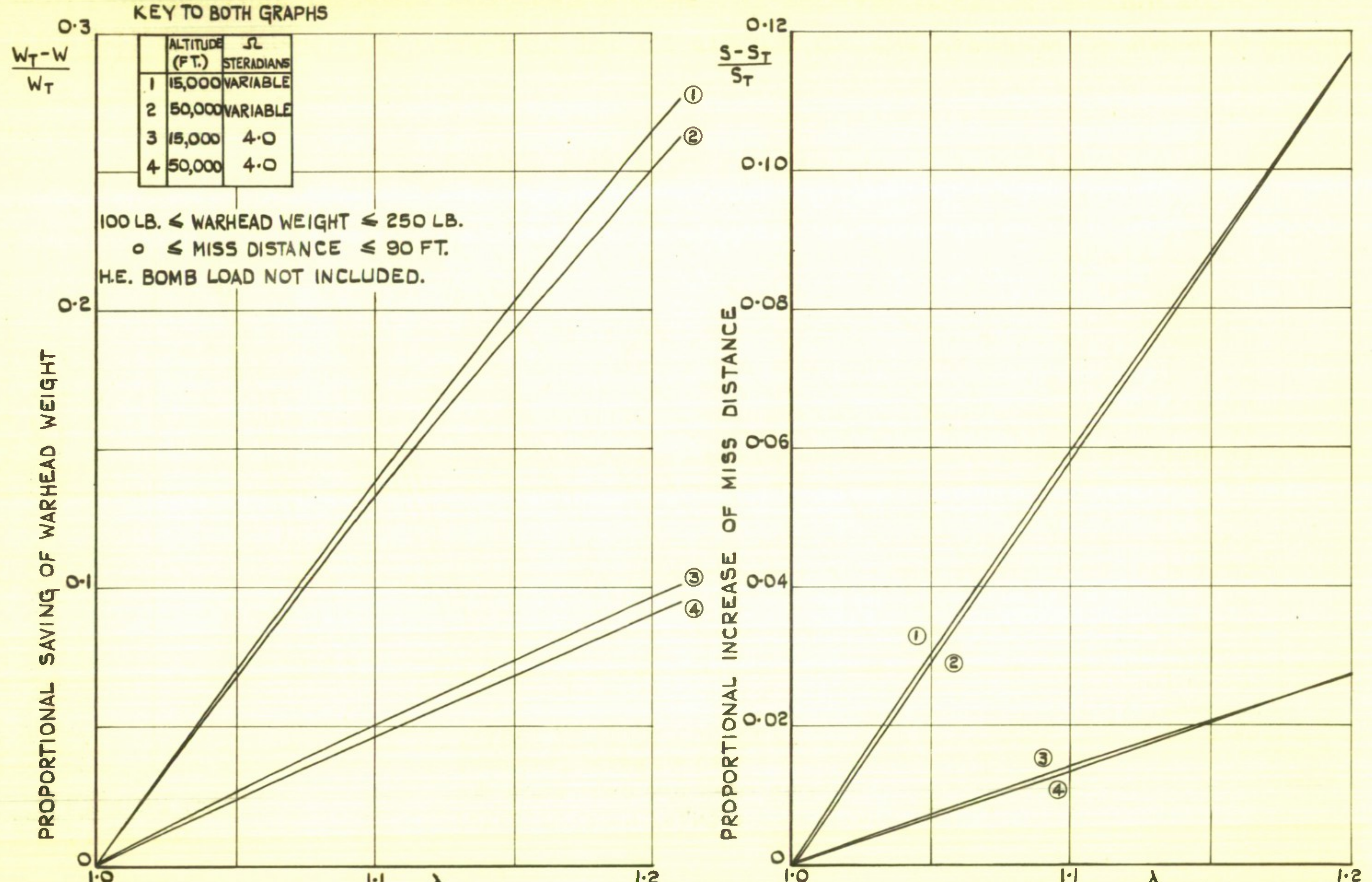


FIG. 2·12. THE PROPORTIONAL SAVING IN WARHEAD WEIGHT AND INCREASE IN MISS DISTANCE, FOR A GIVEN PROBABILITY OF DESTRUCTION, TO BE ACHIEVED BY CHANGING THE H.E. FILLING.

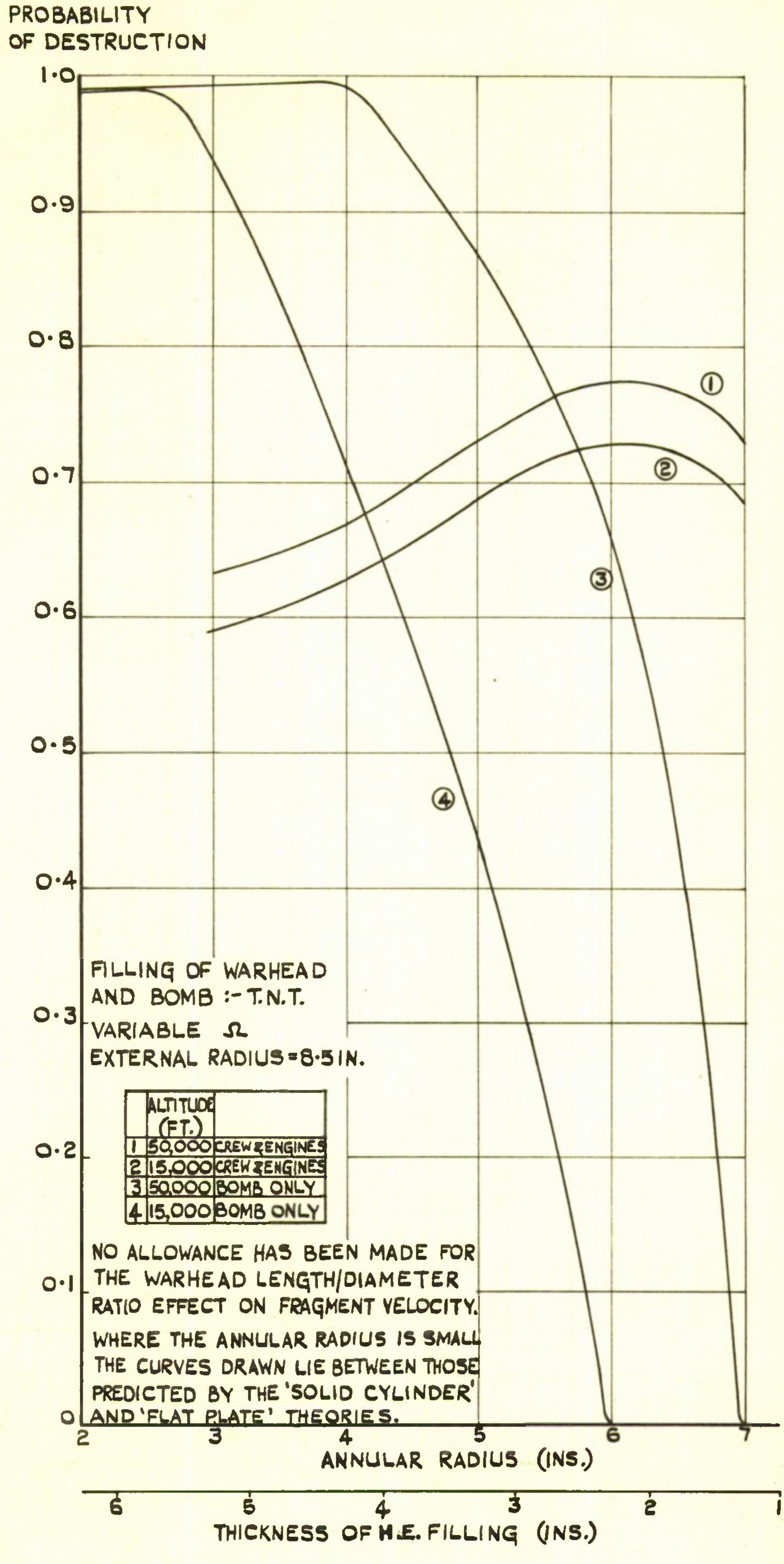


FIG. 2·13. VARIATION OF THE PROBABILITY OF DESTRUCTION OF THE CREW AND ENGINES TOGETHER AND OF THE H.E. BOMB LOAD ALONE WITH THE ANNULAR RADIUS OF A 150 LB. HOLLOW WARHEAD, CONTROLLED TO TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, AT A MISS DISTANCE OF 45 FT.

FIG. 2·14.

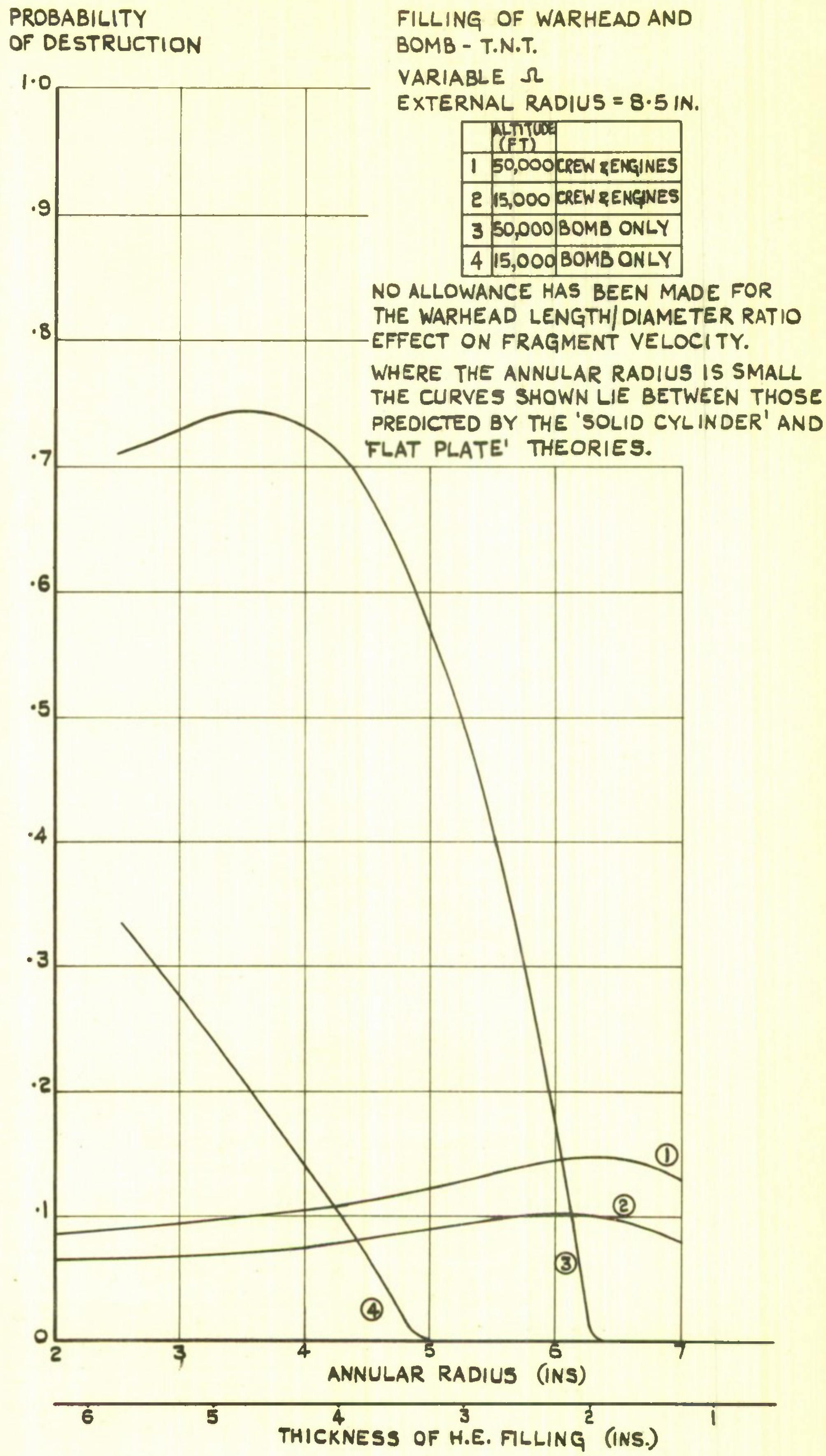


FIG. 2·14. VARIATION OF THE PROBABILITY OF DESTRUCTION OF THE CREW AND ENGINES TOGETHER AND OF THE H.E. BOMB LOAD ALONE WITH THE ANNULAR RADIUS OF A 150 LB. HOLLOW WARHEAD, CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS, AT A MISS DISTANCE OF 95 FT.

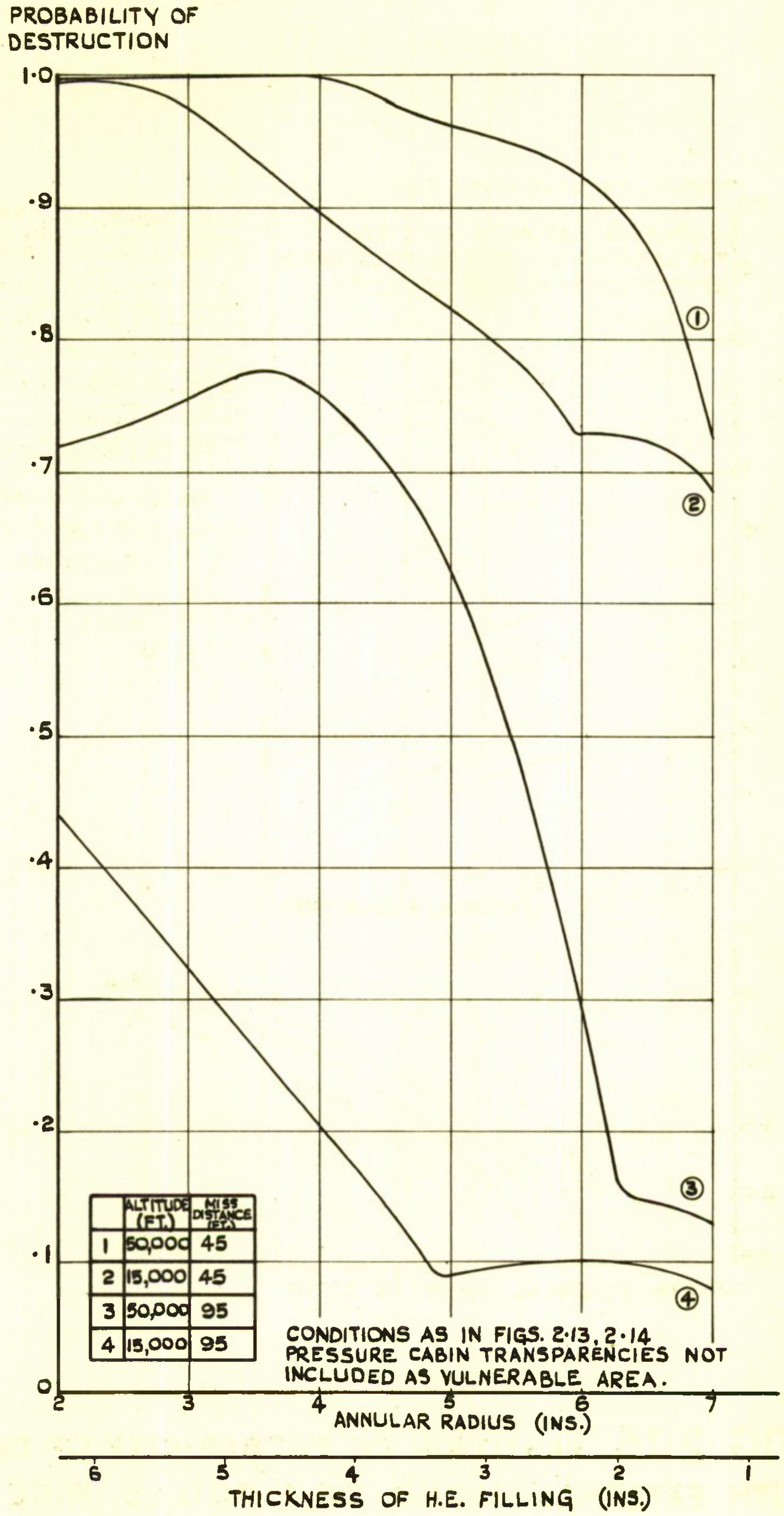


FIG. 2·15. VARIATION OF THE PROBABILITY OF DESTRUCTION OF THE WHOLE AIRCRAFT, INCLUDING THE H.E. BOMB LOAD, WITH THE ANNULAR RADIUS OF A 150 LB. HOLLOW WARHEAD CONTROLLED TO GIVE $\frac{1}{4}$ OZ. (2:2:1) FRAGMENTS.

FIG. 2·16.

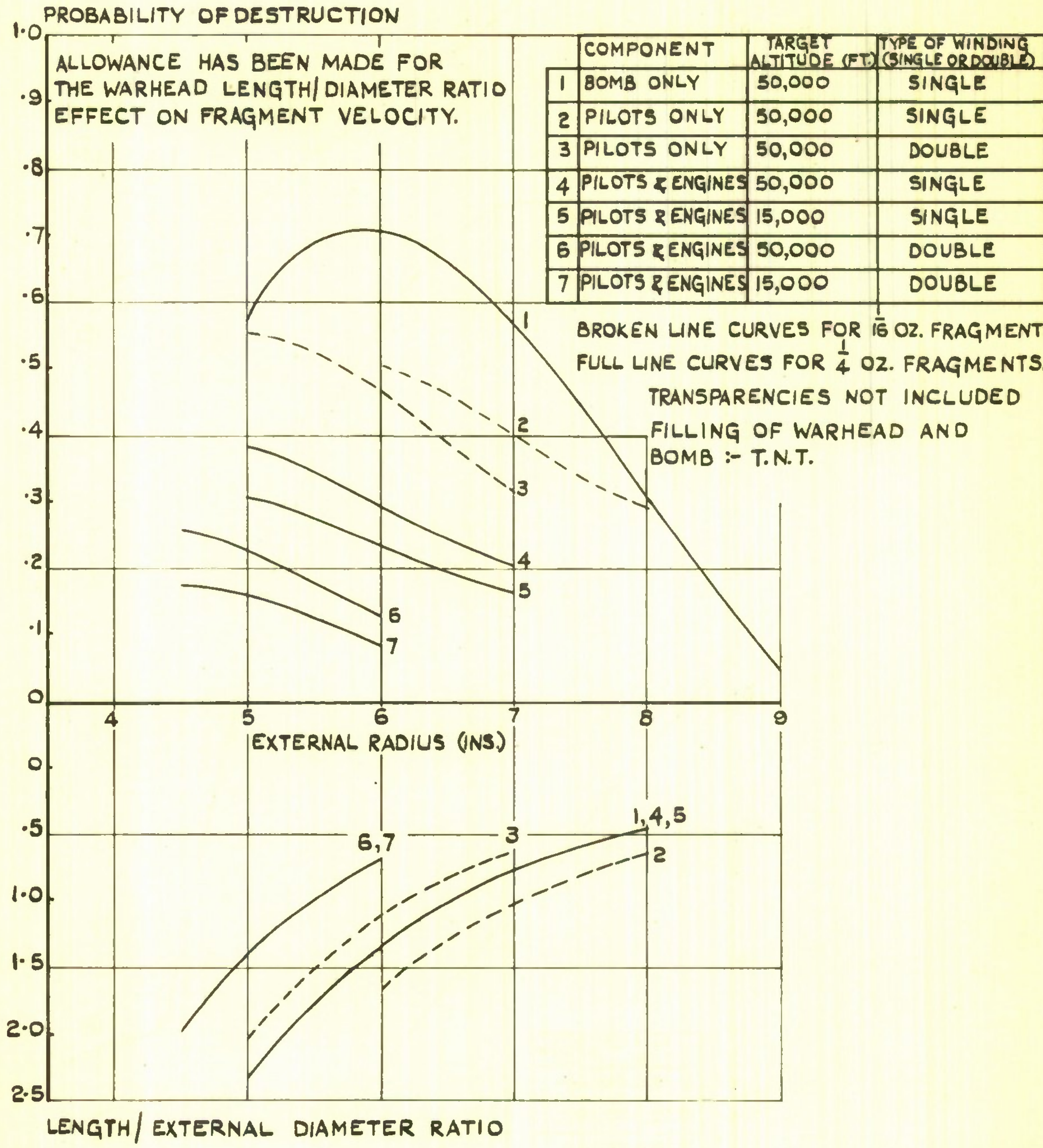


FIG. 2·16. VARIATION OF PROBABILITY OF DESTRUCTION WITH EXTERNAL RADIUS OF A 200 LB. WIRE-WOUND WARHEAD.

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Royal Aircraft Establishment, Farnborough, England
(Technical Note No. GW 120)
FURTHER STUDIES OF THE DESIGN OF GUIDED WEAPON WARHEADS, WITH A DESCRIPTION OF A NOMOGRAPHIC METHOD OF CALCULATING LETHALITY, by J.K.S. Clayton, G.C.A. Ruston, F.I. Reynolds, and others. June '51, 79 pp. incl. tables, graphs. SECRET

A previously developed theory for calculating the survival chance of a typical aircraft exposed to the fragmentation of a cylindrical guided missile warhead was applied to assess the probability of survival

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III. Reynolds, F. I.

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under particular conditions of fragment mass, total warhead weight, charge/case weight ratio, fuze burst range, and height of attack. The criteria for the destruction of the entire aircraft were: lethal damage to at least two of the four engines; injury to the two pilots sufficient to incapacitate both; or, at heights greater than 43,000 feet only, the penetration of the pressure cabin transparencies. The nomogram has proved useful over a period of some months in application to a wide range of calculations.

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