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An Assessment of the Lethality of a Continuous Rod Warhead attacking a T.U.4

by

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Introduction

Considerable development work has been carried out at the New Mexico Institute of Mining and Technology (ref.1) on the design of a warhead, which, when detonated, would expel rods joined together so as to form an expanding circle of metal. This, it is hoped, would be capable of cutting through an aircraft and so achieve the structural damage which earlier designs, using short discrete bar fragments failed to produce. The fabrication of such a novel warhead introduces many difficulties which can only be gradually surmounted by a lengthy process of trial and error (ref.1,2), which is not yet completed for no one method of manufacture produces consistent round to round performance. However in 1953 the Unites States workers considered (ref.1) that a stage had been reached at which the feasibility of their assembly and means of ejection were established sufficiently for some trials to be attempted to check the damaging power against various structural portions of aircraft. Reports so far available (ref.1) indicate that only ten warheads have been fired in an arena in which the targets were aircraft wings, mostly of the 7F7 type, but one B29 wing section was included. Of the total of ten target wings attacked it was judged that nine, including the tougher area of the inboard section of the B29 wing, had sustained 'K' category damage. The single failure to kill a wing was ascribed to the rod's breaking up before arriving at the target. In all these tests the rod approached the targets in a direction nearly normal to the plane of the wing skin so that no information was obtained about the effect the direction of strike would have on the amount of damage produced. Doubts have been expressed in the United Kingdom (ref.3) as to whether the continuous rod would be as effective against the wing structures as it might possibly be against fuselage sections where there are no concentrated load carrying members. Despite this limitation of damaging power, and the fact that it is difficult at present to manufacture a design to perform consistently it appears to be worthwhile to consider what are the chances of hitting an aircraft in an attack by a continuous rod. It is the purpose of the present memorandum to make such an assessment, taking into account the warhead weight, rod length and section, rod velocity and rate of expansion, the direction of attack, the vulnerability of the various sections of the target and the effects of fusing and guidance errors likely to occur.

2 Vulnerability of the T.U.4 to the Continuous Rod

Since a model of the T.U.4 constructed on a convenient scale was immediately available the present study considers the T.U.4 as the target,

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the following sections of which are considered by M.E. Dept. R.A.E. to be invulnerable to the continuous rod, so far as structural kills are concerned:-

the engines,
the first three feet of the fuselage, measured from the nose,
the first nine feet of each wing, measured from the wing tip, together with a band three feet wide along the trailing edge.

For strikes on the tail section to be effective it was at first considered that both tail planes would have to be cut away, and as this would occur so seldom in the attacks being studied here, it was decided to regard the tail section as virtually invulnerable - an assumption which now has little credence (ref.8) but the underestimation introduced in this way is of small numerical significance.

Strikes on the remaining portions of the structure will, it is assumed, destroy the aircraft very soon afterwards; that is the damage will be certainly category 'A' - often it may even be category K (immediate kill) - provided that the cuts extend halfway round the fuselage, or extend chordwise across the wings. A further restriction has been imposed for strikes on the wings, namely that the obliquity of approach of the rod, (measured by the angle between the normal to the wing surface and a generator of the cone on the surface of which the rod expands) be less than some value, which in the absence of experimental data, has been fixed at 45°. In the simulator work the measuring of this angle proved to be particularly difficult, and so the angle actually measured was that between the normal to the surface and the direction of the lateral expansion of the rod. The criterion to be satisfied by this angle was chosen to be 30° - which, it is believed, will tend rather to overcompensate for the inaccuracy introduced by this procedure.

These estimates of vulnerability are based partly on United States findings and partly on judicious extrapolations of the results of damage produced by 3/8" square discrete rod fragments in trials carried out in the United Kingdom (ref.4). United States workers claim that 1/4" square section rod will be capable of severing 75% of

(a) the upper or lower half of the wings (chordwise between spars)

(b) the upper or lower half of the fuselage (spanwise).

There is, however, only meagre experimental evidence to support this claim, so until trials have been conducted to test the effectiveness of the continuous rod, both of the 1/4" square section and 3/8" square section, against heavy structural members attacked <u>from all directions</u>, the validity of the estimates of vulnerability remains open to question.

3 The Warhead

The continuous rod used in this work consists of 3/8" x 3/8" square steel rod, weighing 150 lb, with a total length of approximately 315 feet; when fully expanded it would form a ring of 100 ft diameter. The charge required to expel the rod was chosen by using the same value of the charge/case weight-ratio (0.44) as was used by the United States workers, who measured the resulting velocity of expulsion to be 4,500 ft/sec. The total weight of the warhead was thus 215 lb. It is not certain how closely the ejection velocity is related to the charge/case weight-ratio, since only this one value of the ratio has been used.

In order to take account of the motion of the target between the instant of detonation and the rod strike some quantitative measure of the rod expansion is necessary. If c denotes the loss of lateral velocity (in ft/sec per ft rod radius) suffered by the ring in expanding to radius r (ft), and is assumed to be constant, then it can easily be shown that the time to expand to radius r is given implicitly by $r = \frac{V_o}{c}\left[1 - e^{-ct}\right]$, V_o (ft/sec) is the initial lateral velocity. The United States workers measured the retardation of the velocity of the rod as it expanded, obtaining the value 15 ft/sec per ft rod radius expanded. This figure includes retardation due to the atmosphere (at ground level) as well as that due to loss of energy incurred during expansion. There is at present not much information available on the atmospheric retardation of a continuous rod, nor of discrete rods, so to a first approximation this value has been used on the assumption that it will still be valid at the altitude of the actual attack.

Once the rod reaches its maximum size, it is assumed that any energy remaining causes the rod to break up, and that then it becomes harmless. A slight bonus in lethality may actually be available (ref.4) from the damage caused by the portions of the rod after break-up, but no account is taken of such possibilities in the present study.

4 The Experimental Procedure

Of several methods considered for estimating the probability of hitting a target, it was soon found that only one, using the R.A.E. Lethality Engagement Simulator Mk.I, (ref.5), did not imply invalid or inadmissible assumptions regarding the nature of the encounter or behaviour of the rods. The engagement simulator was modified by fitting a 1/50 scale solid model of the T.U.4 in place of the representational target normally used in fragmentation studies, and by fitting on the missile trolley a bar of length proportional to the maximum radius the continuous rod could attain when fully expanded (50 ft). In this way an analogue simulation was provided of the encounter, enabling a detailed study to be carried out of the manner in which the rod would strike a target for any chosen direction of attack. The measurements made consisted in finding the extent of the regions from within which the warhead could be detonated to expel the rod and hit a vulnerable part of the target, subject to the restrictions on obliquity etc mentioned in section 2 above. Some practical difficulties encountered during the measurements arose because the simulator had not been designed for this task. As a result, the determination of the obliquity of a particular strike was occasionally difficult, but once some experience and confidence had been acquired in handling the simulator, results of a reasonable consistency were finally obtained, the lethal zones being determined to within five feet.

5 Encounter Conditions and Fuse Assumptions

5.1 Directions of Attack

The simulator studies were carried out for two directions of attack - the first from 45° off ahead, 45° below the bomber; and the other from a direction 45° off ahead, abeam the bomber; in both cases the missile was assumed to be travelling at 2000 ft/sec and the target at 500 ft/sec.

5.2 Fuse Assumptions

The time of flight of the rod is defined by the time taken to reach its maximum diameter - in the present case the rod will expand to this size in about 12.5 milliseconds. Because of this short time of flight a constant looking angle type of fuze pre-set to 70° has been used. It was found that for both directions of attack a wing tip would be the first portion of the aircraft to be sighted, hence, in order that the detonation occur within the region where hits could be made, it would be necessary to introduce a delay; the effect of various delays on the lethality is examined below.

6 Results and Discussion

The manner in which the fuze delay affects the lethality can be seen from Fig.1, where various delays have been used for both directions of attack, assuming the absence of fuze performance errors. It is apparent that the best delay for one of the directions is not the best for the other, but as it is unlikely that more than one delay can be allowed for in the fuze, inspection of Figs.1(a) and 1(b) shows that the best chance of hitting the target when attacking from either of the two directions studied would be obtained by introducing a delay of 40 feet. Accordingly a uniform delay of 40 ft has been used to obtain Fig.2 which shows the effect the direction of attack has on the lethality. In Fig.2 the lethality is expressed as a function of the radial R.M.S. Miss Distance, assuming a circular normal distribution of the missile trajectories about a central trajectory passing through the centre of the bomber. Variations in fuze performance have been taken into account by introducing a linear R.M.S. fuzing error of 20 ft. Other curves in Fig.2 illustrate the extent of the change in lethality produced when a 60 ft space delay and R.M.S. linear fuzing error of 30 ft are used for both directions of attack. For convenience in the calculations a space delay has been used here, but in practice the delay would be introduced by a mechanism operating after a pre-set time, implying of course a space delay varying with the closing encounter velocity. However in the present case the closing velocity for the two directions of attack studied here is the same, so that the results shown in the diagrams apply to both types of delay.

A comparison of the continuous rod with a fragmenting warhead and an external blast warhead of similar weights and under similar conditions of encounter and fuze performance is made in Fig.3. The fragmenting warhead lethality includes estimates of its blast and direct hit capabilities, whereas the continuous rod assessment includes direct hits but has ignored any blast bonus that might be available. It can be shown, using the first modification of Fano's formulae, that for the present design, the blast bonus would not necessarily be negligible since the effect would be equivalent to the blast from a bare explosive charge of 40 lb. It should be noted in Fig.3 that the lethality of the blast warhead, and the fragmenting warhead, is not unity when the R.M.S. Miss Distance is zero partly because of the fuzing errors and partly because a uniform delay cannot ensure that the warhead will detonate within the region in which direct hits must occur. In making comparisons in Fig.3 it has to be borne in mind that the lethality of the continuous rod is dependent on the assumptions made regarding its damaging powers, so that at worst the results shown here are hit chances, while at best they are cat.A kill chances in which case the continuous rod would compare very favourably with the other more conventional warheads. As yet it has not been possible to make close comparisons with shaped charge or subprojectile warheads.

A similar assessment to the above has been made for a continuous rod for Talos (ref.6,7), but without using a simulator so that no account was taken of the obliquity, nor the extent of a cut, of particular strikes. The calculations regarding guidance and type of fuzing are similar to those used here, except that the fuse performance for Talos is assumed to be ideal, i.e. no fuzing errors are included. It is however not possible to compare the results directly as the Talos warhead is much bigger than that considered above - it produces a rod with a maximum diameter of 260 ft compared with 100 ft for the one used here - so that it is to be expected that the kill chances would be higher than those derived in the above work.

When total warhead weight (excluding end plates) is taken into account, the design discussed above can be incorporated more readily into the Seaslug missile than the Red Duster missile. If, however, the rod were of 5/16" square section the 100 ft diameter rod would be produced from a warhead of 164 lb total weight. The fuselage remains vulnerable to this rod to the same extent as in the discussion above, but damage to the wing will depend rather on the direction of approach - the whole of the top skin, it is believed, of the outboard section (apart, of course, from the invulnerable portion mentioned in section 2) will be vulnerable to this rod, whereas on the underside only 50% of the interspar section will be vulnerable. The obliquity considerations apply as before.

7 Further Work

It is desirable that the damaging power of the continuous rod be verified by trial against representative aircraft structures attacked from various directions - only then can the potentialities suggested above be confirmed.

Since the simulator work was completed, sufficient information has become available on possible future targets (Type 37, Type 39) for models of these to be constructed; further modifications have been made to the simulator and a new method of assessment (arising partly from experience gained in the work of the present paper) has been developed, so that work has been started on a long term study of second generation warheads, which will include further studies of the continuous rod designed to be fitted into existing and future G.W. projects. Some account will have to be taken of the atmospheric retardation of the rod - an empirical formula has recently become available (ref.7) which may assist in this respect. In addition, future assessments will have to take account of the evidence in some recent trials on the performance of continuous rods, suggesting that the rod begins to break-up before reaching the maximum radius theroetically possible.

8 Conclusions

(1) Provided that trials confirm the destructiveness assumed here, of the continuous rod, it can be concluded that it compares very favourably with the existing fragmenting and external blast warheads.

(2) The lethality depends on the direction of attack and on the fusing - though to a lesser extent than the fragmenting warhead, as is to be expected since the latter has to attack only a few dispersed duplicated components in the target. The blast warhead is less sensitive to fuzing than the continuous rod, but under equal conditions of encounter the results in the present paper suggest that the continuous rod appears to be more effective than the blast warhead.

9 Acknowledgements

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No.	Author	Title, etc.
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6	-	Assessment of a continuous rod warhead for Talos: APL/JHU CF-2111.
7		B.J.S.M. Research Memo No. 55
8	J. K. S. Clayton	Some notes on possible methods of assessing the lethalities of second generation guided missiles. R.A.E. Tech. Memo G.W.247.

Attached

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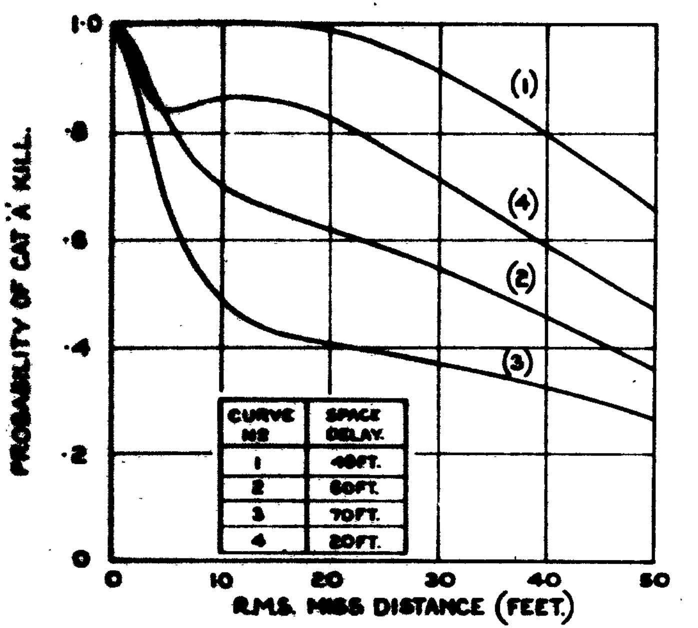
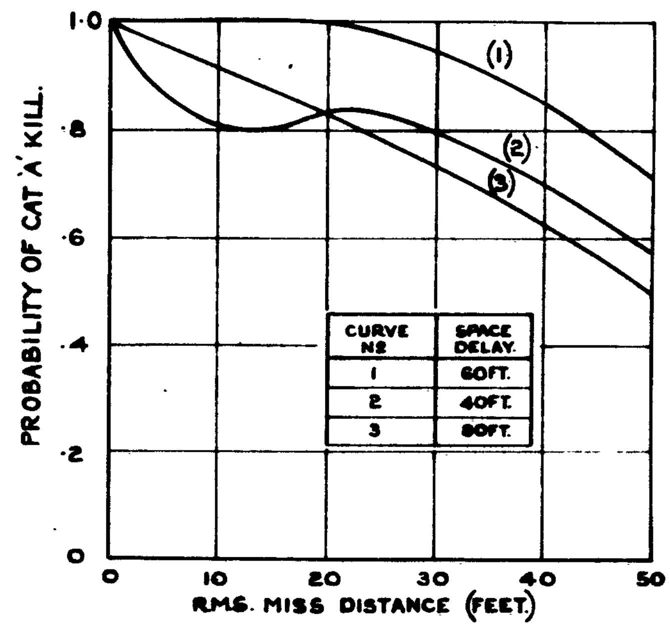


(a) DIRECTION OF ATTACK: 45° OFF AHEAD
45° BELOW.



(b) DIRECTION OF ATTACK: 45° OFF AHEAD, ABEAM.

FIG. 1(a & b) DEPENDENCE OF LETHALITY OF CONTINUOUS ROD ON FUZE DELAY & DIRECTION OF ATTACK, ASSUMING IDEAL FUZE PERFORMANCE.

BLANK SIZE 8" x 13"
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CURVE Nº	DIRECTION OF ATTACK	FUZE SPACE DELAY	R.M.S. FUZE ERROR (σ_f)
1	45° OFF AHEAD, 45° BELOW.	40FT.	20FT.
2	45° OFF AHEAD, ABEAM.	40FT.	20FT.
3	45° OFF AHEAD, ABEAM.	60FT.	30FT.
4	45° OFF AHEAD, 45° BELOW.	60FT.	30FT.

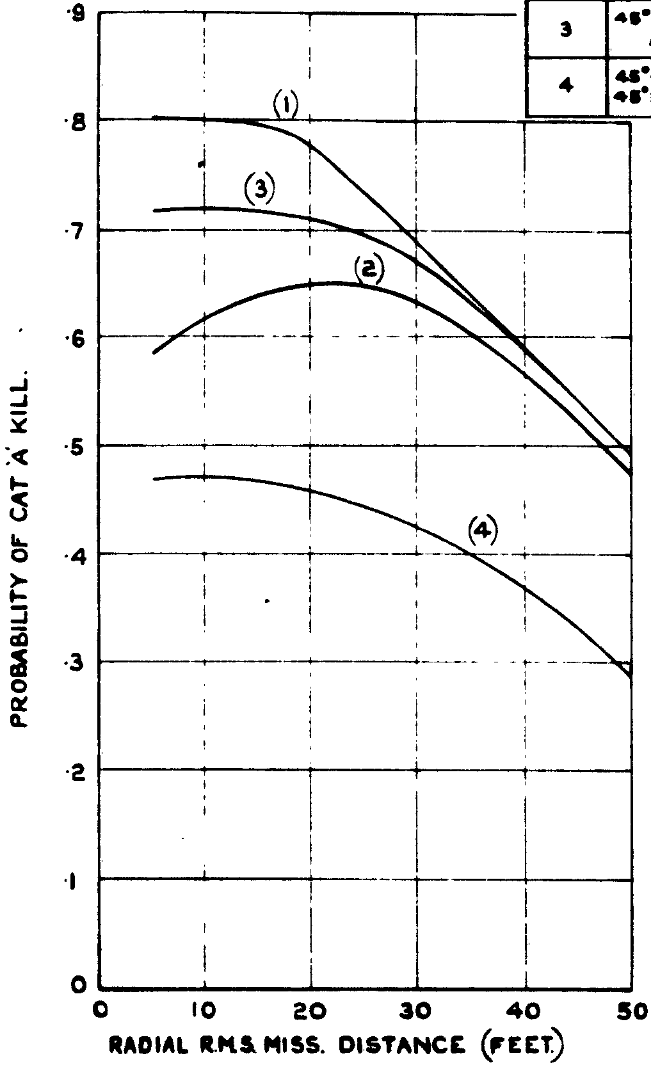

FIG. 2. VARIATION OF LETHALITY OF CONTINUOUS ROD WITH DIRECTION OF ATTACK FOR OPTIMISED SPACE DELAY AND VARIABLE FUZE PERFORMANCE. CURVES Nº 3 & 4 ARE ALSO GIVEN SHOWING EFFECT OF USING A NON-OPTIMUM SPACE DELAY.

BLANK SIZE 8 x 13
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FIG. 3.

CURVE Nº	WARHEAD TYPE.	DIRECTION OF ATTACK.	FUZE SPACE DELAY.	FUZE ERROR (ϵ_f)
1	CONTINUOUS ROD	45° OFF AHEAD 45° BELOW.	40 FT.*	20 FT.
2	EXTERNAL BLAST.	45° OFF AHEAD 45° BELOW.	75 FT.	20 FT.
3	FRAGMENTING WARHEAD, (INCLUDING BLAST EFFECT AND DIRECT HITS)	45° OFF AHEAD 45° BELOW.	75 FT.	20 FT.

* THIS IS THE OPTIMUM SPACE DELAY FOR THIS DIRECTION OF ATTACK.

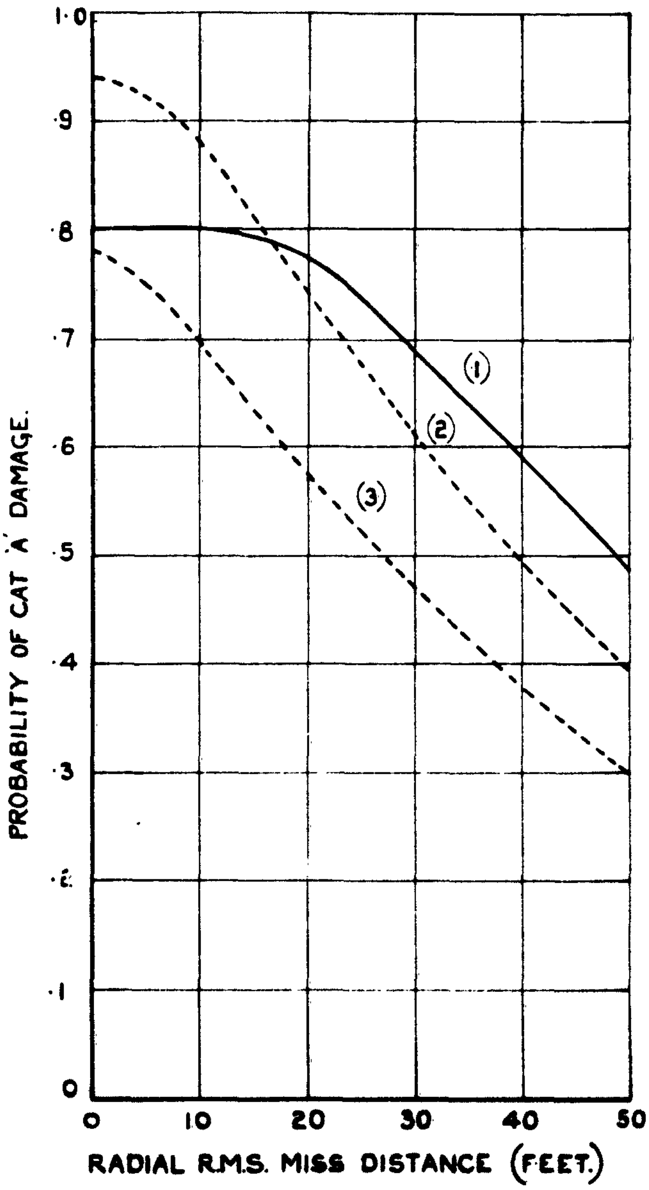

FIG. 3. THE LETHALITY OF THE CONTINUOUS ROD, COMPARED WITH A PURE EXTERNAL BLAST WARHEAD & A FRAGMENTING WARHEAD.

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