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In studying the various firing techniques or strategies that might be used in operating conventional antiaircraft weapons, several strategies might be enumerated. One of the more commonly used is the constant lead firing technique. This report presents an evaluation of the effectiveness of the constant lead technique on the basis of the weapon speed ring characteristics of the M-18 Reflex sight mounted on the quad .50 caliber M-55 weapon, assuming optimum tracking performance.

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Staff Paper

EVALUATION OF THE DURATION OF FLY THROUGH OBTAINED WHEN TRACKING WITH THE SPEED RING SIGHT ON THE M-55 WEAPON

by

Albert L. Kubala

and

Harold E. Christensen

DECEMBER 1968

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HumRRO Division No. 5 (Air Defense)

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PREFACE

The data presented in the paper were collected in connection with research being conducted under HumRRO Work Unit SKYFIRE.

In studying the various firing techniques or strategies which might be employed in the operation of conventional anti-aircraft weapons, several strategies might be enumerated. One of the more commonly used is the constant lead firing technique. This report presents an evaluation of the effectiveness of the constant lead technique on the basis of the weapon speed ring characteristics of the M-18 Reflex sight mounted on the quad .50 caliber M-55 weapon, assuming optimum tracking performance.

INTRODUCTION

Obtaining hits with an anti-aircraft gun is primarily a function of tracking accuracy, proper elevation adjustment of the sight, and choice of proper lead angle. This report is concerned with examining one method which has been used to solve the problem of determining proper lead angle--the speed ring sight. The M-18 reflex sight projects a reticle image upon an inclined glass plate. As the gunner looks through the inclined plate he sees the target and the reticle image. The reticle image contains four concentric circles termed the 100, 200, 300 and 400 miles per hour speed rings. Figure 1 represents a target as it might be viewed through the reticle. The speed rings have been labeled in the figure for clarity. The rings are not labeled on the sight itself. When only azimuth is being considered, the center line of sight is equal to the bore sight (center of sight) of the weapon. The angle between the center line of sight and the line of sight through any speed ring is always a constant value.

The purpose of the speed ring is, of course, to determine the amount of lead angle necessary to compensate for the differences between the time of flight of both target and round so that the rounds fired will have an optimum chance of hitting the target. Unfortunately, no constant lead angle can be optimum at all points along the target's path. As the target approaches crossover, for example, the angular velocity of the target, relative to the gun position, increases. Stated another way, as the target approaches crossover, it travels a continually decreasing amount of actual distance when passing through a given angular distance relative to the weapon. In practice, as a target is acquired, the gunner may select a certain fixed lead angle (speed ring). When he first begins to fire at the target, the lead angle selected may cause the fire to lead the target. Assuming the target continues at the same speed and direction, it should reach a point at which the lead angle selected will place the fire (theoretically, at least) right on the nose of the target. As the target continues, the predicted point of fire will follow down the target until it reaches the tail and eventually, as the target continues toward crossover (midpoint), the firing point may lag the target. This same process is essentially repeated in reverse as the gunner continues to track the target after crossover. Thus, when the speed ring sight is used, the rounds fired would be predicted to hit the target during only a limited amount of the time in which the target can be tracked. This period, during which target hits would be predicted, is termed a "fly through". The term "adequate fly through" is used in this study to indicate a fly through which occurs within the effective range of the weapon.

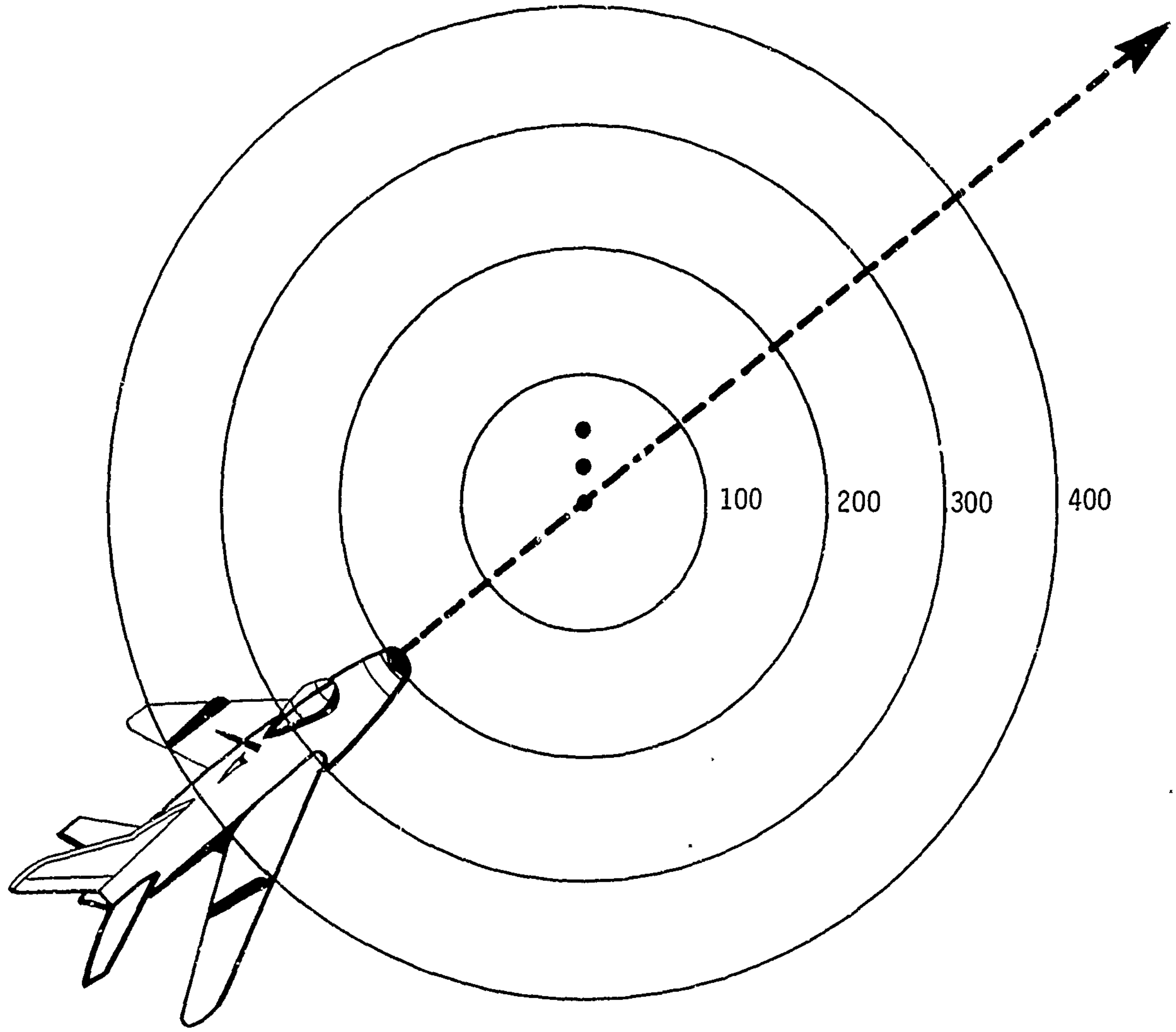

Figure 1. Schematic Representation of Target as Viewed Through Speed Ring Sight

If an inappropriate speed ring is selected, the lead angle may be either too large or too small, so that fire will lead or lag the target at all times and no fly through will be obtained. Target speed obviously has a very great effect on the selection of an optimum speed ring. However, since range of target, as well as speed, affects the lead angle required, it cannot be categorically stated that an aircraft travelling at a given speed should always be tracked using the same speed ring.

On the M-18 sight, the miles per hour values of the speed rings are not to be interpreted directly. Firing doctrine states that targets should be tracked with a speed ring equal to 3/4 of the target speed.[1] There is, however, some question as to whether an adequate fly through can be obtained at all ranges following this doctrine.

The question as to how much latitude is allowable in the estimation of target speed also further complicates the firing problem. If, for example, there are some situations in which only a relatively small error in target speed estimation would result in not obtaining a fly through, this would impose serious limitations.

To evaluate effectiveness of a speed ring sight, it was considered necessary to compute the location on the target path where fly through would occur under various conditions of crossover range, target speed, and choice of speed ring. Three questions were of primary concern: (1) Under what conditions will fly through be obtained? (2) What is the duration of fly through? (3) Where along the tracking course, with respect to crossover, does the fly through occur?

METHOD

The kind of information needed was obtained by plotting the angular distance at which a fly through will occur under various combinations of target speeds, crossover ranges and speed rings.

Conditions of fly through were predicted by the formula

$$R(\text{Tan}\ \phi - \text{Tan}\ \theta) = V_t(T_R)$$

[1] Department of the Army, Field Manual 44-57, Service of the Piece - Multiple Caliber .50 Machine Gun, 7 September 1951, p. 100.

where R = Crossover range.

ϕ = angle between crossover and line of sight using the chosen speed ring (when tracking the nose of the target).

Θ = angle between crossover and bore sight (center of sight).

V_t = velocity of target.

T_R = time required for round fired to reach predicted intercept.

The first half of the equation--$R(\text{Tan } \phi - \text{Tan } \Theta)$--represents the distance which the target must travel from fire to intercept as determined by the lead angle of the speed ring sight. The second half of the equation--$V_t(T_R)$--represents the distance which the target will travel based on target speed and weapon ballistic data. Using assumed values of target speed, crossover range and speed ring, the value for angle Θ was obtained. The value of Θ was used to determine the distance from crossover at which the fly through would be predicted to commence. To predict the end of the fly through, the quantity of 16 yds. (representing the target length) was added to the product on the left side of the equation. The value 16 yds. is, of course, arbitrary and is not intended to imply any actual aircraft length. It should be noted that computations were based on tracking the nose of the target, while weapon doctrine advocates tracking center of mass. This was done because center of mass is not an easily measurable quantity, differing as it does from one aircraft type to another. Angular areas of fly through using center mass tracking will differ slightly from those reported in this study.

The angles between speed rings and the center line of sight were determined empirically by two different observers. The speed ring values used in this study were as follows:

Speed Ring	Angle from Center Line of Sight
100	3.655°
200	7.516°
300	11.920°
400	16.918°

Crossover ranges were selected (within the effective range of the weapon) and fly through paths computed for a sample of speed ring-target speed combinations.

RESULTS

Figure 2 presents an example of three tracking plots using the 300 speed ring to track targets at a crossover range of 500 meters. Assuming perfect tracking, the figure shows where rounds fired at various angular distances prior to crossover would be predicted to lead, lag, or hit the target. For instance, assume a weapon is tracking a 404 mph target at this range with the 300 speed ring; at 25° before crossover the round would be predicted to lead the target by approximately 9-1/2 meters, at 20° the round should just hit the nose of the target, at crossover (0°) the round should hit the tail of the target. (The target was assumed to be 16 meters long in computations.) Again, using the same speed ring to track a 624 mph target flying at the same range, a round fired at 43° prior to crossover would be predicted to lag the nose of the target by approximately 27 meters. It can be noted that if a target slower than 355 mph were tracked, using this speed ring, the fire would always lead the target. If targets at speeds greater than 624 mph are tracked, the range to the aircraft at the time of fly through will be beyond weapon effective range. The three tracking plots in Figure 2 (355 mph, 404 mph, and 624 mph) illustrate respectively, a minimum, optimum, and maximum target speed. The minimum speed for fly through was defined here as the slowest target speed (at a given crossover range) at which the speed ring used will obtain a hit. Under this condition, the projectiles would be predicted to just hit the nose of the target at crossover (assuming perfect tracking). The optimum speed for fly through was defined as that target speed which yields a complete fly through surrounding crossover. This is the longest fly through obtainable in terms of both time duration and angular distance. The maximum speed for fly through was the maximum target speed at which a fly through can be obtained within the weapon's effective range which, for the computations performed, was assumed to be 800 meters. Figure 2 illustrates the minimum, optimum, and maximum target speeds for obtaining fly through under only one set of range-speed ring conditions. Since variation in range of target had an effect on fly through, it was felt that fly through data should be examined across several target crossover ranges.

Minimum, optimum, and maximum target speeds for obtaining fly through at several target ranges are presented in Table 1. In Figures 3, 4, and 5, the minimum and maximum target speeds which

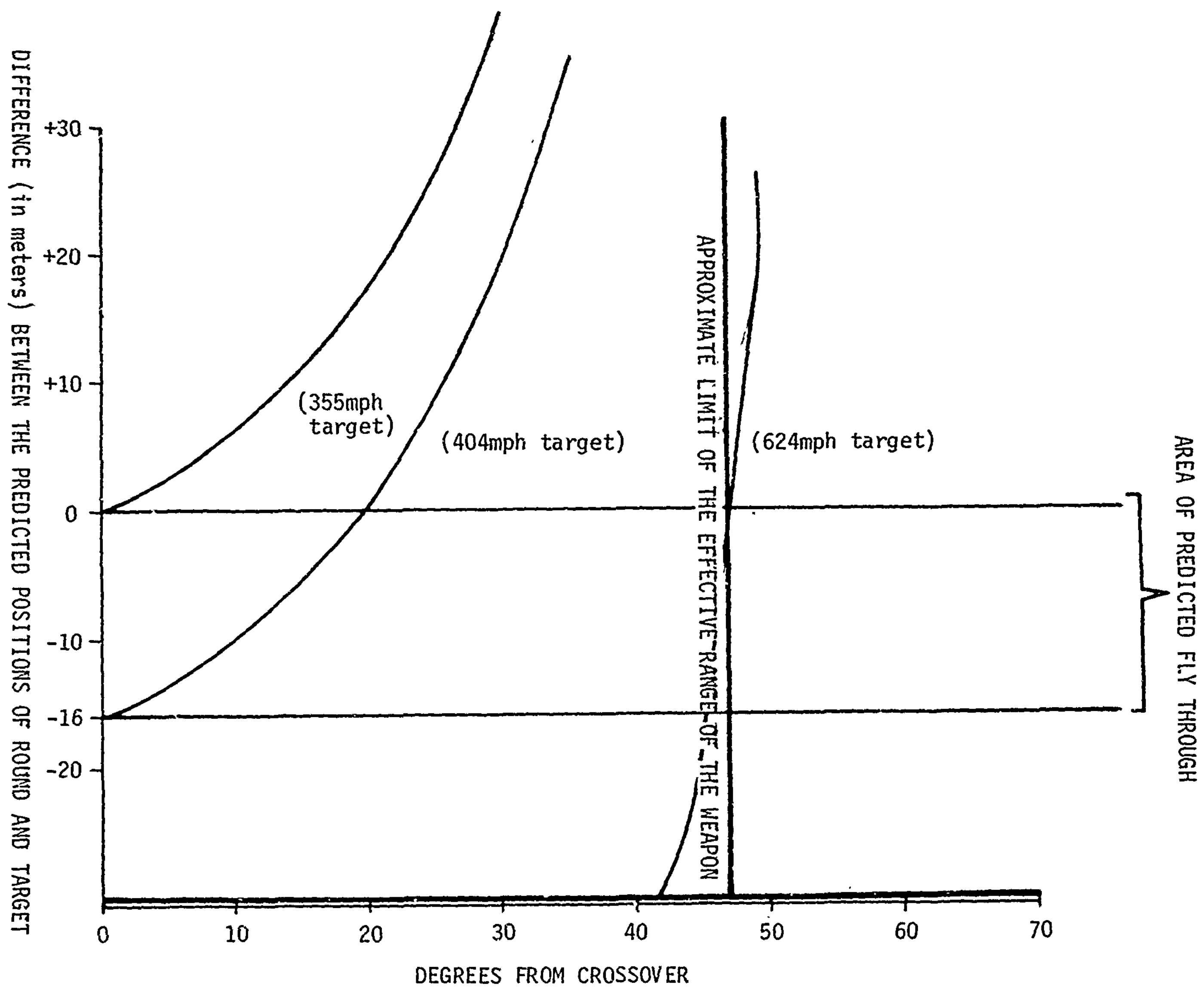

Figure 2. Predicted Fly Through at 500 Meter Crossover Range When Using the 300 Speed Ring to Track Targets of Various Speeds.

TABLE 1

Characteristics of Fly Through
as Determined by
Range and Aircraft Speeds

Crossing Range and Speed Ring	Minimum Target Speed	Optimum Target Speed	Maximum Target Speed Which Allows a Fly Through Within an 800 yd Slant Range
700M - 2	209 mph	242 mph[a]	226 mph
3	334 mph	368 mph	371 mph
4	482 mph	515 mph	551 mph
500M - 2	222 mph	271 mph	358 mph
3	355 mph	404 mph	624 mph
4	511 mph	560 mph	1041 mph
300M - 2	235 mph	322 mph	716 mph
3	376 mph	463 mph	1525 mph
4	542 mph	629 mph	3537 mph
200M - 2	243 mph	378 mph	1373 mph
3	390 mph	541 mph	3500 +mph
4	561 mph	697 mph	3500 +mph
100M - 2	245 mph	517 mph	3500 +mph
3	393 mph	665 mph	3500 +mph
4	566 mph	838 mph	3500 +mph

[a] Computed optimum target speed produces a fly through which is beyond effective range of the weapon.

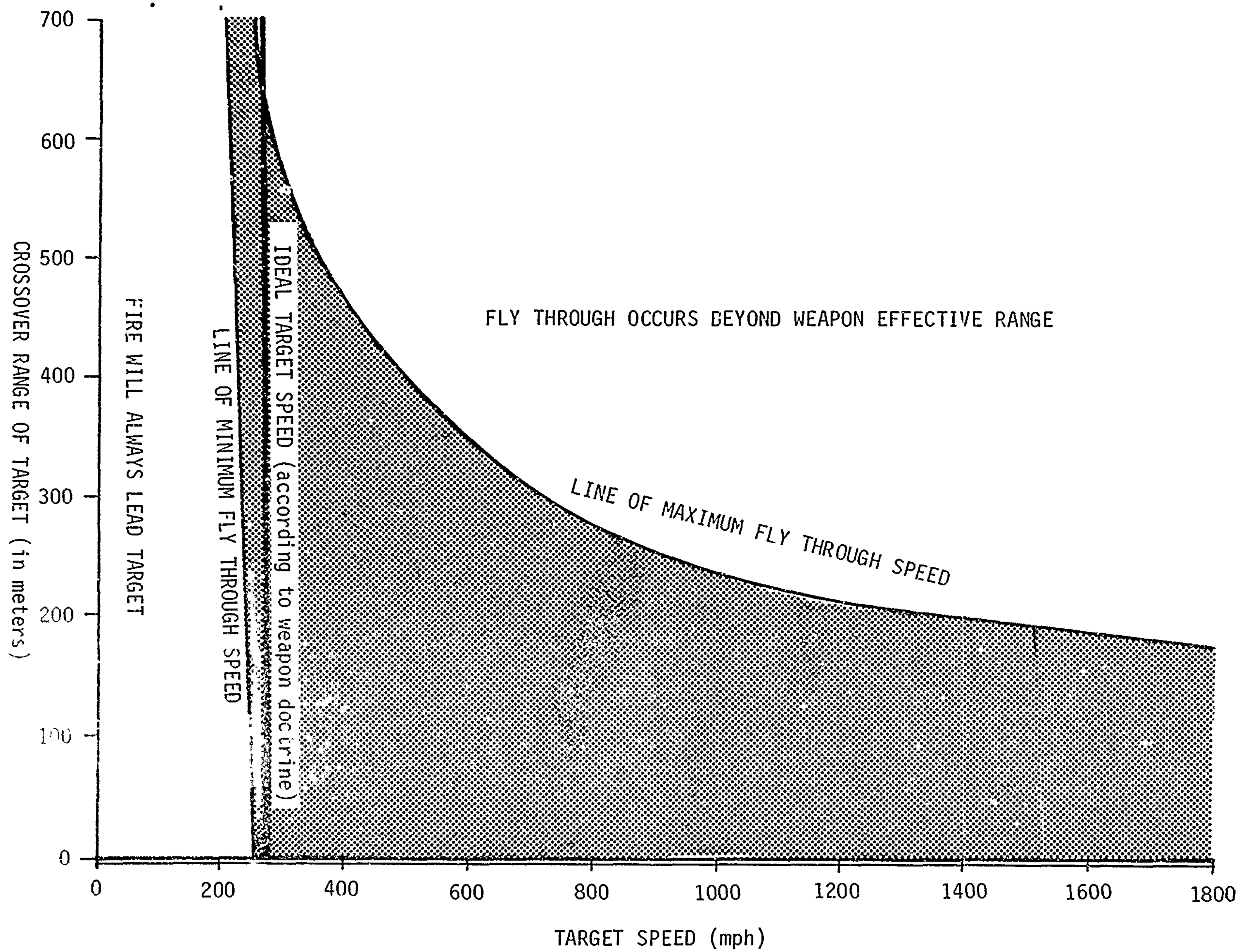

Figure 3. Minimum, Optimum, and Maximum Target Speeds Which Can Produce a Fly Through on the 200 Speed Ring as a Function of Target Range.

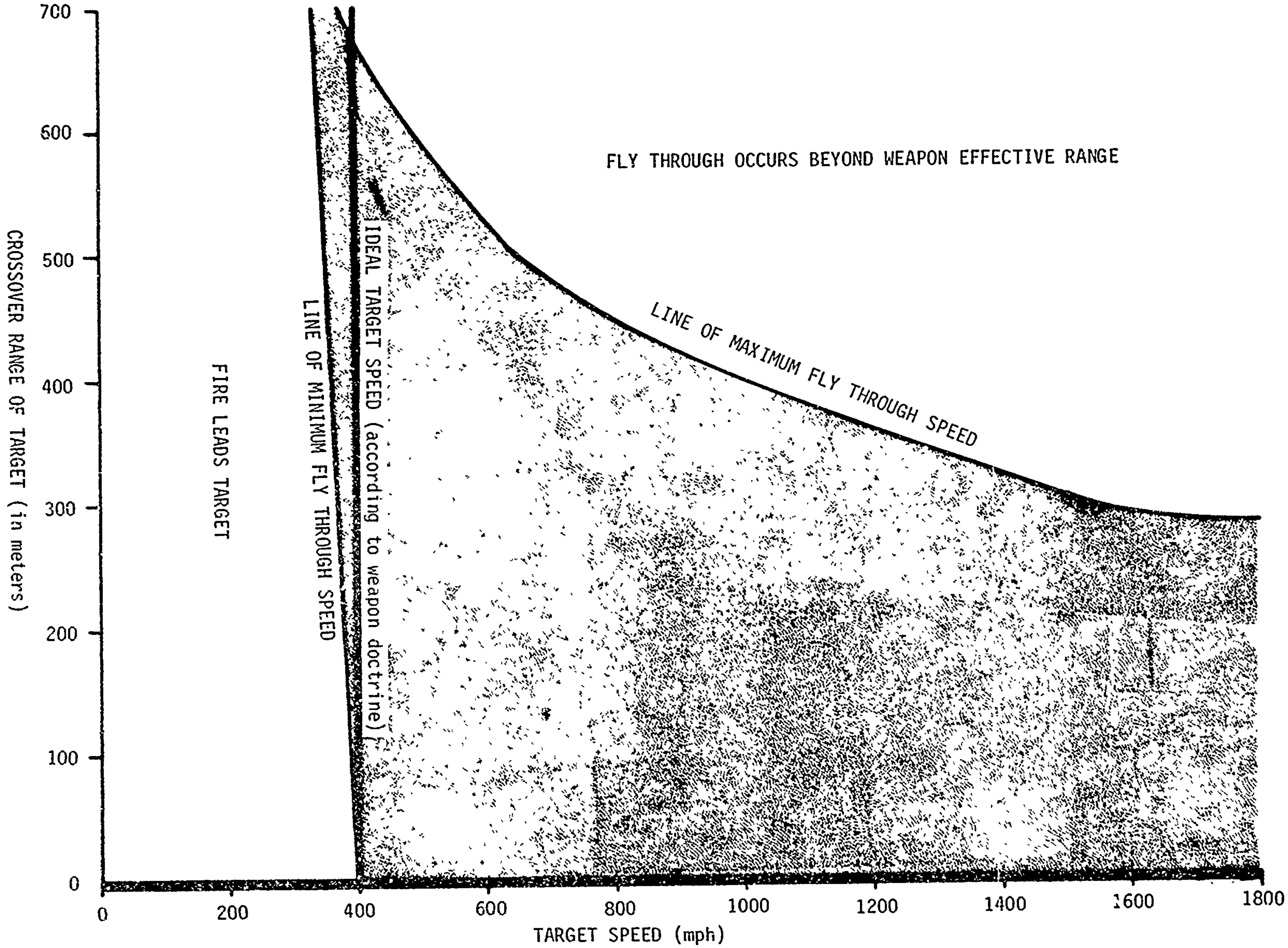

Figure 4. Minimum, Optimum, and Maximum Target Speeds Which Can Produce a Fly Through on the 300 Speed Ring as a Function of Target Range.

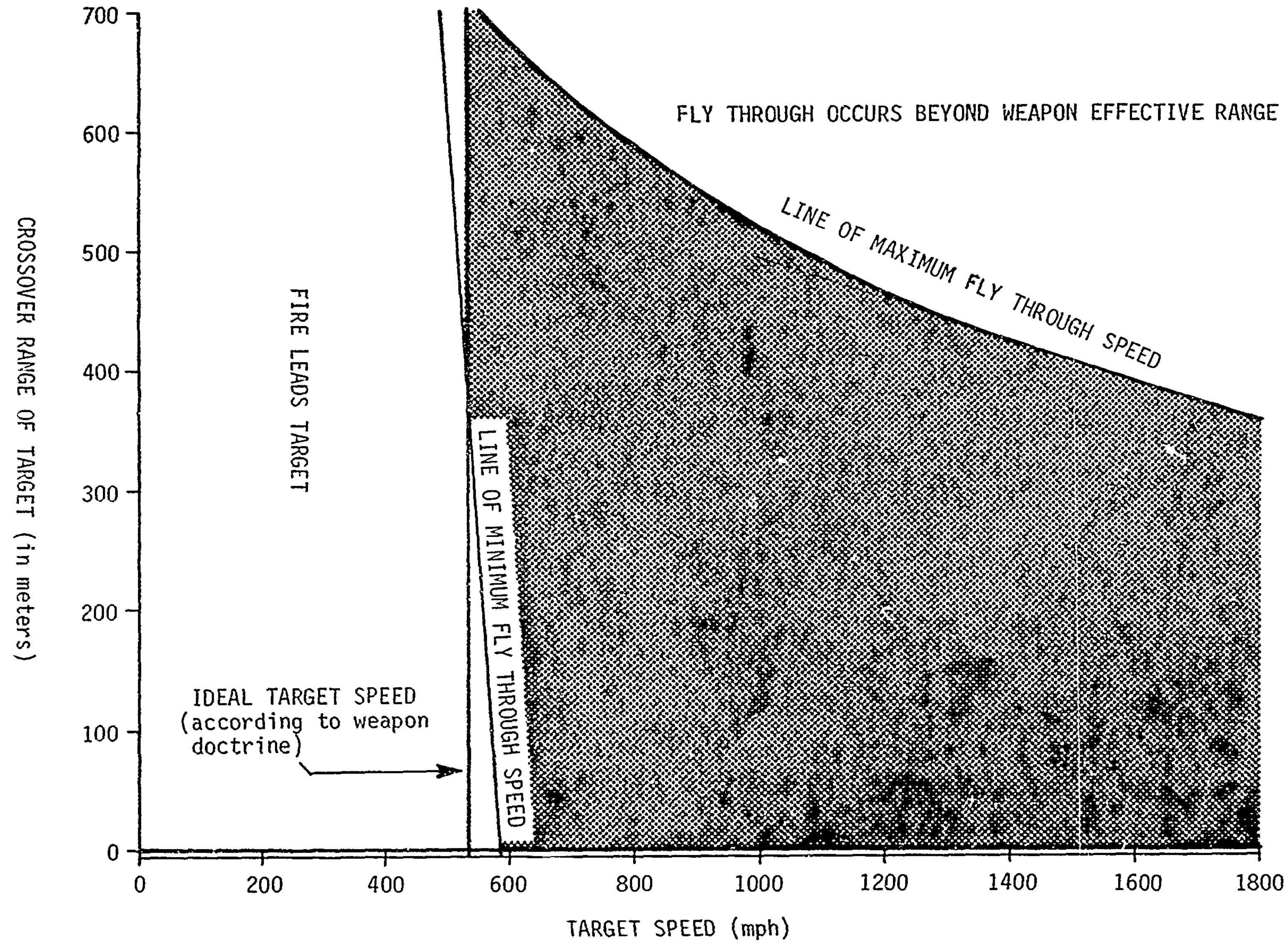

Figure 5. Minimum, Optimum, and Maximum Target Speeds Which Can Produce a Fly Through on the 400 Speed Ring as a Function of Target Range.

are predicted to produce a fly through are plotted as a function of target crossover range. These three figures present the information separately for the 200, 300, and 400 speed rings.

An examination of Figure 3, for example, will indicate that if the 200 speed ring is selected for tracking a target which is travelling at 300 mph, an adequate fly through will occur at the closer midpoint ranges. However, if the target is beyond 600 meters at crossover, the fly through will occur during a portion of the targets path which is beyond effective range. In Figure 5, it should be noted that, if the 400 speed ring is selected for tracking a target travelling at 500 mph (an apparently reasonable choice), no fly through would be predicted to occur.

During an actual engagement of a target by the weapon a situation exists in which the gunner is required to select a speed ring based on his estimation of target speed. Figure 6 presents such a situation to allow comparison of the results obtained from the various speed ring choices which might be made. The target represented in Figure 6 is travelling at 460 mph with a midpoint range of 500 meters from the weapon's position. The figure illustrates the results which would be predicted for each of three possible speed ring choices. If the 400 speed ring is chosen for tracking, no fly through would be predicted to occur. Predicted fire would always lead the target by at least 16 meters. If the 300 speed ring is selected, a fly through would be predicted to occur between 31° and 22° before crossover. If the 200 speed ring is selected, a fly through should occur between 58° and 56° before crossover. However, this would place the fly through at approximately 1000 meters, which is beyond the effective range limit assumed in this study. At the 1000 meter range, while target hits would certainly be possible, the likelihood of hits would be substantially reduced.

It should be noted that all computations were made using only the portion of the target path prior to crossover. A comparable fly through pattern will also occur after crossover, but the angle and duration will not be precisely the same as for the fly through which occurred before crossover.

DISCUSSION

The information derived is summarized as follows:

1. Under what conditions will no fly through be obtained?

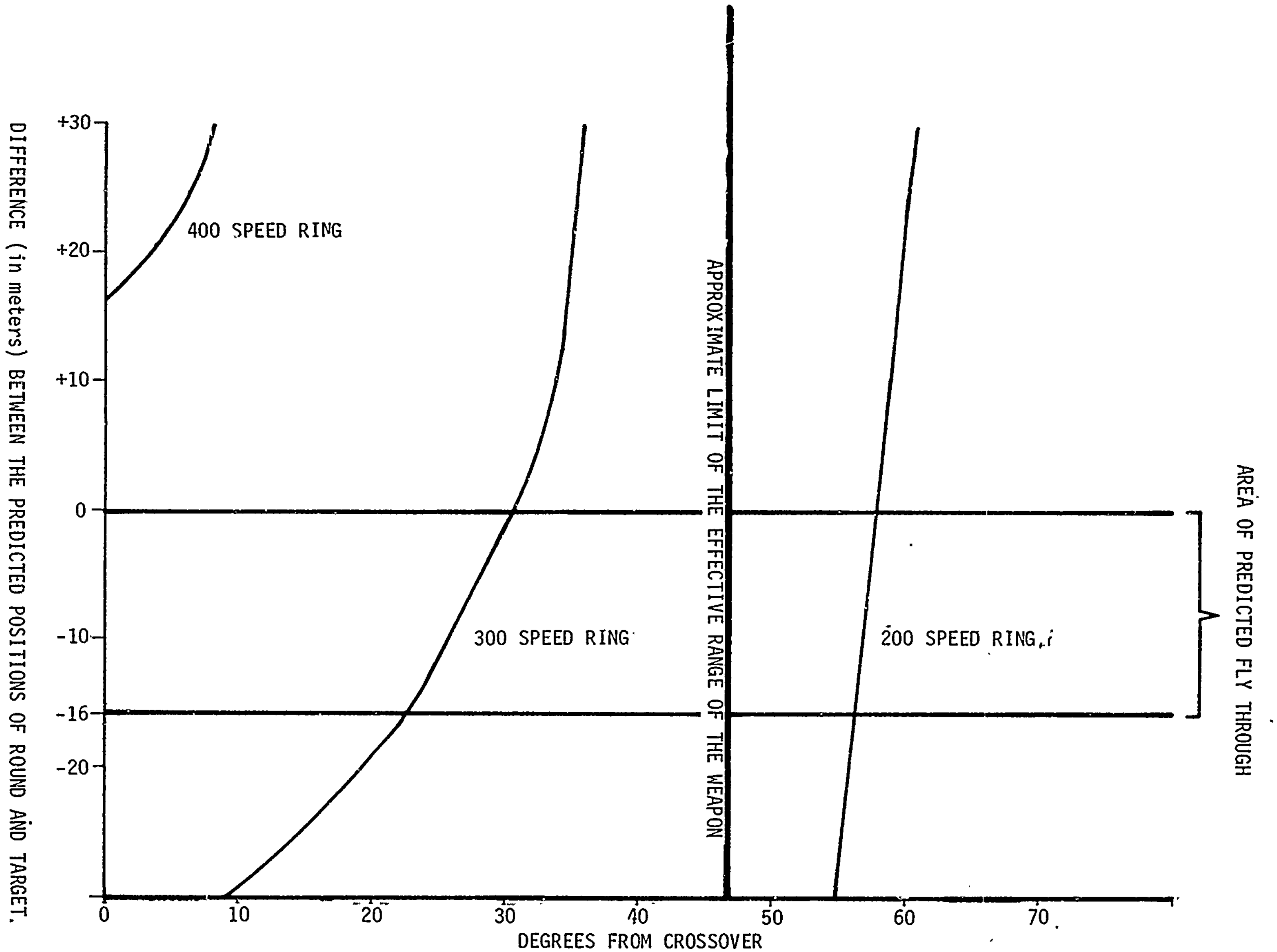

Figure 6. Predicted Results in Tracking a 460mph Target With the 200, 300, and 400 Speed Rings.

a. No fly through will result when target speed is too slow for the speed ring selected. From observing the line of minimum fly through speed in Figures 3, 4, and 5, it can be seen that the minimum target speed to obtain fly through appears to be linearly related to range. Although there is some variation at different ranges, roughly speaking, fly through will not be obtained if speed rings are used for targets slower than the following:

Speed Ring	Minimum Target Speed	Recommended Speed[2]
200	215 mph	(267 mph)
300	370 mph	(400 mph)
400	530 mph	(533 mph)

b. At the opposite extreme, in which target speed is too fast for the speed ring selected, there is no sharp cutoff point at which the fly through will not occur. The limiting factor is generally the slant range to the target during fly through. Thus, high speed targets at greater crossover range are likely to be beyond effective range when fly through occurs. As target speed increases, the fly through will occur further away from crossover; thus, underestimating target speed will be a problem primarily with high speed targets flying at the more distant crossover ranges, while overestimating target speed may be a critical error at all ranges. Since "recommended" ideal tracking speeds (shown in parenthesis above) are quite close to the minimum speeds, slight overestimation of target speed may cause the selection of a speed ring which will obtain no fly through. In fact, if one uses the fourth speed ring according to weapon doctrine, no fly through would be obtained at the crossover ranges closer than 400 meters (see Figure 5).

2. What is the duration of fly through?

[2] Recommended speed figures are based on the weapon doctrine that a speed ring equal to 3/4 of estimated target speed should be used.

It was found that both the angular distance and the time duration of fly through decreased as the distance from crossover at fly through increased. Fly through duration was also found to increase as crossover range decreased.

3. Where does the fly through occur?

In terms of angular distance from crossover, using a given speed ring, distance at fly through will increase as target speed increases. Distance of the fly through from crossover also increases slightly as crossover range increases.

SUMMARY

1. Speculation on the adequacy of the weapon doctrine for choosing the proper speed ring.

As implied under 1 b. of the discussion section, the weapon doctrine may be instrumental in causing speed ring selection errors. When doctrine was followed, the speed rings selected produced, in most cases, minimal fly through, and under some conditions no fly through at all. Based on the data in Table 1, this "recommended" procedure for choosing speed ring will produce a near ideal selection at somewhere between 500 and 600 meter crossover ranges. This doctrine is also very adequate for all ranges greater than 500 meters. With ranges closer than 500 meters, however, the procedure produces extremely inadequate speed ring selection. The vertical lines representing "recommended" choices were inserted in Figures 3, 4, and 5 so that this problem could be seen graphically. One factor of potential significance is that when the gunner overestimates the target speed (chooses too high a speed ring) there is virtually no margin for error and it becomes very likely that no fly through will be obtained. On the other hand, there appears to be a good deal of latitude in underestimating (choosing too low a speed ring). This must be viewed with some concern, especially since it may be humanly impossible for observers to avoid making these critical overestimates of target speed.

2. Difficulties involved in the use of the speed ring method to estimate lead angle.

The findings suggest that at least two general problems exist in using the speed ring sight. First, since an inter-action between target speed and target range affects selection of the proper speed ring, it may not be possible to formulate a rule for speed ring selection which is simple enough to be usable, yet at the same time comprehensive enough to apply to the wide variety of potential engagement conditions. Second, the predicted duration of fly through will be relatively small under most conditions, and the gunner will have no way of knowing where along the target path the predicted fly through is supposed to occur. The gunner will not be able to coordinate his tracking and firing with the fly through pattern which controls his hit probability. A consideration of the problems involved in using the speed ring sight would suggest that alternative methods of adjusting lead angle should be sought and implemented whenever possible.