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THE EFFECT OF TRIM-LIMIT CONVERSION MANOEUVRES ON THE TERMINAL PHASE CAPABILITIES OF THE ARROW WHEN OPERATING AGAINST EQUAL SPEED TARGETS

J. COHEN

MARCH 1958

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THE EFFECT OF TRIM-LIMIT CONVERSION MANOEUVRES ON THE TERMINAL PHASE CAPABILITIES OF THE ARROW WHEN OPERATING AGAINST EQUAL SPEED TARGETS.

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REPORT No.	72/TACTICS/7
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AIRCRAFT:		PREPARED BY	DATE
	The effect of Trim-Limit conversion manoeuvres on the Terminal Phase Capabilities of the Arrow When operating against equal speed targets.	J. Cohen	Mar. 1958
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INTRODUCTION

A brief study has been made to examine the effect of maximum "g" steering on the interception capabilities of the Arrow aircraft, carrying Sparrow 2 missiles. For the purpose of the study it was assumed that the aircraft would be steered manually and that trim-limit g, corresponding to maximum elevator deflection, would be applied to correct any off-course error. A range of co-altitude attacks at 90° and 180° initial course difference was studied, the target in all cases making a 1.8 g turn at constant speed, away from the interceptor. Both lead-pursuit and modified lead-collision trajectories were determined, and in all attacks both target and initial interceptor speeds were M = 2.0. The change in interceptor speed was calculated as a function of the applied normal acceleration along the flight path.

Does this agree with our target + information of our interceptors?

The results of the study indicate the undesirability of over-rapid correction of steering errors early in the interception. This is particularly true in the lead collision mode, where the large lead angles demanded result in sustained periods of flight at high g, loss of speed and consequent increase in the lead angle required. In some cases it was found that the lead angle demanded exceeds the look angle limitation of the A.I. radar and a 70° maximum lead angle was therefore imposed. The end result in most of the cases considered is that the interceptor is unable to follow the target as it continues its evasive manoeuvre and falls away behind the tail of the target before reaching the firing zone.

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[illegible]

1

It is evident that the combination of high target speed and evasive manoeuvre considered represent severe interception conditions. If more reasonable values were taken for these parameters it is expected that a considerably higher proportion of successful attacks would be obtained. However, it is probable that in other respects qualitatively similar results would be found.

INTERCEPTOR-TARGET GEOMETRY

It has been assumed for this study that A.I. lock-on occurs five seconds after detection and that at this time both target and interceptor begin to manoeuvre. Initial studies showed that if the full A.I. range capability were used, the attack rapidly became completely hopeless, the target having ample time in which to evade successfully. For this reason an artificial A.I. detection contour was assumed, the size of this contour being such that, at any aspect angle, the time-to-go for an interceptor flying an ideal lead-collision course is 40 seconds. Fig. 1 shows the form of this contour and the initial geometry of the various attacks that have been examined.

MODIFIED LEAD-COLLISION COURSE

Expressed in terms of the geometry of the attack, the usual equation of a lead collision course is;

$$\sin A^* = \frac{V_T}{V_I + F/T} \sin a$$

where A^* = ideal lead angle

a = aspect angle

V_I = interceptor speed

V_T = target speed

F = missile travel relative to interceptor

T = time-to-go to missile-target collision

It is clear that if the interceptor speed is reduced a larger lead angle will be demanded. To compensate for this, an extra term has been added to the equation to account for the re-acceleration that would ensue if the interceptor flew straight from its present position. Based on the assumption that the interceptor immediately accelerates at constant rate from its present speed to the original combat speed, after which it continues to fly straight at constant speed until missile release, the revised form of the equation is easily shown to be:

$$\sin A^* = \frac{V_T}{V_o + F/T - \frac{(V_o - V_I)^2}{2 f T}} \sin a$$

where V_o = desired combat speed

f = average acceleration.

For all the calculations of this report, an altitude of 50,000 ft. was considered, V_o = 1937 ft/sec. (M = 2.0), and f was taken to be 3 ft/sec^2.

The lead-pursuit trajectories were all based on the usual form of the lead pursuit equation.

RESULTS AND CONCLUSIONS

Figs. 2 through 9 show the interceptor and target flight paths that result from the initial geometries of fig. 1, for both lead collision and lead pursuit modes. In each case the final interceptor velocity, at the end of the calculated path, is shown.

It is seen from the trajectories that lead pursuit steering in general results in a more direct approach to the target than lead collision. Although, as may be seen by reference to table I, there is little to choose between the two modes in terms of attacks which are actually successful, it is obvious that in the cases where both modes fail, lead pursuit comes considerably closer to success than lead collision. The reason for this lies in the smaller lead angle required when following a lead pursuit course, the effect being that the interceptor is better placed when it reverses the direction of turn as the target continues to evade.

In view of the somewhat unrealistic assumptions that have been made for this study it would be dangerous to draw any conclusions concerning the relative merits of lead collision and lead pursuit modes. Other studies (e.g. ref. 1) have shown that when the interceptor has a small speed advantage it has no difficulty in attacking a manoeuvring target in lead collision mode under AFCS coupled steering. Although no comparable work has been done for lead pursuit, there is no reason to suppose that it would show any marked superiority in this case.

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It is clear howevever, that the use of maximum interceptor performance to correct heading errors early in an attack is undesirable. Fig. 10 shows ideal lead angle as a function of aspect angle for the case of $M_I = M_T = 2.0$, altitude = 50,000 ft. Curves are given for lead pursuit and for lead collision with various times to go. It is seen that as the target manoeuvres the lead angle required for either mode increases, a maximum being reached at 90° aspect angle. If the target continues to manoeuvre the ideal lead angle then decreases. If the interceptor attempts to fly on the ideal course at all times, it is forced to reverse its direction of manoeuvre several times during the attack. The resultant lengthening of its path causes it to fall behind the target and reduces the probability of a successful attack being achieved. Fig. 10 shows that for time-to-go greater than 7 seconds, $\frac{dA^*}{da}$ is always numerically greater for L.C. than for L.P. at equal aspect angles. This means that if the target manoeuvres throughout the interception, the L.C. trajectory may be expected to be more curved than the L.P., and the fall-back effect to be more marked. This is shown up clearly on figs. 2 through 9.

The smoothing of the interceptor path necessary to improve the probability of successful attack is achieved in automatic F.C. operation by suitable choice of the A.F.C.S. coupler gains. However, in the manual mode it rests with the pilot to ensure that coarse steering is not used when the time to go is large. Although it is expected that experienced pilots would filter their steering in this way instinctively, it becomes a matter of considerable importance in an aircraft such as the Arrow, where the reserves of power and manoeuvrability are large, and where A.I. detection may occur at very long range. It is hoped that further studies will enable optimum handling techniques to be defined.

Ref. 1. A preliminary study of the effect of the steering loop gains on the interception capabilities of the Arrow/Sparrow 2 weapon system. Technical design report 72/TACTICS/5, March 1958

CASE	LEAD COLLISION	LEAD PURSUIT
A	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Unsuccessful $\dot{R} \rightarrow 0$, $R > R_{max}$
B	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Unsuccessful $\dot{R} \rightarrow 0$, $R > R_{max}$
C	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Unsuccessful $\dot{R} \rightarrow 0$, $R > R_{max}$
D	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Unsuccessful $\dot{R} \rightarrow 0$, $R > R_{max}$
P	Successful $R < R_{max}$, $\delta < \delta_{max}$	Successful $R < R_{max}$, $\delta < \delta_{max}$
Q	Successful $R < R_{max}$, $\delta < \delta_{max}$	Successful $R < R_{max}$, $\delta < \delta_{max}$
R	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Successful $R = R_{max}$, $\delta < \delta_{max}$
S	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$	Unsuccessful $\dot{R} \rightarrow +ve$, $R > R_{max}$

TABLE I
Analysis of the interceptions shown in Fig. 2 through 9.

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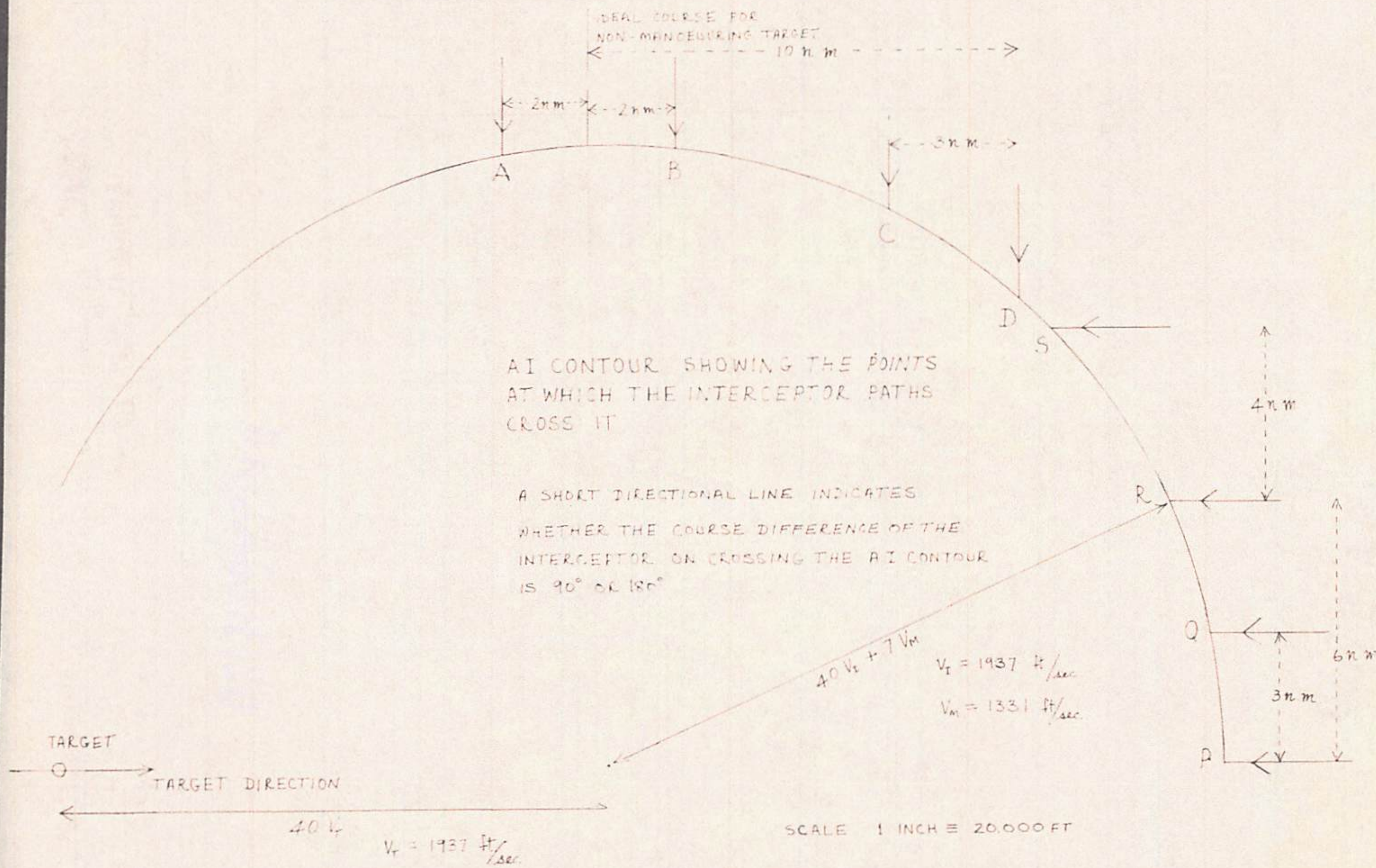

IDEAL COURSE FOR
NON-MANOEUVRING TARGET
10 n m
2 n m
2 n m
3 n m
A
B
C
D
S
R
Q
P
4 n m
6 n m
3 n m
AI CONTOUR SHOWING THE POINTS AT WHICH THE INTERCEPTOR PATHS CROSS IT
A SHORT DIRECTIONAL LINE INDICATES WHETHER THE COURSE DIFFERENCE OF THE INTERCEPTOR ON CROSSING THE AI CONTOUR IS 90° OR 180°
40 Vt + 7 Vm
Vt = 1937 ft/sec
Vm = 1331 ft/sec
TARGET
TARGET DIRECTION
40 Vt
Vt = 1937 ft/sec
SCALE 1 INCH ≡ 20,000 FT

FIG. 1

FIG. 2

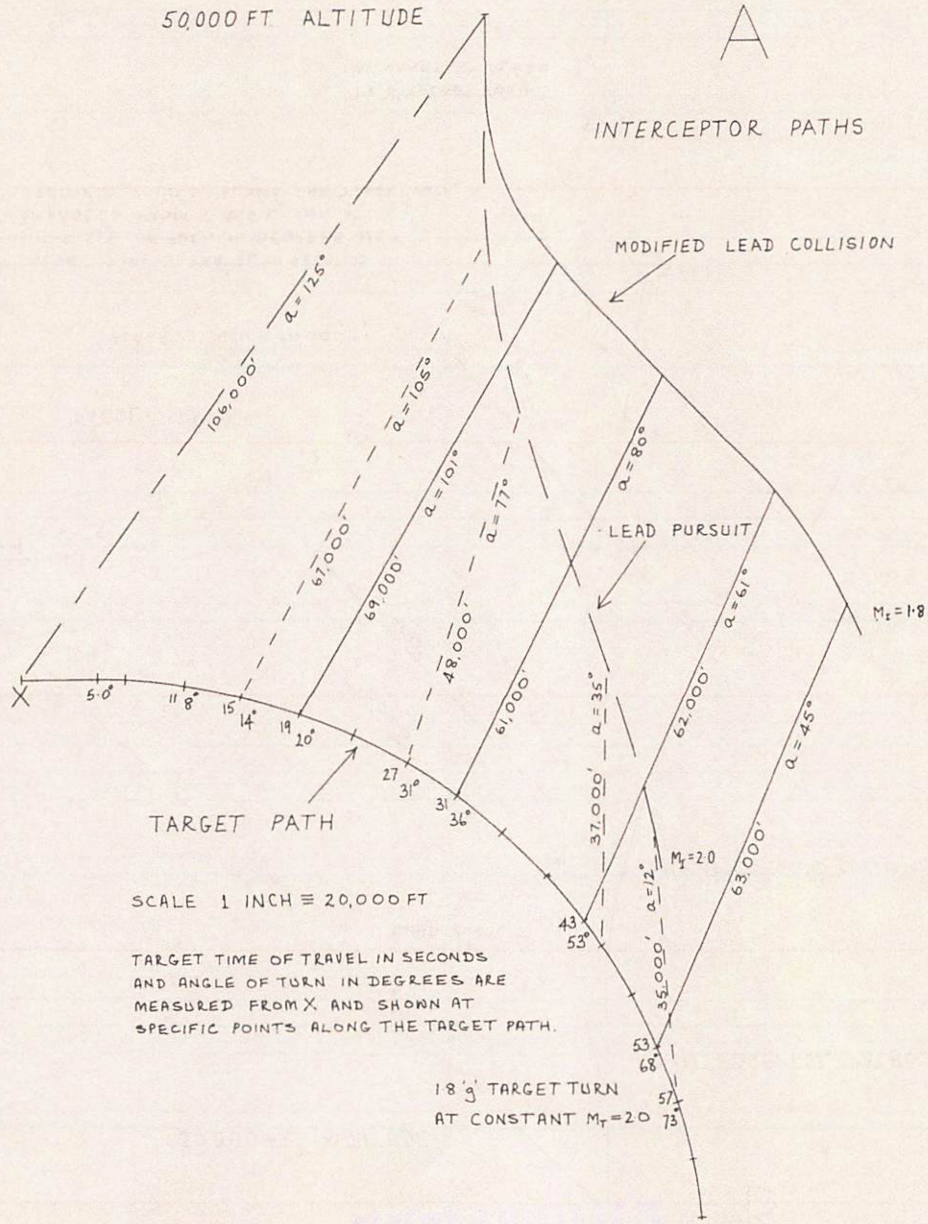

50,000 FT ALTITUDE
A
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
LEAD PURSUIT
a = 125°
106,000'
a = 105°
67,000'
a = 101°
69,000'
a = 77°
48,000'
61,000'
a = 80°
a = 35°
37,000'
a = 61°
62,000'
a = 12°
35,000'
a = 45°
63,000'
$M_I = 1.8$
$M_I = 2.0$
X
5.0°
11 8°
15 14°
19 20°
27 31°
31 36°
43 53°
53 68°
57 73°
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH.
1.8 'g' TARGET TURN AT CONSTANT $M_T = 2.0$

Fig. 3

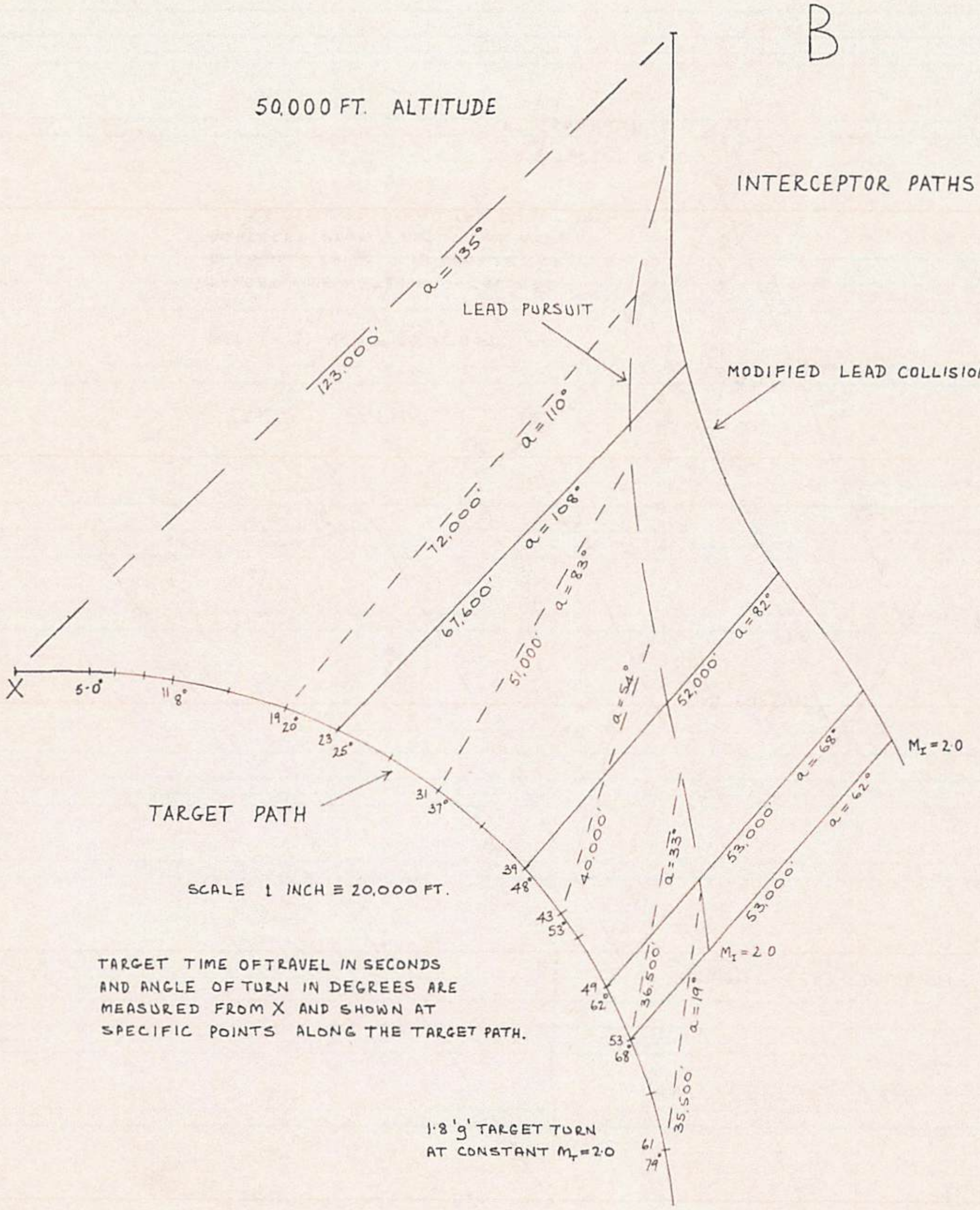

B
50,000 FT. ALTITUDE
INTERCEPTOR PATHS
LEAD PURSUIT
MODIFIED LEAD COLLISION
a = 135°
123,000'
a = 110°
72,000'
a = 108°
67,600'
a = 83°
51,000'
a = 54°
40,000'
a = 82°
52,000'
a = 68°
53,000'
a = 62°
53,000'
a = 33°
36,500'
a = 19°
35,500'
M = 2.0
M = 2.0
X
5-0°
11 8°
19 20°
23 25°
31 37°
39 48°
43 53°
49 62°
53 68°
61 79°
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT.
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH.
1.8 'g' TARGET TURN AT CONSTANT M = 2.0

FIG. 4

C

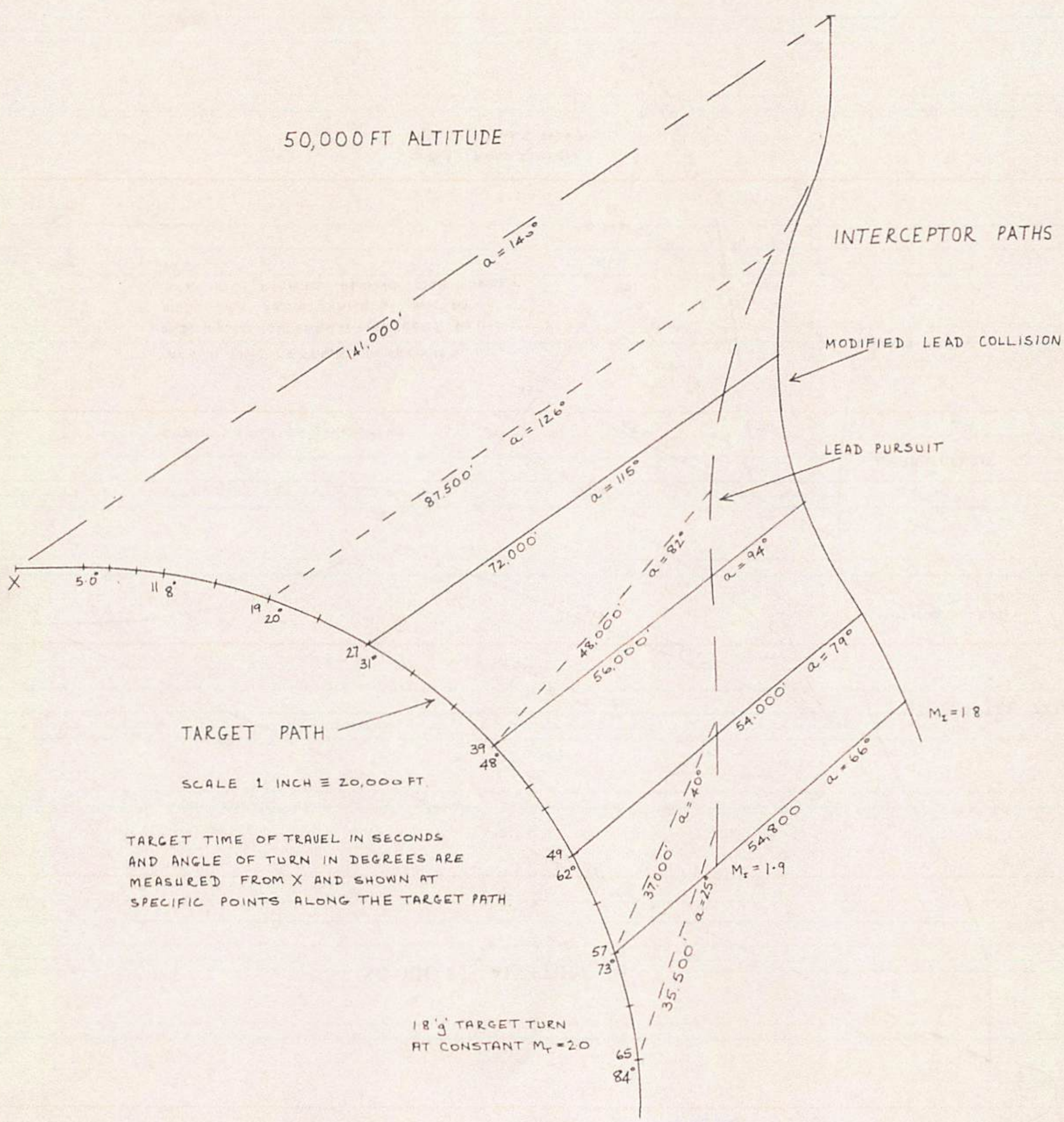
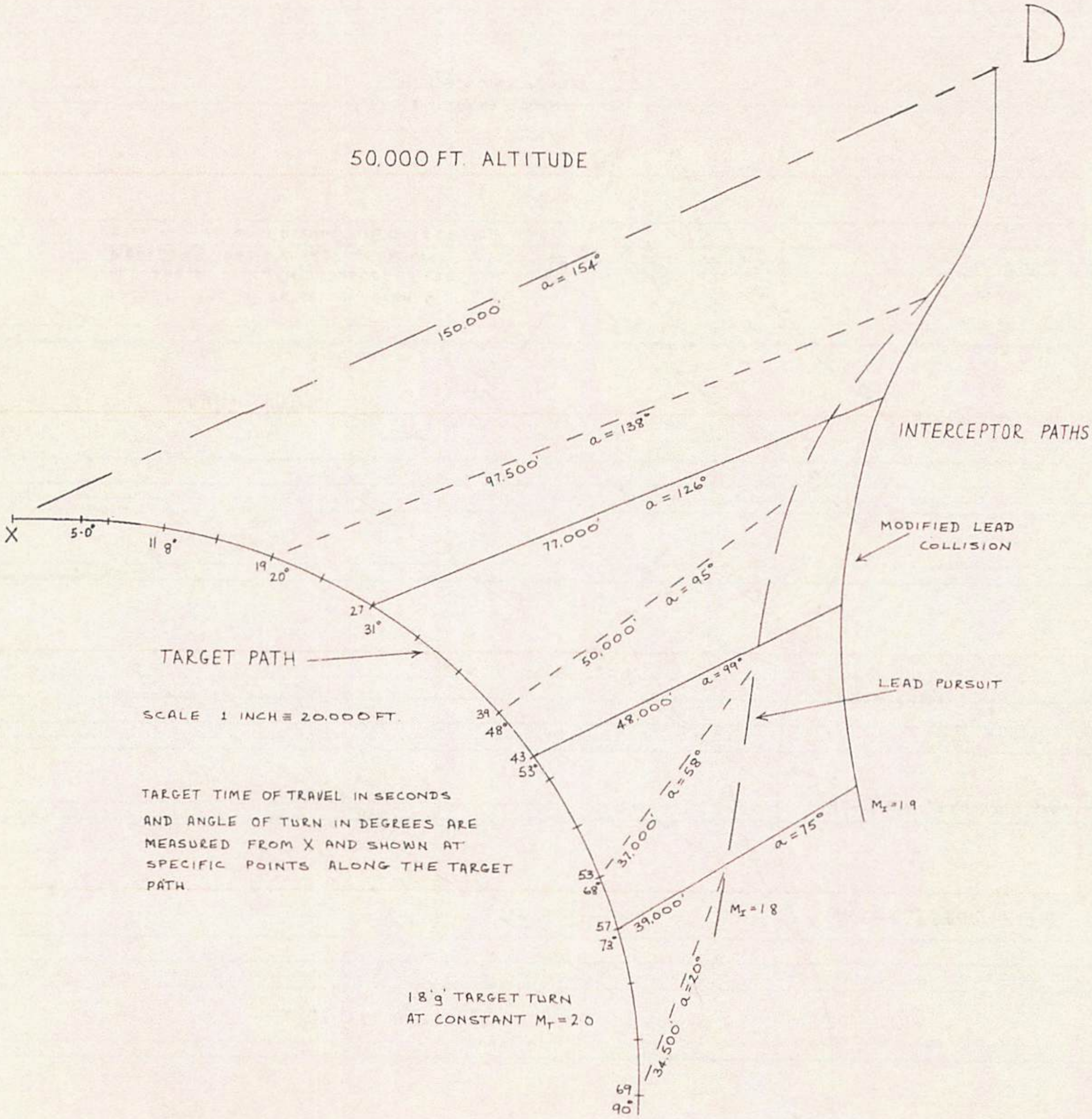

50,000 FT ALTITUDE
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
LEAD PURSUIT
TARGET PATH
X
5·0°
11·8°
19 20°
27 31°
39 48°
49 62°
57 73°
65 84°
141,000'
α = 140°
87,500'
α = 126°
72,000'
α = 115°
48,000'
α = 82°
56,000'
α = 94°
54,000'
α = 79°
37,000'
α = 40°
54,800
α = 66°
35,500'
α = 25°
M_I = 1·8
M_I = 1·9
SCALE 1 INCH ≡ 20,000 FT
TARGET TIME OF TRAVEL IN SECONDS
AND ANGLE OF TURN IN DEGREES ARE
MEASURED FROM X AND SHOWN AT
SPECIFIC POINTS ALONG THE TARGET PATH
1·8 'g' TARGET TURN
AT CONSTANT M_T = 2·0

Fig. 5



50,000 FT. ALTITUDE
D
X
5.0°
11 8°
19 20°
27 31°
39 48°
43 53°
53 68°
57 73°
69 90°
a = 154°
150,000'
a = 138°
97,500'
a = 126°
77,000'
a = 95°
50,000'
a = 99°
48,000'
a = 58°
37,000'
a = 75°
39,000'
a = 20°
34,500'
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
LEAD PURSUIT
$M_I = 1.9$
$M_I = 1.8$
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT.
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH
1.8 'g' TARGET TURN AT CONSTANT $M_T = 2.0$

P

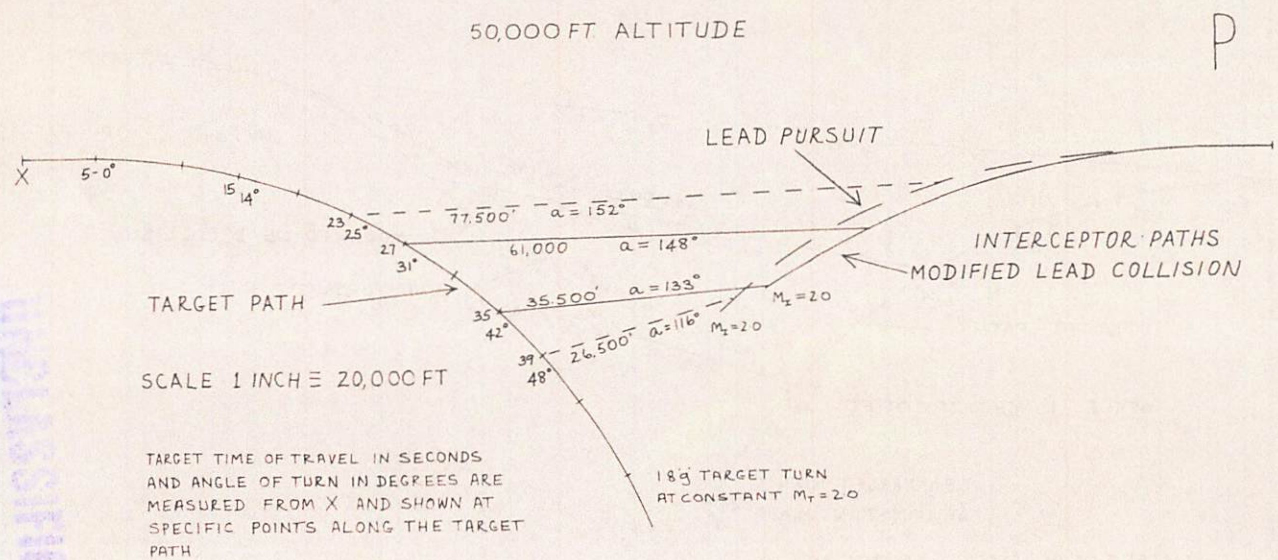
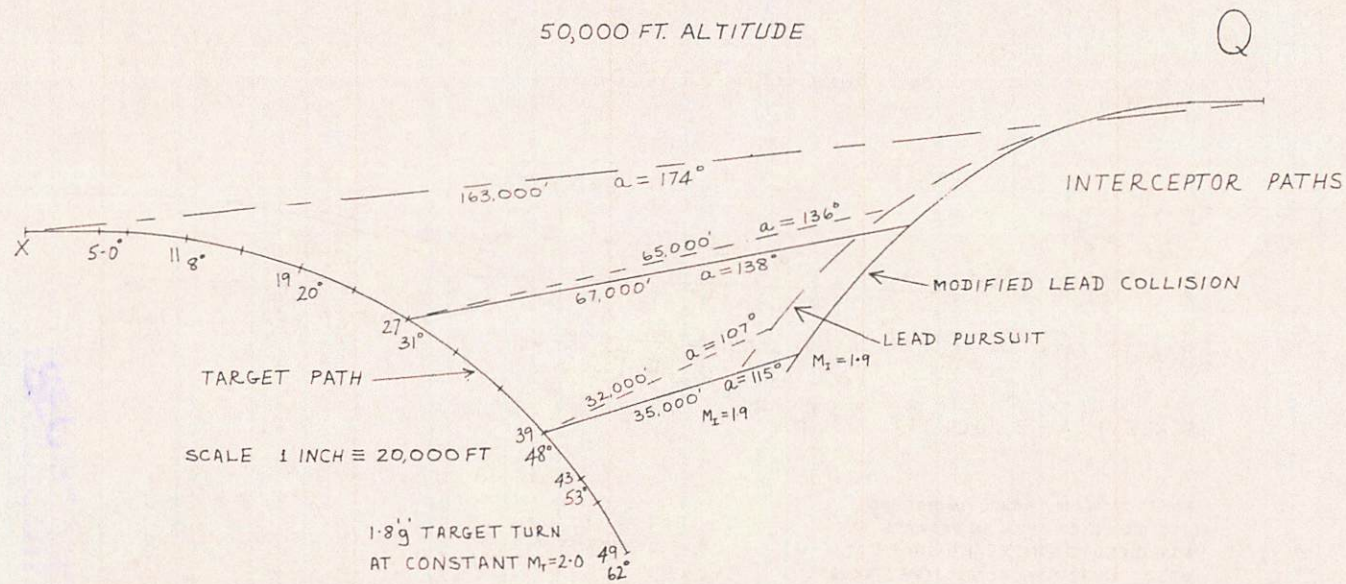

50,000 FT ALTITUDE
LEAD PURSUIT
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
X
5 - 0°
15 14°
23 25°
27 31°
35 42°
39 48°
77.500' a = 152°
61,000 a = 148°
35.500' a = 133°
26.500' a = 116°
M_I = 2.0
M_I = 2.0
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH
18g TARGET TURN AT CONSTANT M_T = 2.0

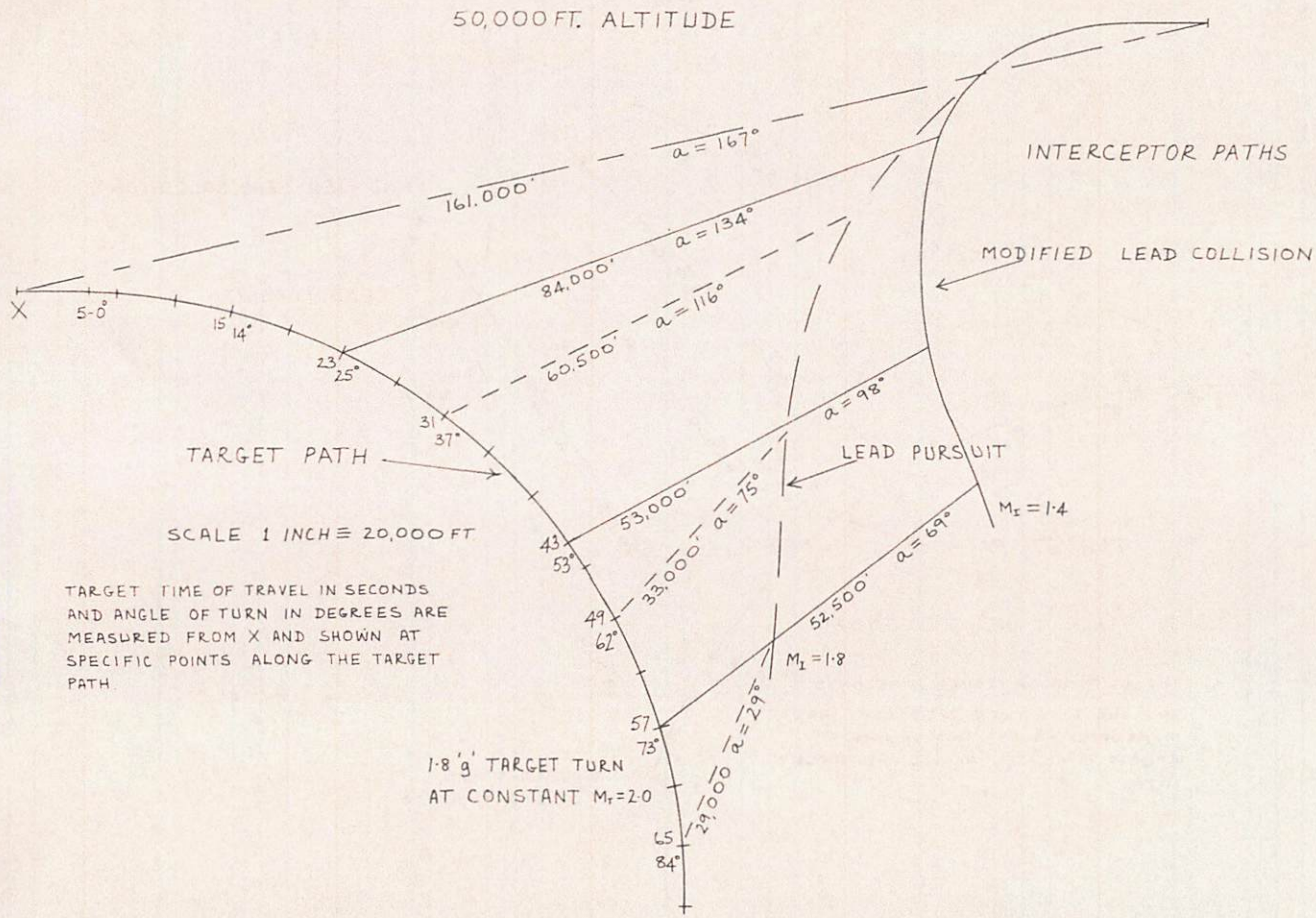
Fig. 6



TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH.

FIG. 7

R



50,000 FT. ALTITUDE
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
LEAD PURSUIT
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH.
1·8 'g' TARGET TURN AT CONSTANT MT=2·0
X
5-0°
15 14°
23 25°
31 37°
43 53°
49 62°
57 73°
65 84°
161,000'
a = 167°
84,000'
a = 134°
60,500'
a = 116°
53,000'
a = 98°
33,000'
a = 75°
52,500'
a = 69°
29,000'
a = 29°
MI = 1·4
MI = 1·8

FIG 8

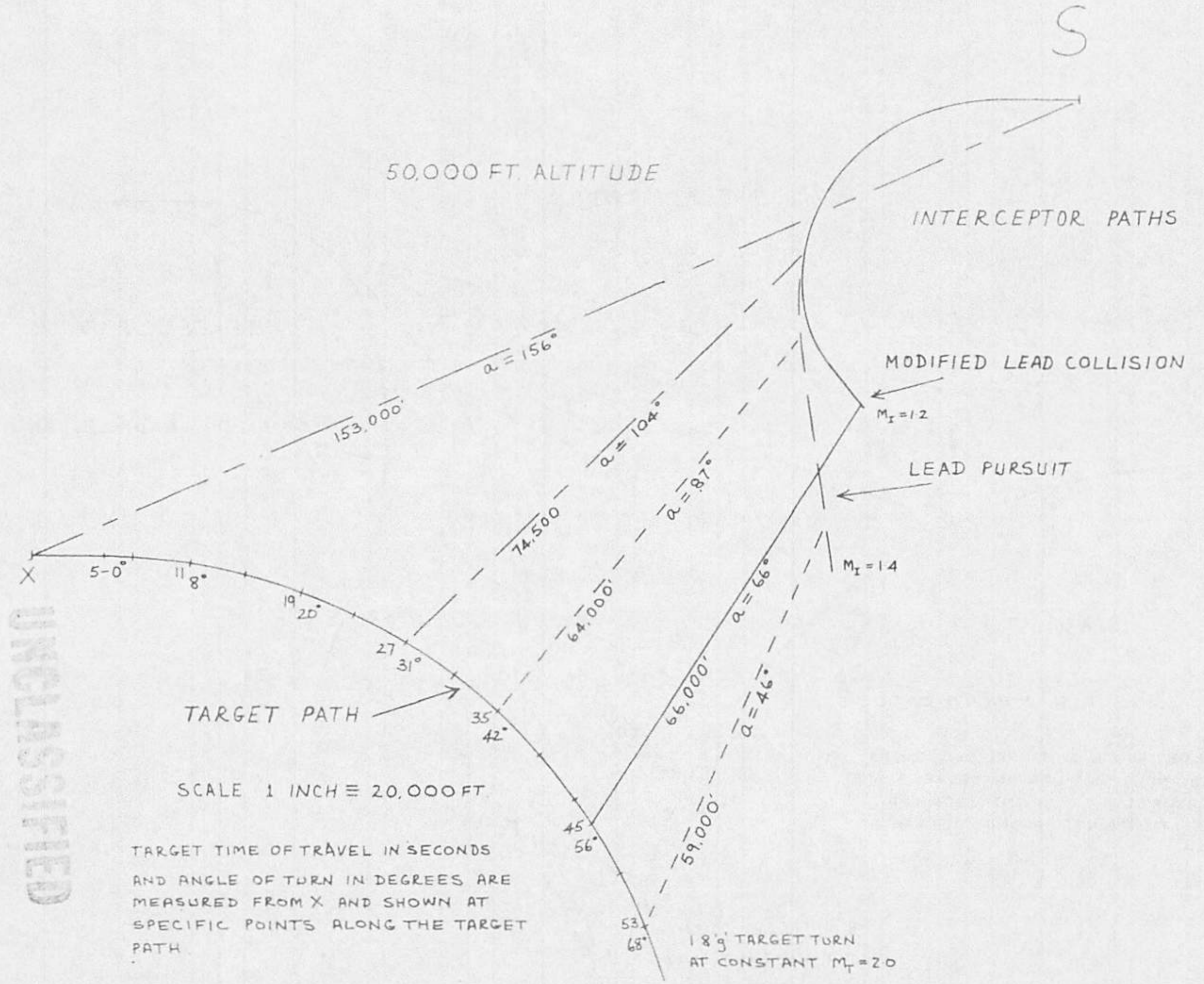

S
50,000 FT. ALTITUDE
INTERCEPTOR PATHS
MODIFIED LEAD COLLISION
$M_I = 1.2$
LEAD PURSUIT
$M_I = 1.4$
$\alpha = 156°$
153,000'
$\alpha = 104°$
74,500'
$\alpha = 87°$
64,000'
$\alpha = 66°$
66,000'
$\alpha = 46°$
59,000'
X
5-0°
11 8°
19 20°
27 31°
35 42°
45 56°
53 68°
TARGET PATH
SCALE 1 INCH ≡ 20,000 FT.
TARGET TIME OF TRAVEL IN SECONDS AND ANGLE OF TURN IN DEGREES ARE MEASURED FROM X AND SHOWN AT SPECIFIC POINTS ALONG THE TARGET PATH.
1.8 'g' TARGET TURN AT CONSTANT $M_T = 2.0$
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FIG. 9

LEAD ANGLE vs. ASPECT ANGLE

$$\sin A^* = \frac{V_T}{V_I + V_M \cdot \frac{t_f}{T}} \cdot \sin a$$

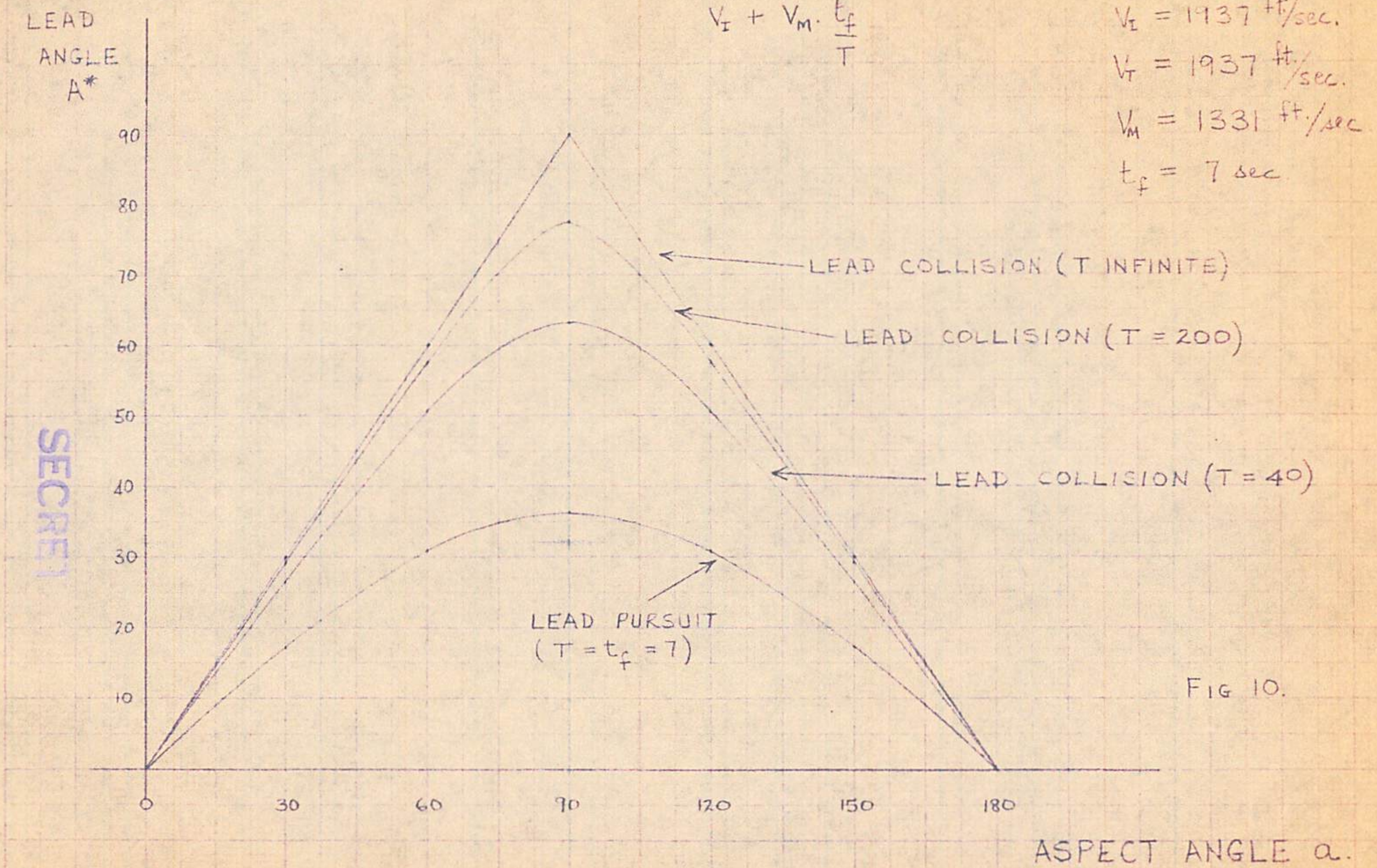

FIG 10.