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SEEKER LOCK-ON RANGE REQUIREMENTS FOR THE SPARROW 1242D MISSILES

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INTRODUCTION

The current program at NAMTC Pt. Mugu for flight development and testing of the Sparrow 2D missile and its auxiliaries has shown that the system performance does not in general meet the specification. On June 30th, 1958, official U.S. participation in this program comes to an end and subsequent development will be entirely Canadian sponsored. It is therefore, desirable that a new specification should be prepared which defines the performance required of the system for use in Canada.

The present report examines the requirements for seeker lock-on range in order to determine the minimum values that will enable the missile to function as a suitable complement to:

(a) The CF100 MK. 5M

(b) The Arrow.

Comparison of theoretical lock-on ranges with measured values of the transmitted power and receiver sensitivity indicates that the required range should be well within the capability of the system for operation in the automatic mode, provided that currently proposed modifications to the seeker system are implemented. However, for optical and spotlight attacks the time required to sweep the range gate and lock on to the target results in a loss of effective range. The specification range must therefore be increased to make allowance for this.

It is considered essential that the lock-on range, and the lock-on detection delay in non-automatic operation should be made compatible with attack capability from all aspects around the clock.

AUTOMATIC MODE

The lock-on range requirement in automatic operation is determined by the minimum missile launch range and the time needed for firing a salvo of missiles. The value must be such that if the first missile locks on when this range is reached, sufficient time remains for launch of all four missiles before the aircraft flies out of the launch zone at the mechanised minimum range.

AUTOMATIC MODE (Continued)

For the CF100 it is thought that current modifications to the missile auxiliaries should reduce the time required for the various events in the firing sequence to values such that a ripple interval of 350 milliseconds could be adopted. With this interval the probabilities of a miss-fire, of the next firing pulse failing to transfer to the next missile in the event of a hangfire, and of detecting a hangfire when none has occurred, should all be less than 1%. However, there are other factors which must be considered in deciding the ripple interval to be used. Although the intention is that missiles should be fired alternately from port and starboard sides, consecutive missiles may be launched from the same side in the event of a hang-fire, or of the other missile on the same side as the first being the only one locked on at the time of the second firing pulse. Thus, it can occur that the second missile in a ripple may be directly in the wake of the first. Fig. 1, a theoretical space-time curve derived from ref.1, shows that the missile moves only 35 ft. in the first .35 sec. and the nozzle is therefore only about 20 ft. ahead of the seeker of the second missile. At this distance it is possible that the ionised exhaust gases could cause the second missile to lose lock at the moment of launch. No data on this effect is available and tests will be required to determine the conditions under which trouble of this kind may occur. For the present it will be assumed that the firing interval will be 500 milliseconds. In this time the first missile will have travelled 70 ft. so that the nozzle is about 55 ft. ahead of the second seeker. It is hoped that this will be adequate to avoid loss of lock-on. On this basis, a salvo of four missiles can be fired in 1.5 seconds from the time of the first lock-on.

In assessing the time required in the launch zone, allowance should also be made for tolerances in mechanising R_{min} in the computer. Assuming the possible error to be 10%, this results in a loss in range of about 1800 ft. in the worst case, i.e. nose attack. With a closing rate of order 1700 ft./sec. it is seen that one second should be allowed for this. It is, therefore, concluded that lock-on must occur at least 2.5 seconds prior to R_{min}. For the purpose of specifying the lock-on range required it has been assumed that the aircraft must remain in the launch zone for 3 seconds.

For the Arrow it is presently proposed that the firing interval should be 0.5 seconds. Since similar considerations to those above also apply here it is unlikely that the interval could be less than this. In fact due to the proximity of the missile path to the nose of the aircraft, there is the additional possibility of unlocking the AI, and the interval may have to be increased. Thus, although the

AUTOMATIC MODE (Continued)

allowance for tolerances in mechanising R_{min} is reduced to about 1/2 second in this case, due to the considerably higher closing speeds, the same minimum time of 3 seconds in the launch zone is assumed for the Arrow.

Lock-On Range

Curves have been prepared showing the lock-on range required to allow 3 seconds in the firing zone, as a function of the course difference at which the attack is being made. It is assumed that the aircraft is flying an ideal lead pursuit course; the aspect angle is then known as a function of the course difference. Fig. 2 shows the radar echoing area assumed for all targets in this study as a function of aspect angle, and corresponds to the B47 profile.

The ranges shown in Figs. 3 through 5 are the lock-on ranges that would be required against a 5 sq. metre target to give the actual ranges required at each course difference, making allowance for the variation of radar echoing area with aspect angle. The dip in each curve at course differences near the beam is caused by the large increase in radar area at aspects near 90°. To illustrate this point, consider the case of M = 2.0 interceptor vs. an M = 2.0 target at 50,000 ft. For an ideal lead pursuit course at 100° aspect angle, the lead angle is 35° and the course difference is therefore 65°. Fig. 2 shows the radar area at 100° to be 100 sq. metres. Since range is proportional to the fourth root of area, the range achieved against a 100 sq. metre target will be

$\sqrt[4]{\frac{100}{5}}$ = 2.12 times the range against a 5 sq. metre target.

Fig. 5 shows a range of 1.82 n.m. as being required to allow 3 seconds in the launch zone at 65° course difference. It therefore follows that the actual range required at this course difference is 2.12 x 1.82 = 3.86 n.m. and this in fact then allows the attack to be made.

Fig. 3 shows the lock-on ranges required to give 3 seconds of firing capability for the CF100 flying at M = 0.8, 40,000 ft. Three target speeds are shown, M = 0.75, 0.9 and 1.1. As would be expected, the most severe requirement corresponds to head-on attack against the highest speed target. However, there is very little spread due to the effect of target speed in this case, and a lock-on range of 4 n.m. would be sufficient to allow at least 3 seconds in the launch zone under any conditions.

Lock-On Range (Continued)

Figs. 4 and 5 show similar curves for the Arrow at 50,000 ft., Fig. 4 being for interceptor speed M = 1.5 and Fig. 5 for M = 2.0. In both cases target speeds of M = 0.9, 1.5 and 2.0 are shown. It is seen that for the aircraft to be able to attack targets flying at speeds up to its own, the missile lock-on range should be at least 4.5 miles for M = 1.5 capability and 5.0 miles for M = 2.0.

It is important to realise that these are the minimum requirements for the missile that can be considered acceptable, since anything less represents a loss of interception capability. It would be incorrect to assume that advantage may be taken of the reduced requirements for aspect angles near the beam in defining an interim system. To do so would enable a target to reduce the possibility of successful attack simply by turning towards the interceptor, thus forcing it to attack head-on. In this configuration it would then be impossible for a full salvo of missiles to be fired.

OPTICAL AND SPOTLIGHT MODES

In the event of the AI being either completely out of action or jammed by ECM, the normal procedure for slaving the missile seeker to the AI in both range and azimuth cannot be followed. If no AI information at all is available, the aircraft is flown on a pure pursuit course and the missile antenna slaved to the boresight axis. Where jamming still permits angle tracking, the missile is angle-slaved to the AI. In either case lock-on is achieved by sweeping the range gate from very short range out to the range at which lock-on may be expected to occur.

In the optical mode unit at present being used in the CF100, the range gate is swept from 1 to 5 miles in 3 seconds. Flight test results from Pt. Mugu indicate that about 5 sweeps are required after reaching the normal lock-on range in automatic mode for solid lock to be achieved. However, only tail attacks have been carried out so far and the results may not be representative of attacks from other quarters.

Figs. 6, 7 and 8 show the number of times that the range gate may be swept before lock-on must occur to allow 3 seconds of remaining launch capability. The curves are all for head-on attacks and are plotted against the expected lock-on range; it is assumed that the range gate is swept from 1 mile to this range. Sweep rates of one, two and three times the present rate on the CF100 i.e. 8000 ft./sec. are shown.

OPTICAL AND SPOTLIGHT MODES (Continued)

Fig. 6 shows that for the CF100 intercepting an M = 0.9 target at 40,000 ft. the minimum lock-on range is 4.0 n.m. with the present rate of range gate sweeping. However, lock-on must occur on the first sweep with this range. To enable two sweeps to be made without increasing the sweep rate, it will be necessary to increase the lock-on range capability to 4.80 n.m. For three sweeps 6.1 n.m. is required.

Figs. 7 and 8 for the Arrow at 50,000 ft. show respectively, M = 1.5 vs M = 1.5 target and M = 2.0 vs M = 2.0 target. It is seen that with the present sweep rate 5.7 n.m. range is required in the first case and 6.9 n.m. in the second to allow one complete sweep to be made. To achieve more than one sweep with the present sweeping rate would be difficult for M = 1.5 and virtually impossible for M = 2.0. Two sweeps could be obtained in the M = 1.5 case by doubling the sweep rate and increasing the lock-on range to 6.0 n.m.; for the M = 2.0 case it would be necessary to treble the rate and increase the range to 6.4 n.m. It is considered that these should represent objectives for interim and final versions of the system.

It should be noted that in constructing these diagrams allowance has been made for the fact that N complete sweeps are not required for the range gate to coincide with the target N times. For example, if detection is to occur on the first sweep it is only necessary that the range gate may be swept from the low end of its travel out to R_{min} - 3R (the range at which 3 seconds of launch capability remains) in the time that the aircraft flies in to this range from $R_{lock-on}$.

THEORETICAL SEEKER CAPABILITY

Fig. 9, based on information given by Bendix Systems Laboratory, shows the theoretical detection range for the Sparrow seeker as a function of average power output and receiver sensitivity. With recent experimental modifications it has been found possible to increase the receiver sensitivity to give a minimum discernible signal at -100 DBM. With an average power output of 16 watts it is seen that detection may be expected to occur at about 8 miles against a 5 sq. metre target.

It is not clear at present precisely what are the criteria determining seeker lock-on. It seems however, that missile launch cannot, or should not occur until solid AGC action is developed. In the present system this occurs at 6 db. above MDS. Taking this as a criterion for effective lock-on it appears that lock-on should occur at 5.75 n.m. Reducing the signal strength requirement to 4 d.b. above MDS or increasing the output power to about 25 watts, THEORETICAL SEEKER CAPABILITY (Continued)

would then increase the range to the 6.4 n.m. required for the highest speed case. It is not known whether such improvements are within the capability of the system. However, it is suggested that a development program should investigate the possibilities for obtaining the required performance in this way.

CONCLUSIONS

This study has shown that the following lock-on ranges against a 5 sq. metre target are required for the Sparrow II seeker in order that the full attack capability shall be available at all course differences.

I. Automatic Operation in Normal Fire Control Mode

a) CF-100 at M = 0.8 .... 4.0 n.m.

b) Arrow at M = 1.5 .... 4.5 n.m.

c) Arrow at M = 2.0 .... 5.0 n.m.

II. Operation in Optical and Spotlight Modes

a) CF100 at M = 0.8 with present rate of range gate sweeping.. 4.8 n.m.

b) Arrow at M = 1.5 with doubled sweep rate............ 6.0 n.m.

c) Arrow at M = 2.0 with trebled sweep rate............ 6.4 n.m.

In each of these three cases it is assumed that the range gate is swept out to the quoted range. Lock-on must then occur within two sweeps after the range is reduced to this value.

It is considered that the most probable tactical situation is one in which the A.I. is jammed, this being particularly so for the Arrow. Current opinion is that the expectation of ECM directed against the airborne radar is of order 80-90%, the most likely form of this being noise jamming, which still allows angular information on the target to be obtained.

It is clear then that instead of being merely a standby mode, the spotlight mode may well become the most usual operational procedure. It is therefore necessary to ensure that the specification to which the Sparrow missile and its auxiliaries are developed should enable the weapons system to function to its maximum capability in this mode.

CONCLUSIONS (Continued)

The requirements for lock-on range given above represent minimum acceptable standards which, if just met, allow very little margin for error in operation for the full systems capabilities to be obtained. It would be incorrect to assume that the only penalty due to taking advantage of the reduced requirements for beam attacks would be a restriction of operations to this quarter. An intelligent enemy would then be able to defeat an attack, or at least to reduce seriously its probability of success, simply by turning towards the interceptor and thus forcing it to attack head-on.

Recent test results with seekers to which experimental modifications have been made, show that the required capability is theoretically obtainable. A number of snags still remain and considerable development will be necessary before such modifications can be made standard. A vigorous development program, with the active participation of all concerned, will be essential if the Sparrow is to become a useful complement to the Arrow.

Ref. 1 Investigation of missile firing order and ripple interval for the CF100 - K. Keeping March 1957.

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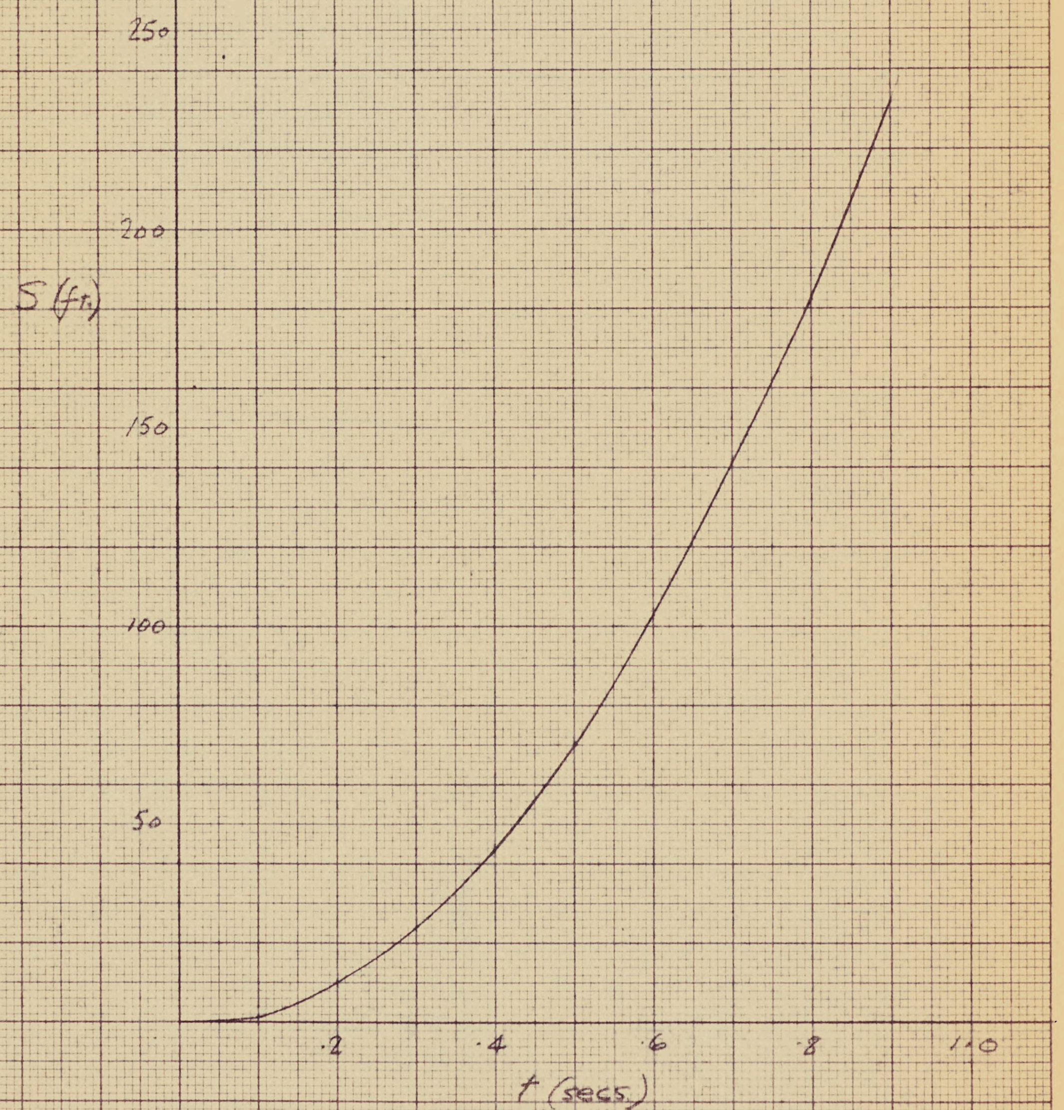
fig. 1

SPACE-TIME CURVE FOR
SPARROW II RELATIVE
TO LAUNCH AIRCRAFT.
(theoretical)



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MADE IN CANADA

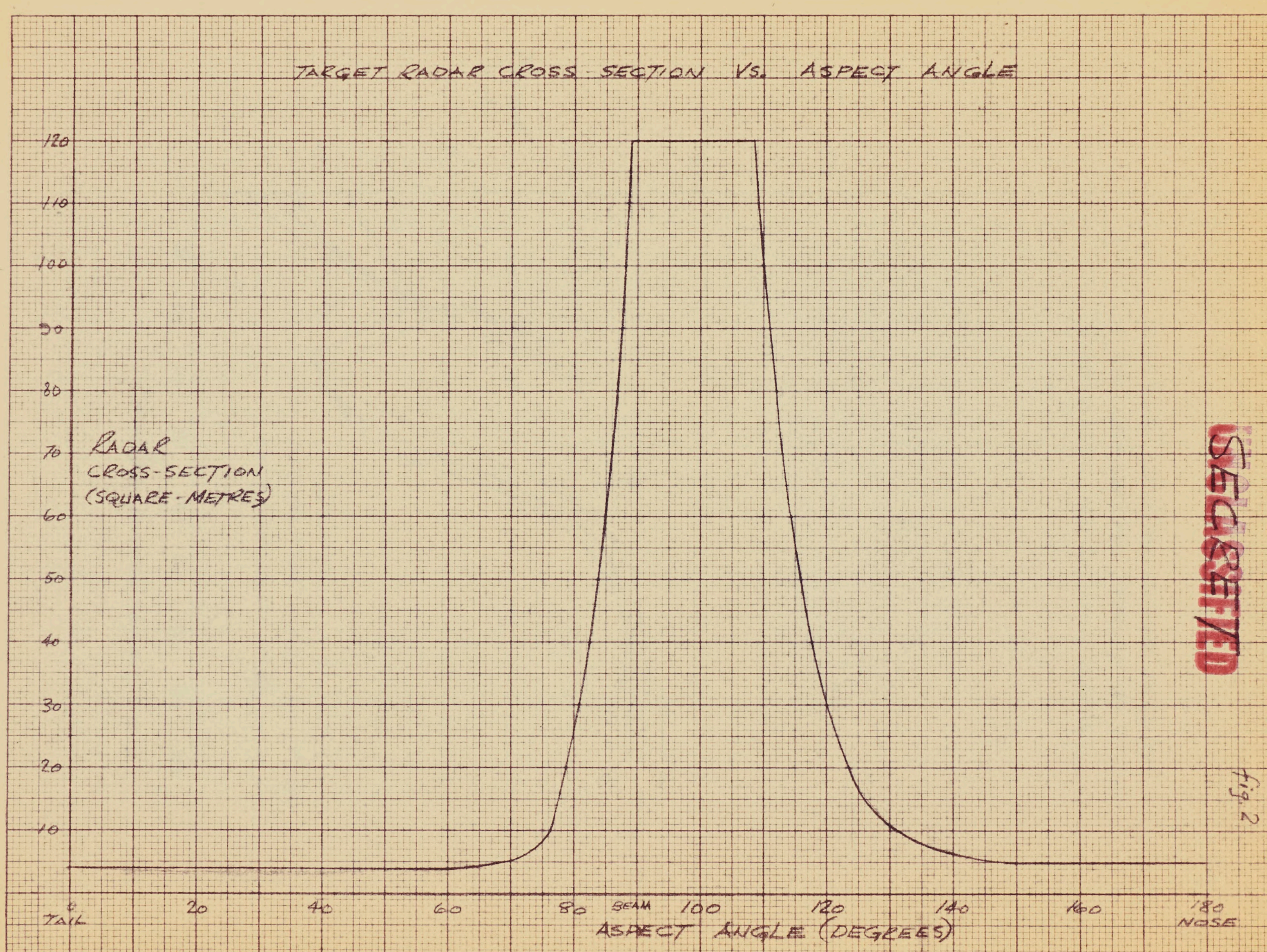

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fig. 3

MINIMUM LOCK-ON RANGE AGAINST
5 SQUARE METRE TARGET TO ALLOW
3 SECONDS IN LAUNCH ZONE

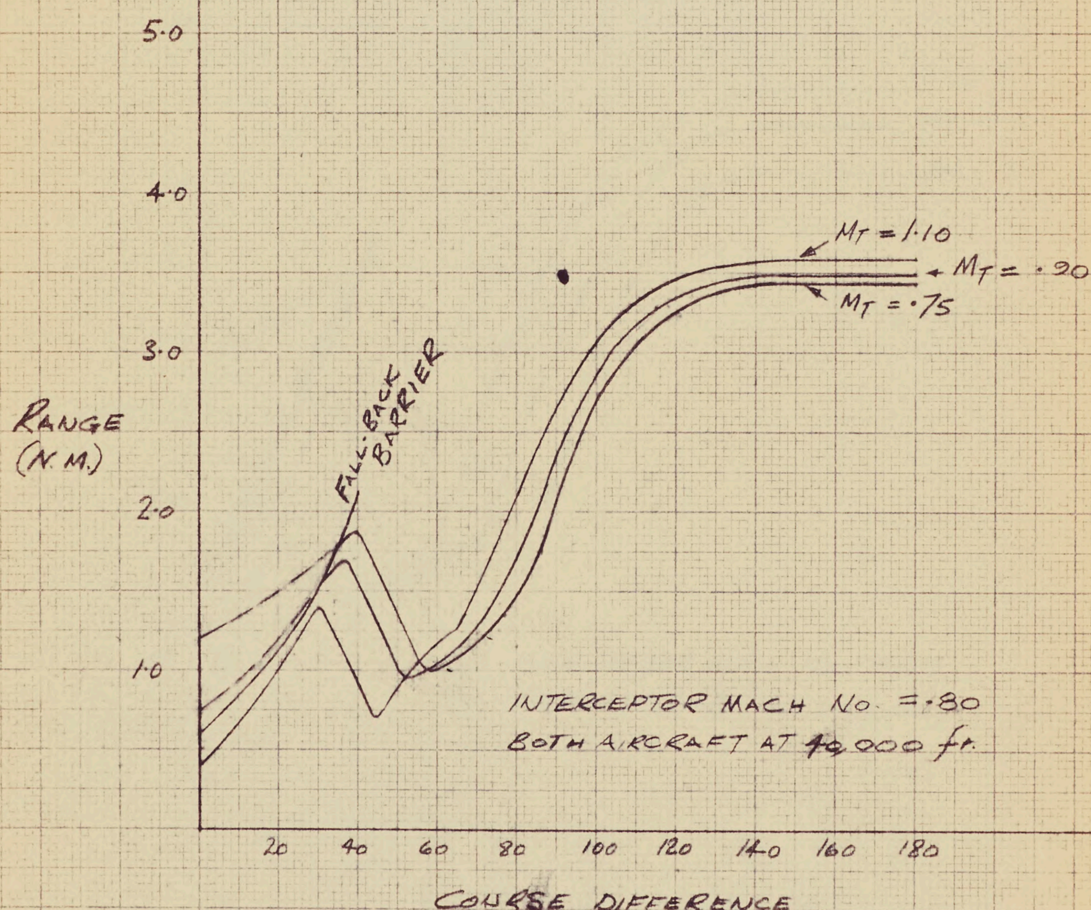

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fig. 4

MINIMUM LOCK-ON RANGE AGAINST 5 SQUARE METRE TARGET TO ALLOW 3 SECONDS IN LAUNCH ZONE

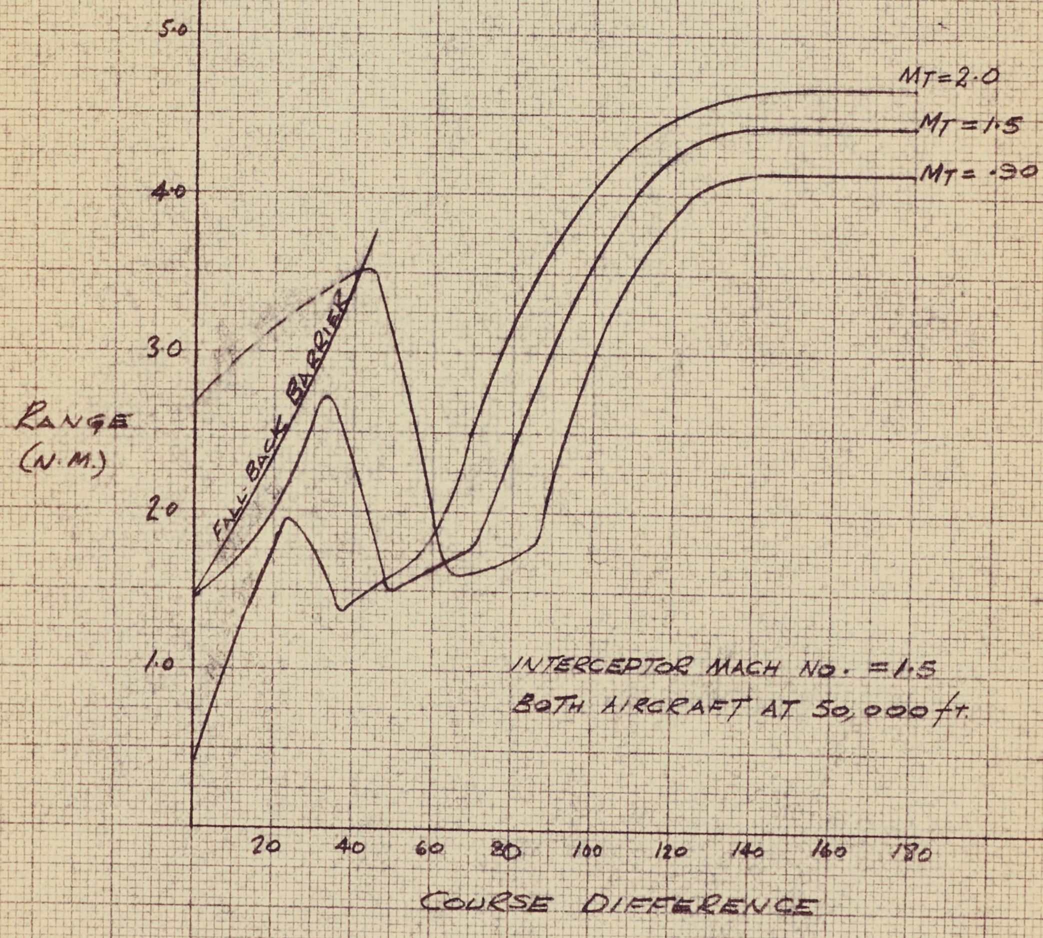

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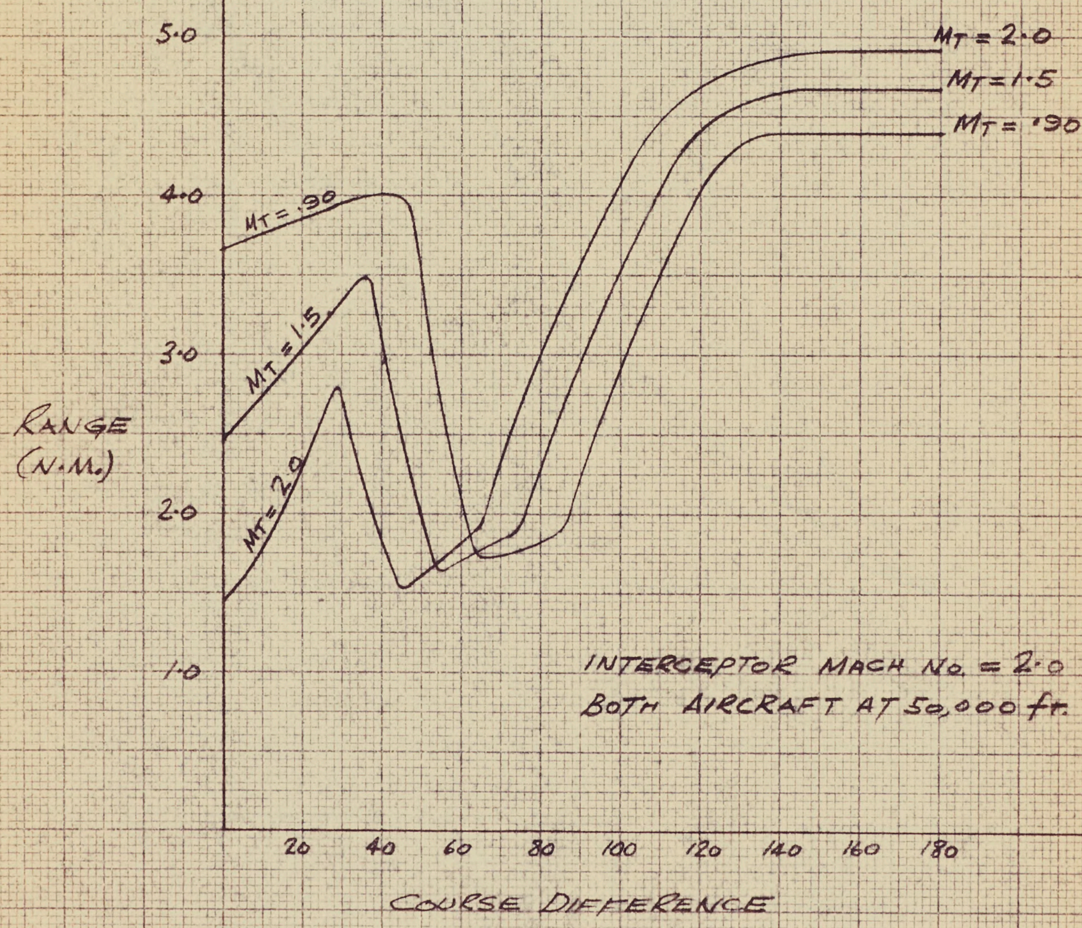
fig. 5

MINIMUM LOCK-ON RANGE AGAINST 5 SQUARE METRE TARGET TO ALLOW 3 SECONDS IN LAUNCH ZONE



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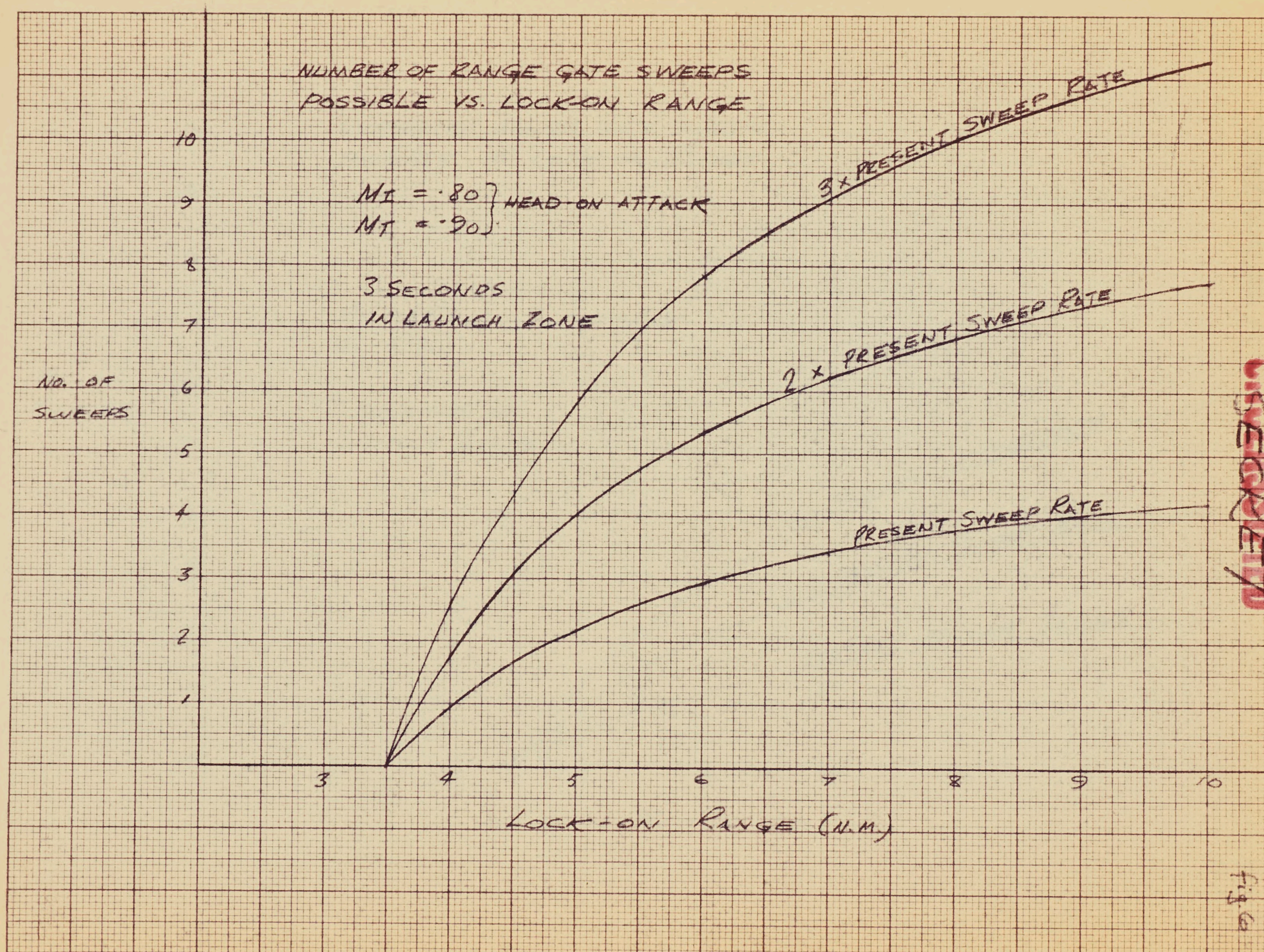
NUMBER OF RANGE GATE SWEEPS
POSSIBLE VS. LOCK-ON RANGE
MI = ·80 } HEAD ON ATTACK
MT = ·90
3 SECONDS
IN LAUNCH ZONE
NO. OF
SWEEPS
10
9
8
7
6
5
4
3
2
1
3
4
5
6
7
8
9
10
LOCK-ON RANGE (N.M.)
3 x PRESENT SWEEP RATE
2 x PRESENT SWEEP RATE
PRESENT SWEEP RATE

fig. 6

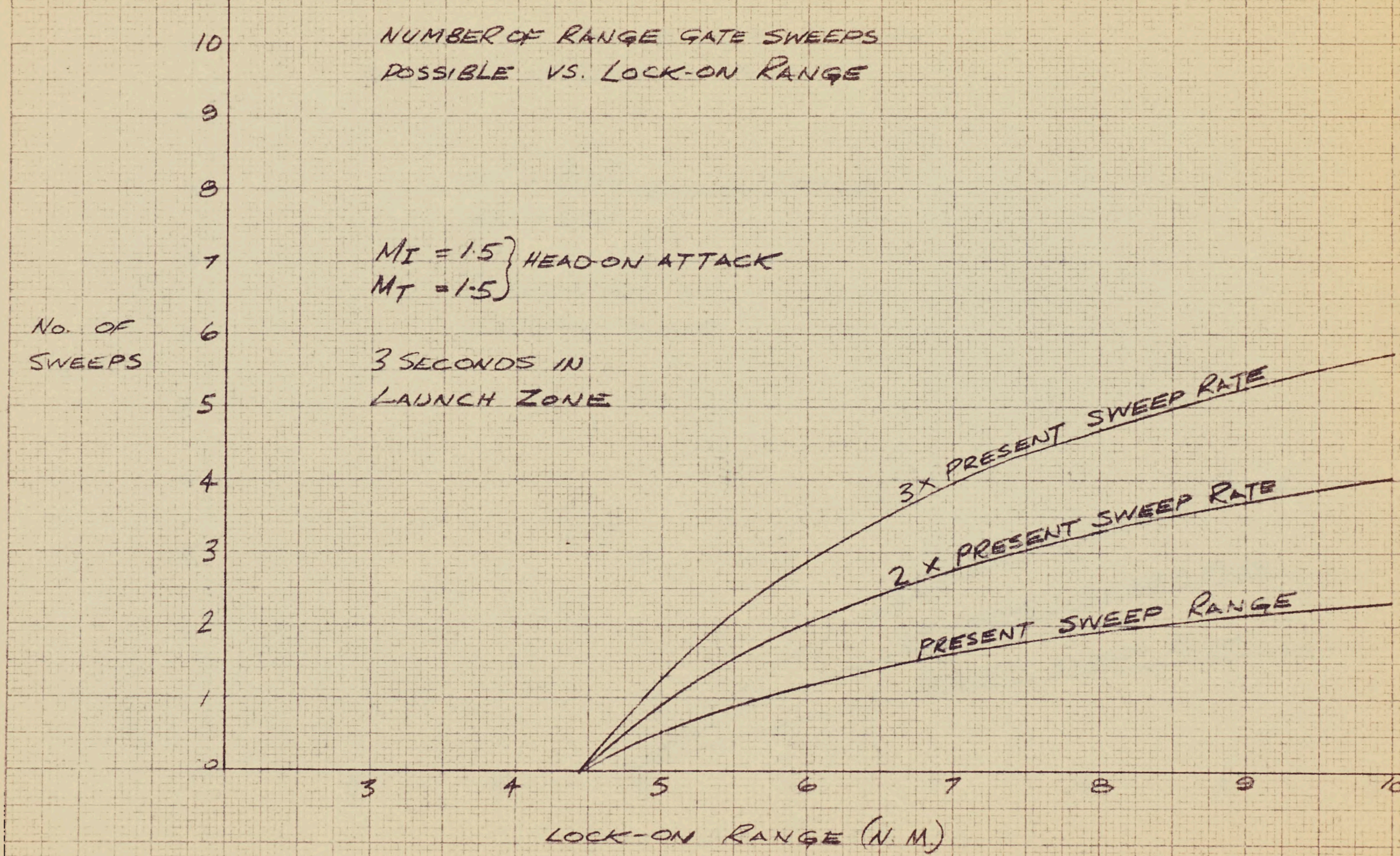
NUMBER OF RANGE GATE SWEEPS
POSSIBLE VS. LOCK-ON RANGE
$M_I = 1.5$ } HEAD-ON ATTACK
$M_T = 1.5$
3 SECONDS IN
LAUNCH ZONE
No. OF
SWEEPS
3 × PRESENT SWEEP RATE
2 × PRESENT SWEEP RATE
PRESENT SWEEP RANGE
LOCK-ON RANGE (N. M.)
0
1
2
3
4
5
6
7
8
9
10

fig. 7

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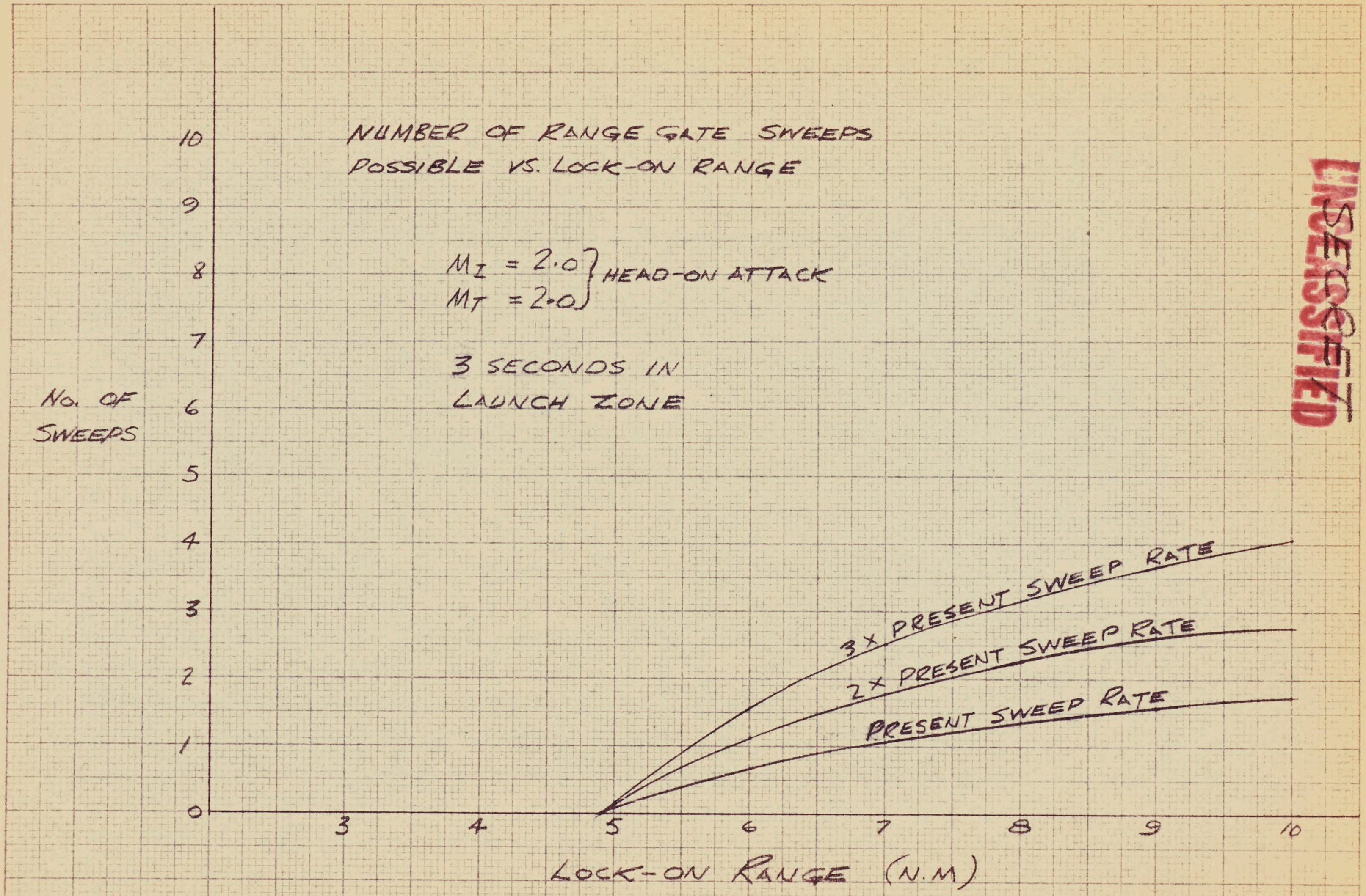
NUMBER OF RANGE GATE SWEEPS
POSSIBLE VS. LOCK-ON RANGE
$M_I = 2.0$
$M_T = 2.0$
HEAD-ON ATTACK
3 SECONDS IN
LAUNCH ZONE
No. OF SWEEPS
10
9
8
7
6
5
4
3
2
1
0
3
4
5
6
7
8
9
10
LOCK-ON RANGE (N.M)
3 x PRESENT SWEEP RATE
2 x PRESENT SWEEP RATE
PRESENT SWEEP RATE

Fig. 8

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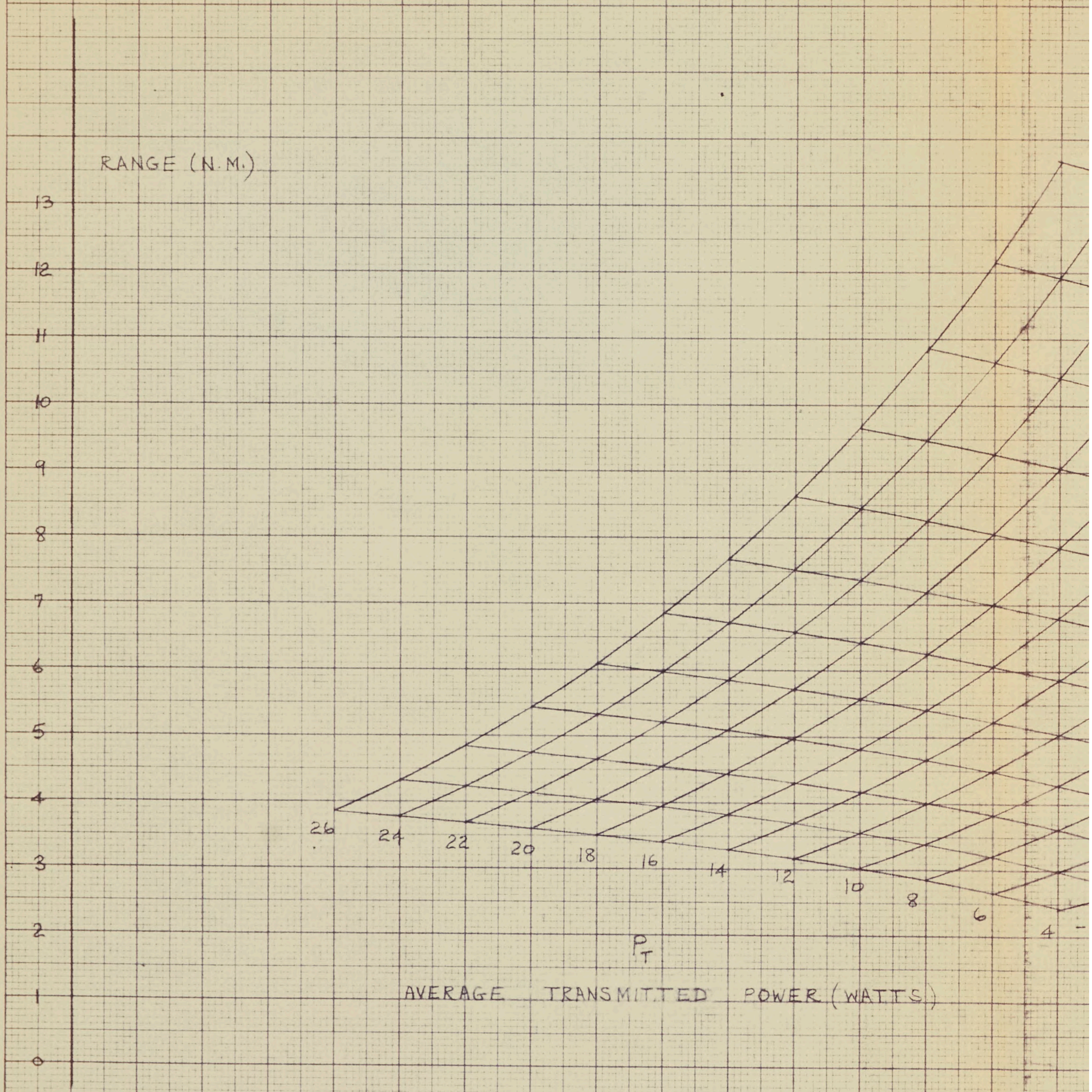
THEORETICAL DETECTION RANGE FOR A SP



FOR A SPARROW IID AGAINST A 5 SQ. METRE TARGET

FIG 9.