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THE CF 105 ASSESSMENT STUDY

SUMMARY REPORT I

Compiled by

R.S. Mitchell & J.T. Macfarlane

DEFENCE RESEARCH BOARD

CANADIAN ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

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PROJECT N-47 SECRET

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Chief Superintendent

This report is based, directly and indirectly, on the work of many people at CARDE and elsewhere. Any listing of sources that contributed to the shaping of the concepts outlined herein would be incomplete. At the risk of serious omissions acknowledgement must be made to the following personnel who gave of time and effort on this study:

Stationed at CARDE:

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Numerous discussions with specialists at CARDE and with various Headquarters directorates have aided appreciably. Conferences with U.K. personnel visiting CARDE and visits to a number of U.S. establishments have greatly facilitated the work.

FOREWORD

This technical memorandum is a review of the portion of the CF105 Assessment Study carried out in the period from April 1, 1956 to April 1, 1957. The investigation has been carried out by CARDE for the Director of Systems Evaluations of the RCAF, under terms of reference laid down by that directorate. The Defence Research Telecommunications Establishment and the Director of Air Intelligence assisted in certain specialized portions of the study, and some contractual support was obtained.

The material herein is intended to outline the aspects of the system that have been studied and to indicate overall results, trends and recommendations. Valuations given should be regarded as smoothed results based on multi-parameter data. Where specific cases are of interest or a more detailed examination is required the reader is referred to the reports listed on page 97 .

ABSTRACT

Summarized in this memorandum are the results derived in the first phase of the CF105 Assessment Study. A description is given of the interceptor and of considerations that pertain to an evaluation of such a system. The limited scope of the study has been established as dealing with the following combat situations:

(a) One fighter against one bomber

(b) High altitude threat (above 35,000 feet)

(c) Conventional guided weapon armament.

This investigation has been concerned only with the phases of the attack that may be termed:

(a) Vectoring phase

(b) A.I. phase

(c) Missile flight

(d) Missile impact.

The vast majority of the work has been concentrated on the A.I. phase.

The latter part of the report is concerned with the details of results, conclusions and trends that have been noted. Where possible recommendations are made either concerning measures which should be adopted or future studies that would be desirable. The main results have been printed on colored pages.

The conclusions are summarized in the table on the following page.

	EXPECTED SUBSONIC THREAT	PROPOSED SUPERSONIC THREAT	MORE ADVANCED THREAT
AIRFRAME	Adequate	Adequate	Some Potential
A.I.	Adequate	Adequate	Growth Potential
WEAPON	Adequate	Marginal	Inadequate
WARHEADS	Marginal	Inadequate	Inadequate
PRESENT G.C.I.	Marginal	Inadequate	Inadequate

Considerations of the Astra I aircraft electronics system in the face of E.C.M. have been interwoven with the various technical discussions. Certain types of jamming cannot be countered by the A.I. and require radical tactical changes to achieve successful interception. These are:

1. High-power barrage jamming
2. Continuous spot jamming with frequency tracking rates exceeding about 2400 mcs/sec.
3. Continuous or responsive C.W. or pulsed scan inverters
4. Forward-downward fired chaff with explosive dispersal.

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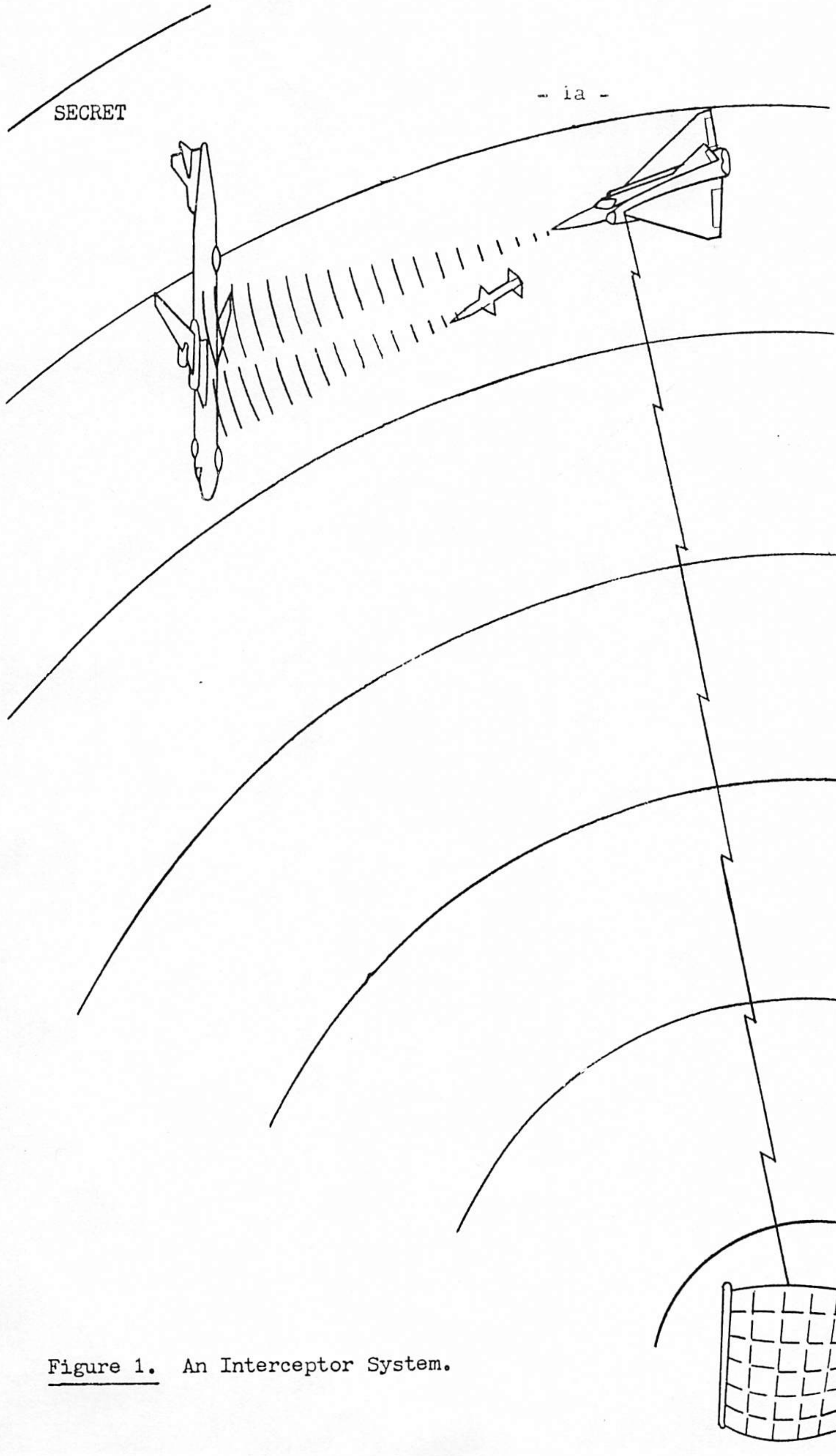


Figure 1. An Interceptor System.

C F 105 ASSESSMENT STUDY

SUMMARY REPORT I

1.0 THE INTERCEPTOR SYSTEM

An interceptor system may be analysed from two points of view:

(a) the components from which the integrated system is built,

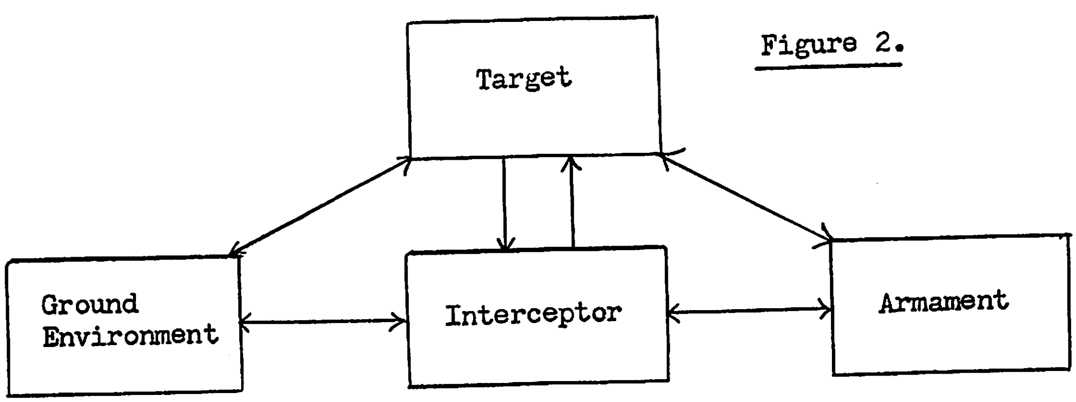
and

(b) the time sequence of events during the operational mission.

1.1 Interrelation of Sub-systems

An interceptor system is the ensemble of ground radars, communication network, navigation equipment, computers, weapon carrier, airborne electronics, and weapon, whose combined purpose is to stop an enemy bomber threat. The principal sub-systems are illustrated in figure 1. They may be thought of as two closed loops as shown in figure 2, with numerous loops, closed or open, inside each of the blocks depicted.

Figure 2.



The complete failure of one section may render the system inoperative. On the other hand, high performance of one part of the system may compensate for poor performance of another.

The system is integrated in the sense that each unit is designed with regard to its function in relation to the other components. The inputs to the various sub-systems are the outputs of other members and cognizance must be taken of the limits and tolerances that are imposed on these quantities by the performance of the components. These inputs and outputs are subject to degrees of randomness due to the accuracies, capabilities, and serviceability of the equipment, the effects of atmospheric conditions, and the characteristics and tactics of the threat.

In the block diagram of figure 2 it will be noticed that the arrows point in both directions. This expresses the fact that each entity may influence the others both in operation and in design requirements. For example, the type of target dictates the kind of ground radars required, while the latter may influence the bomber's ECM requirements and tactics.

The system of interest in this report is that in which the CF 105 supersonic aircraft is to be the weapon carrier. A description of the main entities is given in the following sections.

1.2 Attack Phases

In the same way that the physical system may be divided into sub-systems for analysis, an attack mission may be divided into phases. As illustrated in figures 3 and 4, these are:

(a) The vectoring phase.

(b) The AI phase.

(c) The weapon phase.

(d) Warhead impact and fighter breakaway.

The Vectoring Phase - During this part of the attack the interceptor is presumed to be under GCI control, which directs the fighter aircraft into a region in space, relative to the bomber, so that AI contact may be made. More specifically the interceptor must be placed in a proper position relative to the target, and with the correct heading, so that weapon delivery may be completed. Ideally, the orientation of the attack should be such that the kill probability is maximized. Indeed for high speed targets positioning accuracy required by the weapon may be a more decisive factor than the particular potential of the weapon per se.

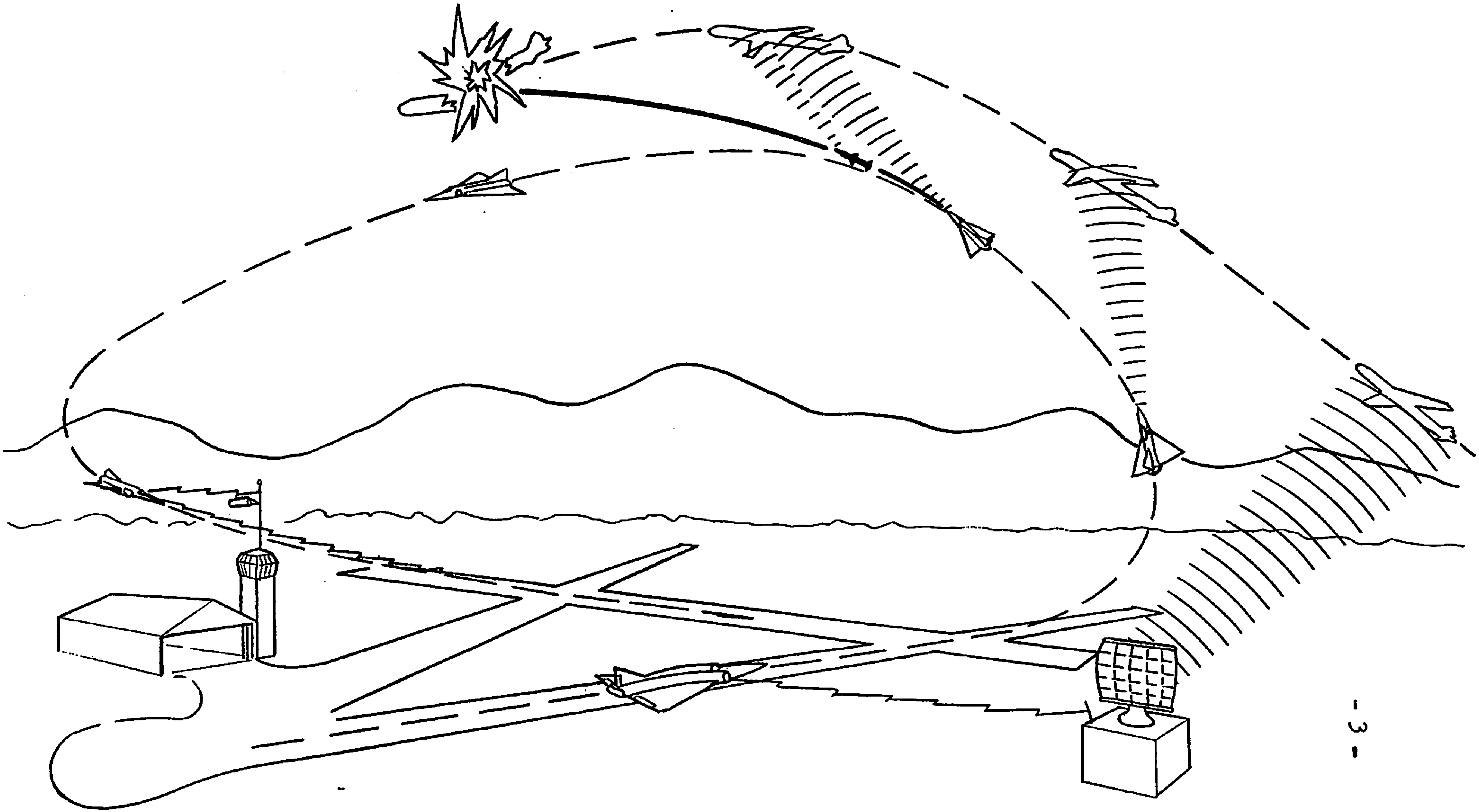


Figure 3. Interception Phases.

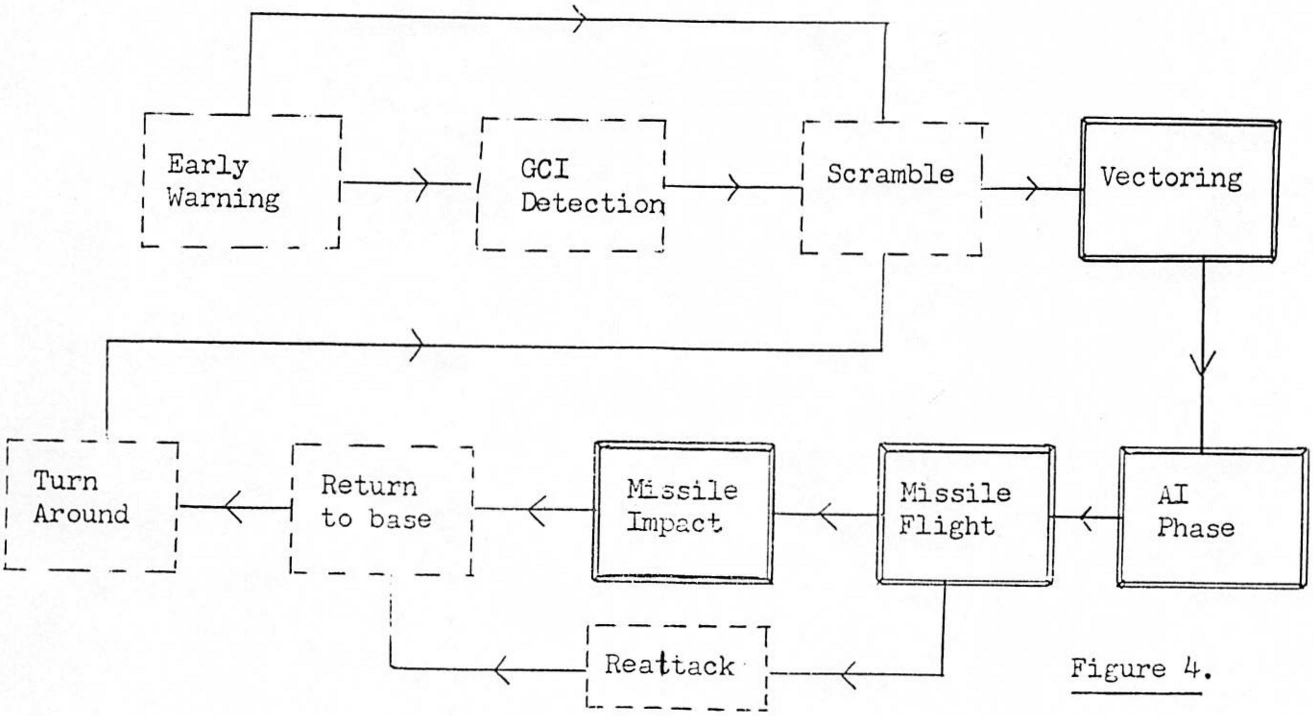


Figure 4.

The AI Phase - Within a certain range from the target the interceptor is considered to be receiving data from its own radar. Manoeuvres may be required to correct for GCI placement errors to permit successful launching of the weapon. How well this may be done will depend on the interceptor's radar and aerodynamic characteristics; the bomber's speed and manoeuvre capabilities, and on ECM considerations.

The Weapon Phase - The missile's characteristics and limitations dictate the range and heading relative to the target required for the weapon to be launched successfully. These restrictions in effect define the objective for the AI phase. The flight path of the weapon will determine the miss distance which is achieved.

The Engagement Phase - Considerations of warhead burst, fuzing, and target vulnerability determine the weapon's chance of achieving a kill. Studies of the final engagement are important, not only to determine the overall lethality, but also because they reflect back on other phases. If certain approaches of the weapon are found to give a higher kill probability than others, this will dictate a preferred launch position, therefore the desired position for AI contact and so the required tactics for the ground controlled phase.

Auxiliary Phases - The block diagram of figure 4 shows more than the four principal attack phases outlined above. Preliminary to the ground control phase, early warning of attack may have been used to alert the interceptors, and to assist in detection of the target by the ground control radars. After the interceptor has launched its missile against the bomber, it may reattack the same target, or engage a second bomber, before terminating its mission. These three phases, early warning, reattack, and return-to-base, must be considered in any studies where the total time duration of a fighter sortie is important.

2.0 EVALUATION OF EFFECTIVENESS

A brief discussion of the considerations involved in the evaluation of an interceptor system is given in this section. The purpose is to demonstrate the complexity of the problem and to place in proper perspective the limited study which is summarized in this report. An outline of the scope of the CARDE study is given, and relevant subjects which have not received attention are highlighted.

2.1 Method

The methodology by which optimal design of a weapon system is set up, or by which an existing or proposed system is evaluated, is called "weapon system analysis". A complete assessment of the worth of an interceptor system considers

(a) performance of equipment,

(b) base installation and manpower needs,

(c) deployment and operational use of forces,

(d) production schedules and cost,

in the light of an enemy threat potential.

A more restricted assessment is one in which only technical aspects of component performance are considered without regard to the logistic and economic problems of providing the system, or to the operational problems of using it. Such a restricted weapon system analysis, which may be called a "technical evaluation", would show what level of defence can be provided by an existing or proposed system.

The CARDE assessment of the CF 105 Interceptor System is a restricted study of this sort.

2.2 Criteria of Effectiveness

Careful attention must be paid to choosing the proper criterion of success. Quantities which might serve as standards of evaluation are

(a) attrition potential

(b) cost

(c) interception probability

If operational factors such as the size and deployment of attacking and defending forces, can be included in the evaluation, a useful measure of worth is the attrition which can be inflicted on an invading bomber force by the defending interceptors. If economic and logistic aspects of the problem are studied, the cost of providing a given level of defence, whether absolute or partial, becomes the most meaningful criterion. In a purely technical assessment a more limited criterion must be used. Here the effectiveness of the interceptor system is best described in terms of the probability of successful interception of a bomber or of a raid. It is a limited form of this criterion that is used in the present study.

2.3 Computation of Effectiveness

Interception of a bomber threat requires success in

(a) detection of the threat

(b) positioning of the interceptor

(c) survival of the interceptor until missile launch

(d) missile flight

(e) operation in the face of enemy countermeasures

This concept may be expressed as the probability of successful interception, written symbolically as

$$P_E = P_D \cdot P_P \cdot P_S \cdot P_K \cdot R \cdot P_J$$

where

P_D = probability of detecting the threat.

P_P = probability of successful positioning of the interceptor

P_S = probability of survival of the aircraft until missile launch.

P_K = lethality or kill probability of the weapon system.

R = reliability of the system.

P_J = probability that the system will not be degraded due to electronic countermeasures.

An interceptor system effectiveness study must, to be complete, provide numerical values, or ranges of values, for each of these factors.

2.4 Scope of Work to Date

Work at CARDE has proceeded within the framework of the following situation:

(a) one interceptor against one bomber

(b) high altitude targets (above 35,000 feet)

(c) conventional guided missile armament.

The first assumption is not entirely realistic, but work based on it does provide a valid measure of the interceptor's worth and points out the most critical system parameters, at the same time keeping the study within reasonable bounds. Tactical recommendations based on a one-to-one assessment must be examined critically, however, before they are applied to a multiple attack situation.

In figure 4 the phases which have received attention at CARDE are outlined in solid lines. The dotted blocks represent areas which are outside of the scope of the study. Most of CARDE's effort has been concentrated on evaluating the placement probability P_P for the CF 105 against various targets. Some work has been done, and is continuing, towards finding values for P_K, P_J and P_S. The problem of ground environment, and so the determination of P_D, has not been attempted. The accuracy of ground control has been retained as a parameter, however.

The most immediate requirement from the CARDE study was an appreciation of the effects on system usefulness of variations in performance of the AI radar and of the aircraft. Attention has been concentrated on supersonic targets since this is the most severe requirement.

An extensive parametric study has been undertaken in which wide ranges of values for the following are used:

(a) aircraft turn capability

(b) AI radar performance

(c) ground control accuracy

(d) target velocity

(e) target manoeuvre

(f) target altitude

(g) missile characteristics

(h) attack modes

(i) attack course difference

From the results, the appropriate value of placement probability for a given set of values of these parameters may be obtained.

3.0 THE CF 105 AIRCRAFT

The CF 105 is a two-seater all-weather interceptor designed for five minutes combat at 50,000 feet and Mach 1.5, but capable of speeds a little beyond Mach 2 for short lengths of time. It is powered by two Orenda PS-13 (Iroquois) engines, maximum thrust per engine at sea-level being 22,000 lbs.

3.1 Aircraft Geometry

The CF 105 has a delta wing planform with negative camber and 4° anhedral. There are 5% chord notches and 10% chord drooped extensions on the outboard sections of the wings. These improve the pitch-up and buffet characteristics and the lateral static stability. A three-view drawing of the aircraft is shown in figure 5.

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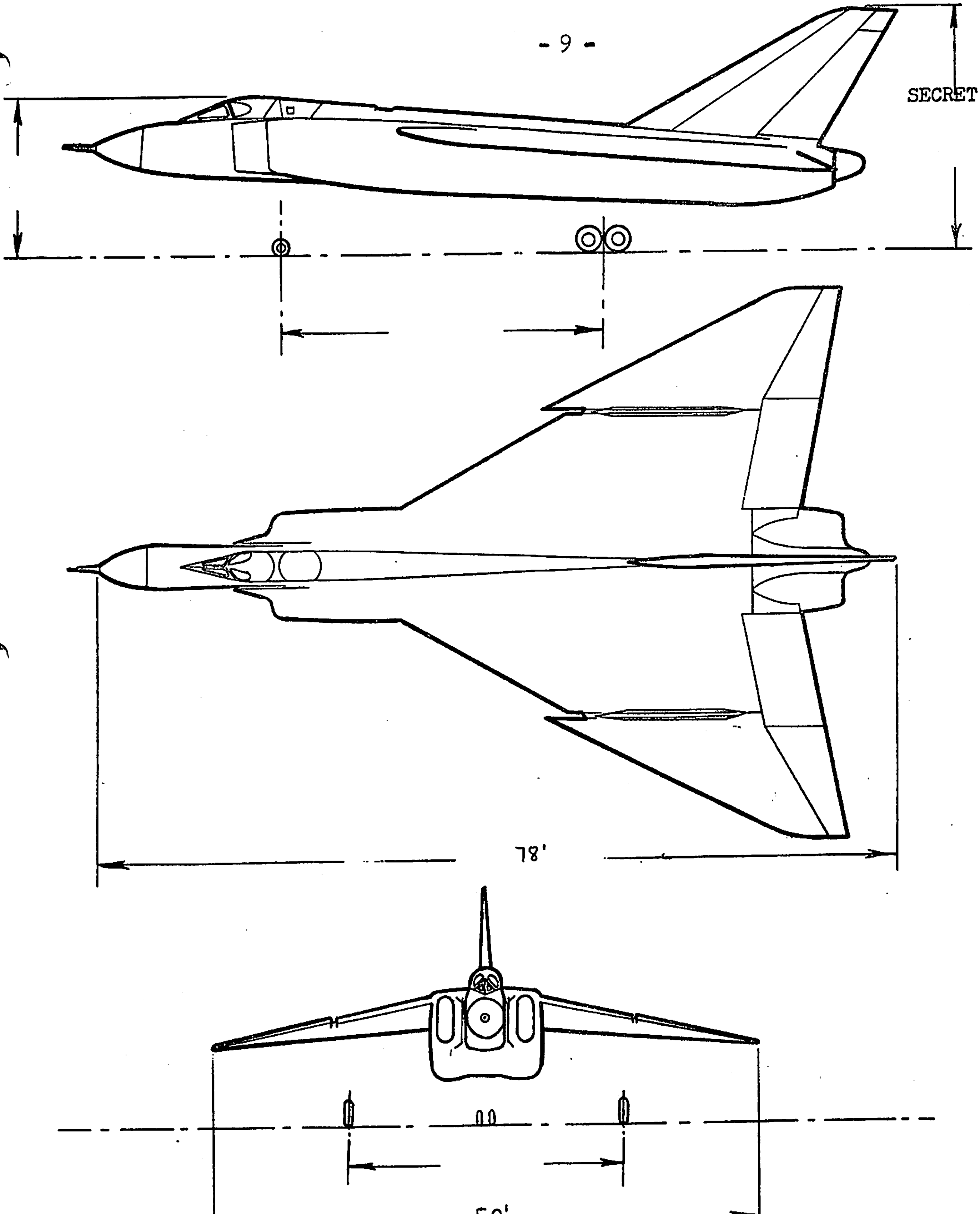


Figure 5. The CF 105 Interceptor.

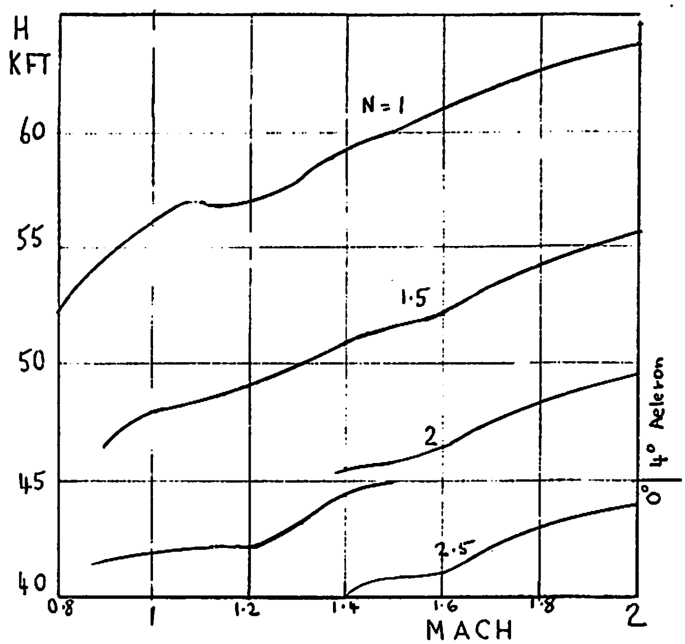


Fig. 6. Available Steady G's.

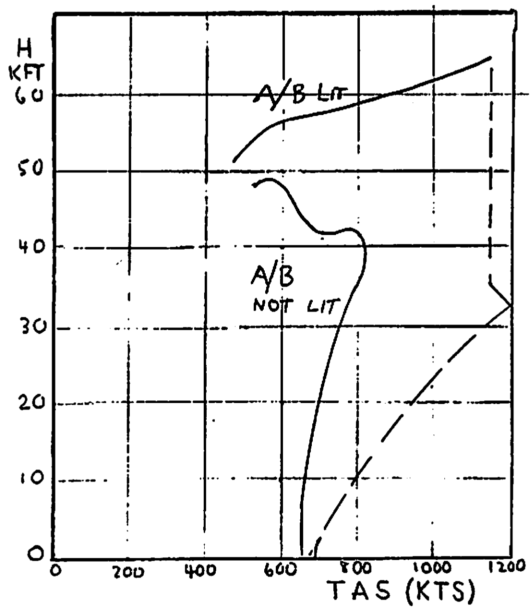


Fig. 7. Maximum Level Speed.

3.2 Aircraft Performance

Performance data using the latest AVRO estimates, extracted from AVRO's Periodic Performance Report, Number 10, are reproduced here. Figure 6 shows the variation of altitude and Mach number for various steady state normal accelerations at combat weight with afterburners lit. Figure 7 shows the maximum level speed as a function of altitude. The loading and performance under standard atmospheric conditions are summarized below.

WEIGHT:

Take-off Weight with 15,672 lbs fuel (78.9% Max)	Lb.	59,336
Operation Weight Empty	Lb.	43,664
Combat Weight	Lb.	51,500
Normal Design Landing Gross Weight AIR 7-4 - MIL-S-5701 . . .	Lb.	45,854
Wing Loading at Normal Take-Off Weight	Lb/Sq.Ft.	48.4
Power Loading at Normal Take-off Weight	Lb/Lb.Thrust	1.34

SPEED:

True Airspeed in Level Flight at Sea Level at Combat Weight		
Maximum Thrust A/B Lit	Kts.	700 *
Maximum Thrust A/B not Lit	Kts.	671
True Airspeed in Level Flight at 50,000 Ft. at Combat Weight		
Maximum Thrust A/B Lit	Kts.	1147 *

CEILING:

Combat Ceiling at Combat Weight, Rate of Climb = 500 F.P.M. Maximum Thrust at 2.0 M.N. A/B Lit	Ft.	63,300

RATE OF CLIMB:

Steady Rate of Climb at Sea Level, Combat Weight		
Maximum Thrust at M.N. = .92 A/B Lit	F.P.M.	60,600
Maximum Thrust at 527 Kts. A/B not Lit	F.P.M.	27,200
Steady Rate of Climb at 50,000 Ft., Combat Weight Maximum Thrust at M.N. = 2.0 A/B Lit	F.P.M.	14,500

TIME TO HEIGHT:

Time to 50,000 Ft. M.N. = 1.5 from Engine Start at Take-Off Weight Maximum Thrust A/B Lit	Mins.	4.33

MANOEUVRABILITY:

Combat Load Factor at Combat Weight	
Maximum Thrust at M.N. = 1.50 at 50,000 Ft. A/B Lit	1.63
Maximum Thrust at M.N. = 2.00 at 50,000 Ft. A/B Lit	1.96

---

* AIR 7-4 Placard Speed

TAKE-OFF DISTANCE:

Take-off Distance over 50 Ft. Obstacle at Sea Level at Take-off Weight = 59,336 Lbs.

Maximum Thrust A/B Lit	Ft.	2,850
Maximum Thrust A/B not Lit	Ft.	4,430
Maximum Thrust Hot Day A/B Lit	Ft.	3,460

LANDING DISTANCE:

Landing Distance over 50 Ft. Obstacle at Sea Level at Normal Design Landing Gross Weight	Ft.	4,810

STALLING SPEED:

True Stalling Speed in Landing Configuration at Combat Weight at Sea Level	Kts.	111.5

RANGE:

Combat Radius of Action at 50,000 Ft. Climb at 527 Kts. T.A.S. Accel. to M = 1.5 @ 30,000 ', Climb @ M = 1.5 to 50,000', Cruise-out at M.N. = 1.5, Combat for 5 Mins. at M.N. = 1.50, Cruise-back at M.N. = .92, 15 Min. Stack at 40,000 Ft., 5 Min. Fuel Reserve on landing

High Speed Mission with 15,672 Lbs. Fuel	N.M.	200.0
High Speed Mission with Full Internal Fuel (SG = 0.78)	N.M.	302.0

Combat Radius of Action at 50,000' Mission as above except Cruise-out at M.N. = .92

Maximum Range Mission with 15,744 Lbs. Fuel	N.M.	300.0
Maximum Range Mission with Full Internal Fuel (SG = 0.78)	N.M.	450.0

Ferry Range Mission at Economical Cruise Speed (Cruise climb from 36,500' to 41,500' at M = .92) including 15 Mins. Stacking at 40,000 Ft., 5 Min. Fuel Reserve on Landing

Range with Full Internal Fuel and 500 Gal. - External Tank (SG = 0.78)	N.M.	1460.0

4.0 THE ASTRA I ELECTRONIC SYSTEM

For the CF 105 aircraft, the Radio Corporation of America is developing the ASTRA I Electronic System. It is a modern electronic control system in which flight controls, target detection and tracking devices, armament firing functions, communications, and airframe are one integrated system. A simplified block diagram showing the principal system components is given in figure 8.

The RCAF specification to which the ASTRA I system is designed, requires a detection range of 25 miles on a target of 5 square meter radar cross section. This is to be provided by a high power pulsed X-band radar. The principal characteristics of the radar and the antenna are as follows:

Magnetron peak power output 1 megawatt

Frequency range 8800 - 9400 Mc/s

Search Mode P.R.F. 330, Pulse width 2.5 μs

Track Mode P.R.F. 1000, Pulse width 0.5 μs

Antenna Diameter 32 in.

Antenna Gain 35 db

Antenna Beam width 2.7°

Polarization completely variable

Tracking rate limits 0.1 to 228 °/sec

Search Scan 140° x 13°

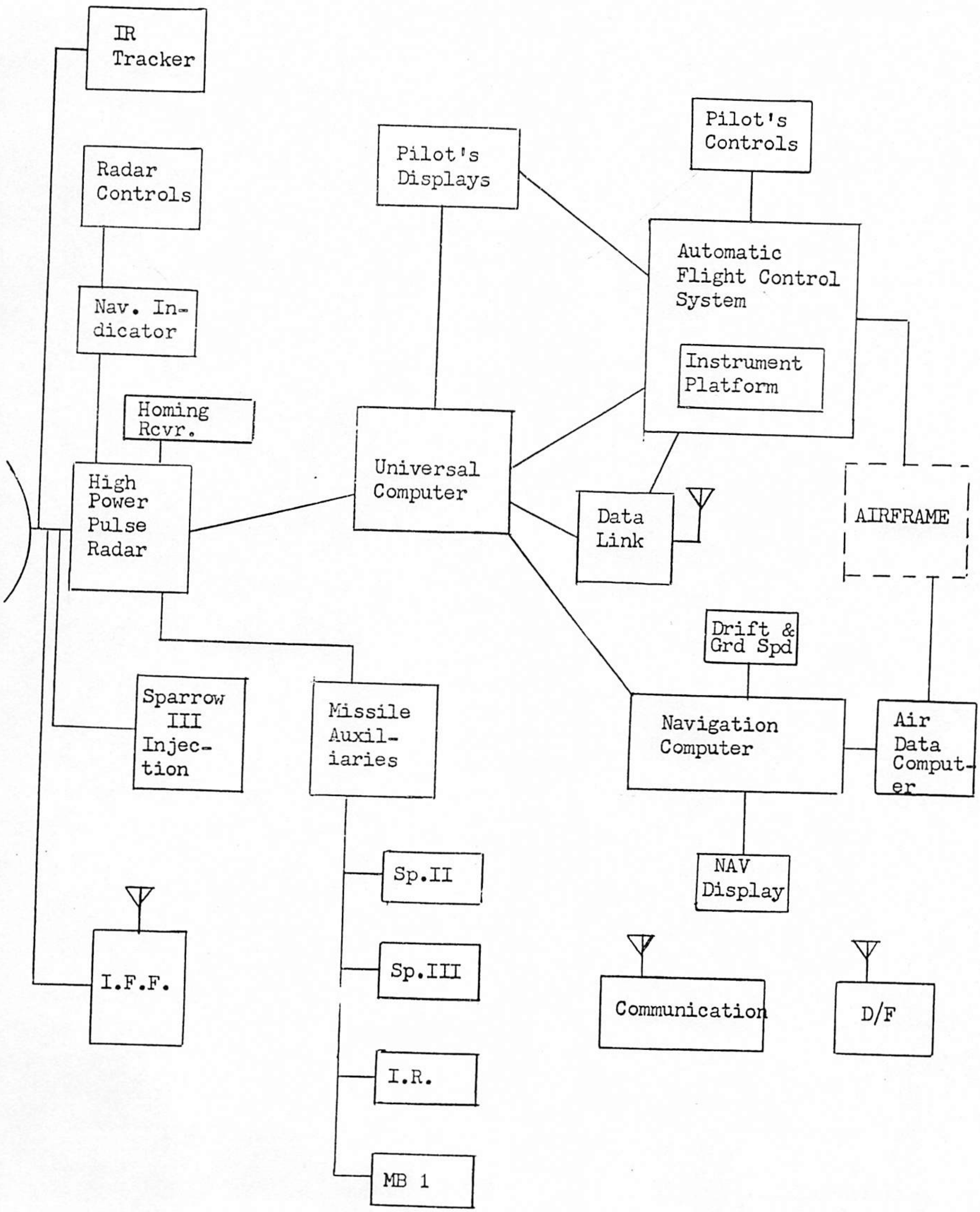
Azimuth Limits ± 70°] Rectangular field

Elevation Limits + 75°, - 45°] Rectangular field

Track Scan-Conical with 75 cps nutation rate, and 1.5 db crossover

Receiver Overall Noise Figure ≈ 10 db

Figure 8. Simplified Block Diagram of Electronic System.



In addition to active detection and tracking of targets, provision is made for passive tracking on ECM transmissions using a homing receiver, and for infrared tracking using an IR detector slaved to the AI antenna.

Provision is made in the missile auxiliary and fire control subsystems for the use of Sparrow II, Sparrow III, and long range unguided rockets, as armament. Both lead collision and lead pursuit attack modes are provided by the universal computer.

Automatic or manual interceptor control is permitted at all times by the automatic flight control system which can combine inputs from the fire control computer, the air data computer, the data link, and manual controls. Appropriate filtering and limiting action is provided.

The Navigation computer will be able at all times to determine the geographic position and heading of the aircraft using data from TACAN, the air data computer, data link or manual inputs, and provide this information to the fire control computer, the navigator's display, and the automatic flight control system.

5.0 TARGETS

Two classes of target are considered in the CARDE Assessment, the high subsonic swept-wing bomber, and the supersonic bomber. Both are considered as realistic threats for the operational period of the CF 105 which is assumed to terminate in 1970. The subsonic bomber should exist in large numbers until 1965, whereas the supersonic bomber may begin to appear in 1960. Other bomber threats of higher performance may also exist in the time period. These could be air-breathing unmanned aircraft of higher speed and altitude capability than the manned bombers studied in this evaluation. The sketch in figure 9 shows the time scale of various bomber threats which may have to be faced.

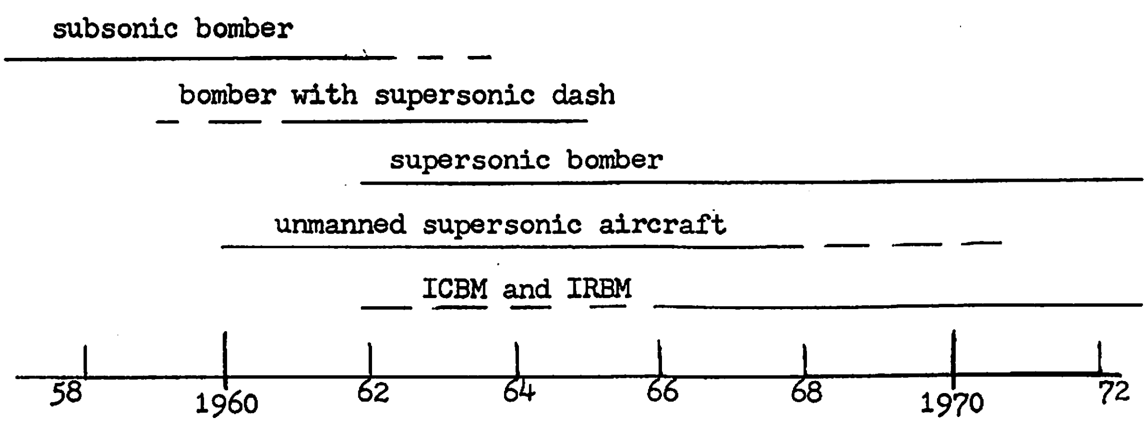


Figure 9. Time Scale of Threat.

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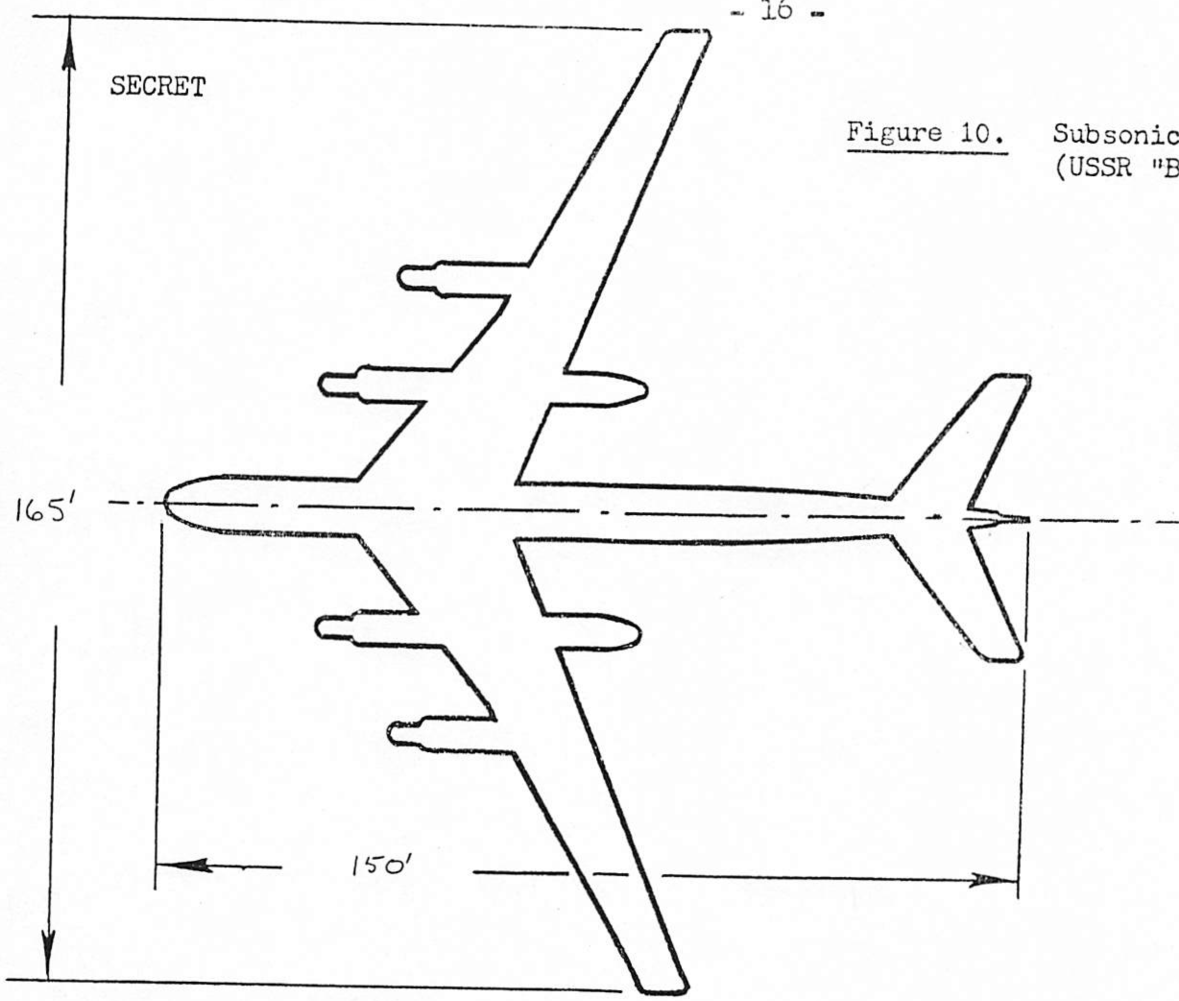


Figure 10. Subsonic Target (USSR "Bear") .

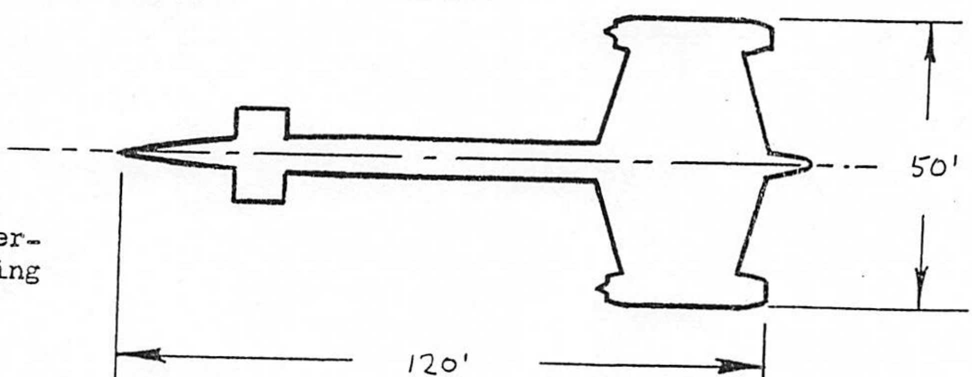


Figure 11.

Hypothetical Supersonic Straight Wing Bomber.

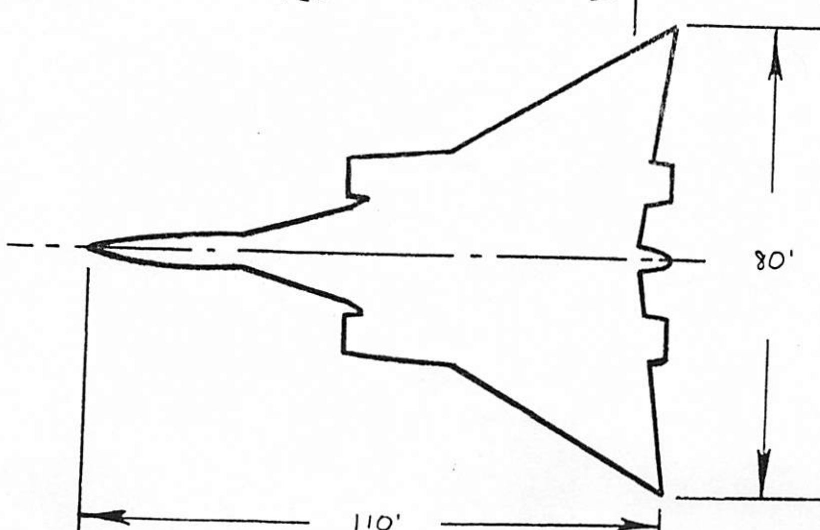


Figure 12.

Hypothetical Supersonic Delta Wing Bomber.

5.1 Performance Characteristics

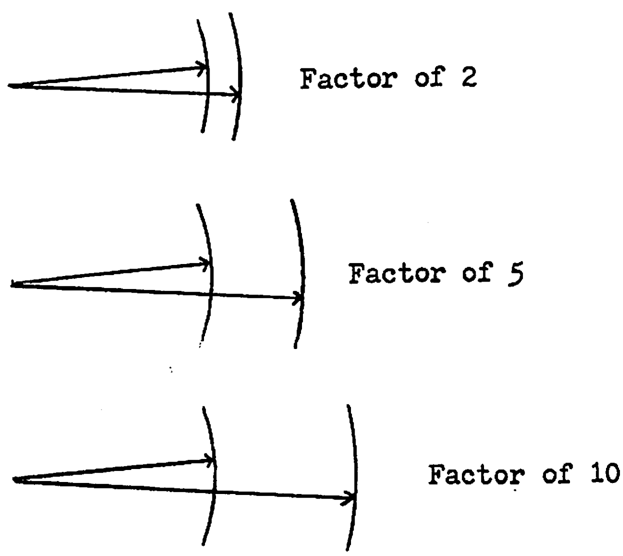
(a) Subsonic Target - The subsonic bomber which is being considered in the CARDE work is the Bear swept wing turbo prop bomber. Salient characteristics are given in figure 10.

(b) Supersonic Targets - No definite supersonic bomber has been designated to CARDE as representing a typical threat. Two basic types of high speed bomber, having the same performance but differing in configuration, have been proposed. These are illustrated in figures 11 and 12.

5.2 Radar Cross Section

Calculation of interceptor placement probability requires knowledge of the available detection range of the AI radar. This quantity is a function of aspect for a given target, and is different for different targets, varying as the fourth root of the radar cross section. Figure 13 shows how the cross section value is an insensitive parameter in determining detection range. Errors in assumptions regarding this parameter for a given target therefore have a small effect on the calculated radar range.

Figure 13.



Radar Range

$$= K \left[P_T \cdot A \right]^{\frac{1}{4}}$$

Dependence of Radar Range on Target Cross Section A.

For the subsonic bomber considered as a target in this study, values of B-52 cross section have been used in determining the acquisition contours. Two different contours are proposed for the supersonic targets; one for a "Delta" target having large head-on reflection area and one for a "Straight wing" target. The values of radar cross section used for the three targets are tabulated here.

Aspect / Target	Tail			Beam					Nose	
	0	30	60	80	90	100	110	120	150	180
Subsonic Swept Wing	4	4	4.5	140	*-	100	30	10	4	4
Delta Supersonic	8.0	5.9	22.4	-	200	-	-	18.7	16.6	17.5
Straight Wing Supersonic	1.0	1.0	4.0	12.0	-	-	-	2.75	2.25	2.5

* - very large

Table I. Radar Cross Section Values

5.3 AI Acquisition Range

Acquisition range is that range at which the AI radar, after detection of the target, may be locked on to it so as to provide steering instructions. In a track-while-scan or manual tracking mode, it would be defined as that range at which steering instructions can commence, after detection of the target. It has been assumed in this study that the median value of acquisition range is equivalent to the range for 80% probability of detection. This assumption is illustrated in figure 14.

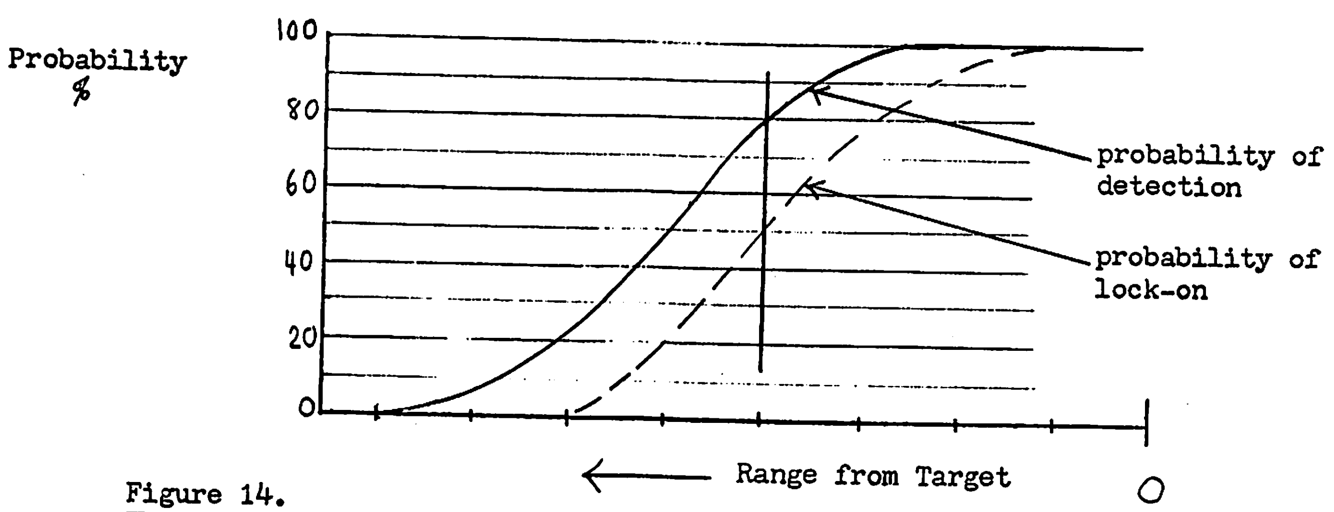


Figure 14.

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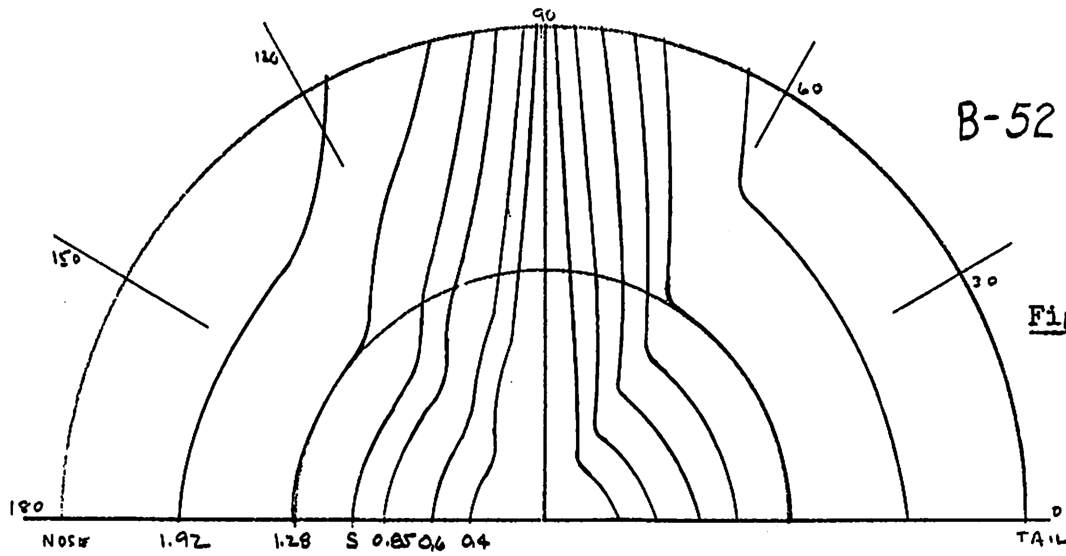


Fig. 15.

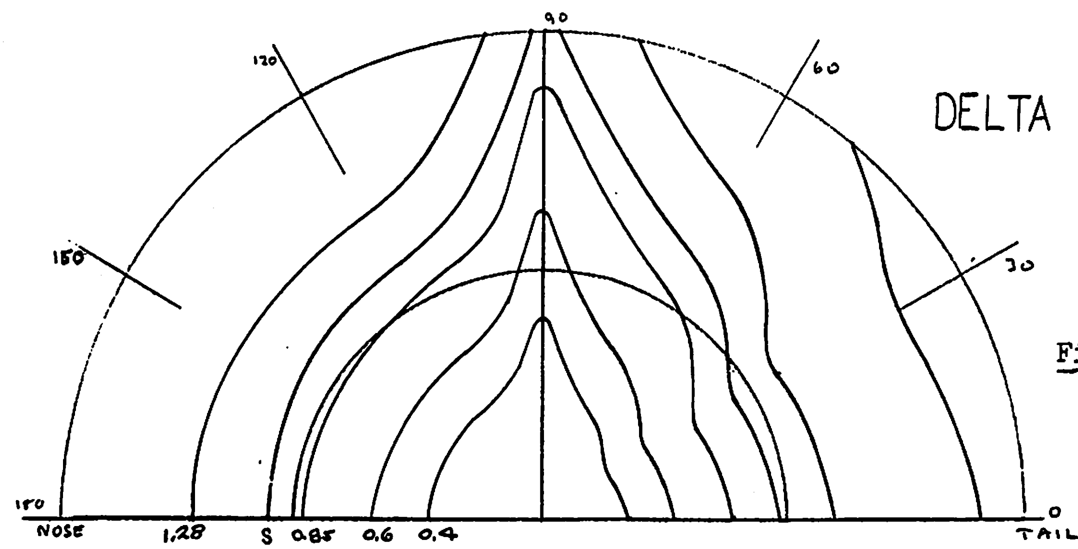


Fig. 16.

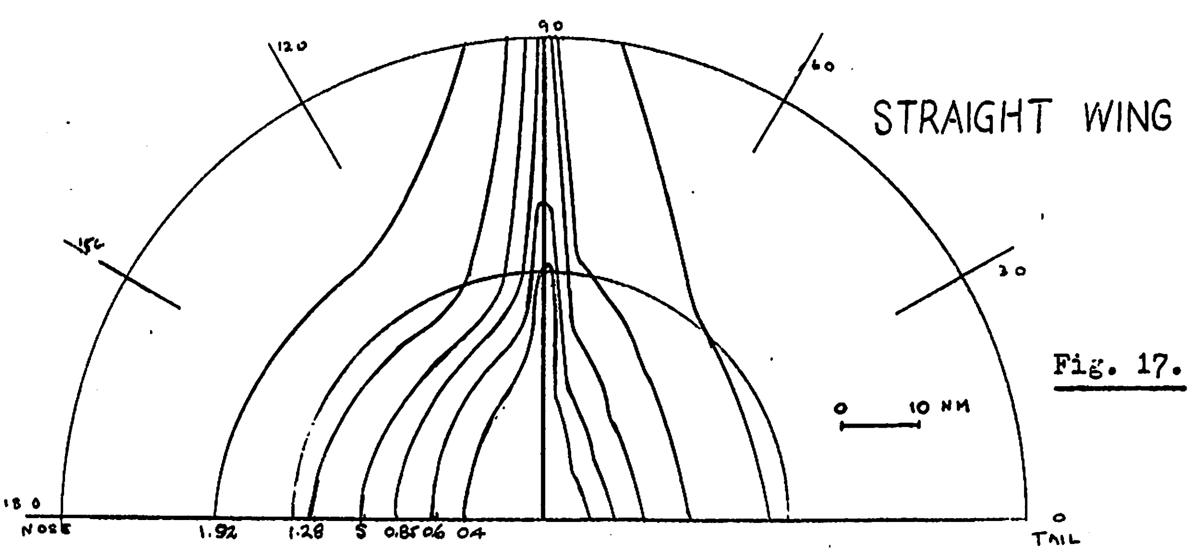


Fig. 17.

The RCAF Specification for the ASTRA I AI system states a range of 25 nautical miles for 80% probability of detection of a target having 5 square meters reflection area at X-band. This figure has been used in computing expected acquisition range for the targets considered in this study.

Figures 15 to 17 give polar graphs of expected acquisition range for the three targets. Contours are given for various degrees of AI performance, designated on the graphs, and throughout the study, as

S:	Range required by RCAF Specification.
1.92S:	Range proposed by RCA for final development.
1.28S:	Range proposed by RCA for the degraded system.
.85S: .6 S: .4 S:	Various degradations of the specification which may be due to maintenance, enemy countermeasures, atmospheric conditions, operator inexperience, or may represent range actually obtainable if the target has a smaller radar cross section than that proposed here.

Semicircles are drawn on the graphs to indicate the 30 nm lock-on range capability demanded by the specification, and the 60 nm limit of the search presentation.

6.0 GROUND ENVIRONMENT

The ground environment in which the CF 105 interceptor will function is at the present time indeterminate. It could be similar to the present-day system which uses manual ground tracking of the target, and voice link communication. Such a system can function with close or broadcast control, depending on the navigation capability of the interceptor. It is more probable that some semi-automatic or automatic system such as SAGE, BADGE, or CAGE, where automatic tracking and data link for communication are used, will become available.

The CARDE assessment has not concerned itself with studies of possible ground environments. Ground control accuracy has been retained as a parameter however, so that when the nature of the system and its performance are known, these data may be combined with the results of the CARDE study so as to determine the overall system effectiveness. Conversely, the CARDE results may be used as a basis for defining the ground control accuracy which will be required for the operation of the CF 105 interceptor system.

The measure of ground control accuracy used in this study is the standard deviation, σ, of the displacement of the interceptor track, relative to the target, from the ideal line of approach. Assuming that errors about the ideal line are symmetrical, σ is the half-width of the corridor in target space, in which 68% of interceptors will be placed. This concept is illustrated graphically in figure 18.

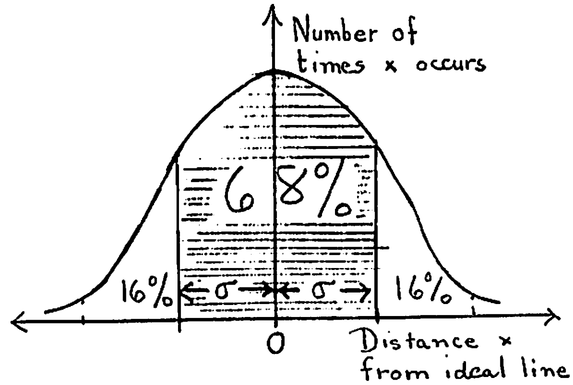


Figure 18. Distribution of Interceptor Tracks.

The range of values assumed for σ throughout the CARDE study is from 1.5 to 9 nautical miles. Present day ground environment can achieve a placement accuracy of about 3 miles for subsonic interceptors and bombers. As aircraft speed increases accurate placement becomes more difficult; more automatic methods should however reduce time delays and errors in ground control. It is felt that the range of values which has been used is realistic for the operational period of the CF 105.

7.0 ARMAMENT FOR THE CF 105

It has been proposed that the CF 105 will be armed with some member of the Sparrow family of missiles, or with long range unguided rockets. Provisions are being made in the electronic system for launching the rockets, Sparrow II, Sparrow III, and an infra-red version of Sparrow.

While the performance of these missiles for subsonic launch against subsonic targets is well known, little information is available concerning their behaviour when launched at supersonic speeds against supersonic targets at high altitudes. However, as will be pointed out in Section 17 of this report, the reasonable approximations which have been employed should yield accurate results.

8.0 INTERCEPTION TACTICS IN THE AI PHASE

Although the ground control may direct the interceptor to a position roughly suitable for its attack, the final approach will be made under the guidance of the aircraft's own AI radar and fire-control computer. The interceptor, after detecting the target by means of its AI radar, will attempt to fly a course which will bring it within suitable range of the target, and with proper heading, for delivery of its weapon.

This section introduces and discusses some concepts which are used in the study of the AI phase of the attack, and which form the basis for the computations of probability of interceptor placement.

8.1 Mode of Attack

It is expected that the interceptor will be steered for a missile attack by one of the following methods:

a) lead collision

b) lead pursuit

c) some combination of (a) and (b).

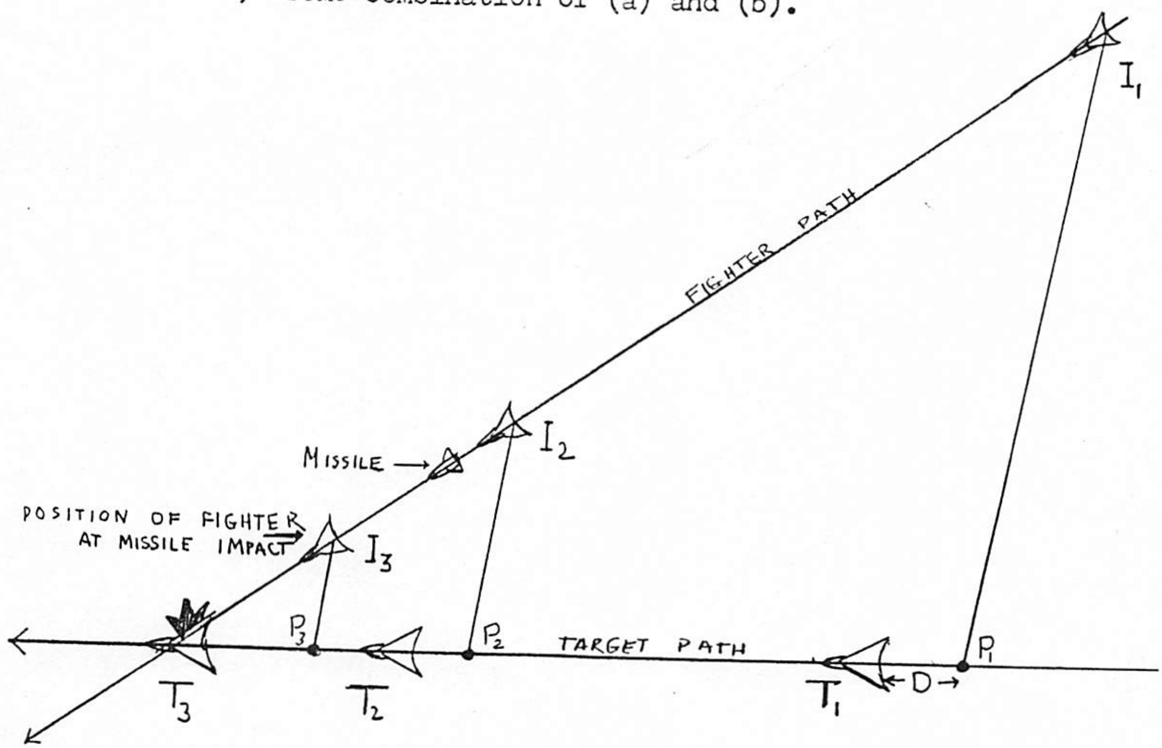
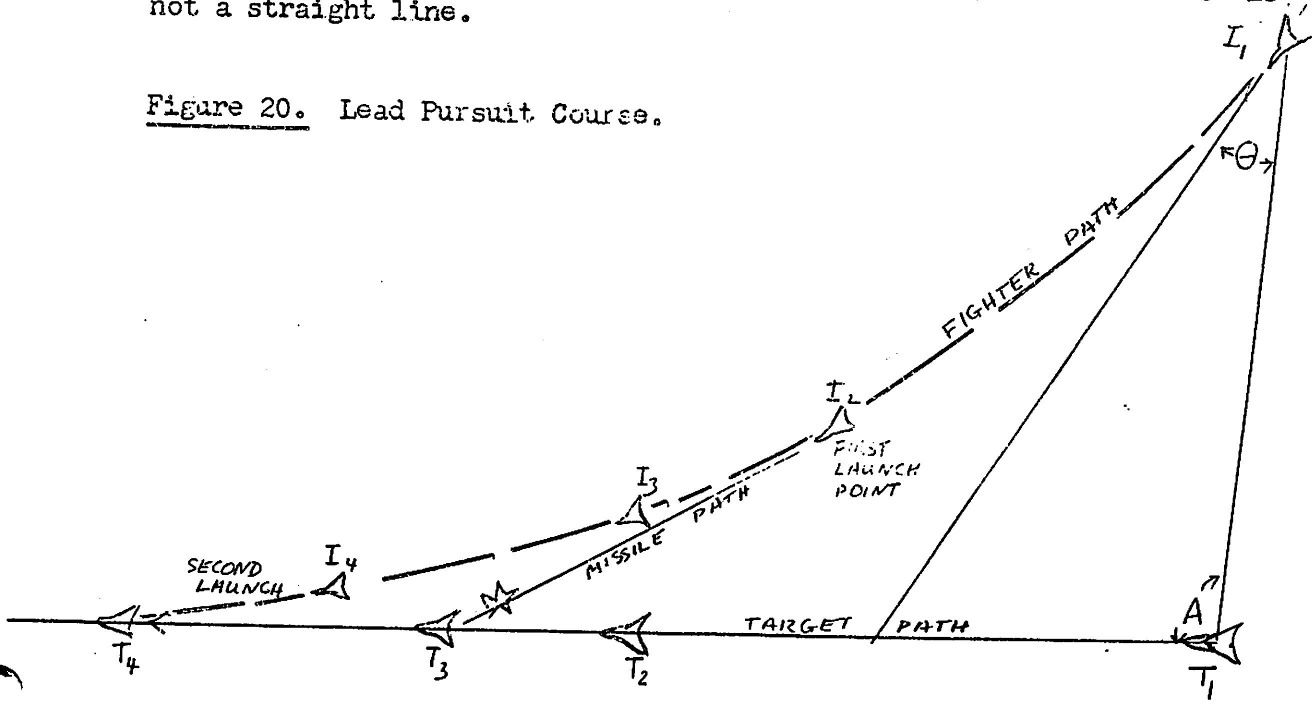


Figure 19. Lead Collision Course.

(a) A lead collision course is illustrated in figure 19. It is assumed that the missile is launched so that its flight time is t, a fixed quantity for all aspects. If the average missile velocity is V_M and the interceptor velocity V_I, then the relative travel, F, of the missile is $(V_Mt - V_It)$. The missile range is $(V_It + F)$; a missile's launch characteristics can be described in terms of t and F. A lead collision course is defined as the straight line interceptor course which permits launch of the missile with relative missile flight F, with the missile continuing on the same straight line after launch. The interceptor, being slower, passes behind the target, at a distance $D = FV_T/V_I$ where V_T is target velocity.

For a non-evading target, the lead collision course is a straight line, and the line of sight to P constant in direction. For an evading target the formulas given above are no longer exact, and the course is not a straight line.

Figure 20. Lead Pursuit Course.



(b) A lead pursuit course is illustrated in figure 20. During such a mode the interceptor is always pointed at some point ahead of the target, such that if the missile were released, it would be on a collision course with the target. If A is the aspect angle, the angle of lead θ is determined by $\sin \theta = V_T/V_M \sin A$. In this type of course the interceptor follows a curved path and the interception requires a longer time.

(c) Combined mode. In a lead pursuit attack mode the interceptor is always correctly headed for missile launch, provided the correct value of V_M is used in computing the lead angle. A lead collision course however, which is a straight line course, requires less interceptor manoeuvre, and provides a shorter interception time.

It has the disadvantage of requiring launch over a more restricted depth of allowable launch range. A combined course, where the first part is flown in a lead collision mode, and the latter part in lead pursuit, combines the advantages of both modes.

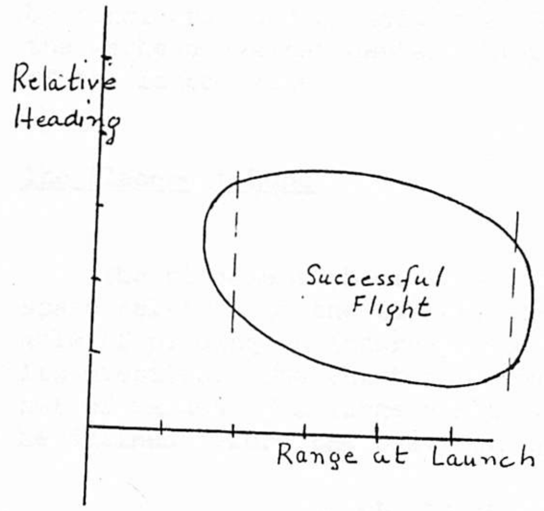


Fig. 21. Typical Allowable Launch Conditions for a given aspect.

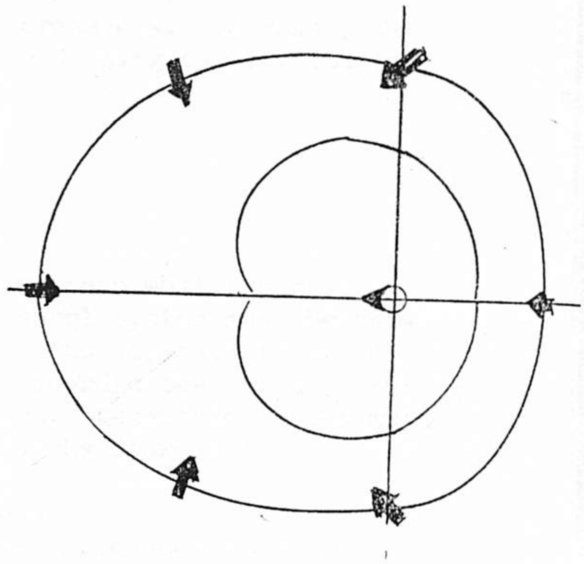


Fig. 22. Typical polar plot of missile launch zone in target coordinates.

8.2 Missile Launch Zone

A missile launch zone is defined by the maximum and minimum ranges permitted for launch, and the allowable values of missile heading relative to the target course. These quantities for a given missile are functions of:

Target Aspect
Target velocity and evasion
Interceptor velocity at launch
Altitude of Target and Interceptor

If a maximum allowable miss distance is assumed, a set of values of allowable launch ranges and headings may be defined for a given set of engagement conditions. A typical graph of such a launch zone for Sparrow type missiles is shown in figure 21. If a family of these curves for different aspects is available, a polar launch zone showing the variation of maximum and minimum launch range may be drawn. A parameter which must be chosen when this is done is the minimum allowable heading error from the ideal heading, usually taken as 10°. An example of such a polar launch zone is given in figure 2 2.

These launch zones are defined on a kinematic basis only - other factors may modify the parameters. The maximum range may be restricted by insufficient seeker range; the minimum range may have to be increased

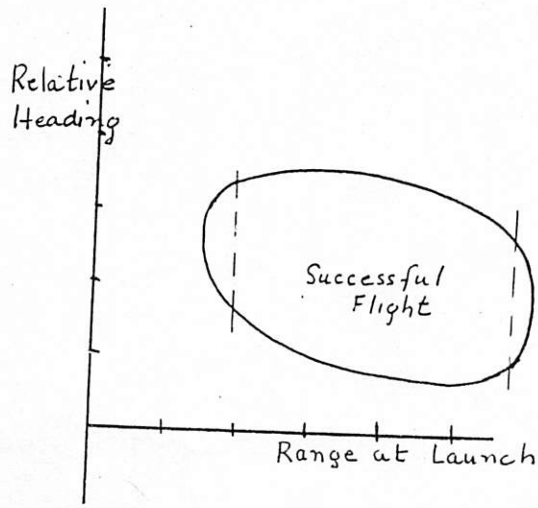


Fig. 21. Typical Allowable Launch Conditions for a given aspect.

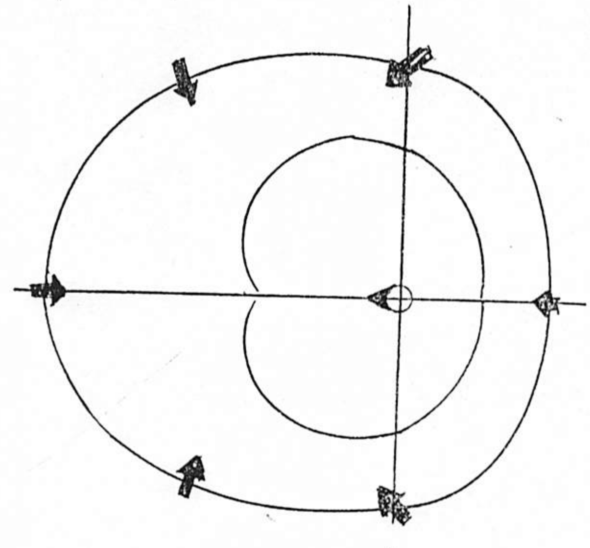


Fig. 22. Typical polar plot of missile launch zone in target coordinates.

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Target Aspect
Target velocity and evasion
Interceptor velocity at launch
Altitude of Target and Interceptor

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These launch zones are defined on a kinematic basis only - other factors may modify the parameters. The maximum range may be restricted by insufficient seeker range; the minimum range may have to be increased by considerations of safety in interceptor breakaway. Lethality of the warhead against certain targets may forbid using certain sectors of the launch zone.

8.3 The Placement Zone

The placement chart is a diagram showing into what region of space relative to the target, the ground control system must be capable of placing an interceptor, in order for the aircraft to launch its missiles. The chart is drawn in target coordinates for a given set of values of a large number of parameters. Quantities which must be defined before the positioning diagram may be drawn are:

Target and Interceptor Speeds
Initial Interceptor course difference relative to target
Target Evasion (lateral acceleration)
Interceptor turn characteristics
AI Radar look angle limit
Missile Launch Zone

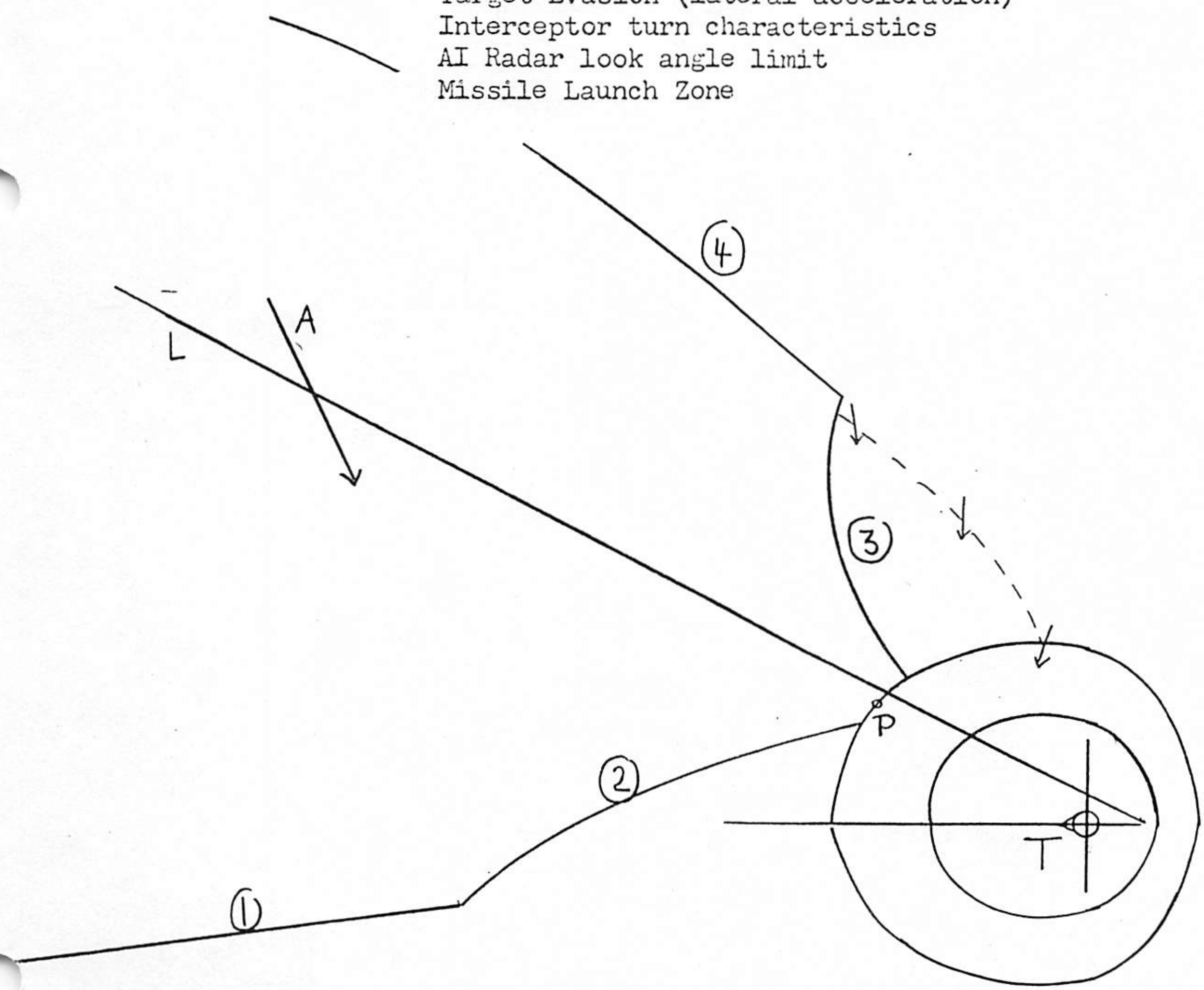


Figure 23. Typical Placement Chart.

A typical placement zone is drawn in figure 23. The vector A indicates the initial heading of the interceptor and T represents the target, with the missile launch zone drawn around it. The point P on the launch zone is that point at which the missile may be launched with the given initial heading. There is a region along the launch zone for which this heading is usable when the heading error allowance is taken into account. The ideal approach line L , along which the controller attempts to put the interceptor, passes slightly behind the target; it also passes near the point P .

If the original interceptor approach line is behind the correct line L , a turn to starboard must be made if the aircraft is to enter the launch zone at a correct heading for some more astern aspect than P . Curve (3) is the locus of the last point at which the turn may be started. It may be started sooner, but not later. In this sense the locus is a barrier called the manoeuvre barrier. Similarly curve (2) is the manoeuvre barrier for those cases in which the interceptor is initially ahead of the required line, and a port turn is required.

Curve (1) is the extension to the forward manoeuvre barrier; this is the line before which the corrective turn must be started if the target is to be kept in view on the AI radar. It is called a "look-angle barrier".

Curve (4) is the extension to the rear manoeuvre barrier. The interceptor which is approaching at the given initial course difference must make a starboard turn before crossing this line, in order to keep the target in view throughout the turn, and also, in the case of fighter speed disadvantage, to avoid falling behind the target.

8.4 Placement Probability

The probability of success in converting an approach into a successful attack may be found from the placement chart if the AI acquisition range and the ground control placement accuracy are known. A method for making the computation of placement probability P_p is illustrated in figure 24.

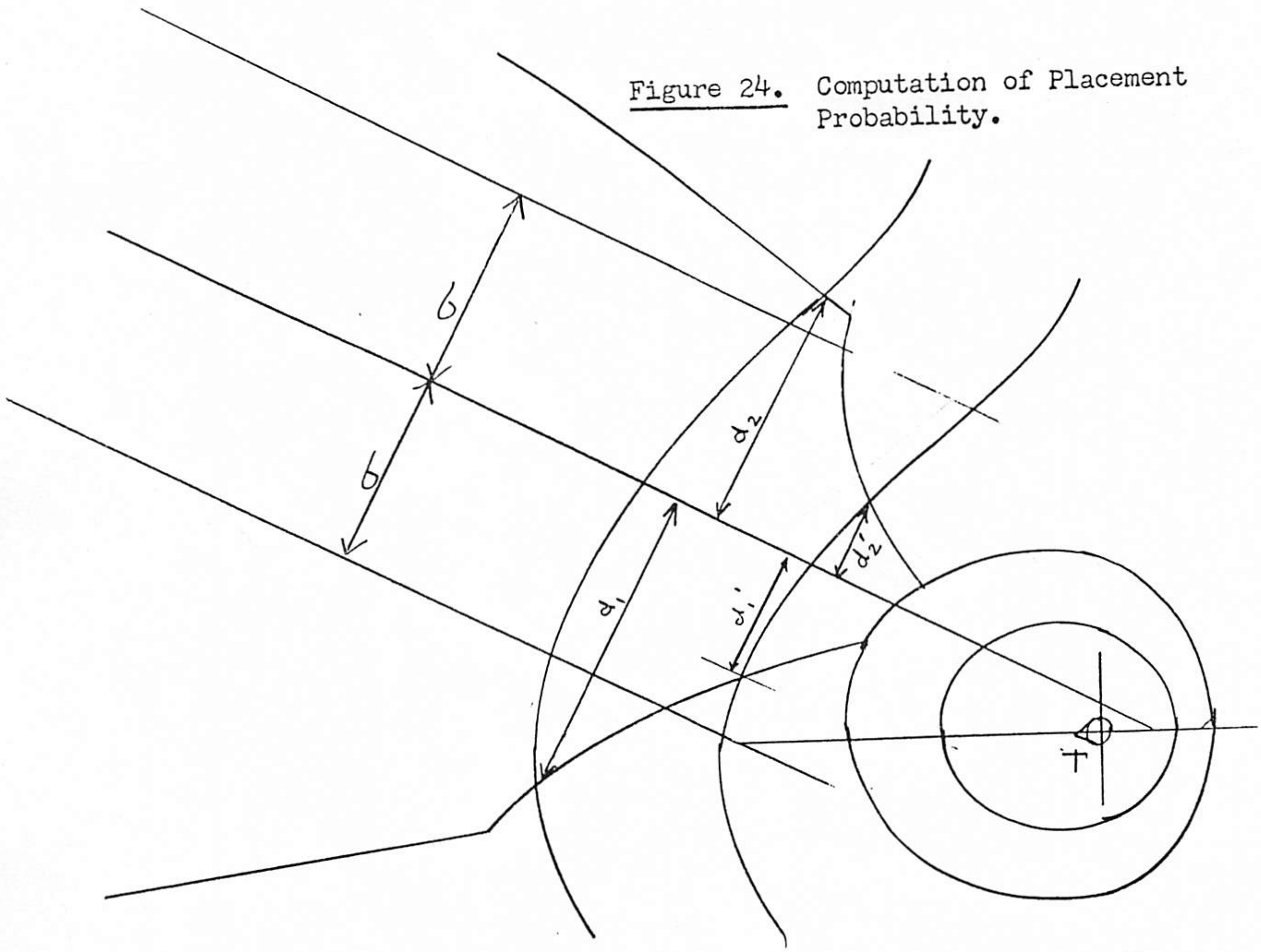


Figure 24. Computation of Placement Probability.

The 50% contour of probable AI acquisition range is drawn on the placement chart. This defines a curve before which corrective turns may not be initiated because of lack of information. Then the width of the allowable placement zone at the AI contour, when compared to the standard deviation of the ground control placement accuracy, gives a measure of the probability of success.

9.0 SUMMARY OF SYSTEM CAPABILITY

The study to date indicates that the CF 105 system has the following interception potential:

(a) Targets up to 58,000 ft. altitude can be intercepted in co-altitude attacks.

(b) Targets up to 70,000 ft. altitude can be intercepted in climbing attacks.

(c) Probability of positioning is 80% for targets of Mach number up to 2.5.

(d) For the subsonic bomber, target evasion load factor of 2.5 can be countered.

(e) For the supersonic bomber, target evasion load factor up to 1.4 can be countered using proper tactics.

(f) If correct tactics are used, chaff may be overcome.

(g) Against a supersonic target using barrage jamming of the AI, probability of successful positioning will be no greater than 10 or 20%, unless homing techniques are used.

(h) If the target uses a sophisticated technique of spot or repeater jamming the AI radar system loses all effectiveness.

Figure 25 compares the altitude capabilities of the system with the threat altitudes. The missile performance is the principal limiting factor at high altitudes. Interceptions at low altitudes have not been studied.

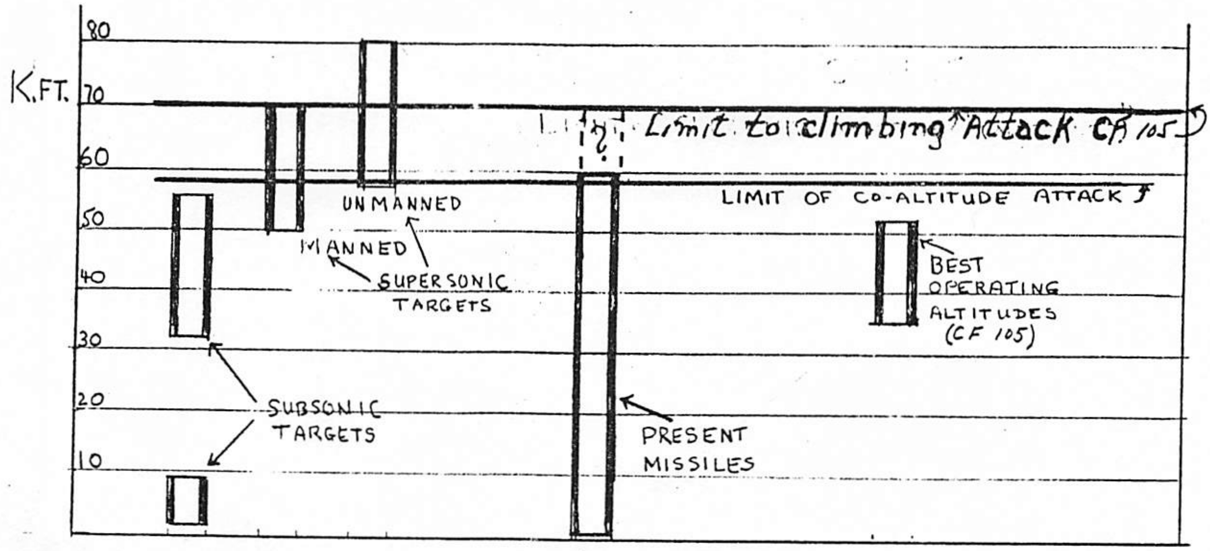


Figure 25. Targets, Interceptor and Missiles.

Figure 26 illustrates the variation of positioning probability with target speed. It must be realized that if these values of probability are to be attained, improved GCI is necessary. Since ground control accuracy decreases with increasing target speed, the present day system would not be adequate for controlling interceptions at supersonic speeds.

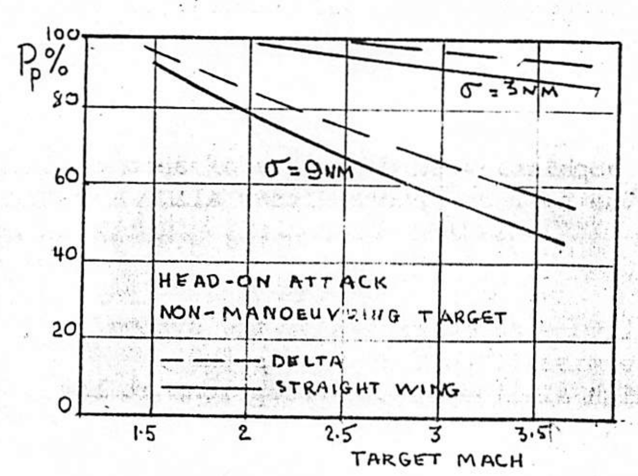


Fig. 26. Effect of Target Velocity.

The probability of successful interception is generally less for a target that will evade than for one that will not. The amount by which system performance is degraded by manoeuvre is very dependent on the evasion tactics which the target adopts.

10.0 EFFECTIVENESS AGAINST SUBSONIC BOMBERS

The CF 105 has a high capability of interception for subsonic targets such as Bear or Bison. Because of the interceptor speed advantage the placement zone will in most cases be limited only by the initial look angle and the time required for interception. The available look angle of the Astra System is large enough that even for the poorest GCI control accuracy which has been considered ($\sigma = 9$ n.m.) the placement chance is essentially 100%.

10.1 Interception Time

How severe the time factor may be depends on the speed chosen by the interceptor for its attack. A summary of the average time required for interception of a Mach 0.85 target is given in figure 27, for both supersonic and subsonic interceptions. It may be noted that in the supersonic case the duration of the AI phase of the attack is never greater than five minutes. The longer times shown for tail chase for the subsonic interceptor are rather unrealistic since it is most likely that the CF 105 would accelerate in this case, and so reduce the interception time.

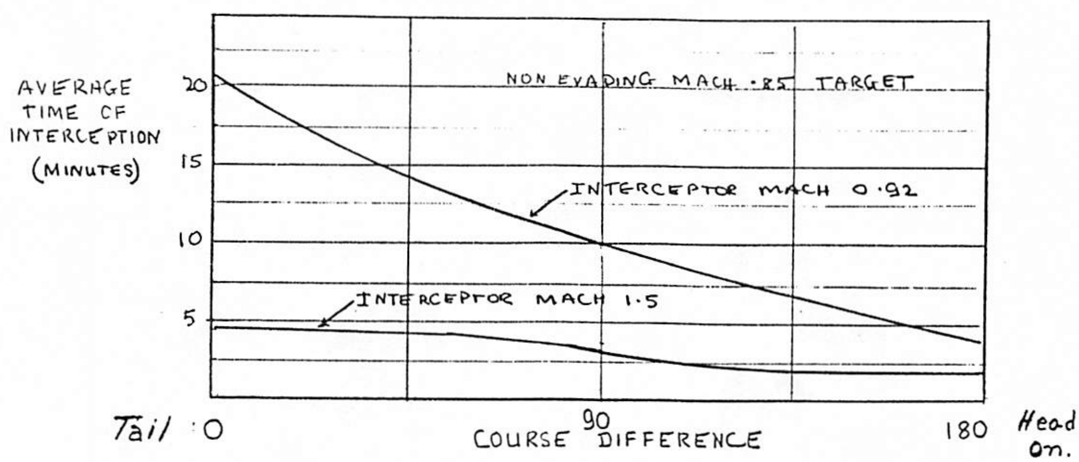


Fig. 27. Interception time for CF 105 against Subsonic Bomber.

If a figure of 10 minutes is adopted as a maximum interception time, the corresponding bomber penetration which results, from the beginning of the AI phase, is about 60 nautical miles. Computation of the total penetration which occurs between entry of the target into GCI cover, and missile impact, requires consideration of geographical factors. This topic has not been studied in the CARDE assessment.

10.2 Interception Chance with Degraded AI

If the interceptor chooses to attack at Mach 1.5, there will be some reduction in placement probability if the AI radar performance is seriously degraded. Table 2 gives values of P_p when the AI is subject to barrage jamming (2 watts transmitted power within the radar bandwidth).

Table 2.

Placement Probability for Mach 1.5 Interceptor vs Mach 0.85 Bomber (AI Range degraded to 0.33 of Specification)

σ N.M / Course Difference	1.5	3	4.75	6.75	9.0
70°	100	93	80	65	58
150°	85	65	55	51	45

The limiting factor in the placement zone is the manoeuvre barrier. It is seen that for this case the chance of success is better for rear aspect attacks.

If the interceptor is attacking at its subsonic speed, M .92, the placement probability for this amount of degradation remains above 85% since the manoeuvre barrier is not so restrictive.

The figures quoted here indicate that the crossover range available against a barrage jammer is sufficient to provide a reasonable probability of success in this case. The clear range of the AI against spot jamming is so small that no interception capability exists in this case, if reliance is placed on AI radar tracking only.

The figures given in Table 2 are for the probability of interception at the first approach. If the interceptor continues in its turn it will eventually reach a point from which interception can be made. However, in the course of the manoeuvre it will lose sight of the target in many cases, and will have to continue the turn using extrapolated target path, or obtain instructions from G.C.I.

Studies of a multiple target situation may reveal that traffic and saturation problems may limit reattack capability. The necessity of controlling many interceptors may require a limit on the amount of turn permitted to each. The difficulty of retaining identity of a given target and interceptor over a long period may make reestablishment of GCI control for a second pass difficult to achieve.

10.3 Evasion of the Subsonic Target

Bomber manoeuvres cannot prevent interception, but can force the fighter into a tail chase at reduced speed and so considerably increase the time required for interception. The implications of this would become apparent in an operational study with reference to geography.

10.4 Missile Performance

It appears that missile performance against the subsonic threat is adequate. The target altitude and Mach number range is well within the capabilities of Sparrow family missiles. Some doubt may be expressed, however, as to the effectiveness of fragmenting warheads with present V.T. fuzing. (See Section 22.0).

11.0 THE PARAMETERS OF THE INTERCEPTION PROBLEM

In the rest of this report the analysis is restricted to supersonic targets. Some attempt has been made to discuss separately the effect of each system parameter on the probability of successful placement. It must be stressed that such division is quite artificial, since the many parameters cannot be rigorously divorced one from the other.

Figure 28 is an attempt to display graphically the main parameters which affect the interception problem.

Whenever one of these parameters is isolated in order to demonstrate its effect on the system, values for the others must be postulated. However, trends which are discovered with one set of values can not be assumed to be universally true. In general, a study which starts at any one point on the circle of parameters, continues around the circle so that all must be discussed.

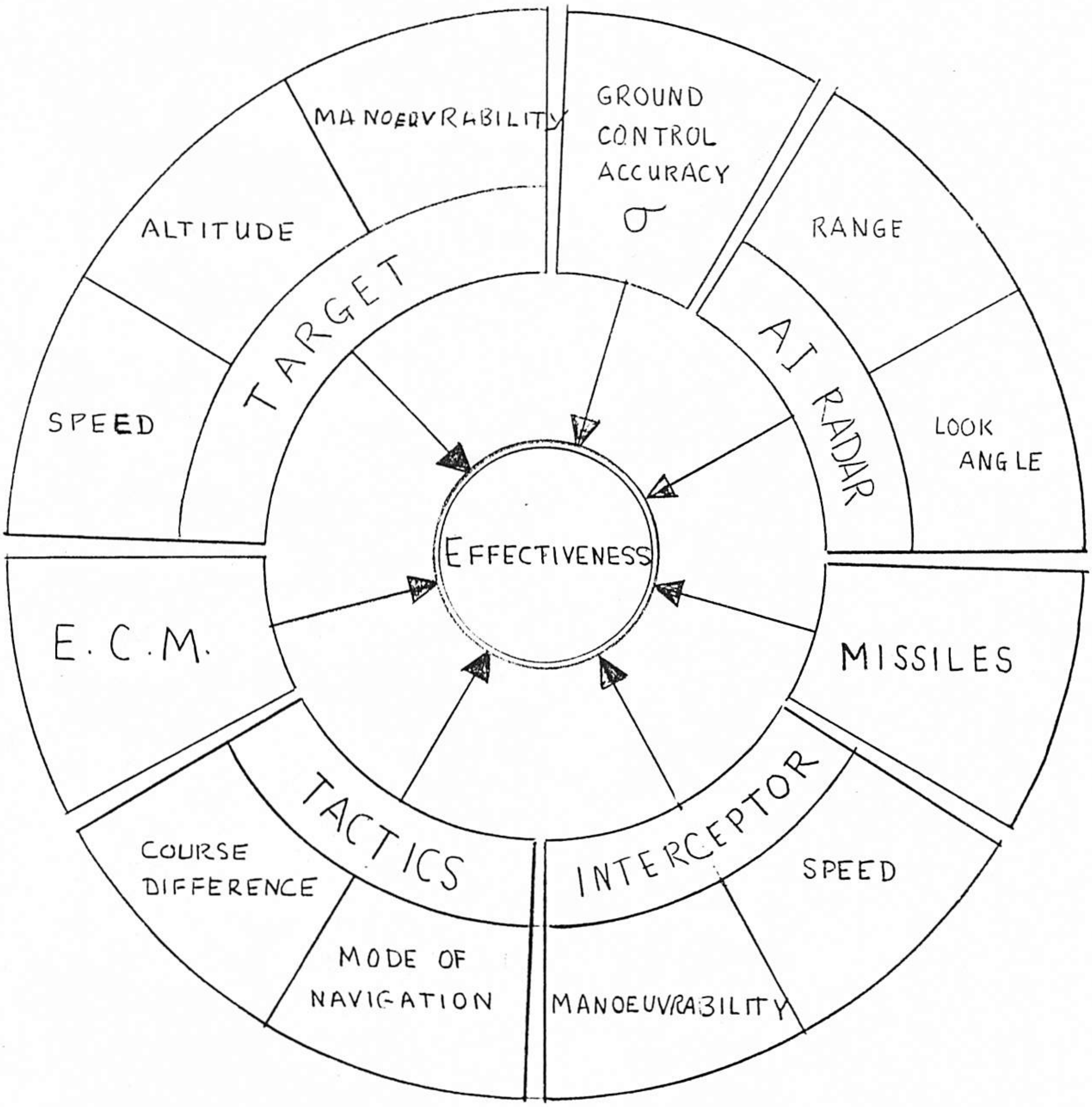


Figure 28. Principal Parameters of the Interception Problem.

12.0 PRESENTATION OF RESULTS ON PLACEMENT PROBABILITY

In general results have been presented in graphical form to permit easy interpolation.

12.1 Basic Graphs

Primary results on placement probability have usually been displayed as graphs of P_p as a function of AI range performance. Other parameters are assumed constant. Compilations of these graphs will be found in the quarterly progress reports of the study (see list of references). A set of curves for a typical case is reproduced in figure 29. By discussion and comparison of such families of curves, the effects on the system of other parameters may be readily derived.

12.2 Contours of Constant Probability

A second way of presenting results is shown in figures 30, 31 and 32. In this type of graph, values of σ and R which provide a given value of P_p are plotted. The resulting curves are contours of constant P_p (isoprobs). The three examples shown are for slightly different cases. If a certain value of probability is required of the system, the region to the right of or below the corresponding contour will provide it or a better value. If σ is known, the required value of R is determined; or if radar range performance is known, the required accuracy σ may be found.

In presenting conclusions in this report it has been assumed that an acceptable level of placement probability is 85%. The graphs of figures 30-32 show that the value of P_p chosen as the standard of acceptable performance will have a marked effect on any results.

Indicated trends may not apply without modification, if a different level of success were to be used as a criterion.

12.3 E.C.M.

A careful analysis of the effects of electronic countermeasures on the Astra I AI system has been made by the Defence Research Telecommunications Establishment. The results of this work have been interwoven into the analysis.

Typical Presentation of Results

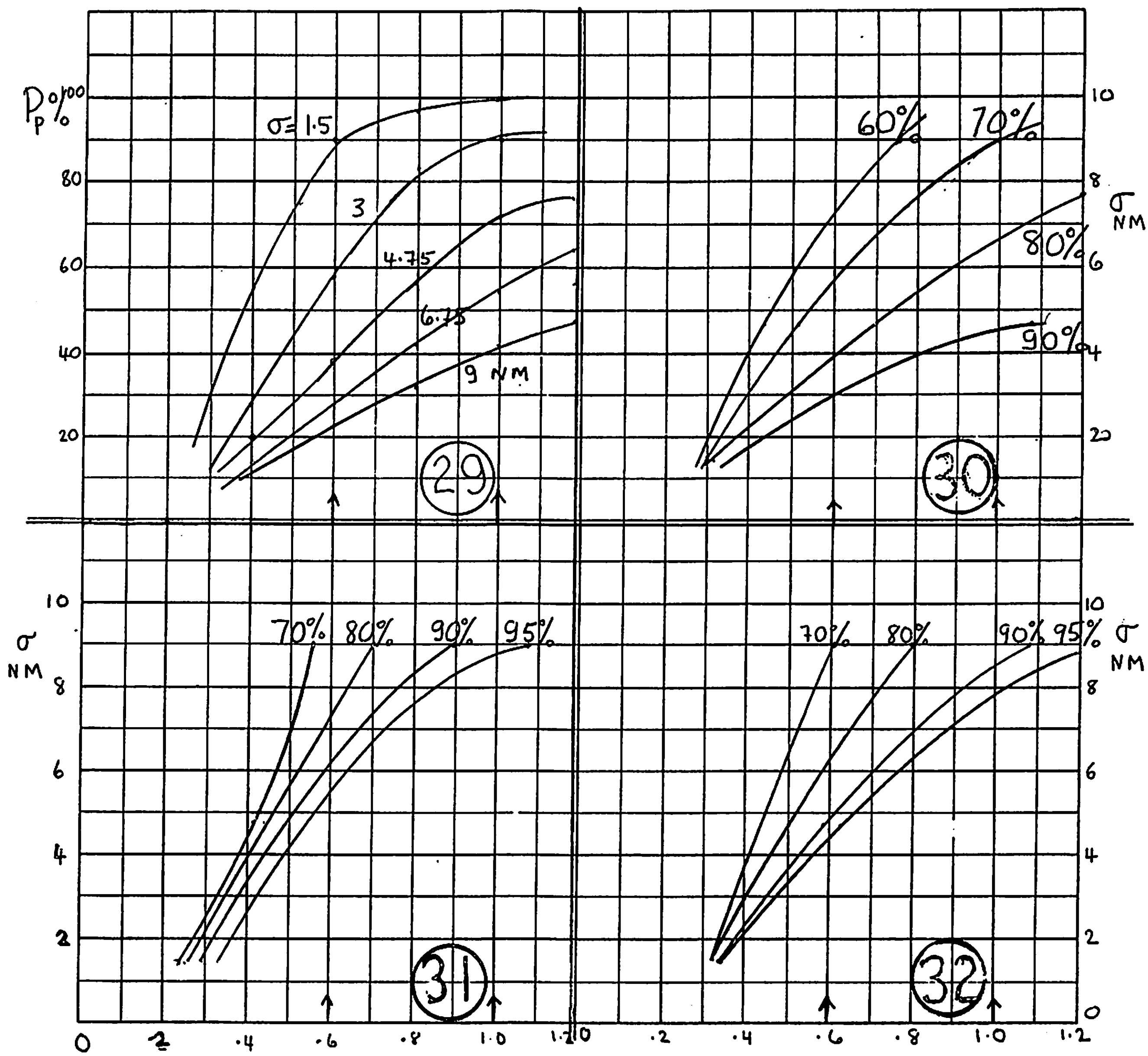


Fig. 29: Typical Probability/Range Curves
τ = 110°
M_T = 2.0 N_T = 1.05 Delta
M_I = 1.5 N_I = 1.2 Constant Speed

Figs. 30, 31, 32: Contours of Constant P_p in the σ/R Plane
M_T = 2 Delta
M_{I_o} = 1.5 Buffet Limit Turn

Fig. 30: N_T = 1.0 τ = 110°
Fig. 31: N_T = 1.0 τ = 180°
Fig. 32: N_T = 1.12 τ = 180°

13.0 AI RANGE

One of the more important parameters of an interceptor system is the acquisition range obtainable on the target. In this study, acquisition range contours corresponding to the specification range performance have been defined for the targets being considered (Section 5.3). This range is a function of target aspect; however between 110° and 250° aspect the median acquisition range contours are roughly circular for all targets. The head-on values of lock-on range S for the two supersonic targets are 34 nm for the delta wing and 21 nm for the straight wing. Thus the range obtainable on the straight wing target is about 0.6 of that for the delta, for the same radar performance.

In presenting graphs where one of the variables is AI Range, it is convenient to express R as a multiple of S, rather than in nautical miles. The range scale on the graphs in this report is that for the delta target; the more pessimistic specification range for the straight wing target is at 0.6 S on the delta scale.

The dependence of acquisition range on closing rate is not quoted in the RCAF Specification. The value of closing rate, for the target and interceptor speeds considered in this study, varies from 3000 to 4000 ft/sec. only, so that the resulting uncertainty in the actual value of S in any case is not great.

13.1 Degradation of AI Range Performance

The specification to which an electronic apparatus is designed represents a performance level of which it is capable, since acceptance tests on each equipment are required. The actual performance of equipment in service may be better or worse than the specified requirement for many reasons. Available measuring techniques in the field may not allow optimum tuning; logistic problems may not permit replacement of vital components at small levels of degradation as may be necessary to maintain high overall performance.

Enemy action in the form of electronic countermeasures may cause degradation of the radar range performance. The probable degradation due to barrage jamming, and due to spot or repeater jamming, have been computed and are illustrated in figure 33.

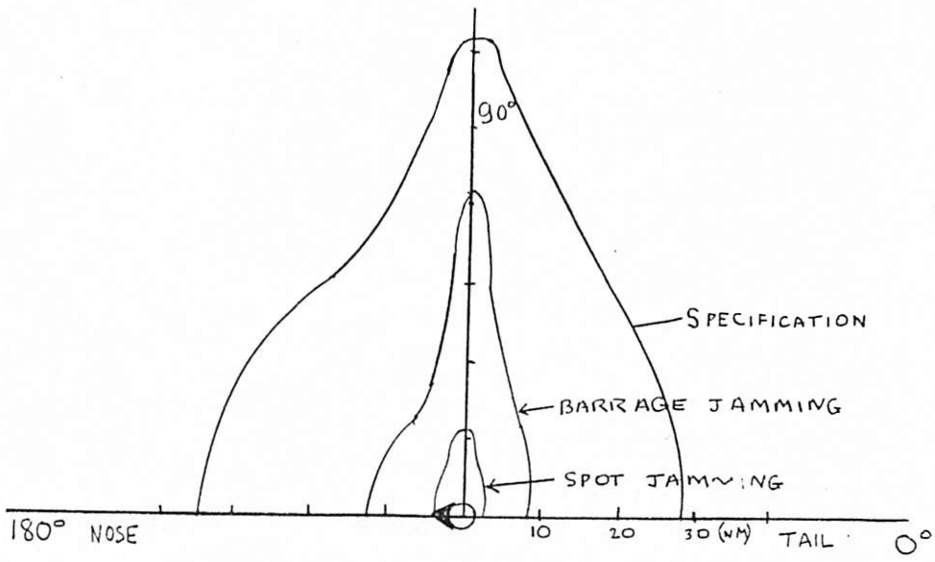


Figure 33. AI Range under ECM (Delta).

The assumptions on which these degradations are based are as follows:

Barrage Jamming: 2 watts jammer power radiated in the radar bandwidth (image channel jammed)

Spot or Repeater: 300 watts in a 20 Mc/s band within 10 Mc/s of the radar frequency.

The relationship between the specification range and various probable performance levels are shown graphically in figure 34. Because of the great variation in this parameter, a large range of values has been used throughout the study, so that system effectiveness for any proposed value of this parameter may be obtained.

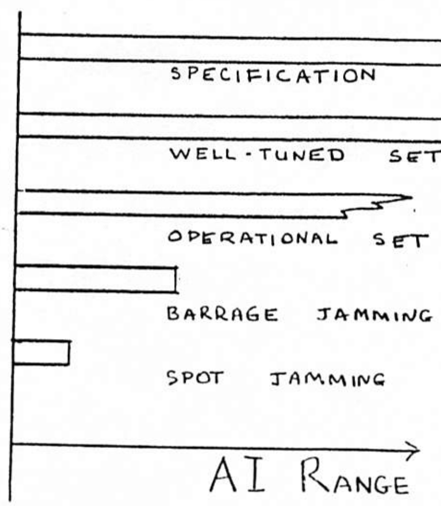


Figure 34. Degradation of AI Performance.

13.2 Relation of P_p to AI Range Performance, Non-Evading Targets

Against a non-evading target, probability of interception placement always increases with increasing AI range, and for a large enough range, becomes 100%. Figure 35 shows a typical graph of P_p as a function of R . Usually the curve starts with a very steep slope, followed by a knee, and then a "plateau" or gradual increase to some maximum value. This maximum will always be 100% if the average ground control error σ is less than 5 miles. The position of the knee on the curve is important, since in general, probabilities are good above the knee, but critical below.

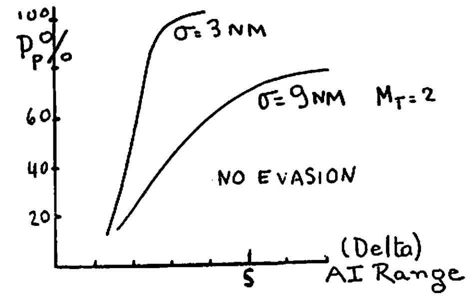


Fig. 35. Typical P_p/R Curves.

For values of σ below 5 n.m., the knee occurs between 0.4S and 0.7S for the Delta contour, and between 0.5S and 0.9S for the straight wing target. For these values of σ also the probability at the knee is above 70% for beam attacks and above 85% for head-on attacks. These results are illustrated in figures 36 and 37 below.

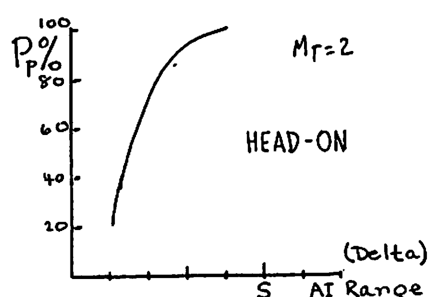


Fig. 36.

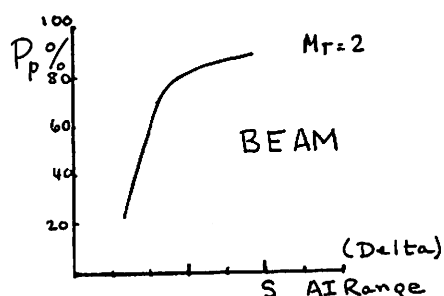


Fig. 37

P_p/R Relationships for Non-Evading Targets.

13.3 Relation of P_p to AI Range Performance, Evading Targets

The effect of target evasion on the placement zone is discussed in section 20 .. If the target evades intelligently, and if the interceptor tracks intelligently, the same general functional relationship between P_p and R is true. A typical P_p graph for the evading case is given in figure 38. The knee is less pronounced in general, and the plateau occurs at a lower value of P_p , and at higher values of AI range.

For values of σ below 5 n.m., the knee occurs between 0.5 and 0.9 S for the delta target, and between 0.7 and 1.2 S for the straight wing target. The probability at the knee is about 50% for beam attacks and 85% for head-on attacks. These results are illustrated in figures 39 and 40 below.

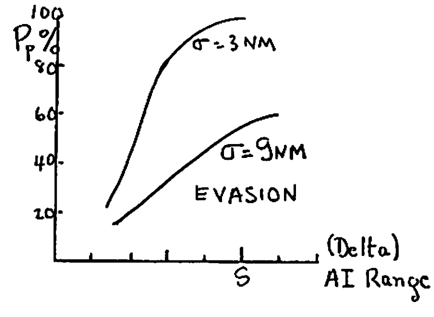


Fig. 38. Typical P_p/R Curves.

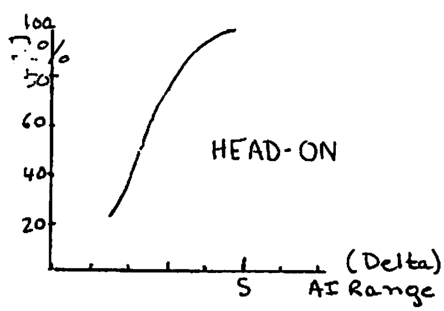


Figure 39.

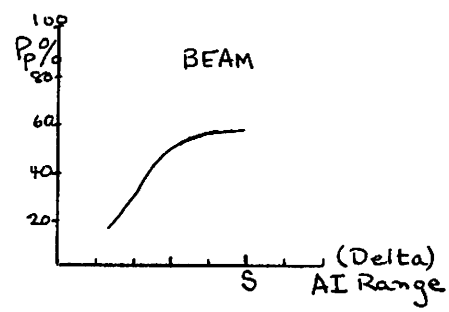


Figure 40.

P_p/R Relationships for Evading Targets.

14.0 EFFECT OF GROUND CONTROL ACCURACY

The task of the Ground Controlled Interception Radar during the vectoring phase of a single interceptor - single target engagement, is to place the interceptor on a lead collision attack course against the target. In a close control system the ground radar must determine the position and velocity of both target and interceptor, and compute the required course for interception. In a broadcast control system the position and velocity of the target are computed on the ground, and those of the interceptor by its own navigation devices. In both cases errors in both measurement and computation exist. The effect of these errors is discussed in this section.

14.1 Effect of Aircraft Velocity on σ

For a given ground control system, the accuracy of position data and of velocity computations deteriorates as target velocity increases. For example, present day GCI radars which have a static accuracy of about $\frac{1}{2}$ n.m., provide a placement accuracy of about 3 miles for sub-sonic (M = .75) interceptions. Figure 41 shows how the average placement error varies with the velocity of the target.

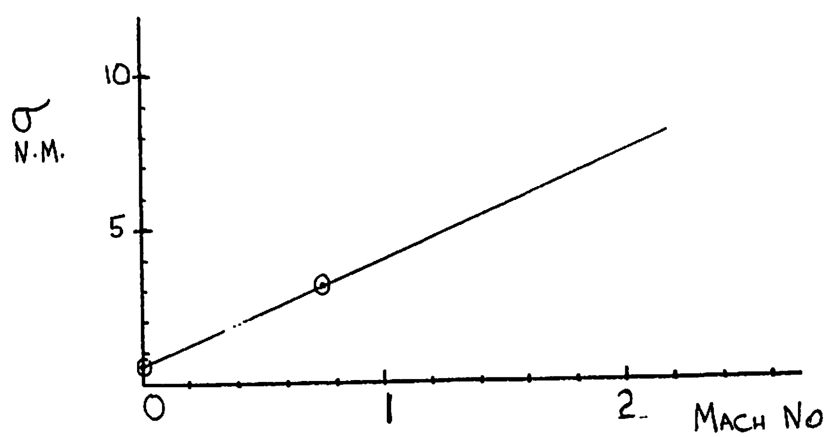


Figure 41. Variation of σ with velocity.

Thus present day GCI should be able to provide a σ of about 7 n.m. for a Mach 2 interception.

14.2 GCI Errors

The GCI error has been inserted into this study in terms of the average positioning error of the interceptor perpendicular to the ideal approach line in target coordinates. A range of values of the standard deviation of this error, from 1.5 to 9 n.m., has been used.

For a given ground control system the value of σ may not be constant throughout the area controlled by a single GCI radar; and the accuracy obtainable may depend on the course difference which the interceptor is to use. These variations have not been considered explicitly in this study.

14.3 Variation of P_p with σ

As would be expected, the placement probability improves with GCI accuracy (i.e. as σ becomes smaller). Low σ values mean that the interceptor can be placed close to the ideal line, so that if this line lies between the front and rear placement barriers, high placement probability results.

The graphs of figures 42 and 43 illustrate the dependence of positioning probability on ground control accuracy for two typical cases, a beam attack and a head-on attack.

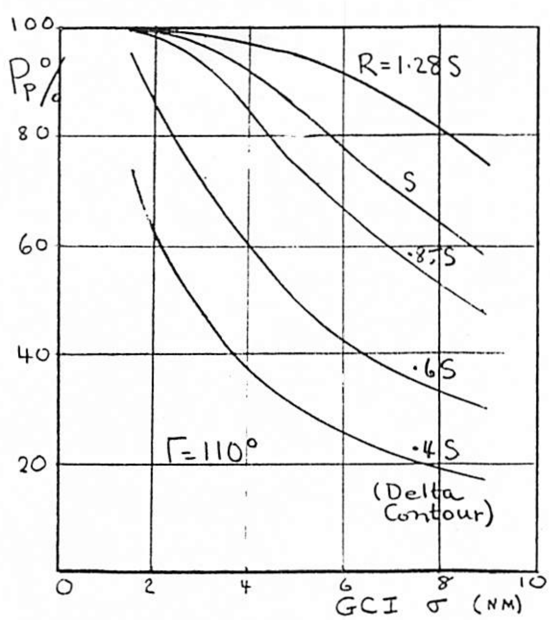


Fig. 42. Beam Attack.

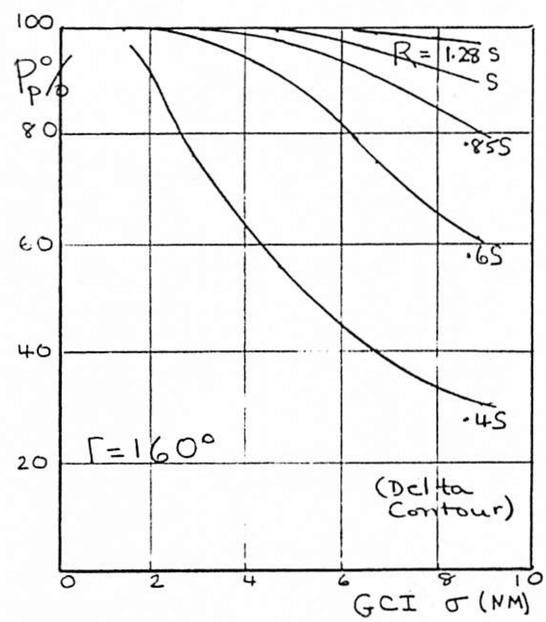


Fig. 43. Head-on Attack.

Variation of Placement Probability with GCI Accuracy.
Mach 2 Evading Target.

For head-on attacks, if AI range is very good (.85 S for delta target, or 1.4 S for the straight wing) the value of σ is not important. However, for smaller values of AI range, the probability falls off seriously with decreasing GCI accuracy.

For beam attacks, a low value of σ is required even if the AI performance is very good.

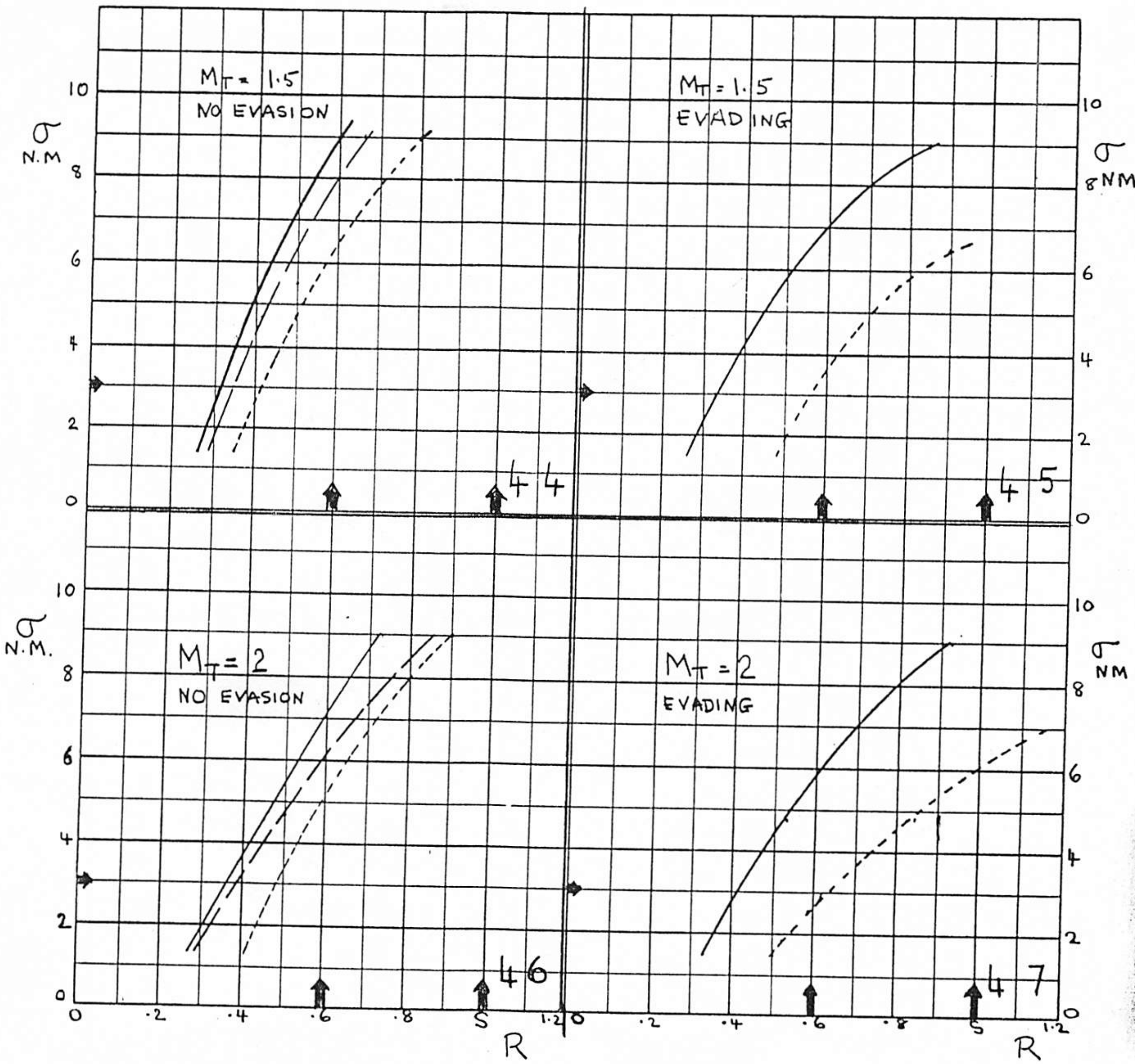
15.0 CF 105 SYSTEM REQUIREMENTS FOR AI RANGE AND GROUND CONTROL ACCURACY

The values of AI range performance and ground control accuracy which are required to operate the CF 105 interceptor system are summarized graphically in figures 44 to 47. These are contours of constant placement probability, drawn for $P_p = 85\%$. All are drawn for a near head-on attack, on course difference of 160°. Degradation of the system is so great for attacks on course difference of 110° that results for that case are not presented here. The variation of P_p with course difference is discussed in section 19 of this report.

Results are given for Mach 2 and Mach 1.5 targets at 50,000 feet altitude. Non-evading and manoeuvring targets are considered and various ways of operating the interceptor are indicated.

Tables 3 to 6 on page 46 summarize the conclusions which may be drawn from these graphs.

Contours of Constant Probability of Placement.



Figures 44, 45, 46, 47:

P_p = 85%

Γ = 160°

Delta AI Contour

Interceptor Tactics:

------ M_I = 1.5, Constant speed turn (1.63)

— — — M_{I_o} = 1.5, Buffet limit turn

———— M_{I_o} = 2, Buffet limit turn

(Acceptable values of σ and R are to the right of the contour).

SUMMARY OF AI RANGE REQUIREMENTS

Table 3. AI Range Performance Requirements
($85\%\ P_p$ criterion)

$\sigma = 3$ n.m.

No E.C.M.

Target	Evading	Non-Evading
Straight Wing	85% of Spec.	70% of Spec.
Delta	50% of Spec.	40% of Spec.

Table 4. AI Range Performance Requirements
($85\%\ P_p$ criterion)

GCI jammed ($\sigma = 9$ n.m.)

Target	Evading	Non-Evading
Straight Wing	160% of Spec	130% of Spec
Delta	Spec	80% of Spec

AI DEGRADED BY E.C.M.

Table 5. σ Requirement in the ECM case (85% P_p criterion)

Target \ Jamming	Barrage	Spot
Straight Wing	Nil	Nil
Delta	1.5 n.m.	Nil

Table 6. P_p in the ECM case (σ = 1.0 n.m.)

Target \ Jamming	Barrage	Spot
Straight Wing	50%	10%
Delta	92%	10%

In general, with the specification value of AI performance, and a GCI average error of 3 nautical miles, the system has a high interception potential against even the straight wing target.

16.0 EFFECT OF INTERCEPTOR PERFORMANCE ON PLACEMENT PROBABILITY

The CF 105, in common with other supersonic aircraft, decelerates sharply on making high load factor manoeuvres at altitude. The general conclusions presented throughout this report are based on the simulation of the actual aircraft performance. The interrelation of drag and thrust characteristics with varying Mach number complicates a discussion of the effects of interceptor characteristics.

Two different sets of aerodynamic estimates have been used. Comparison of results obtained with the two sets of data are given in this section.

Some studies have been made on the effect of using turns at load factors below the aircraft buffet limit. These also are reported in this section.

In the early part of the CF 105 assessment, firm estimates of the aircraft performance were not available. The placement problem was studied for supersonic targets and constant speed interceptors of various turn capabilities. Some general conclusions which were obtained in the course of these studies are presented in this section because of their intrinsic interest although they do not represent the actual interception capability of the CF 105.

16.1 Placement Studies with a Constant Speed Interceptor

Graphs of the variation of placement probability with available interceptor power limited load factor are given in figures 48 and 49. It is seen that P_p increases rapidly with N, at low values of N. A knee in the curve is reached, followed by a plateau or gradual increase in P with greater N. The knee is more pronounced with good values of AI range than with poor.

It is not useful to increase the turn capability beyond the value required to reach the plateau of the P/N curves. Table 7 on the following page summarizes the conclusions which can be drawn from figures 48 and 49. Specification performance of the AI radar is assumed.

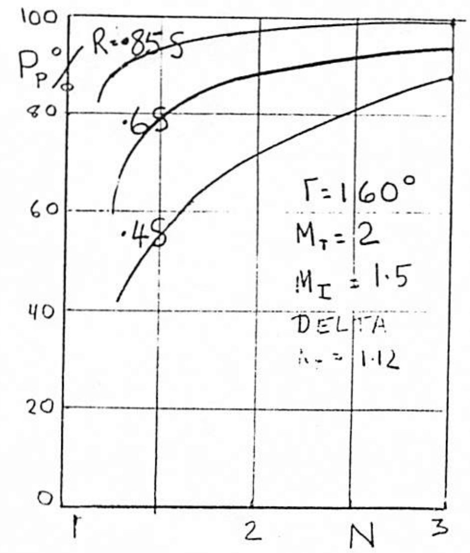


Fig. 48. σ = 3 n.m.

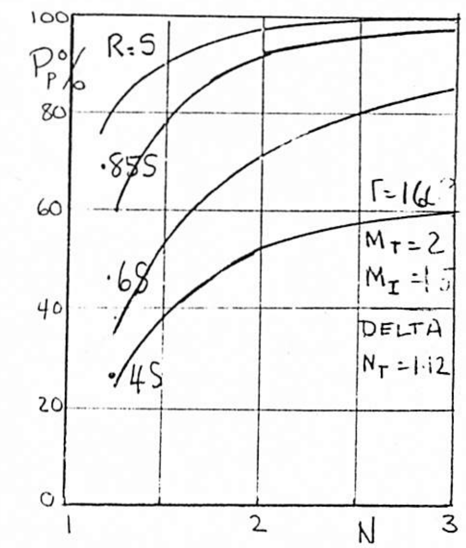


Fig. 49. σ = 4.75 n.m.

Effect of Load Factor on Placement Probability for Constant Speed Interceptor.

Table 7.

Values of Maximum Useful Power Limited Load Factor σ = 3 n.m.

Target	Plateau N	N for 85% P_p
Straight Wing	2.5	3.0
Delta	2.0	1.3

16.2 Comparison of Aerodynamic Estimates

Before firm estimates of the aircraft performance based on high speed wind tunnel tests became available, extrapolated data were used. These estimates were pessimistic, allowing a power limited load factor of only 1.29 at Mach 1.5 at 50 K ft. altitude. More recently, the presently accepted estimates became available. These predict better performance, quoting a power limited load factor of 1.63 at Mach 1.5 and 50 K ft. altitude.

The pessimistic estimates used in the CARDE study permit a power limited load factor of 1.63 at Mach 1.5 and 45,000 ft. altitude. The present more optimistic data provide a load factor of 1.29 at Mach 1.5

and 56,000 ft. altitude. Thus the difference in performance of the two interceptors can be interpreted as a difference in altitude capability.

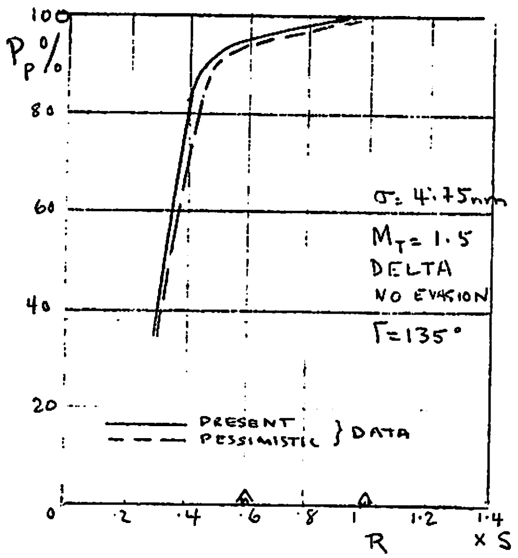


Fig. 50. M_{I_0} = 1.5

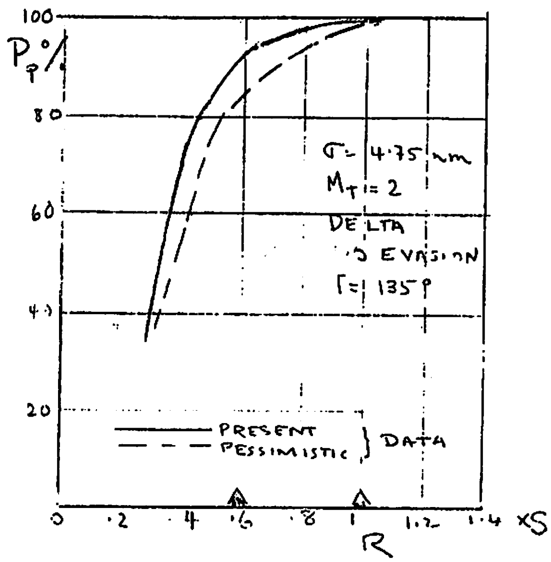


Fig. 51. M_{I_0} = 2.

Variation of P_p with aircraft performance estimates, non-evading target.

Figures 50 and 51 show, for a typical case, the difference in the placement probability for the two sets of aerodynamic data. In general the pessimistic data produce values of placement probability only slightly inferior to those obtained with the more optimistic ones, despite the apparently great difference in performance figure.

It may be concluded that the value of power limited g-capability at Mach 1.5 and 50,000 ft. altitude is not a satisfactory criterion of aircraft performance. It is difficult to suggest an alternative single figure which can be used as a standard of comparison. Figures 50 and 51 point out that results derived in the CARDE study will still be representative of the CF 105 system effectiveness if future aerodynamic performance estimates vary considerably.

16.3 Variation of the Load Factor Limit on the Decelerating Interceptor

The variation of placement probability with interceptor load factor limit for a typical head-on attack is shown in figures 52 and 53. P_p is seen to be greatest when the interceptor manoeuvres as sharply as is permibbible.

For beam attacks this conclusion is not universally true. When the interceptor approaches behind the ideal line and decelerates greatly on turning it tends to fall behind the fall-back barrier and fail in its attack. Figure 54 shows how the size of the placement zone is increased for beam attacks if more gentle turns are made when the interceptor is behind the ideal line. For poor values of σ this results in an increased value of P_p .

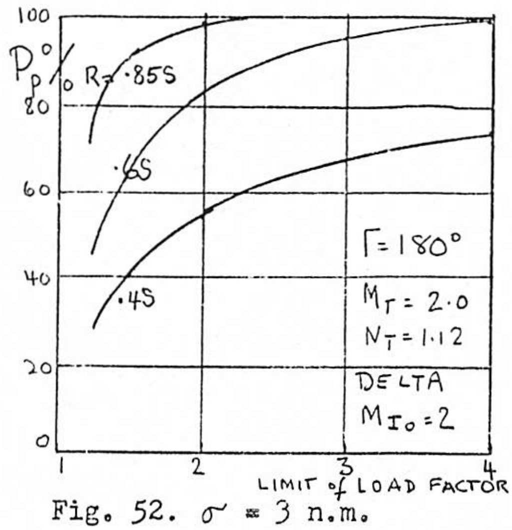


Fig. 52. σ = 3 n.m.

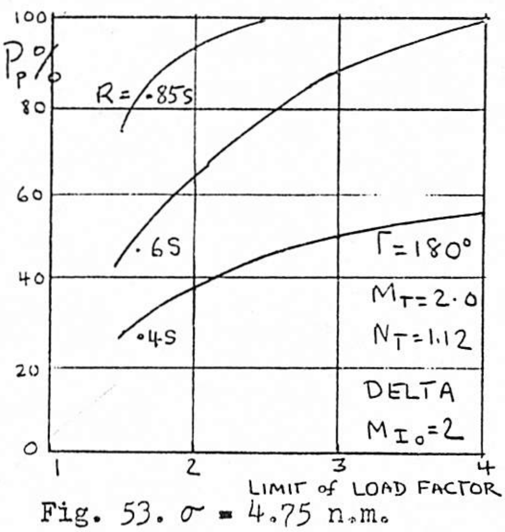


Fig. 53. σ = 4.75 n.m.

Variation of P_p with Interceptor Load Factor Limit (decelerating interceptor).

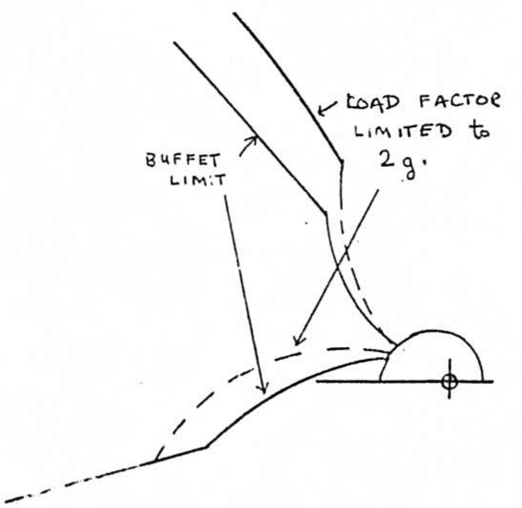


Fig. 54. Placement Zone for Beam Attack on Non-Evading Target.

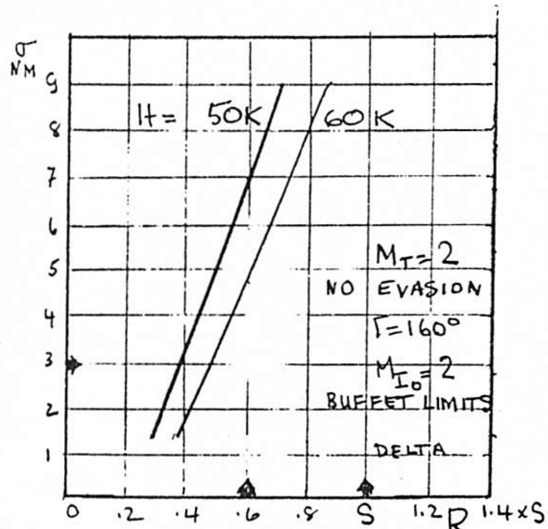


Fig. 55. Contours of 85% P_p for Co-Altitude Attacks at Different Altitudes.

16.4 Effect of Altitude

The curves of figure 55 give contours of constant probability for co-altitude interceptions at two different altitudes, 50,000 and 60,000 ft. These results are for a non-evading target. The manoeuvrability of the CF 105 is less at the higher altitude. For a given value of σ , a somewhat higher value of AI range performance is required at the higher altitude. For σ = 3, .4 S is sufficient at 50,000 ft., but .5 S is required at 60,000 ft. Comparison with results on non co-altitude interceptions which are discussed in section 25 , shows that the CF 105 should start the AI phase of its attack on a 60,000 ft. target at an altitude of 50,000 feet or less.

CONCLUSIONS ON AIRCRAFT PERFORMANCE

(a) A single all-inclusive statement cannot be made on what is an acceptable level of aircraft performance.

(b) Supersonic aircraft tend to manoeuvre above their power limit at high altitude and therefore decelerate.

(c) If power limited turns are considered, a plateau value of load factor can be stated for specific desired attack potential.

(d) Assuming decelerating turns, the difference in placement probability resulting from using the accepted performance description of the CF 105, or more pessimistic data is small (about 5% maximum).

(e) The value of power limited g-capability at a given altitude and speed is not a good criterion of aircraft performance.

(f) Lacking a suitable criterion, each aircraft performance description must be evaluated by independent analysis.

(g) A decrease in load factor capability can be interpreted as a loss in altitude capability which can often be compensated by non-coaltitude attacks.

(h) A decrease in load factor capability can be compensated by an increase in AI range performance.

17.0 EFFECT OF MISSILE LAUNCH ZONE PARAMETERS

The missile armament affects the operational capability of the system through its launch zone characteristics. Placement probability is relatively insensitive to variations in launch zone parameters. Figures 56 and 57 show to what extent P_p is affected by the launch parameter variations which have been considered in this study. The missile launch range was allowed to vary from 15000 to 55000 feet, and the heading error from 5° to 20°. In these graphs the R - σ plane is divided into regions; the absolute variation, in % of the placement probability, which results from launch zone variation over the limits chosen, is indicated for each region.

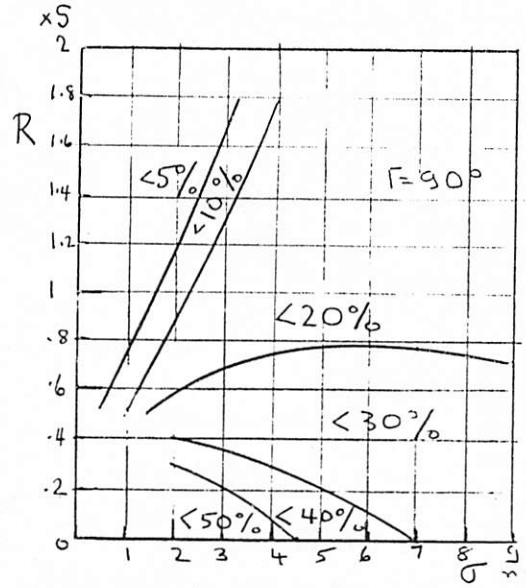


Fig. 56. $\Gamma = 90°$

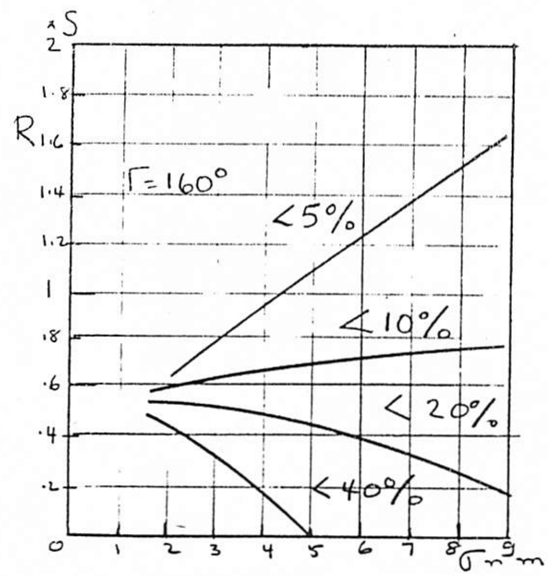


Fig. 57. $\Gamma = 160°$

Regions of % change in P_p due to Launch Zone Variation.

Comparison of the two figures shows that the launch characteristics are more critical for course differences near 90° than for those near 180°.

Essentially these figures show that if the system is operating very well as regards AI range and GCI control accuracy, little is gained or lost by changing missile performance. If both AI range performance and GCI accuracy are poor, the situation cannot be saved by a moderate variation in missile tactical capability. Only in the case where the AI range is greatly degraded, but the GCI accuracy high, can the missile performance influence markedly the overall result. This case may occur, for example, if the AI radar is jammed, but the GCI is not.

The following paragraphs describe for this case, the way in which launch zone parameters affect placement probability. The effects are greatest for values of σ between 2 and 4 n.m. and for R = .4 S.

17.1 Heading Error

Changes in heading error allowance affect only the manoeuvre barrier of the placement zone. If the permitted error is greater, the manoeuvre barrier moves closer to the target and P_p increases for AI acquisition ranges within this region. The trend is still more pronounced for manoeuvring targets. Figure 58 shows the magnitude of variations in P_p for a typical case, for values of heading error between 5 and 20 degrees, for both non-evading and evading targets. From work done at Hughes Aircraft Company, and a brief check at CARDE, it appears that increasing the heading error allowance above 20° has little effect.

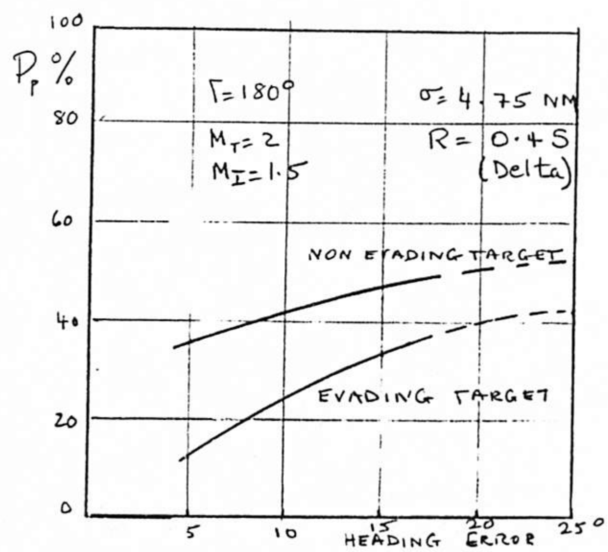


Fig. 58. Variation of P_p with Missile Heading Error Allowance.

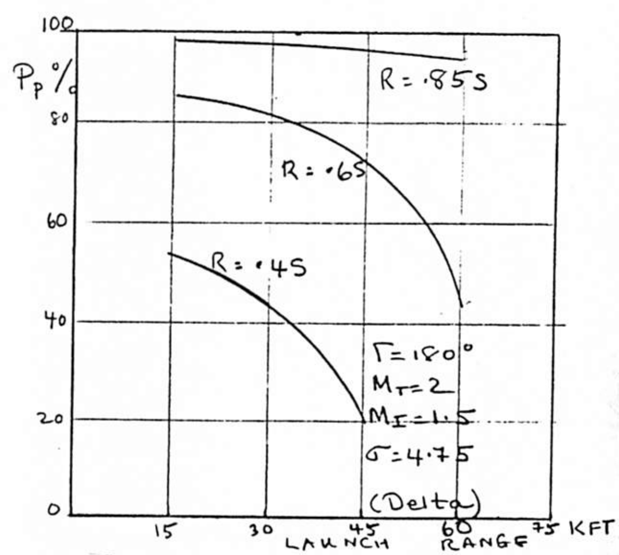


Fig. 59. Variation of P_p with Missile Launch Range.

17.2 Launch Range

A change in missile launch range affects the manoeuvre and the fall-back barriers. When the AI acquisition contour intersects the manoeuvre barriers, decreasing the missile launch range increases the placement probability. The magnitude of this trend is shown in figure 59 for a non-evading target.

For an evading target this effect is reversed: an increase in launch range increases placement probability. In the results obtained in the study, the effect of launch zone parameters are so interwoven with effects of target evasion that it is difficult to assign a definite magnitude to each one separately. In a typical case, with a target load factor 1.25, a change of 25,000 feet in launch range produces a variation of 20% in P_p, for values of σ and R in the initial region being considered.

There is a rather pronounced decrease in P_p if the launch range approaches the AI acquisition range. As a rough estimate, for a 40° turn, 50,000 feet separation between the AI contour and the launch range contour is sufficient to complete the conversion manoeuvre.

Greatest values of P_p for both evading and non-evading targets are obtained for a launch zone of greatest allowable depth between maximum and minimum range.

17.3 F-Circle

The concept of lead collision course has been outlined in section 8. In this navigation mode the missile is assumed to have a fixed time of flight from any allowable launch point. These points are then all on a circle, called the F-circle (see figure 60a). If an interceptor uses this mode of navigation, the launch zone must be approximated for steering signal computation, by a suitable F-circle. Figure 60b gives an indication of how the interceptor heading, when flying a lead collision course, compares with the heading allowed for launching a Sparrow type missile, for a typical case. This shows that a lead collision course may not use the total capability of the missile.

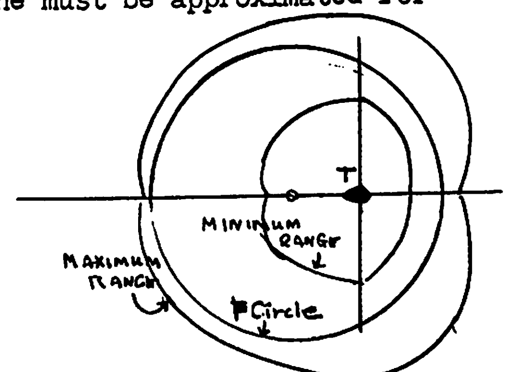


Fig. 60a. Comparison of Typical F-Circle and Launch Zone.

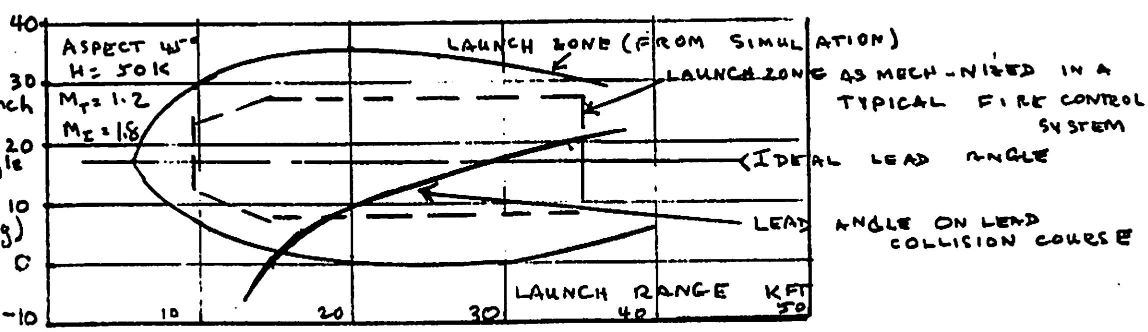


Fig. 60b. A Launch Zone for the Sparrow II Missile.

Where the interceptor flies a lead-collision course, changes in the value of F-pole produce very small changes in P_p . A change in F-pole from 15,000 feet to 25,000 feet increases P_p by only 2% absolute. The larger F-pole is slightly better in all cases.

17.4 Restrictions on the Launch Zone

The probability of positioning an interceptor for missile launch is seriously affected if certain target aspects, or sectors, are prohibited. A typical example of such a restricted launch zone is that for a first generation IR missile, or for the Velvet Glove type fixed guidance head missile. If the permissible cone of attack is small, target evasion can produce nearly zero placement probability.

The Sparrow type missile has all-round launch capabilities. However, this requires that the missile seeker have sufficient range. If this guidance range is less than the minimum launch range as defined by dynamic considerations, the missile cannot be launched. This seeker range deficiency may exist at forward aspects for high interceptor and target speeds. The effect on the placement zone is shown in figure 61. The central position of the zone is now forbidden, only the shaded portions being permissible initial interceptor positions. The resulting effect on P_p for a non-evading target is shown in figure 62. For an evading target, the placement probability falls almost to zero if the front aspects are forbidden.

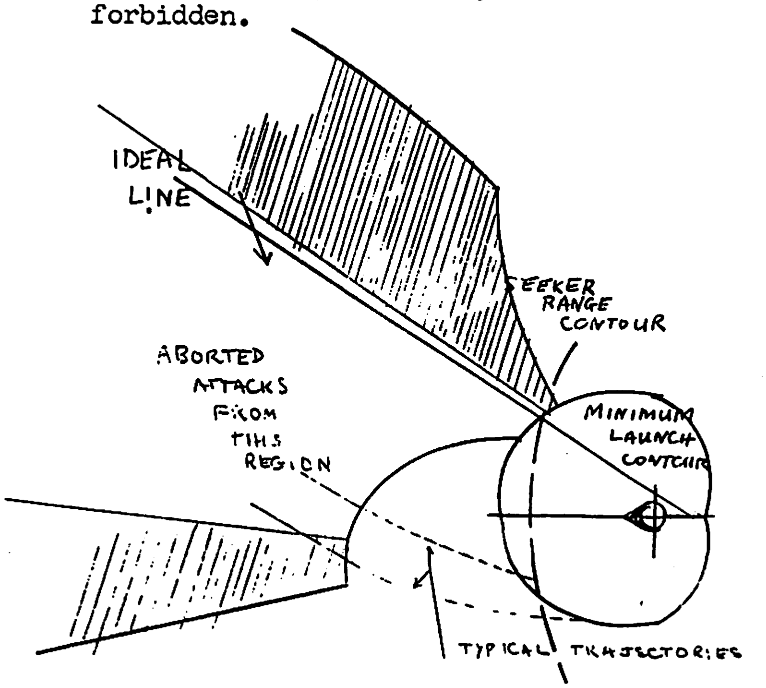


Fig. 61. Typical Placement Zone. Launch from Forward Sector Prohibited by Low Missile Seeker Range.

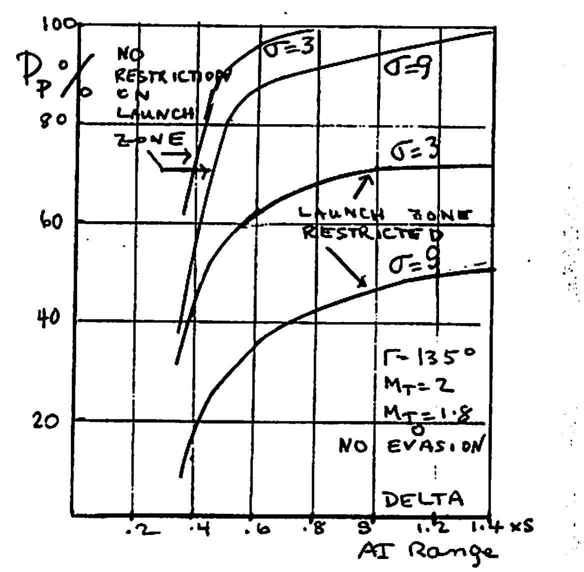


Fig. 62. Reduction in Placement Probability Caused by Prohibited Region of Launch Zone.

SUMMARY OF CONCLUSIONS ON LAUNCH ZONE EFFECTS

(a) P_p is relatively insensitive to variations in launch zone parameters.

(b) Consequently the fact that only approximations to Sparrow missile launch zones were used in the CARDE study does not invalidate the results.

(c) If AI range is degraded but GCI accuracy remains good, a short launch range and large heading error allowance increase P_p appreciably.

(d) Increase in allowable missile heading error beyond 20 degrees does not increase the placement probability.

(e) P_p is more sensitive to launch zone parameters for evading targets than for straight flying targets.

(f) P_p is more sensitive to launch zone parameters for beam attacks than for head-on attacks.

(g) Variation in the value of F-pole used in lead collision navigation has little effect on P_p .

(h) It is useful to have a missile with great depth of launch zone, where the maximum range is large and the minimum range is small. This will provide optimum launch range for both evading and non-evading targets.

(i) It is most important that there be sufficient seeker range at all aspects.

18.0 INTERDEPENDENCE OF PARAMETERS

In section 11, it was pointed out that the numerous system parameters are interdependent and cannot be viewed in isolation one from the other. Certain topics are more closely related than others. In particular, the factors of missile launch range, AI acquisition range, and interceptor manoeuvre capability must frequently be thought of together. Figure 63 illustrates the regions of influence of these parameters in terms of range from the target. It is an attempt to show where the influences of the various parameters blend.

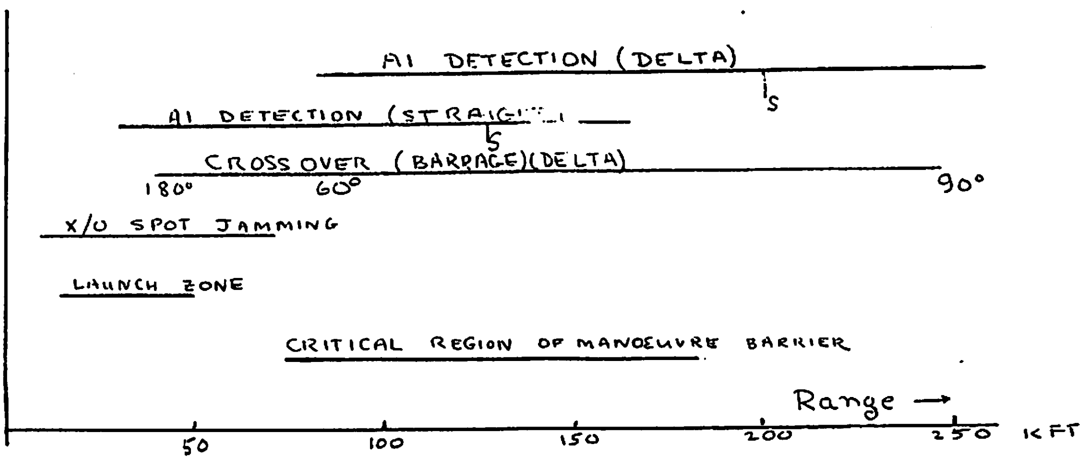


Fig. 63. Range Relationships.

19.0 EFFECT OF COURSE DIFFERENCE

The width of the allowable placement zone is in general greater for attacks from forward aspects than for near-beam attacks. The variation of P_p with course difference between the interceptor and bomber is summarized in this section.

19.1 Non-Evading Targets

Figures 64 to 66 compare contours of constant probability of placement, for head-on and beam attacks. The three figures are drawn for different interceptor tactics. It is seen that in all cases attacks at higher course difference demand smaller values of AI range. Similarly, for a fixed value of AI performance, the placement probability is higher for head-on attacks. The amount by which P_p varies with Γ depends on the interceptor tactics used, attacks at higher initial speed showing the least degradation for beam approach.

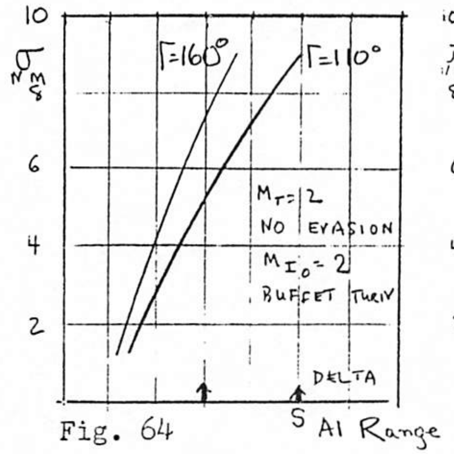


Fig. 64

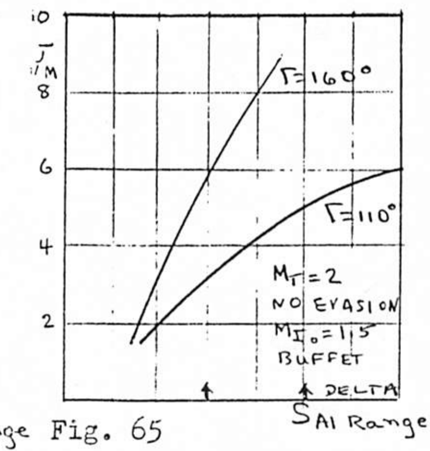


Fig. 65

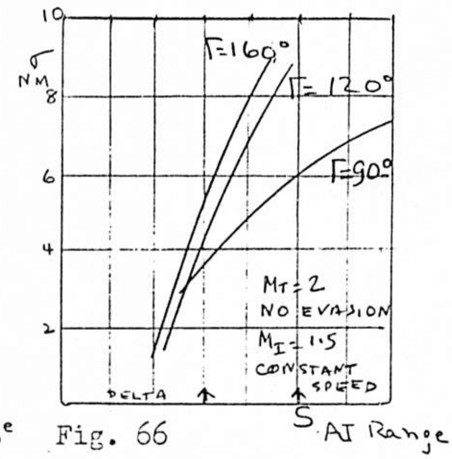


Fig. 66

Contours of 85% Placement Probability for a Non-Evading Target. Effect of Course Difference.

19.2 Evading Targets

Figures 67 and 68 give contours of 85% P_p for different Γ for evading targets. In this case the degradation for beam approach is much greater than for non-evading targets. The standard level of placement probability (85%) is not attainable for Γ = 110°; for 135° a σ of 4 miles is needed and the initial interceptor speed must be Mach 2. Greater tactical freedom exists for head-on attacks. The anomalous behaviour of the contours for Γ = 110° and 135° is a consequence of the evasion tactics assumed in the study. This is discussed further in Section 20.

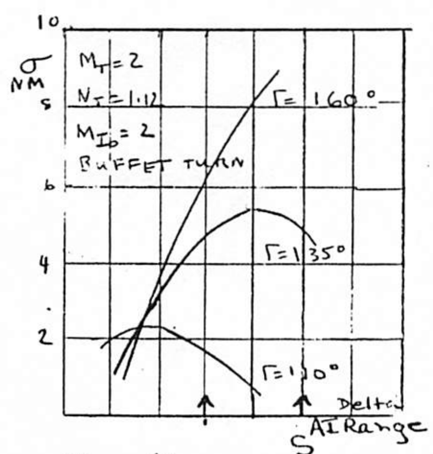


Fig. 67

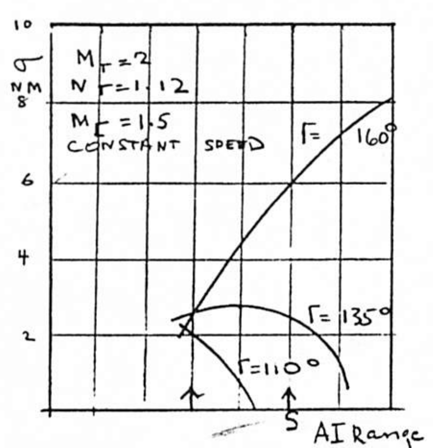


Fig. 68

Contours of 85% Placement Probability for an Evading Target. Effect of Course Difference.

CONCLUSIONS OF THE EFFECT OF COURSE DIFFERENCE

(A) Figure 69 summarizes the region of desirable and less desirable course differences. It also indicates that for course differences near head-on the aircraft operates in a region ahead of the bomber which is relatively free from the effects of chaff.

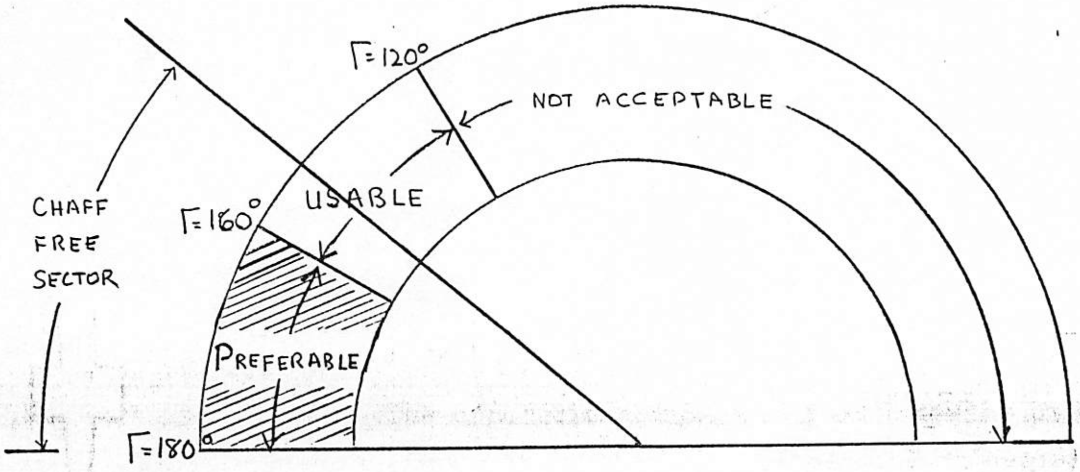


Fig. 69. Effect of Course Difference for a Mach 2 Target.

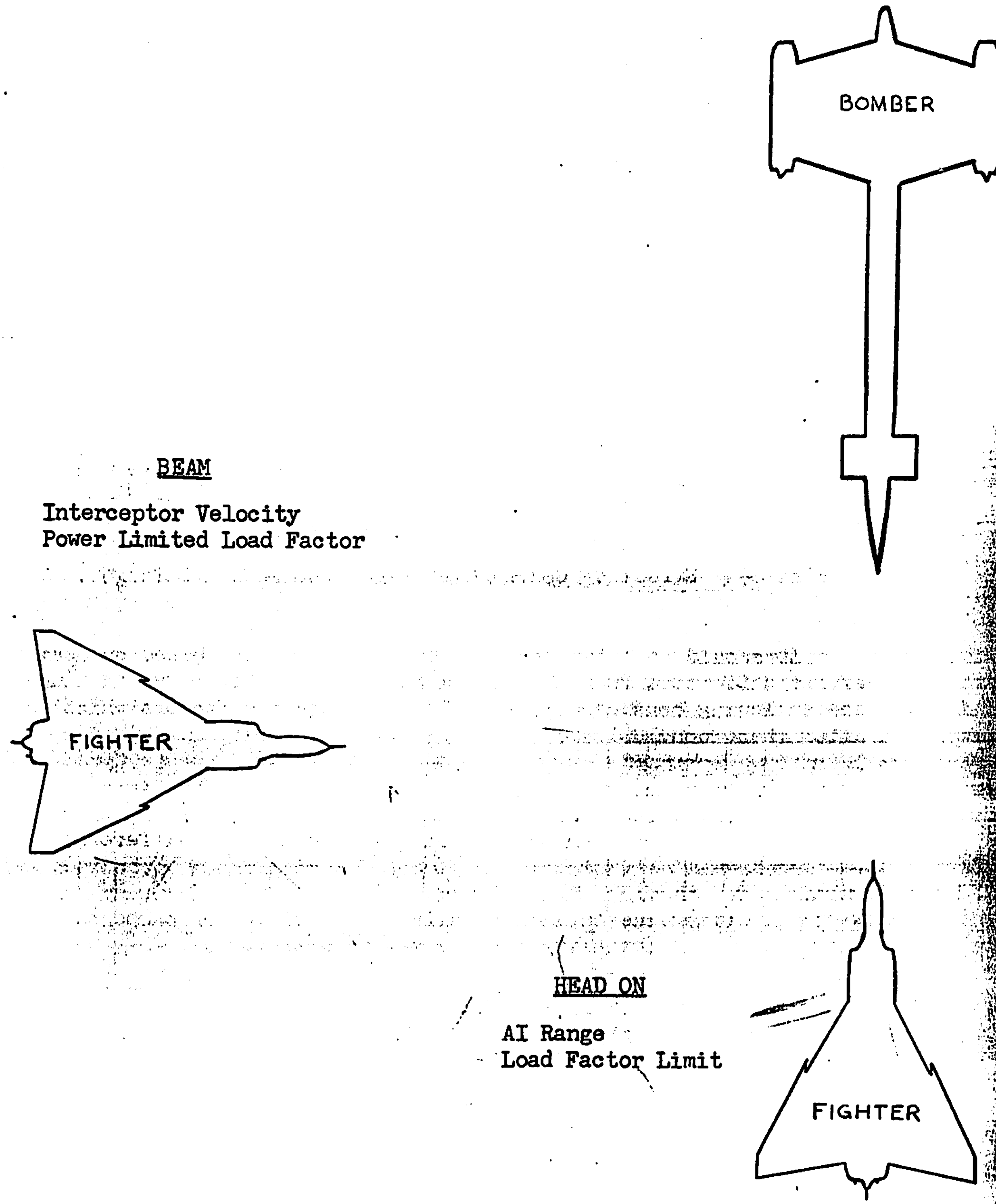
It should be noted that these conclusions are based on desirable course difference from the placement point of view only. A study of the following considerations could add weighting factors which would alter these conclusions:

(i) The penalty of complicating the vectoring phase problem by demanding a given course difference.

(ii) The optimum missile attack direction based on lethality studies may be different.

(B) Figure 70 outlines the dominant factors that influence the success or failure of head-on and beam attacks.

FIGURE 70 - CRITICAL FACTORS FOR HEAD ON AND BEAM ATTACKS.



20.0 EFFECT OF TARGET EVASION ON PLACEMENT PROBABILITY

The question of evasion by the target during the AI phase of the attack is usually ignored in interceptor studies. This assumption is made more because of difficulty in handling the subject analytically than from a conviction that evasion will not occur. Yet it is dangerous to assume that conclusions regarding desired tactics, which are obtained from a study of straight flying targets, may be applied if the target is expected to evade.

Whether or not bombers will evade can not be decided on past experience. The postulated introduction of high altitude supersonic bombers, and the existence of highly effective bombs which even if delivered in small numbers can cause immense damage, create a totally new era in strategic air warfare. Since any bomb delivered to the target area will pay tremendous dividends, it is to the bombing aircraft's advantage to use any means available for penetrating our defences. Among these means are extensive use of electronic countermeasures, and target manoeuvres in the event of interception.

In reading this section, it must be borne in mind that

(a) this work is a first attempt only to solve a complex problem,

(b) the conclusions depend very much on the assumptions regarding tactics employed by the bomber.

20.1 Assumptions

The studies on evasion which are reviewed in this report are concerned with coplanar interceptions only. The target flight path has been assumed to be a straight line, or a circular arc whose radius depends on the lateral acceleration used. The effect of evasion is measured by its effect on the value of placement probability computed for the first interceptor approach to the bomber. Considerations of re-attack when this is possible have not been included.

The bomber manoeuvre load factors which have been permitted are modest, the maximum being 1.25. In some cases the amount by which the bomber turns off course was restricted.

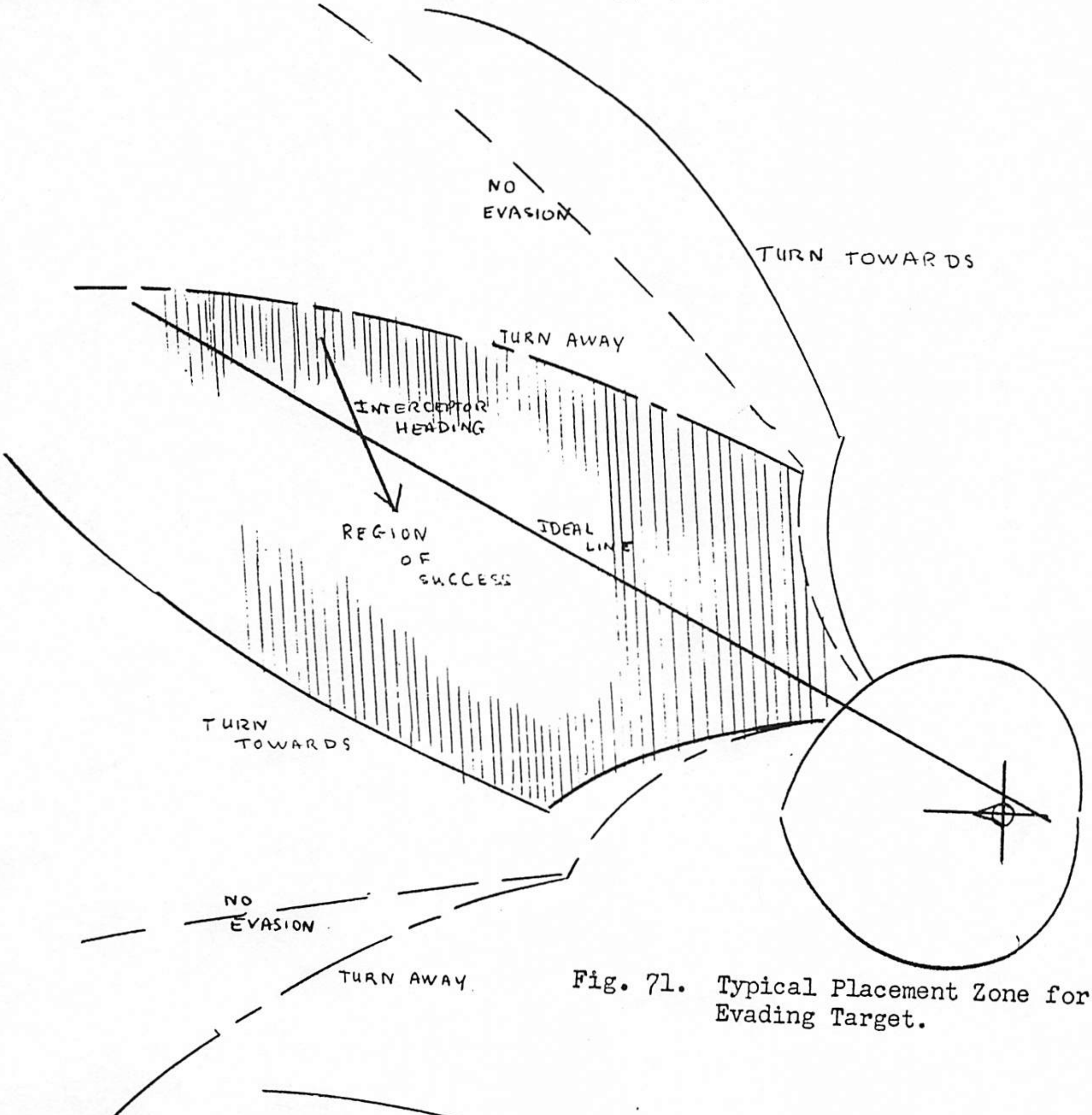


Fig. 71. Typical Placement Zone for Evading Target.

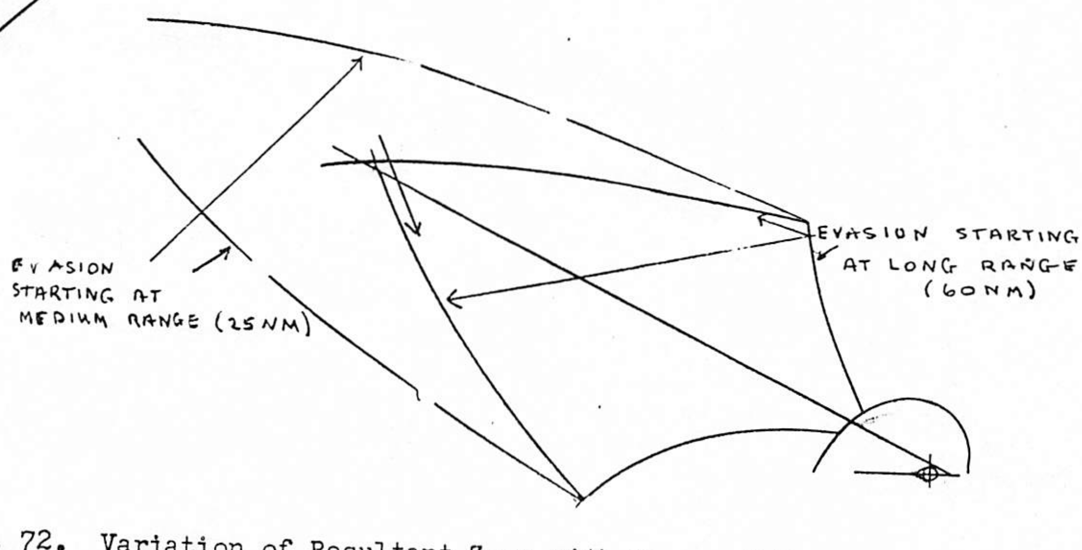


Fig. 72. Variation of Resultant Zone with Range of Initiation of Target Manoeuvre.

20.2 Effect of Evasion on the Placement Zone

A typical placement chart for an evading target is drawn in figure 71. Two sets of barriers are drawn, one for a target turning towards the interceptor, the other for a target turning away. It is seen that the effect of evasion, seen geometrically, is a rotation of the placement zone in the direction of the bomber's turn. The amount by which the zone is rotated depends on the rate of bomber evasion; the shape of the barriers depends on when evasion is initiated.

The evasion is assumed to occur during the AI phase of the attack. Thus the ideal approach line is the same as in the placement zone for a non-manoeuvring target. If the interceptor is approaching behind the ideal line a bomber turn towards it aids interception, and a turn away reduces the chance of success. If the interceptor is placed ahead of the ideal line the reverse is true.In computing placement probabilities only the part of the placement zone which is common to both cases has been used in this study. This is tantamount to assuming that the bomber will always evade in the manner most advantageous to its escape. This is not unreasonable, since the bomber requires only a simple computer and a listening device which can measure the aspect at which the attacking fighter appears.

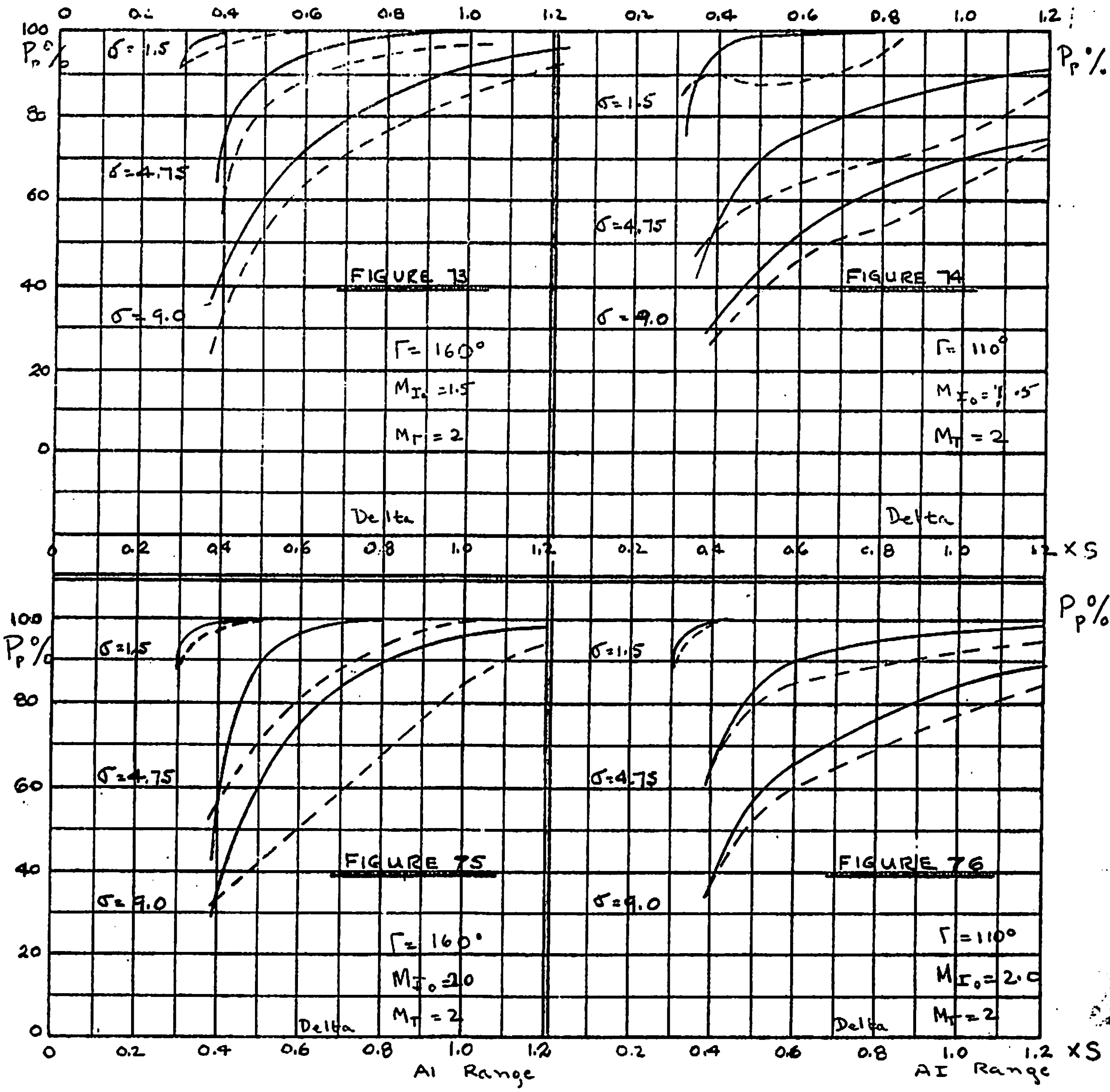
Figure 72 shows how the size and shape of the resultant placement zone vary with the instant of commencement of target manoeuvre. Typical expected AI acquisition ranges for the Astra system are indicated on this figure. If the full effect of evasion is to be realized, it should being at some time before lock-on. However, evasion beginning at lock-on still appreciably degrades the chance of interception. In this study both cases have been considered.

For intelligent evasion before lock-on the bomber also requires an AI radar. The interception then becomes a duel between two essentially similar machines. This problem has not been carried further than the derivation of probabilities of interception at the first interceptor approach.

20.3 Effect of Manoeuvre Beginning at AI Lock-on

Figures 73 to 76 compare the placement probability for evading and non-evading targets for two course differences, and for two values of initial interceptor speed. In no case has the interceptor a speed advantage. Evasion was assumed to begin at interceptor lock-on. These graphs show:

(a) For head-on attacks against non-evading targets P_p is higher for higher approach speed.



Effect of Evasion on Placement Probability.

Figures 73 and 74 M_{Io} = 1.5 Figures 75 and 76 M_{Io} = 2.0

non evading target ————

evading target – – – – –

(b) For head-on attacks against manoeuvring targets P_p is higher for lower approach speed.

(c) For beam attacks the degradation in P_p is greater for lower approach speeds.

(d) For beam attacks against either manoeuvring or straight flying targets P_p is greater for higher approach speeds.

(e) These graphs again demonstrate the conclusions made in section 19 on the variation of P_p with course difference.

20.4 Effect of Evasion starting at Long Range

If evasion begins at some range longer than possible AI lock-on range, placement probability may be very seriously decreased, or even reduced to zero. The effect is illustrated in figure 77. It is noted that if evasion begins at very long ranges (50 nautical miles or more) P_p is not much better for a small value of GCI error than for large σ.

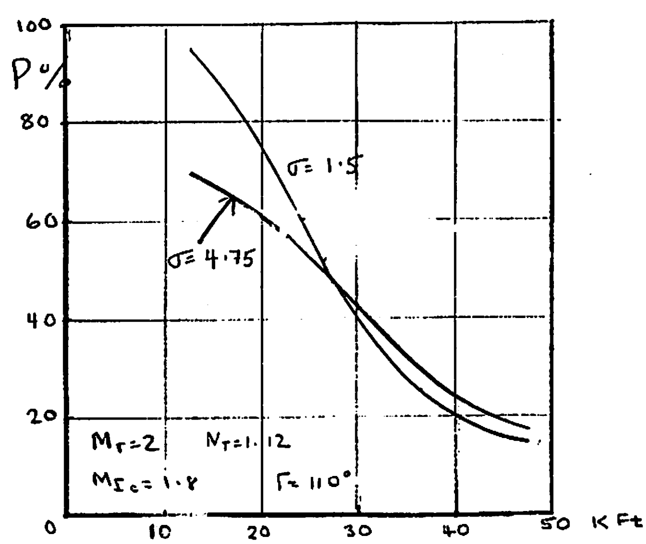


Figure 77. Variation of P_p with Range of Initiation of Target Evasion.

20.5 Bomber Turn Rate

The effect of evasion on the placement probability increases as bomber turn rate is allowed to increase. This is shown for one target-interceptor speed ratio in figure 78, assuming that evasion begins at lock-on.

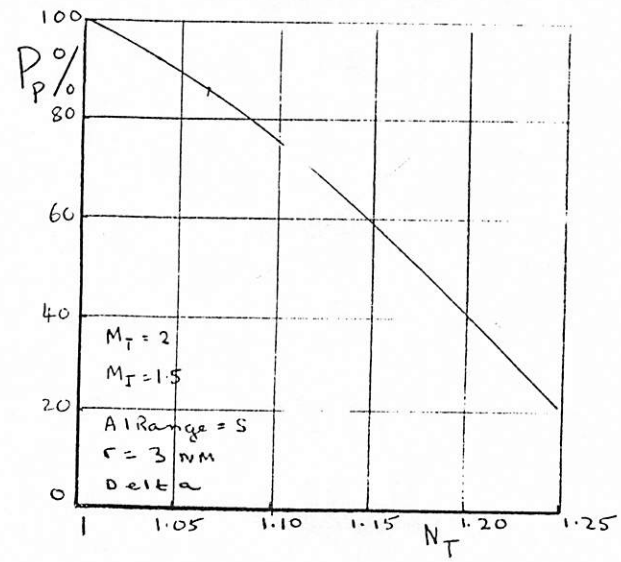


Figure 78. Variation of P_p with target evasion load factors.

20.6 Amount of Target Turn

In many tactical situations it may be reasonable to assume that the amount by which the bomber may turn off its original course is restricted. The rather confused conclusions are summarized in table 8 for head-on and beam attacks.

TABLE 8. Effect of Evasion
Variation in amount of Target Turn.

$M_T = 2$, $N_T = 1.25$, $M_I = 1.8$, DELTA	Head-on Attacks		Beam Attacks	
	good σ	poor σ	good σ	poor σ
good AI	P_p = 100% 0° to 60°	Linear variation in P_p 95% for 0° 60% for 60°	$P_p \approx$ 100% 0° to 30° Drop to 0 at 60°	Linear variation in P_p 85% at 0° 20% at 60°
poor AI	P_p = 95% 0° to 60°	$P_p \approx$ 25% 0° to 60°	P_p 90% - 0° 30° - 30° no degradation	$P_p \approx$ 25% 0° to 60°

CONCLUSIONS ON TARGET EVASION

(1) Evasion by a high speed bomber appreciably reduces the chance of interception (P_p).

(2) Evasion reduces P_p more for beam attacks than for head-on attacks.

(3) Lock-on by the interceptor should be delayed as long as possible, so as not to give warning to the bomber.

(4) The better approach path for an interceptor against an evading target is one on a collision course on a point ahead of the target rather than behind.

(5) Thought should be given to flying a collision course on the target itself when evasion is possible but uncertain.

(6) Evasive turns by a Mach 2 target against a Mach 1.5 interceptor of more than 60° does not in general cause further appreciable reduction in P_p .

21.0 APPRECIATION OF MISSILES

This portion of the study has assumed that the armament for the CF 105 aircraft is a guided missile; either Sparrow II or Sparrow III. Given below is a brief review of the capabilities and limitations of these missiles. This assessment has been hampered, as have also similar attempts of RCA, by the lack of detailed information on these weapons. This statement is especially true with regard to Sparrow III.

21.1 Tactical Capabilities

It has been shown in section 17 that tactically a guided missile is characterized by its launch zone. It was illustrated that this factor, within limits, has a relatively small effect on the placement problem.

Since Sparrow II and Sparrow III are essentially the same aerodynamic configuration and of approximately the same weight, their overall trajectory performance does not differ very much from each other. The launch zones of the two missiles are roughly of the same order of magnitude. Sparrow III, because of its navigation system, tends to have longer range capabilities about aspect angles of 135°. However this variation is of slight overall importance. It must be concluded that, tactically, or from a launch zone point of view, there is practically no difference between Sparrow II or III.

A word should be said concerning the state of knowledge of these launch zones. Information on the subject appears to be quite meager. This is especially true of launch zones for supersonic launch against supersonic targets.

For Sparrow II, there are only some fifteen cases that have been examined. These are all for a launching aircraft that has a speed advantage over the target. The information on Sparrow III as published in a Raytheon brochure is not based on actual Sparrow III simulation, but by extrapolation from subsonic results, guided by a knowledge of general missile studies.

Although the detailed characteristics of the launch zone do not affect the placement of the aircraft to a great extent, however, it is necessary for the designer of a fire control computer to know quite exactly what these conditions are; otherwise poor missile flight performance could result. It does not appear that the manufacturer of the system has sufficient detailed data to perform his task.

21.2 Seeker Characteristics

In section 17 it was observed that the missile seeker range could strongly influence the system effectiveness, if it restricted certain attack directions. It would appear that if the specified CW power of the AI can be achieved, the range of Sparrow III could be twice that of Sparrow II.

21.3 Overall Capabilities (Altitude and Speed)

It is rather doubtful that the performance of the Sparrows can be relied upon above 60,000 feet altitude. They were originally designed for a maximum altitude of about 50,000 feet. Alterations have improved their altitude capabilities and work is underway to extend their performance up to 70,000 feet, but at the expense of stability.

It is felt that at least 4 g lateral acceleration is required of a missile to overcome launching error, gravity and target evasion. On this basis the present Sparrow has capabilities only up to 60,000 feet, as shown in figure 79.

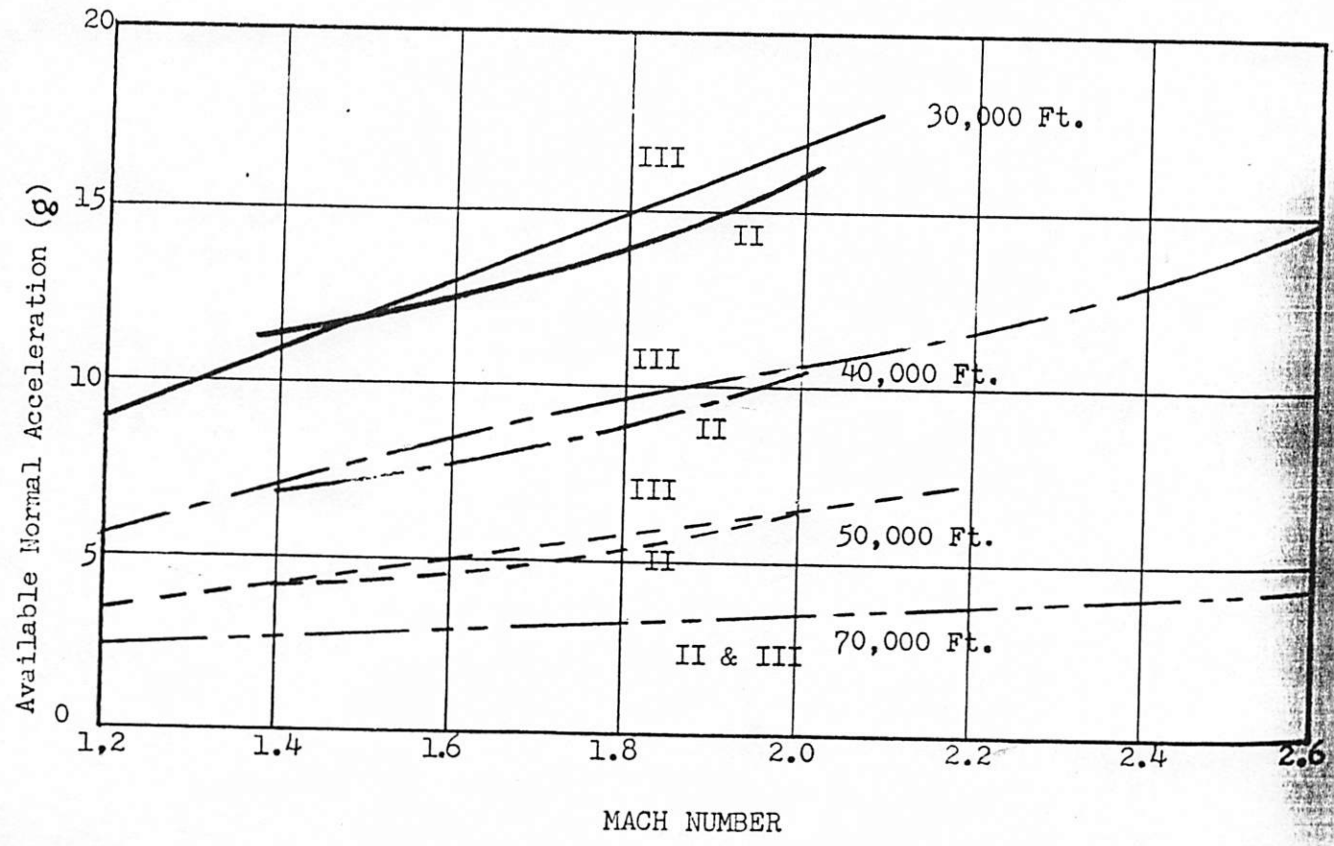


Fig. 79. Available Normal Accelerations of Sparrow II and III.

Concern might be expressed for the possible wide variations in miss distance that might occur at high altitudes. If the missile stability is reduced the effect of noise on missile dispersion could be severe. It is felt that sufficient studies of the terminal phase under noise conditions have not been made. R.A.E. has expressed their concern that something catastrophic might happen to the spread in miss distance at high altitudes.

It should also be noted that the figures quoted from trial results could be misleading. To date, only low altitude trials have taken place. Attacks have all been from a stern aspect against relatively slow and small drone targets. Performance could be much less heartening at high altitudes against faster aircraft.

The measurement of miss distance is also a question. There seems to be the tacit assumption in most cases that the radar center of gravity is at the center of gravity of the target, which is not necessarily so. Another disturbing factor is that in all tests to date the seeker slaving has been done manually. Automatic acquisition has not been proven, and because of high speeds it will be very necessary for the CF 105.

Concerning blind launch, it should be noted that primarily Sparrow III has this capability built into it, while Sparrow II is attempting to attain this capability. They have one successful blind launch firing, but it should be viewed with some reserve.

21.4 E.C.M. Capabilities

Few detailed data are available on the behaviour of these missiles under E.C.M. conditions. What can be said is little more than an estimation.

Since Sparrow II is K-band, there is less likelihood of there being jammers in this band in the immediate future. However, there could be such developments during the life of the CF 105.

Sparrow III has a narrower bandwidth, although in a more conventional part of the spectrum. The narrow bandwidth requires more sophisticated jammers, which could be built for this time period.

21.5 Missile Navigation

Sparrow II has a different form of navigation from Sparrow III. Sparrow II is fully active and flies a constant bearing course.

Sparrow III is semi-active and flies a proportional navigation course. This latter type of navigation tends to place somewhat less acceleration demand on the missile system and should produce less severe transient manoeuvre to correct initial launching errors.

21.6 Missile Launch

Provided both types of missile can be launched blind there does not appear to be excessive demand placed on the aircraft during the AI phase apart from achieving the tolerable heading for missile launch. Both Sparrow II and Sparrow III have been launched successfully from aircraft in banks up to 70°. A question remaining in this regard is the possible detrimental effects that might occur to the aircraft performance if the missiles are extended while the interceptor is under lateral acceleration.

The missile commitment time has been quoted as from 1 to 2 seconds. In the most severe case this could cut 6000 ft. from the depth of launch zone. If this proves to be a serious restriction, which at present does not seem to be the case, the signal for maximum firing range could be made to include this dead time.

21.7 Supersonic Launch

For launching above Mach 1.5 both missiles will need provisions for cooling and modified radomes. The problem of cooling is a bigger modification on Sparrow III than on Sparrow II. On the other hand the development of Sparrow III is supported by U.S. agencies while that of Sparrow II is not. Aerodynamically both vehicles are acceptable for launch up to Mach 2.2.

21.8 Choice of Weapons

Considering navigation, possibilities for blind launch and increased seeker range, there appears to be some preference for Sparrow III as a weapon. However it is questionable whether the advantages are strong enough to warrant a change to Sparrow III.

Generally it is felt that neither Sparrow II nor Sparrow III is an ideal choice for the CF 105. Both are limited in performance so that modification will have to be made for supersonic launch and even then they do not extend the altitude capabilities of the aircraft. As pointed out in section 22, it is felt that their warheads are inadequate. Essentially they are first generation missiles being married to a second generation aircraft. It is felt that attention and thought should be given to the next generation of missiles - generally called Sparrow X.

GENERAL CONCLUSIONS ON MISSILES

(1) Neither Sparrow II or Sparrow III is a good complement to the CF 105.

(2) More advanced missiles should be analysed as possible armament for the CF 105.

(3) There is little to choose between Sparrow II or Sparrow III tactically.

(4) More information is needed on dispersion in the terminal phase.

(5) Both Sparrow missiles must be modified for supersonic launch;

a) in regard to cooling
b) in regard to radome.

(6) Regarding ECM, Sparrow II has advantage in its remote frequency range, Sparrow III in its narrow band. Both features may be overcome by enemy jamming in the 1963-1965 era.

(7) There is insufficient information available on supersonic launch zones.

(8) Sparrow III is probably the better missile, but it is questionable whether the improvement warrants the cost of a change in production plans.

(9) Blind launch of Sparrow II cannot be regarded as a proven capability.

(10) The payload of the Sparrow warheads appears inadequate.

22.0 FUZE AND WARHEAD

The final missile engagement or impact phase of an interceptor attack determines whether or not the threat has been killed. The subject of lethality is concerned with evaluation of the probability of kill, P_K .

The following factors influence the lethality of a missile:

(a) Distribution of missile trajectories relative to a target, for a given launch condition.

(b) Variation of miss-distance with launch heading error.

(c) Distribution of launch heading errors.

(d) Fuze triggering point.

(e) Warhead blast geometry.

(f) Vulnerability of the target components.

In any analysis of the lethality problem each of these quantities must be known if a reliable answer is to be given. Much of the uncertainty as to the effectiveness of the Sparrow missile family lethality stems from the lack of information on items (a) - (d) of this list.

22.1 Vulnerability

At high altitude the only vulnerable components of the bomber may be:

(a) Pilots

(b) Engines

(c) Structure

Fuel fires appear to be questionable above 40,000 ft. altitude. Components which are usually considered vulnerable, such as fuel and control lines are generally so well shielded that their contribution to overall vulnerability is negligible.

If the vulnerability of current aircraft is difficult to assess, that of hypothetical supersonic bombers is nearly impossible. The seriousness of structural damage in high speed flight is still very much in doubt. The effects of warhead blast at high altitudes and speeds are also little understood.

22.2 Fuze Triggering Point

All-round attack capability is a desirable missile characteristic. It is achievable only if the fuzing device can detonate the warhead at the proper point along the missile trajectory for any aspect of approach. The difficulty which this implies is illustrated in figure 80.

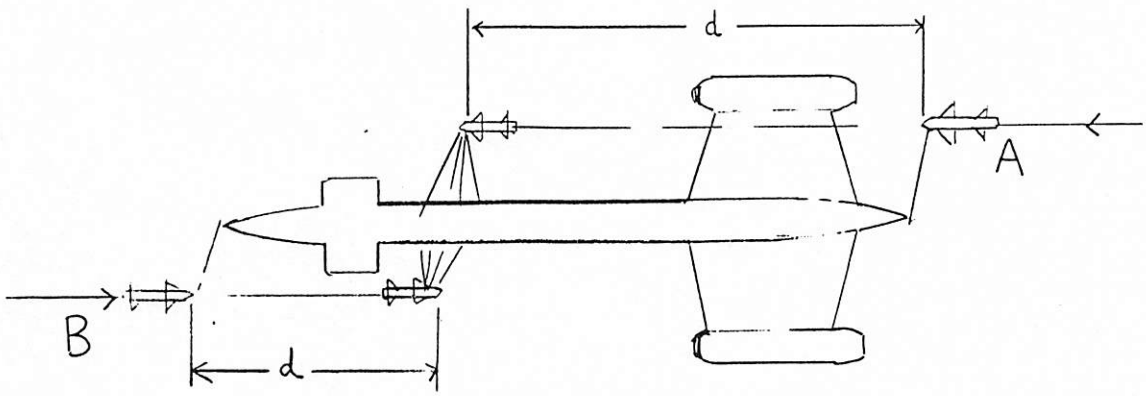


Figure 80. Influence of Approach Angle on Required Fuzing Characteristi

The missile (A) in the figure is approaching from the rear, and its VT fuze triggers on the tail surfaces. If it is desired to burst the warhead near the cabin, which is a distance d from the triggering point, a time delay d/V_c must be used (where V_c is the closing velocity). However, if the missile approaches as at (B) the time delay must be much shorter since the distance d is smaller. Thus an intelligent fuze should be able to compute the correct value of d as a function of aspect and the target configuration.

There is strong indication that the fuze warhead combination of the Sparrow II missile is strongly aspect dependent. If a restriction of the missile capability is acceptable, a preferred attack aspect may be chosen. It would be preferable to make use of aspect information so that correct fuzing could be provided for all approach directions.

The complicated picture of fuze-warhead geometry is to be investigated in the continuation of the CF 105 Assessment Study.

22.3 Sparrow Warheads and Miss Distance Considerations

The Sparrow II fragmenting warhead is said to have a 30 foot lethal radius. The relationship of this circle of potential damage to the dimensions of the USSR "Bear" bomber is illustrated in figure 81. The proposed continuous rod warhead has a useful radius of some 22 feet only.

While simulator studies considering point targets indicate a 30-foot miss distance; the actual miss distance obtained from vulnerable parts of a large target may be much greater. The incorrect assumption that the missile seeks the centre of gravity has been used in the lethality studies which tend to give optimistic results. Douglas work is based on this assumption, and on the additional one of ideal fuzing.

The results of missile firings against drone targets do not furnish the miss distance distributions which would be required for a lethality study. These test flights should be mistrusted because:

(a) They are at relatively low altitude.

(b) Slow targets and launch aircraft are used.

(c) Tail aspect attacks are almost exclusively used.

(d) Drone aircraft are easier to destroy than are manned targets.

(e) Very few firings have been instrumented so as to provide exact miss distance and fuze triggering point data.

(f) Miss-distance will be greater on larger targets due to increased scintillation.

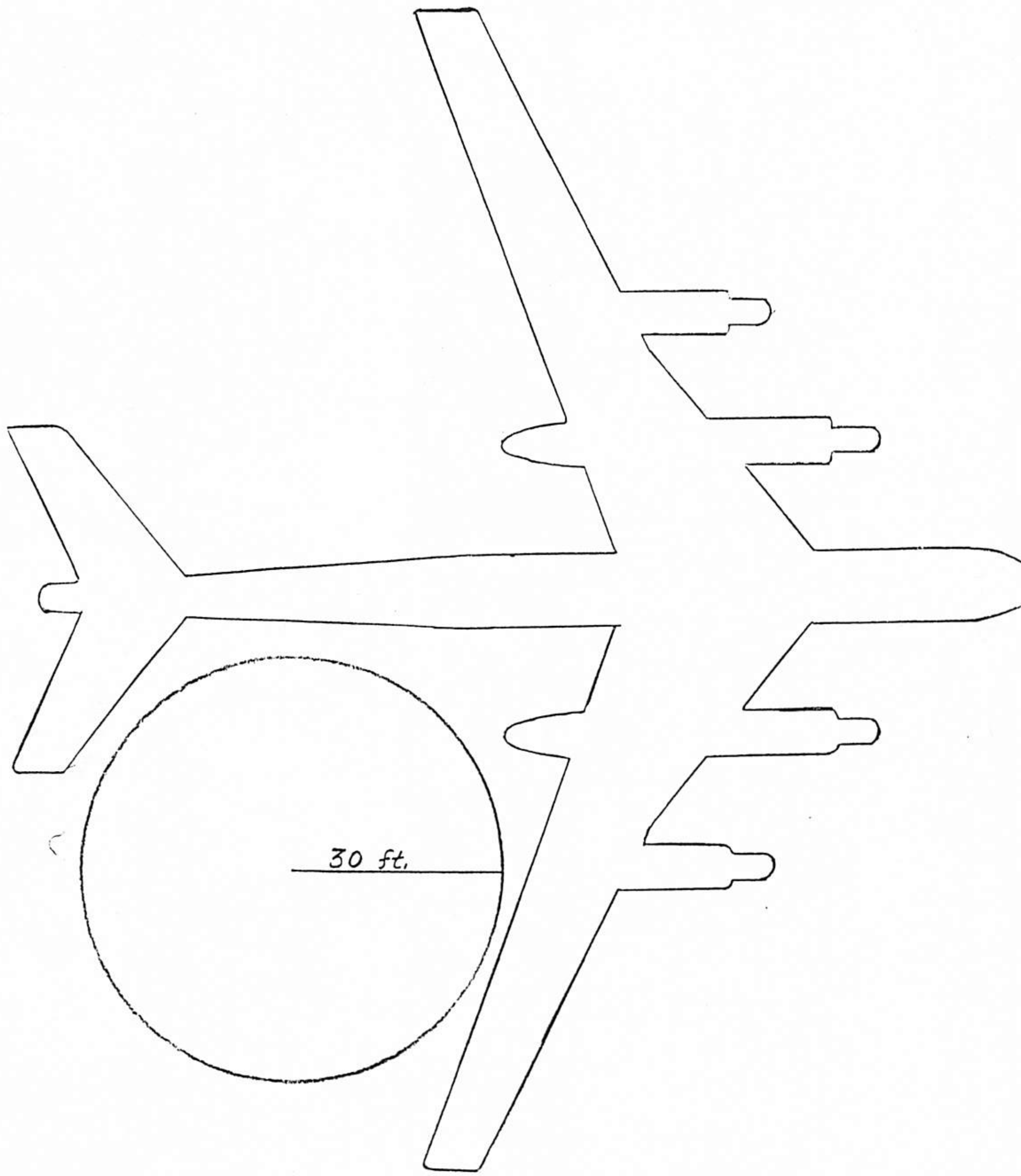


Figure 81. 30 foot Lethal Circle in Relation to the U.S.S.R. "Bear".

CONCLUSIONS ON MISSILE FUZE AND WARHEAD

(1) A velocity dependent time delay fuze does not appear to give satisfactory all-round performance.

(2) Fragmenting warheads of 50 - 75 lb. weight do not appear to have a high kill potential against high altitude targets.

(3) With the present Sparrow fuze, there is a preferred aspect of attack for a given fuze setting and a given target configuration. This could influence the demands on the AI phase and the vectoring phase of the attack.

(4) Test firings to date do not give a complete picture, nor one which can be applied in lethality analysis.

(5) Rod warheads appear to have a higher kill potential than a fragmenting type of the same weight.

23.0 NOTES ON INTERCEPTION TACTICS UNDER ECM

Recommendations on desirable tactics have been made throughout the text in a number of the technical sections. These have generally dealt with fighter speed control, G.C.I. positioning, and direction of attack. There is given below a brief summary of some techniques which could increase the fighter's attack efficiency, under ECM conditions.

23.1 True Collision Course

If range can be determined from GCI or if crossover under ECM conditions occurs at ranges exceeding 30,000 yds., the fighter may execute a true collision course by nulling line-of-sight rate. If the resultant lead angle is less than 30° the missile may be launched from a true collision course. If the lead angle is greater than 30°, a pre-launch turn to 30° lead angle will provide successful launch.

23.2 Fixed Lead Pursuit Course

A fixed lead angle can be chosen which will allow firing of the missile at all aspects with no pre-launch turn. This tactic is most effective against targets which are slower than the interceptor. It is feasible with crossover ranges down to 9000 yards. The Sparrow II seeker, if unjammed, will provide range soon enough for successful launch in most cases. Launch command might also be given by GCI.

23.3 Pure Pursuit with Tail Cone Launch

If the crossover range is less than 2000 yards, a pure pursuit course can be flown against targets slower than the fighter or fast targets in formation. Pre-launch ranging might be obtained from GCI, optical visual, Sparrow II seeker or radar crossover. This course has the advantage that it allows best use of IR tracking and does not require a prediction of the expected crossover range. It is probably advisable whenever GCI is jammed and semi-passive ranging is unsuccessful.

23.4 Navigator Control

If chaff jamming or inverse scan does prevent lock-on, it is possible for the navigator to guide the fighter on a successful lead collision course by visual examination of the B scope in the search mode. This tactic has been tested in Project Sprint.

23.5 It will be noted that method 1 requires successful passive angle tracking by radar [or I.R.] to provide angular rates. This can be denied by a responsive jammer or a barrage jammer amplitude modulated at near conical scan frequency. Methods 2 and 3 are feasible using angular information from hand track or search only.

23.6 The question of slaving the missiles before launch is somewhat uncertain. Both Sparrow II and III can be made to perform independent range or speed lock. It appears possible to angle slave from hand track since the effective missile angle tracking beamwidth is about 10°. By the same token it may be possible to angle slave in the presence of inverscan jamming of the A.I.

24.0 G.C.I. AND VECTORING PHASE

Although the GCI and vectoring phase of the attack are not the direct concern of this study, a few observations may be made as a result of contiguous investigation. They are mainly of a qualitative nature.

24.1 Scramble

A very limited map study has been done of a Mach 2 raid with scramble 10 minutes after the raid enters Pinetree. The CF 105's time deficit to Mach 2 was taken as 2.1 minutes; i.e. the actual climb-out and acceleration of the 105 can be represented as the delayed take-off 2.1 minutes later of a fighter with an immediate velocity of Mach 2. The main result is the conclusion that unless the 105 is scrambled as a Mach 2 crosses the mid-Canada line, nearly all interceptions over Eastern Canada will occur within 125 miles of the proposed Bomarc sites, and Bagotville squadrons will be of little use because of the advanced position of their base. The situation improves, of course, against slower targets, but pre-Pinetree scramble appears to have considerable merit for all supersonic raids.

24.2 Mission Speed and Altitude

The CF 105 is capable of numerous combinations of mission speeds and ranges, and in many defense situations it will be necessary to depart from the standard "long range" and "high speed" missions laid down in the specifications. The map planners and sector controllers should be free to choose the mission speed best suited to counter the raid, and in some cases this will be the fighter's maximum level speed. The radius estimated by Avro for a Mach 2 mission is 260 n.m. which is more than adequate for most of the intercept situations requiring Mach 2 missions.

Mission altitude will normally be the altitude for lowest fuel consumption and will increase with increasing mission speed. The transition to attack altitude will usually be made shortly before AI detection.

The above considerations imply that the programming of CF 105 missions in an automatic computer must be more complex than programming of a Bomarc, if best tactical use is to be made to the aircraft.

24.3 G.C.I. Control Under A.I. ECM

If the AI radar is jammed but the GCI is unjammed and accurate, ($\sigma = 1\frac{1}{2}$ n.m.), it is possible to complete the interception by GCI control. AI or IR angle tracking is required just before launch to angle slave the missiles. It is believed that Sparrow II/III will be capable of independent range/speed lock without AI assistance.

24.4 Effect of Multiple Aircraft on the Placement Problem

The terms of reference of this study limit it primarily to the analysis of one fighter versus one bomber. However, there are certain areas in which one-versus-one results are not applicable to the more realistic multiple intercept situation:

(a) Traffic Restrictions on Manoeuvre - In the present GCI system, the two main problems of multiple interception are "Confusion" and "Collision"; i.e. fighters lose identity and mutually interfere with each other's attacks. As a result, the amount of the fighter's corrective turn is usually limited to $\pm 40^{\circ}$. Provided GCI radars of the CF 105 era are powerful enough to work on skin paints without IFF, the confusion problem will probably be solved. However, traffic coordination may still require some restriction on the amount of corrective manoeuvre or the amount of time consumed in corrections. This has an adverse effect on the manoeuvre barriers (which assume unlimited correction) and hence on placement probability.

(b) Alternate Targets - During a large mass raid the whole concept of GCI positioning error changes since with bomber spacings of 3 miles or less, there will always be a bomber on which the fighter is correctly positioned. GCI vectoring errors thus need no longer cause placement errors; they merely reduce the efficiency of target assignment. The effect of this is difficult to assess. It appears that by properly spacing and briefing the fighters, a large raid can be attacked with perfect GCI placement, fairly uniform target assignment and few double intercepts.

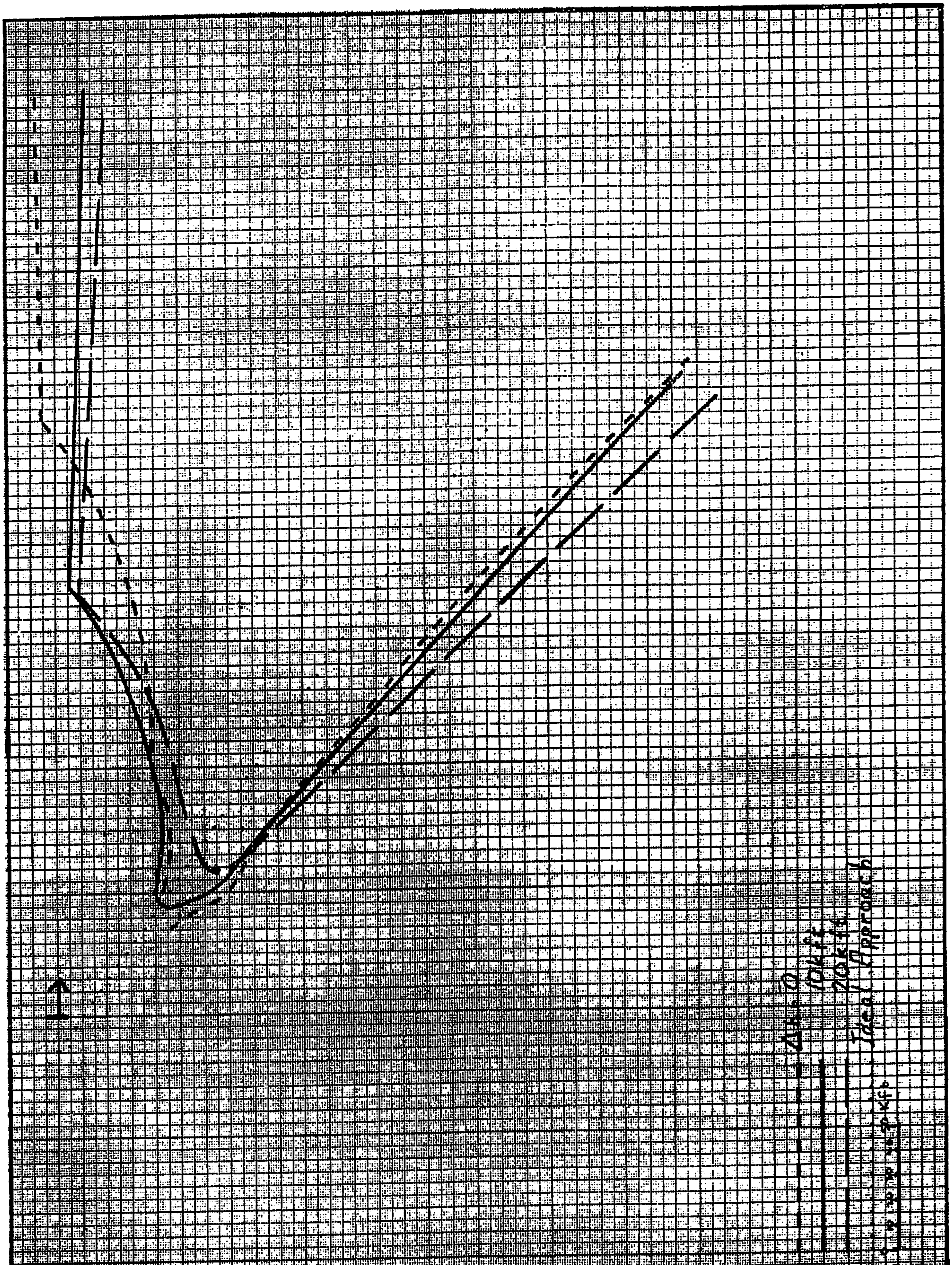
The relative importance of factors (a) and (b) depends on the size and spacing of the raid. Against small compact raids whose dimensions are roughly equal to those of the fighter formation, the one-against-one study predictions are probably too optimistic. Against large (say, 200 plane) raids, the 1 vs 1 study predictions are too pessimistic.

25.0 POSSIBILITY OF NON-CO-ALTITUDE ATTACKS

A three-dimensional simulation of the interception problem has been set up at CARDE. Preliminary results have been obtained for climbing attacks against a non-evading Mach 2 target at 60,000 ft. altitude. Placement zones have been obtained for initial interceptor altitudes of 40,000, 50,000 and 60,000 feet. A typical set of zones for one course difference is reproduced in figure 82. ($\Gamma = 110^{\circ}$, $M_{Io} = 2$ $M_T = 2$).

The results show that variation in interceptor approach altitude does not change appreciably the horizontal limits of the placement zone. Only if AI range performance is poor, is there any advantage in a co-altitude attack.

It appears from these results that the ideal approach line is no longer ideal, but that it would be preferable to vector the interceptor to a point ahead of the target. The interceptor loses speed rapidly during high load-factor manoeuvres, so that it is easier to turn into a lead-collision course from ahead of the usual ideal line than from behind, where acceleration would really be required.


Δh = 0
10kft
20kft
Ideal Approach

26.0 OTHER PROBABILITIES

In section 2.3 the quantity expressing probable effectiveness of the system was written as the product of six component probabilities. The major effort in the study has been the determination of placement probability. However, some observations can be made on the other quantities.

It is important to note that in a many-component expression the value of each must be high if the product is to have a reasonable magnitude. For instance, if each probability is 90%, then

$$P_E = (.9)^6 = .53 \text{ or } 53\%.$$

Or if each is 85%, then

$$P_E = (.85)^6 = .38 \text{ or } 38\%.$$

26.1 Values of Some Probabilities

It has been shown in this study that through the use of proper tactics, and for specification level of AI performance and a 3 n.m. of GCI control, placement probability of 90% can be obtained.

Typical values of the kill probability P_K for a 2 missile salvo, are 90% for a continuous rod warhead and 39% for a fragmenting warhead, against a subsonic swept wing aircraft. Whether these figures can still be used in considering a supersonic target is doubtful.

No estimates are available on the probability of detection of the target by the ground radar (P_D), the survival of the interceptor (P_S) and the system performance against jamming (P_J). Generous values might be

$$P_D = 98\%, \quad P_S = 98\%, \quad P_J = 85\%$$

The unreliability of equipment contributes to system degradation to a large extent. Trials with current airborne electronic systems show that 85% is an optimistic value for system operability. Similarly the best quoted figures for missile reliability is 85%. Thus the best combined reliability factor would be the product of these, or 72%.

It is felt that these figures are an upper limit. Probably more realistic values would be 70% and 50%, for a combined figure of 35%.

26.2 CONCLUSIONS

If the best values of all these probabilities are taken the overall value of effectiveness becomes

$$P_E = P_D \times P_P \times P_S \times P_K \times R \times P_J$$

$$= .98 \times .95 \times .98 \times .90 \times .72 \times .85$$

which gives 50%.

The more pessimistic values give

$$P_E = .98 \times .95 \times .98 \times .39 \times .35 \times .85$$

which gives 11%.

The most influential factors in the overall effectiveness are seen to be:

(a) Lethality

(b) Reliability

(c) Electronic Counter Measures.

27.0 E.C.M.

Tentative conclusions on the systems potential in the face of E.C.M. have been interspersed throughout this report where such considerations appeared to be appropriate. A brief summing up of the picture as outlined by studies at R.C.A., D.R.T.E. and CARDE is given in this section. Tactical expedients have been discussed in Sections 23 and 24.

27.1 Effectiveness of Astra I Anti-Jam Features

It appears possible by judicious use of the anti-jam facilities of the Astra I to defeat or minimize most types of jamming with no change of interception tactics. Certain types of jamming cannot be countered by the AI and require radical tactical changes to achieve successful interception. These are:

1. High-power barrage jamming.

2. Continuous spot jamming with frequency tracking rates exceeding about 2400 mcs/sec.

3. Continuous or responsive C.W. or pulsed scan inverters.

4. Forward-downward fired chaff with explosive dispersal.

27.2 Multiple Aircraft Situations

In multiple aircraft engagements, barrage jamming is the most likely threat, since most types of spot or responsive jammers require listening devices which would be confused by transmissions from other jammers. The barrage jammer may be amplitude-modulated at random frequencies near the conical scan frequency to hinder passive angle tracking, as in 3 above.

27.3 Early Use of Anti-Jam Devices

In high speed interceptions, time will be at a premium and it is suggested that certain anti-jam features of the Astra I, e.g. random frequency programming and IR tracking be used on all missions to save time in assessing and countering the ECM threat.

28.0 FUTURE WORK

The results reviewed in this report are based on the first year's work. In some respects this exposition is premature since a number of topics are still under study. A better understanding of some of the parameters may be forthcoming in the following months. However, it was felt that it was most advisable to present whatever trends are evident as soon as possible. It is planned to continue the study for another year. The areas which it is intended to investigate include:

(1) Three Dimensional Attack Simulation - The work in the study of non-co-altitude attacks will continue, for several targets and different fighter approach tactics.

(2) Fire Control Studies - The proposed Astra I fire control system will be evaluated, and possible improvements to it investigated.

(3) Missile Studies - It is planned to extend the present knowledge of permissible launch conditions for Sparrow type missiles for supersonic targets and interceptors. In connection with the lethality studies, it will be necessary to determine the distribution of miss distance and of missile end-course trajectories.

(4) Lethality - Lethality assessments for at least two targets, the subsonic Bear and a hypothetical straight-wing supersonic bomber are to be conducted.

(5) E.C.M. - DRTE is making a study of the effects of ECM on the Sparrow missile seeker and fuze. The results of this study will become available within the year. Investigations of anti-ECM tactics will be continued.

(6) Long Range Rockets - The use of long range unguided rockets as a weapon to be carried by the CF 105 will be considered. This includes launch zone, placement, and fire control studies, and should include both subsonic and supersonic targets.

(7) Low Altitude Targets - A short study of the effectiveness of the CF 105 system against subsonic targets at 2000 ft. altitude is planned.

(8) I.R. Work - It is planned to make a brief investigation of the tactical effectiveness of the CF 105 interceptor system using infrared AI and missiles.

OVERALL CONCLUSIONS

The broad conclusions that can be drawn from the study are summarized in Table 10. It should be emphasized that the last three rows of the table represent opinions rather than conclusions. However, they are supported by study and thought in contiguous areas so that they cannot be refuted by merely another opinion. A detailed examination of the individual subjects is required to prove or disprove these statements.

A column entitled "more advanced threat" has been designated, not because a specific attacking weapon has been designated, but because war-time situations often demand that equipments be used in roles over and above that for which they were designed. It is therefore felt that a margin of growth potential should be present in all major subsystems.

TABLE 10.

	EXPECTED SUBSONIC THREAT	PROPOSED SUPERSONIC THREAT	MORE ADVANCED THREAT
AIRFRAME	Adequate	Adequate	Some Potential
AI (not jammed)	Adequate	Adequate	Growth Potential
WEAPON	Adequate	Marginal	Inadequate
WARHEADS	Marginal	Inadequate	Inadequate
PRESENT G.C.I.	Marginal	Inadequate	Inadequate
DISTRIBUTION OF GROUND BASES	Adequate	Restrictive	Inadequate

RECOMMENDATIONS

In the light of the study reviewed herein, the following recommendations are made.

1. That effort be made to obtain information on second generation missiles. Sparrow X and advanced Falcon (GAR Z).
2. That in the light of the above information, consideration be given to the feasibility of equipping the CF 105 with a more advanced missile.
3. That effort be made to gain the information required to determine the effectiveness of Sparrow type fragmenting and rod warheads with their associated fuzing systems.
4. That a detailed study be undertaken to examine the problems involved in the operational employment and deployment of the CF 105.
5. That effort be made to obtain the Specification range for the AI radar and a ground environment accuracy on supersonic targets ($M_T = 2.5$) of 3 n.m. minimum.
6. That for supersonic threats, attacks be made near course difference of 180°.
7. That, if feasible at present, interception trials be conducted to determine the problems associated with head-on attack.
8. That an investigation be carried out on the vectoring phase to determine the problems, penalties and probabilities of obtaining a specified course difference.
9. That when evasion is expected of a subsonic target, the interceptor be vectored on a rear attack at a speed just slightly above the target's speed.
10. That when evasion is expected for a supersonic target, the interceptor be vectored on a near head-on attack and be placed on a collision course on a point somewhat ahead of the target.
11. That a flight trials program be initiated to investigate tactics in the presence of AI jamming.

12. That a study be made of procedures to be adopted when the GCI control accuracy is very degraded by jamming.

13. That a study of the problem of multi-aircraft situations be undertaken, which among other things would attempt to determine:

    (a) The ECM picture in the case of multiple interceptors and multiple targets.

    (b) Restrictions that may be imposed on interceptor manoeuvres by traffic problems.

    (c) Target assignment considerations.

    (d) The possibility of using a preferred attack course difference.

    (e) Scramble and vectoring procedures.

14. That support be given to a study to establish criteria and procedures for the technical assessment of Guided Weapons.

15. That in conjunction with 4 above, a study be made of the CF 105's attrition potential and its measure of worth in terms of cost and protection.

16. That the interceptor performance be maintained above the pessimistic level used in the CARDE assessment (1.29 g at M 1.5 at 50,000 feet).

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