CARDE TECH. Letter N-47-3 Copy No. 23.

DESCRIPTION OF PROGRAMME
FOR CF-105 ASSESSMENT STUDY BY CARDE

by

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Systems Group

CANADIAN ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT.

Valcartier, Quebec MAY 1958.

CANADIAN ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT
DEFENCE RESEARCH BOARD

Technical Letter No. N-47-3 Date 4 May 1956 Copy No. ....

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PROJECT
CF-105 ASSESSMENT

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Systems Group

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SUMMARY

1.0 A review of the general interceptor-weapon problem and its application to the CF-105 system is given. It is noted that major uncertainties exist concerning many of the elements to be studied. This increases the work involved in the study because of the greater range of values which must be considered and the importance of securing the maximum of up-to-date information on pertinent development of sub-systems and on other similar studies.

2.0 To achieve a worthwhile result within the resources and time available the CARDE study must be limited to particular aspects of the general problem. The basic objective of the CARDE portion of the study will be to determine whether the performance of the CF-105 with an available missile type will be sufficient against targets indicated by intelligence. The chief result which it is intended the CARDE study should achieve is an evaluation of the effectiveness in countering a threat that is likely with a system made up of known or relatively fixed sub-systems such as the ground environment and the CF-105 aircraft if the fire control and weapon sub-systems are well selected and well designed to the probable limits of engineering science and the arts involved. This evaluation and judgment will be tempered by the knowledge in the establishment of the existing state and probable progress in these fields of endeavour. The problems of main concern may be summarized as follows:

a) Initial reviews of the validity of the basic assumptions

b) Assessment of placement chance

c) Assessment of chance of kill.

It is estimated that this restricted study will require a minimum of 20 man years.

It is expected that DSE will provide assumptions and data on ground environment which will not be studied directly at CARDE. The AVRO estimates of aircraft performance will form a basis for the investigation, but departures from these stated characteristics will be considered as distinct possibilities. Weapon and fire control studies will be based on modifications or anticipated developments of existing equipment.

A review is given of the problems that will not be studied by CARDE and which should be pursued by other establishments if an overall evaluation of the Interceptor System is desired.

Detailed discussions of several of the problems that are proposed for CARDE study are given as Appendices.

The following recommendations were made:

(a) A headquarters agency should be responsible for directing pertinent data to the Systems Group at CARDE as it becomes available.

(b) If other groups are to investigate problem areas outside the scope of the CARDE study, a coordinating group should be designated to oversee the problem as a whole and determine that the work of each group is mutually compatible.

(c) Both DRB and R.C.A.F. Headquarters should be prepared to support visits to the U.S.

(d) It has been pointed out that it will be necessary to seek aid from industry. The necessary financing for this work should be arranged immediately.

1.0 INTRODUCTION

CARDE has been requested to make preparations to undertake a study of the CF 105 weapon system for the RCAF and DRB. The study was originally scheduled to have begun on April 1st, 1956. However no approval to proceed has been received. Preliminary planning and study for the evaluation has been in progress for several months by the Systems Group, and it is their work which is presented here.

Though there have been a number of discussions among the organizations involved, the proposed terms of reference of the problem have not yet been transmitted to CARDE. This report might therefore serve as background for their formulation. An attempt is made to outline the problems of an interceptor-weapon system, and to indicate in some detail the portions which CARDE may be expected to consider. A tentative programme of work and scale of effort is given, and the assumptions and data on which the study must be based are discussed.

At this stage of planning, only broad problem areas can be outlined. As the study progresses these problems will be defined more definitely and subsidiary problems may be generated. For this reason the progress of this proposed work will be described in quarterly reports, of which this is the first. While these will be compiled by the Systems Group of CARDE, it is planned in future that personnel concerned with specific problems shall contribute commentaries on their work, together with technical expositions, which will be inserted as appendices, or published as separate reports. It is considered that this sytem of reporting will keep the Headquarters and related study groups informed of CARDE's activities and enable those responsible for the work to maintain effective control combined with the necessary flexibility.

In this report, individual sections have been made self-contained, at the expense of some repetition. Several of the appendices were originally written as outlines of problems to groups in CARDE and have been reproduced here without editing.

2.0 A GENERAL REVIEW OF THE INTERCEPTOR PROBLEM

A study of the type contemplated may usually be broken down into a number of rather self-contained problems, the solutions to which may be developed in relative isolation. In order to ensure that emphasis is placed on appropriate aspects, and that the various results will be mutually compatible, each problem must be studied in proper relation to its place in the overall situation.

The general concept of an interceptor defense system,and the interrelation of its parts, are outlined in this section. In subsequent sections the problem is particularized to the case of the CF 105 and attention is then focussed on those aspects of the problem which might profitably be studied by CARDE.

2.1 The Concept

The problem to be considered is that of attempting to counter an enemy air threat by means of an intercepting aircraft armed with some type of projectile. The present concept of future air defense envisions the interceptor system as an integrated whole consisting of ground environment, airframe, power plant, radar, universal electronic computer, data links, and weapon subsystem consisting of airframe, power plant, guidance, fuze and warhead. The system is "integrated" in the sense that each unit is to be designed with regard to its function in relation to the other components. The inputs to the various sub-systems are the outputs of some other member and cognizance must be taken of the limits and tolerances that are imposed on those quantities by the performance of the components. In particular, attention must be given to the possible cumulative effects of errors throughout the system. The target, interceptor, weapon combination may be thought of as two closed loops as depicted in Figure 1., with numerous loops both closed and open inside each of the blocks depicted.

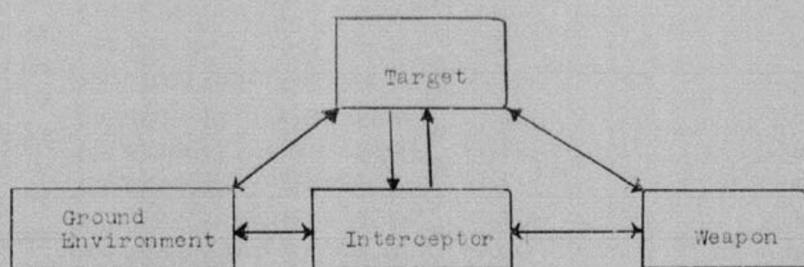


Figure 1.

The inputs to the various "boxes" are subject to degrees of randomness due to the accuracies, capabilities, and serviceability of the equipment employed, the effects of atmospheric conditions, and the characteristics and tactics of the threat.

Several major problems may be associated with each division in Figure 1. A more complicated picture is shown in Figure 2, to illustrate the complexity of the problem and interrelations between subsystems rather than to indicate the organization of the proposed study.

An assessment of such a system is necessarily couched in terms of probability. The overall quantity (P_e) expressing the effectiveness of the system will be composed of several component probabilities. It may be written as

$$P_e = P_d \times P_p \times P_s \times P_l \times P_r \times P_j$$

where

P_d = Probability of detecting the threat.

P_p = Probability of positioning the aircraft.

P_s = Probability of survival of the aircraft until missile launch.

P_l = Lethality or kill probability of the weapons system.

P_r = Overall reliability.

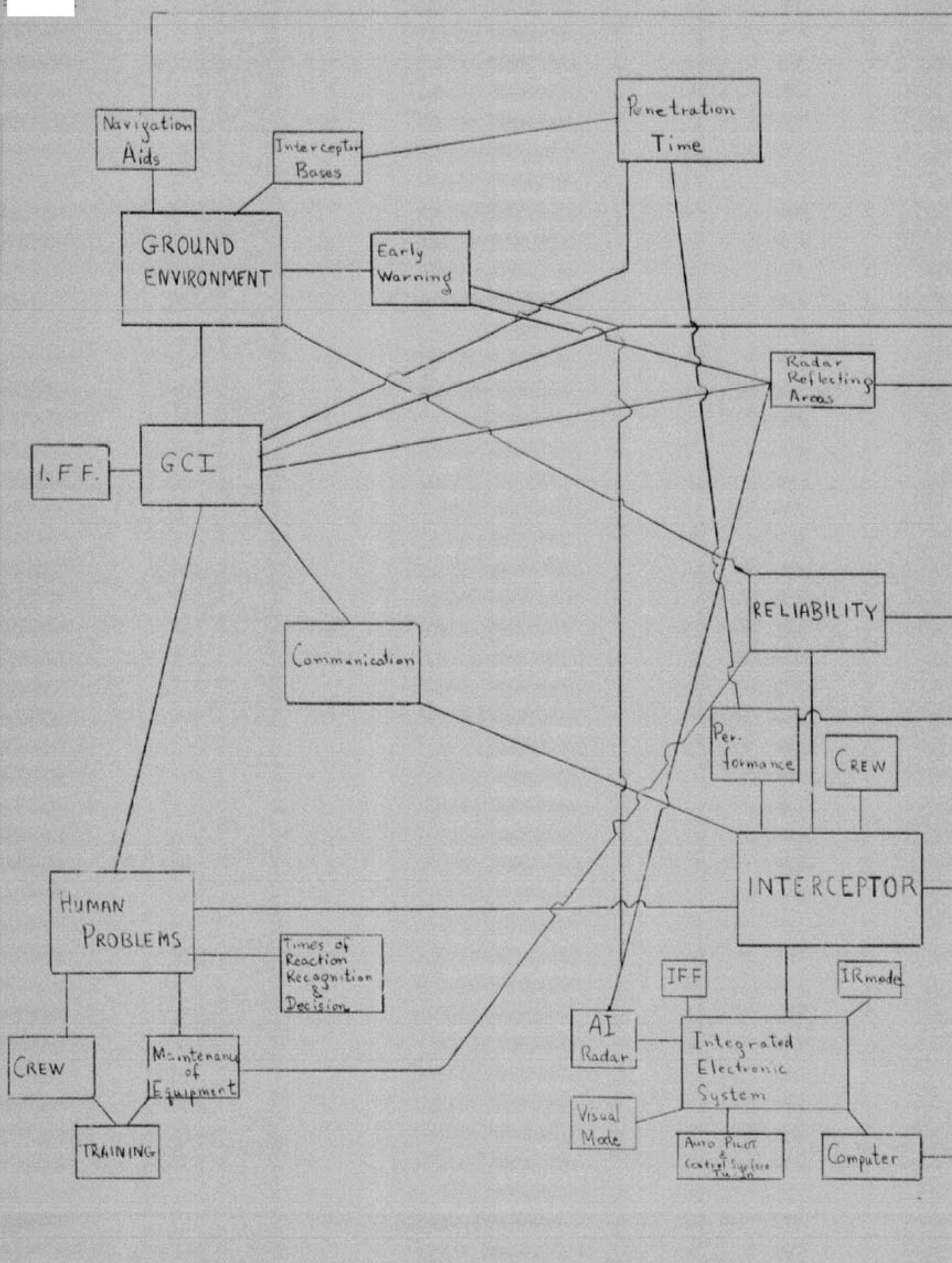
P_j = Probability of the system not being degraded by jamming combined with the probable degree of degradation.

These quantities in turn are themselves complex ingredients composed of many factors. For example P_p includes both the probability of making AI contact and the probability of being satisfactorily headed when this is accomplished. If multiple runs are made or a salvo of missiles fired, the form of the expression for P_e may be changed, but the components will remain the same.

The overall problem may be divided for purposes of discussion into three general phases: ground control, A.I. control and the attack phase. In addition there are the subjects of multiple attack and return to base which may be considered.

2.2 Ground Control Phase

There are two major aspects to ground control, the strategic and the tactical. The strategic problem of ground environment is concerned with the areas to be defended, the amount of penetration by the enemy which may be permitted, and the amount of early warning which may be obtained. These considerations influence the positioning



Navigation Aids
Interceptor Bases
Penetration Time
GROUND ENVIRONMENT
Early Warning
Radar Reflecting Areas
I.F.F.
GCI
RELIABILITY
Communication
Per-formance
CREW
INTERCEPTOR
HUMAN PROBLEMS
Times of Reaction Recognition & Decision
CREW
Maintenance of Equipment
TRAINING
IFF
IRmode
AI Radar
Integrated Electronic System
Visual Mode
Auto Pilot
Computer

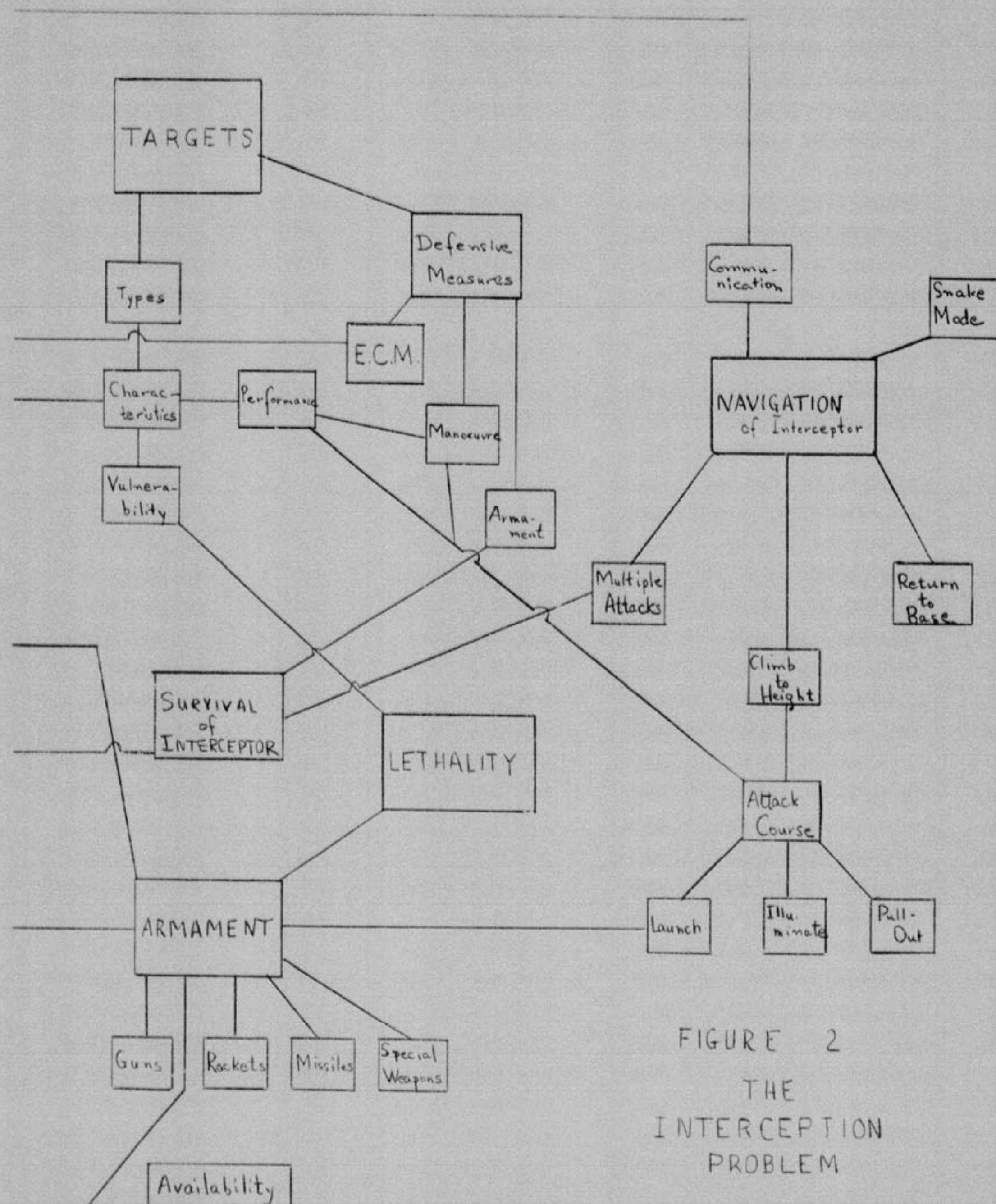


FIGURE 2

THE INTERCEPTION PROBLEM

of GCI stations, and interceptor bases and determine the required range, endurance, and climb capability of the interceptor aircraft, but are in general excluded from the scope of this study. From the tactical point of view the ground control phase includes the initial detection and assignment of the target and the positioning of the interceptor so that it may detect the target with its own radar and have an initial position and heading such that an attack is possible.

Before the interceptor system can become active as a measure of defense, the target must be detected by the GCI which controls the interceptor aircraft, and an alert given. The probability of detecting a target depends on a number of factors, including

a) characteristics of the radar installations

b) methods of surveillance

c) maintenance and training

d) effects of atmospheric conditions

e) enemy countermeasures.

There are thus involved considerations of equipment performance, personnel training, serviceability, and tactics.

Once a target has been detected and identified as such, and the interceptor scrambled, the GCI problem is to position the interceptor so that it makes AI contact with the target in such a position and on such a relative heading as will enable it to complete a successful attack. The relative positioning of the interceptor and target aircraft depends on a knowledge of the following factors:

a) range to target

b) azimuth angle to target

c) altitude of target

d) speed of target

e) heading of target

and the same five factors with respect to the interceptor.

Depending on the type of control to be used a computer either on the ground or in the aircraft must use the above data to compute a course so that a satisfactory A.I. contact may be established. The probability of this being accomplished depends on

a) the accuracy of the input data

b) the characteristics of the computer and data link and the A.I. radar set

c) target and interceptor performance

d) enemy countermeasures such as (i) manoeuvre, (ii) E.C.M.

In evaluating these probabilities it must be borne in mind that the desired data will be degraded by numerous causes and that the G.C.I. must position and steer the interceptor so that it can not only launch its missile but launch it so that its fuze and warhead will ultimately be positioned to do maximum damage to the target.

The study of the navigation problem of the G.C.I. involves the relation of the desired course difference at A.I. contact with the flight characteristics of the interceptor so that the course which will optimize the chances of success can be determined and evaluated. Also involved at this early stage is the decision concerning the type of attack which should finally be attempted, pitch-up, diving, zoom, or co-altitude attack.

The problem becomes further complicated by the consideration of target assignment in the case of multiple targets, and of the control of a large number of interceptions by the same GCI station.

2.3 <u>A.I. Control</u>

After A.I. contact in a suitable position is achieved, the interceptor will rely on its radar and fire control system to reach a position relative to the target so that a missile or rocket may be successfully launched. For a given course difference and speed ratio between target and interceptor there is a region of values of range and aspect relative to the target from which, if A.I. contact is made, a successful attack run may be initiated. The size of this region depends on the following parameters:

a) permissible launch zone of weapon

b) angular rate of turn of interceptor

c) maximum detection range and angle of look of A.I.

d) target evasion

e) further restrictions imposed by launch requirements of particular weapons

f) interceptor/target speed ratio.

The size of this region must be delineated to determine the probability of positioning the interceptor for a successful attack. The calculation of this area with its associated permissible interceptor headings is usually referred to as the placement problem. This is the pivot on which the general assessment of the interceptor system depends.

In a more subtle manner the characteristics of the fire control system may have a deciding effect on the situation. Particular aspects of the system that may critically affect overall effectiveness are the modes of attack, time lags, accuracies and the relative merits of automatic and manual aircraft control. In addition a variable interceptor speed arising from manoeuvre in any plane produces complications in the computation of attack courses, or unacceptable inaccuracies if computation is not attempted. All this must be studied and evaluated.

2.4 Attack Phase

In the attack phase attention is focussed on weapon performance which involves aspects of launching, missile flight, (guided and unguided), fuzing and warhead characteristics. The last two are often combined with target properties and considered under the heading of lethality. This complex problem is much neglected and often oversimplified by the consideration of miss distances only.

One of the limiting factors mentioned in section 2.3 was the permissible launch zone of the weapon. Analytically the simplist launch criterion is a range that gives a constant time of flight for all aspects relative to the target and a given permissible heading error at launch. However such a rule may place an unnecessarily tight restriction on the launching condition and ignore a portion of the weapon's capabilities. A launch region bounded by maximum and minimum launch ranges, which vary with aspect angle relative to the target makes the attack phase more flexible (and the fire control computer more complicated). In addition the final kill probability of a missile with an influence fuze and a given warhead will have maxima for particular launching conditions. It is desirable to establish these particular conditions. Such an attempt will influence the type of navigation chosen in the GCI Phase and the type of fire control computer and procedure employed during the A.I. Phase.

These problems are more complex when thought of in three-dimensional terms of a snap-up attack and various missile approach directions for fuzing and warhead firing.

2.5 Additional Problems

Two additional problems which have a bearing on the overall effectiveness of the interceptor system are those of a second pass by the interceptor, and of return to base. In present planning these are not being considered as immediate problems but they are important and are included for the sake of completeness.

2.5.1. Multiple Attacks

It may seem desirable that an interceptor be able to carry out more than one attack during a mission. This may be a re-attack if the first one failed, or an attack on a second target. The conditions on which this capability depends are the range, speed and missile load of the interceptor, and techniques which may be designed for re-establishing G.C.I. contact and positioning the interceptor for a second attack run. When many interceptors are being controlled by the same G.C.I., this phase will complicate the traffic problem.

2.5.2. Return to Base

The problem of guiding an aircraft to its base, or an alternate landing field, may be a difficult one under combat conditions. Optimization of flight path for return to base may increase the available combat performance or combat time of the aircraft and so affect the overall system effectiveness.

3.0 STATUS OF THE CF 105 INTERCEPTOR SYSTEM

The preceding sections reviewed the problems involved in the general situation of meeting an enemy air threat by means of intercepting aircraft. The subject of immediate interest is the study of this problem with regard to the CF 105 supersonic all-weather interceptor system. The concept of many of the items of this system is still in a state of flux so that in certain cases a range of possible values rather than specific quantities must be associated with pertinent parameters. Although this situation increases the scope of the work, it includes the advantage of ascertaining how the variation of these parameters influence the overall effectiveness of the system.

3.1 Airframe

The design and development of the aircraft has been undertaken by Avro Aircraft Limited, Malton, Ontario, to the RCAF specification Air 7-4, "Supersonic All-Weather Interceptor Aircraft, Type CF 105". The primary role of the aircraft is stated to be high-altitude, all-weather, night and day interception and destruction of enemy bomber aircraft. The secondary role is the same at low altitude. The aircraft is to be designed to fulfil its primary role and limitations will be accepted in the fulfilment of the secondary role.

The design of the aircraft has been established as a delta configuration with all up weight of about 60,000 lbs, powered by two P.S. 13 engines. This engine is being developed by Orenda Engines Limited, a company associated with Avro, and is to be developed to a thrust of 25,000 lbs with afterburning. The aircraft is to be capable of supersonic performance (maximum Mach number about 2.0) and the combat ceiling is to be about 60,000 feet. The first prototype CF 105 is scheduled to fly in 1957, and development should be completed so that the aircraft will become operational in 1961.

At present tunnel tests and model firings are in progress to determine aerodynamic performance of the aircraft. Avro issues their estimates of performance as development proceeds. Present indications are that performance will not meet the RCAF specification in all respects. Current estimated characteristics are described in section 6, below and in appendix B3.

3.2 Aircraft Electronic System

The CF 105 is to be provided with an integrated electronic system comparable in scope and function to the Hughes MX 1179 system with certain modifications. It is understood that proposals have been received from several U.S. companies and that the final decision among these is pending. The general intention is to obtain a system adapted to handle the Sparrow family of missiles and to fit both Canadian and U.S. ground environments.

It should be emphasized here that as yet the revised RCAF specification, Air 7-6 for the electronic system is not available at CARDE.

3.3 Weapons

While it is thought that the weapons carried by the CF 105 will be advanced versions of the Sparrow family, it is understood that no definite commitment has been made. Guided weapons that may be chosen will not necessarily have radar seekers, since consideration presumably will be given to infrared missiles. The position to be adopted with regard to nuclear weapons has not been defined.

3.4 Ground Environment

The ground environment in which the CF 105 is to operate has not yet been established. It is thought that it will probably be either the Sage or the Badge system. Although the general concepts of these systems are established, there is some disagreement as to their relative merits as applied to Canada. Information is scarce concerning the performance of these systems (accuracies and time delays) especially when this is to be estimated for future development.

4.0.0 ORGANIZATION OF STUDY

The above description has been concerned with the interception problem as a whole. Any study carried out by CARDE will necessarily be restricted to certain phases. Before attempting to detail the actual problems relating to the CF 105 interceptor system that CARDE might profitably consider, an examination of the philosophy that may direct such an investigation is given.

4.0.1 Philosophy of Study

Since CARDE is essentially a technical establishment the view of the problem will be somewhat different from an operational research type of study. The basic interest will not be one of strategy, but the interplay of tactics and equipment performance; where equipment is to be understood to have a broad meaning such as aircraft, fire control or weapon subsystems. Where it seems feasible to do so, some study may be directed to equipment itself to gain a better understanding of the problem and if opportunities arise to suggest changes or alternatives that might be sought.

Whenever possible there will be an attempt to support such studies by experimental work. In this regard it should be noted that computing facilities, such as REAC and lethality engagement simulators are essentially experimental tools. The object of these experiments may not be to obtain a complete set of data for the absolute evaluation of a problem, but to gain enough quantitative information that there will be some assurance that the theories involved are justified.

4.0.2 Division of Work

The actual problem associated with the overall study may be divided into three categories:

a) Problems that are not CARDE's direct responsibility

b) Problems in which CARDE has an interest but is not the prime mover

c) Problems that will be principally CARDE's responsibility.

A discussion of what areas of the general problem belong to each division is given in the sections immediately below.

The CARDE contribution to the CF-105 assessment will necessarily omit some phases, not because of their relative unimportance, but because of CARDE's lack of facilities, knowledge, and specialized personnel for this work. However, if an overall evaluation of the interceptor system is desired these problems should be pursued by competent establishments. These complementary studies would then modify the CARDE results to provide a better measure of the system effectiveness.

4.1.0 OUTSIDE ACTIVITIES

Problems which are not considered to be the direct concern of CARDE are those related to strategy and support. They may be classified as pertaining to:

a) Geography

b) Manpower

c) Weather

d) Availability

4.1.1 Geography

Many of the strategic aspects of the ground environment problem are related to geographical questions. These include a definition of the areas to be defended, of the amount of penetration which may be allowed, and consequently the siting of GCI stations and interceptor bases. The omission of geographic elements of this sort from the CARDE study implies that certain characteristics of the CF 105 aircraft, particularly range, endurance, and climb capability, cannot be evaluated. Any CARDE results which bear on these points will only be with respect to the chance of making an attack on a certain target without reference to the location of the encounter in time or space.

Geographical considerations also affect the input assumptions to lethality studies. Any work on this subject at CARDE will be concerned with K - kills since the importance of lesser kills is not evident, and their study would multiply an already heavy work load.

4.1.2 Manpower

A consideration which is of extreme importance is the provision of trained manpower for the maintenance of various portions of the proposed integrated electronic control system. Here is a problem which requires immediate planning: that of training the large number of skilled electronic technicians or engineers, which an advanced weapon system will need. This demands a careful examination of the time required for proper training of an electronic technician, and of the level of intelligence and experience of recruits required for this training. This study should be carried out in cooperation with technical personnel who have intimate knowledge of the skills required for adequate servicing of equipment. To keep a proper perspective, cognizance must be taken of the estimated total number of "black boxes" that will require maintenance in connection with ground environment, families of guided missiles and mobile units.

Two references may be cited which highlight this rapidly growing problem. An ADC report on Project Harlequin notes that the MG-2 system appears to be the highest level of electronic complexity with which present technicians may cope. This may be due to service training; however, T.C. Fry of Bell Telephone Laboratories, in a recent address to the Mathematical Association of America raised the suggestion that the solution may require changes in the whole education system. He was speaking on a subject with slightly different emphasis but the problem is the same. (See American Math. Monthly Vol. 63 No.2).

This problem of maintenance personnel will be neglected in the CARDE study. However, it should be noted that two factors which enter the CARDE problem as assumptions must be recognized as functions of maintenance. These are accuracies and material reliability, both of which depend on the care and understanding of equipment.

4.1.3 Weather

The extent to which atmospheric conditions will affect the operation of the interceptor system is a question which should be studied and clarified. Entities which may be affected by adverse weather are GCI detection, location and height finding accuracies, communication links, time for aircraft to attain combat altitude, A.I. capabilities, and aircraft recovery after a mission. A statistical evaluation of weather conditions to be encountered should be included in an overall assessment of the system.

4.1.4 Availability

The general assumptions which CARDE makes regarding weapon and ground environment capabilities will be governed by what it is thought might be achieved in the time scale of the CF 105 interceptor system. CARDE is however unable to define rigidly the availability of any equipment which the study shows may be desirable. Nor will an attempt be made to evaluate aircraft and weapon availability as it may be affected by the nature or scale of maintenance support at the base.

4.1.5 Other Operational Aspects

The CARDE study will consider only the situation in which one interceptor attacks one target. The only exception to this premise will be in studies such as E.C.M. where several target aircraft must be assumed. Implications of the size and frequency of bomber raids that may be expected, and the interceptor establishment required for an assumed degree of defence, will not be discussed. Another operational problem which will not be studied by CARDE is that of the techniques of controlling multiple interceptions.

4.2 NON-CARDE SUPPORTING STUDIES

In Section 4.1 some problems were outlined which may form part of an overall system evaluation, but which may be studied separately, the results being later combined with those of the CARDE assessment. Another class of problems is those which CARDE is not prepared to undertake due to lack of personnel, knowledge, or facilities, but which must be done to provide input data for some phases of the CARDE Study.

The chief area in which preliminary analysis of a subsystem is required but cannot be done at CARDE, is that of the ground environment. It is understood that DSE will supply information which CARDE requires concerning GCI characteristics. This may be in the form of definite values, or of ranges of probable values, of the important parameters which influence the placement probability.

Other areas in which study may be required in order to provide information to CARDE are Electronic Counter Measures, human engineering, missile trajectories in aircraft flow fields, and further target studies.

4.3 CARDE PROBLEMS

The basic objective of the CARDE portion of the study will be to determine whether the performance of the CF-105 with an available missile will be sufficient against foreseeable targets. This investigation is to be carried out with the understanding that essentially one interceptor and one target are involved, and within the limitations discussed in the following sections. Much is uncertain regarding aircraft performance, weapons to be used, and ground environment, so that in many cases a range of values must be considered rather than one specific case. This procedure greatly multiplies the work, but as a byproduct there may be obtained an understanding of what parameters are most critical and where emphasis should be placed in improving performance.

Hope has been expressed that this study may point out some of the characteristics that would be desirable in the ground system, and how much variation from the original requirements may be sanctioned in aircraft performance. It would seem also that one of the prime purposes of this study would be to examine the relative merits of the various weapons that may be used and to show how the system's effectiveness may vary with the weapon. While these points of view will be kept in mind, it must not be construed that this is a design study to determine the required characteristics of any particular component. Indeed, as explained in Section 2.1, no single subsystem may be considered as an isolated unit, but only as a link in a chain in which there is mutual dependence.

CARDE's chief concern may be summarized as follows:

a) Assessment of placement chance

b) Assessment of chance of kill

c) Initial reviews of the validity of the basic assumptions.

The various questions that may be investigated in these problems are outlined in the following section. In several instances detailed previews of the work involved are given in the appendices.

Listed below are general problems that require investigation according to the present concept of the CF-105 weapon study. It is considered that the program outlined herein is the minimum that should be undertaken to produce worthwhile results. Certain items, because of their direct bearing on the points of interest and because of personnel and time considerations will be of more immediate concern than others. The sequence of work is described in Section 5. below. Detailed discussions on techniques and methods of attacking many of these problems are given in Appendix A, and more detailed statements of assumptions to be made and data required by CARDE for the study in Appendix B.

4.3.1 <u>Missiles</u>

Since information on launch zones for high altitude, high speed targets is not available for the missiles of interest, and is needed before placement of the aircraft may be considered, a study of the subject must be made. It is proposed to carry it out in three stages. (See Appendix A1).

a) 2-dimensions (preliminary look)

b) 3-dimensions - to determine whether an interpolation from 2-D results is possible

c) 2-dimensions - a more thorough investigation of the missile problem.

4.3.2 Placement Charts

The key point in the evaluation of the interceptor is the computation of the chance of placement. Since the problem as envisaged involves many parameters, the task is heavy. This study may be divided into two parts:

a) The two-dimensional problem of positioning the interceptor for a co-altitude attack.

b) The three-dimensional problem of placement when the interceptor and target are at different altitudes. (See Appendix A2).

4.3.3 Lethality

A meaningful evaluation of the interceptor system can only be obtained if the lethality of the weapon concerned and the vulnerability of the proposed targets are considered. An attempt will be made to study these questions by means of literature surveys, visits, and a limited amount of study using the engagement simulator which has been built at CARDE.
(See Appendix A3).

4.3.4 Missile Stowage and Launch

The adverse effects of the blinding of the missile seeker at launch by the aircraft structure, for certain aspects of the target, will be investigated. A study of the trajectories of missiles through the aircraft flow field to obtain a measure of the dispersions produced may be required.
(See Appendix A4).

4.3.5 Target Aircraft

Investigation of the proposed target aircraft may be required to determine manoeuvre capabilities, and to estimate radar reflecting areas. These problems are made more difficult by the fact that certain of the specified threats are of a hypothetical nature, whose configurations are not known.

4.3.6 Fire Control

It is recognized that the fire control problem is one of the areas where the CARDE study may be most fruitful in pointing out future equipment developments that will be required, especially in relation to attacks where target and interceptor are at different altitudes. This problem has not yet been investigated

with respect to the CF-105 study, but it is thought that it may impose a heavy work load.
(See Appendix A6).

4.3.7 E.C.M.

This subject has been very little examined, both here and elsewhere, in its relation to aircraft interception studies. It is felt that some consideration will have to be given to it if the assessment is to have any real application.
(See Appendix A5).

4.3.8 Ground Environment

It is understood that DSE will provide CARDE with all pertinent information, or a statement of acceptable assumptions, on this subject.

4.3.9 Further Areas of Study

There are certain additional subjects which could profitably be studied, but restrictions on time and effort may curtail their investigation. Examples are as follows:

a) Low altitude targets

b) Nuclear weapons

c) Second pass capabilities against the same target

d) Material reliability

4.3.10 Data Gathering and Checking

A member of the Systems Group spent time at DND HQ in November and December, 1955, in becoming familiar with the problem and in preliminary data gathering. Inquiries for information took the form of memoranda to appropriate Directorates in RCAF Headquarters on types of threat, aircraft performance, AI characteristics, missile data, and ground environment. The returns varied in the amount of data given and none were entirely complete. Much delay was experienced in having the replies transmitted from Headquarters to CARDE.

The data requirements for solution of the problems which CARDE feels able to attack are outlined in Appendix B. Some elements are needed for more than one problem, while others are of more limited application. An indication is given of what information is already at hand, and what is lacking.

Known documentary information now available in Canada has been screened in a preliminary way by a member of the Study Group and pertinent documents have been requested. However there may be other information of which CARDE is not aware and readers of this report are requested to cooperate in drawing new material to CARDE's attention. However, much of the detailed technical data required is not contained in known reports available in Canada. The assistance of the Canadian Joint Staff in Washington will be most necessary to put CARDE in touch with appropriate sources of information.

Data required for the CARDE portions of the CF-105 evaluation, and which is not yet at hand, may best be obtained by means of visits by appropriate CARDE personnel to the proper establishments. Areas in which it appears such visits are essential are:

a) Missile Launch Zones - Visits to US establishments studying the future development and the use of the Sparrow family of missiles (i.e. Sparrow II, Sparrow III, and IR Sparrow) by high altitude interceptors should establish what launch zones are available and what values of the parameters have been considered for co-altitude or for snap-up attacks. The object of the visits should be to obtain quantitative data on missile characteristics and performance, analysis and evaluation techniques and future engineering development prospects.

b) Missile Warhead and Fuze - Evaluation of the weapon system involves knowing kill probability of the weapon. This is a function of the type of warhead and fuze, and of the vulnerability of the targets. At present CARDE has little or no information concerning the fuzing systems of the Sparrow missile family. Detailed warhead and vulnerability information is almost entirely restricted to fragmenting type warheads against B-29 and B-50 targets. If the study is to be realistic, information must be sought on new types of fuze-warhead combinations and their anticipated performance against targets of the 1960-65 era.

c) Systems Evaluations - Visits to U.S. groups carrying out analyses of interceptor-missile systems should be considered with a view to comparing methods of solution and determining what broad areas have already been studied and conclusions reached.

d) Fire Control and AI - A fairly comprehensive qualitative review of the present status of fire control and AI is given in a recent visit report CARDE T.L. N-47-1. The fire control portion of the study has not yet been commenced. It is expected that as the work progresses it will be necessary to arrange visits to obtain additional detailed information on fire control, especially for differential altitude attacks.

e) Interception Trials - Theory must be guided by experience. It is therefore necessary to consult with personnel carrying out experimental trials on aircraft interception to retain the proper view of the subject.

A current Canadian project, "Sprint", on interception trials should give useful information. However there are certain limitations when viewed in the light of the CF-105 study. The aircraft used in Sprint are CF-100's and the interceptions represent a Mach 0.80 target attacked by a Mach 0.85 interceptor using an E-5 fire control system modified to give correct steering signals for Sparrow II attacks. Results of trials being carried on elsewhere using more advanced aircraft (such as the F-102) and more sophisticated fire control and ground environment would be most valuable.

f) Ground Environment - Although the basic assumptions and information on ground environment is expected to be supplied to CARDE by DSE it will be necessary for this Establishment to be familiar with the subject so as to make intelligent use of the data, judge its completeness and estimate the range of parameters to be considered. A report by S.Z. Mack on a course on the Sage-system is expected shortly which will give a forecast of the U.S. ground environment. The validity of the DSE assumptions and the Canadian requirements would be considerably clarified by a ground environment study in parallel with the CARDE CF-105 Study.

4.4.1 Visit Preparations

It is proposed that members of the Systems Group visit DRM and selected Washington agencies to determine where further visits should be made in the U.S. to obtain the information outlined in the above sections. It is envisaged that this preliminary visit might take place in late May with other visits following at the earliest practical dates.

5.0 OUTLINE OF PROGRAM

A summary is given here of a tentative program which may act as a guide in the course of the work, and in estimating what effort will be required. It should be emphasized that this proposal is to be regarded as a flexible structure, subject to change as the study is periodically reviewed in the light of work accomplished, data received and the suggestions inherent in results.

In viewing this program, the state of the problem must be recognized. The airframe is still under development and several characteristics are subject to change; a contract for the airborne electronics has not yet been let; the ground environment in which the weapon system is to operate is defined only in general terms; a definite decision has not yet been made as to what weapon will be carried; or rather what future development of what weapon should be presumed; the threats, particularly the supersonic ones, must be described in hypothetical terms.

If a realistic attitude is to be taken, the work outlined in Section 4.3 above should be considered only as Part I of the study, covering the first year's activities. To obtain a reasonably complete picture extended work will be necessary as Part II, extending into the second year. Many of the really useful results regarding specific missiles, E.C.M., and fire control, could be expected to come from this portion of the work.

5.1 Resources Required

A general list of subjects that should be covered in the CARDE study has been given in Section 4.3. An estimate of the number of man months that would be required to carry out this program is given below. Such estimates must be viewed with some tolerance, especially in connection with work in the form of an investigation. When a topic is relatively unexplored, new methods may have to be devised, and this may be an unpredictable and time-consuming task. When work must be done on a computer account must be taken of serious equipment breakdowns. Often, too, errors are found or new concepts come to light which necessitate the reworking of large areas of a problem. In view of these uncertainties, only minimum man-month requirements may be given.

		Man Months
(a)	Direction and Coordination	18
(b)	Reports and Briefing	10
(c)	Missile Studies	40
(d)	Placement Studies 2-D	40
	3-D	40
(e)	Lethality	24
(f)	Fire Control	24
(g)	E.C.M.	12
(h)	Other Work (Ground Environment; Drawings and Models; Target and Interceptor aerodynamics; Stowage and Launching)	40
	TOTAL	248

In a word, the shortest study that would yield worthwhile results will require at least 20 man years. This statement must be viewed in the correct perspective. It does not mean that there is required twenty men working for a year, nor is the work load uniformly distributed over CARDE. The greatest burden would fall on G-Wing. As for the effort demanded, a concentration of manpower is required at the beginning of the study to allow techniques to be devised early, basic data to be gathered and general calculations to be carried out. Once this phase of the work is completed the tying together of results and editing a report should yield sharply reduced demands on the number of personnel. Even in the initial phase the work is not evenly distributed. In the beginning the demand will be for skilled and experienced professionals to devise methods and chart the course of the work. Once the procedures have been reduced to routine computation or machine operation the work may be turned over to less experienced workers with only part-time supervision by the senior personnel. The load on senior personnel in the preparation of final reports may be considerable.

However, regardless of how the effort may be distributed, it appears imperative that CARDE be able to call on outside help. The most readily available would seem to be industry, both to supply computer operators and human computers, and consultants versed in special fields of research and analysis, such as radar, and fire control. It is considered that $ 120,000 should be budgeted for this purpose in fiscal year 1956/57 and probably a similar amount in the following year if the study is extended.

5.2 Planned Sequence of Work

a) Preliminary Phase

The work of this phase, which consists of preparation for the study, has already been undertaken. This includes:

i) Planning of resources and activities

ii) Assessment of information sources

iii) Missile two-dimensional preliminary study

iv) Definition of problem limits, and outline of problems to CARDE Wings.

b) First Quarter

i) Missile Studies: 3-dimensional study, and preparation for extensive 2-dimensional study

ii) Aircraft Placement Problem: exploration of techniques and initiation of two-dimensional work

iii) Visit preparation, including proposed preparatory visit

iv) Literature studies on warhead, vulnerability

v) Initiation of stowage problem

vi) Initiation of lethality studies

c) <u>Second Quarter</u>

i) Termination of Stowage Problem

ii) Continuation of Aircraft Placement Problem: 3-dimensional work

iii) Missile trajectory studies in two-dimensions

iv) Visits for information

- Missiles
- Fire Control

v) Initiation of fire control analysis problem

vi) Evaluation of Infrared AI possibilities

vii) Aerodynamic problems: dynamic behaviour for snap-up attack, launch dispersion of missiles

viii) E.C.M. problem: comparison of systems under E.C.M., homing on jammers

ix) Continuation of Lethality studies

d) <u>Third Quarter</u>

i) Computation of placement probabilities

ii) Continuation of problems initiated in the second quarter

iii) Lethality and Vulnerability computations

iv) Preparation of Technical memoranda on various phases of the study

v) Planning of second year work

e) <u>Fourth Quarter</u>

i) Preparation of first annual report

ii) Preliminary technical studies of second year work

6.0 SUGGESTIONS AND RECOMMENDATIONS

The following suggestions are made, which, if implemented, will facilitate the progress of the evaluation.

(a) A headquarters agency should be responsible for directing pertinent data to the Systems Group at CARDE as it becomes available.

(b) If other groups are to investigate problem areas outside the scope of the CARDE study, a coordinating group should be designated to oversee the problem as a whole and determine that the work of each group is mutually compatible.

(c) Both DRB and RCAF Headquarters should be prepared to support visits to the U.S.

(d) It has been pointed out that it will be necessary to seek aid from industry. The necessary financing for this work should be arranged immediately.

APPENDIX A-1

MISSILE STUDIES

1.0 INTRODUCTION

Before instituting a study of the possibility of placing an aircraft in a position relative to a target so that it may launch a missile (guided or unguided) it is necessary to know what is the permissible region (launch zone) about the target for launching an attack. The determination of this zone requires an intimate knowledge of the characteristics of the weapon to be used. The size and shape of launch zone not only determines to a large extent the probability of placing the aircraft in this region, but may also dictate the courses that should be flown by the interceptor prior to the attack. It may also influence the characteristics and procedures of the ground environment.

This appendix is in three parts. Part I is a general outline of the missile problem, Part II describes work already done in two dimensions, and Part III discusses briefly a three-dimensional simulation now in progress.

PART I

2.0 INFORMATION ON LAUNCH ZONES

It had been hoped when the CF-105 study was in the preliminary planning stage that detailed information on the weapon performance could be obtained elsewhere and this phase of the work would not form part of the study (Memo from Analysis section to Supt. "G" Wing, Jan 3, 1956, S/N-47-3). Much of the desired information is not available. Queries to the RCAF (D Arm E-2) did not produce the details desired (S/N-47-3) and a recent visit to the U.S. by interested parties was on a somewhat different subject (T.L. N/47-1) and did not yield direct results.

Many of the tactical situations of interest involve relatively high speed, high altitude targets. It is understood that with regard to the Sparrow family little work has been done for these conditions.

2.1 Missiles of Interest

The main interest of the RCAF at present seems to be directed toward the Sparrow family of missiles, especially Sparrow II. On this weapon a good deal of information is available, except on aspects of supersonic launch and details of the fuze. Concerning

Sparrow III, except for the aerodynamics which are similar to Sparrow II, information is quite limited. It is understood there is also an I.R. Sparrow, but nothing definite is known.

Some preliminary study is already being attempted on Sparrow II (See section below and T.L. N-47-2). Before very much could be done concerning other members of the family a visit seems necessary.

In view of the attention given to the MX1179 it would seem advisable to consider the Falcon missiles. Information on these weapons should be fairly complete and an intensive programme of document searching should uncover the desired details, or at least enough to considerably reduce any REAC work.

3.0 PHILOSOPHY OF MISSILE STUDIES

Some basic ideas concerning the nature of missile studies may be mentioned before considering the work in more detail. As far as the CF-105 study is concerned it should be noted that the characteristics of a particular weapon will probably be somewhat different when the aircraft is operational than they are today. It therefore seems inadvisable to limit the study to the actual performance of the missiles today. The scope of the work should be planned with the following objectives in mind:

(a) To estimate the capabilities of the missiles of interest

(b) To ascertain what future developments may be expected to add to these capabilities.

(c) To gain a broad understanding of missile types, in particular

(d) To indicate what parameters are most critical.

These objectives may seem somewhat wider than the immediate needs of the study would demand; however it should be noted that the actual weapons for the CF-105 have not been definitely established so that a general outlook is required. It is felt also that knowledge concerning air-to-air weapons in general will be useful if CARDE is to advise the RCAF. circumstances.

3.1 General Point of View of Programme

The principal point of interest for future use of air-to-air missiles is the three-dimensional missile trajectory, the result of an attack in which the interceptor and target are at (even greatly) different altitudes. It is planned to commence the present study with co-altitude trajectories. Enough two-dimensional work will be done in the first phase of the problem to give an adequate idea of the variation of launch zones with altitude, for certain few values of the more vital internal missile parameters. The three-dimensional study will be conducted to determine actual launch zones in three dimensions, for the same internal missile parameters. An effort will then be made to determine a reliable procedure for reproducing three-dimensional launch zones by interpolation from two-dimensional results. This would allow future work to be done in two dimensions only, allowing the missile study to proceed at a faster rate.

If no consistent procedure for interpolation can be found, it may be necessary to prolong the three-dimensional phase of the study and to delay or cancel the third, two-dimensional, phase.

3.2 Programme of Missile Studies

It is intended that the REAC will be used for most of the study. The immediate aim will be to provide a basic fund of knowledge concerning missile behaviour at high altitudes, and with supersonic launch velocities. It is planned to adopt a three stage programme.

(a) 2-D trajectory study.

(b) 3-D trajectory study.

(c) Further 2-D trajectory studies based on results of (a) and (b).

3.3 First 2-D Work

This portion of the work has been completed. It constituted a preliminary look at the problem in two dimensions. The REAC work was started in February and terminated March 16th. The chief variables of interest in this study were relative speeds and altitude, with brief attention to a few selected missile internal parameters. The work was done by the

Systems Group personnel and has been reported on in Technical letter N-47-2, of which the text is given in Part II of this appendix.

3.4 3-D Work

The prime purpose of the three-dimensional study is to determine whether interpolation from two-dimensional results is possible. The study is in the advanced planning stage and the set-up on the CARDE REAC was begun March 19th. This set-up is more refined than that used for 2-D work so that an additional and valuable result of the work will be an indication of how serious certain simplifying assumptions concerning missile representation may be. This 3-D work is to be carried out by the C.D.C. personnel now stationed at CARDE.

3.5 Further 2-D Work

The above two steps are to be regarded as "quick looks". The results of these studies should indicate the avenues of study that most probably will yield fruitful results in a more intensive study.

4.0 LAUNCH ZONES

The missile study is based on a determination of permissible launch zones for various hypothetical missiles, flown against expected target threats. By launch zone is meant the extent of allowable heading errors and launch ranges for different aspects of the target. The criteria used in determining whether a particular set of conditions results in an acceptable trajectory are some or all of:

a) Miss distance
b) Approach angle
c) Final missile velocity
d) Final missile closing speed
e) Time of missile flight
f) Oscillatory nature of trajectory

The admissible values of the first two of these quantities depend on the type of warhead and fuzing used in the missile. CARDE has unfortunately no information regarding the characteristics of warheads and fuzes that may be used in any missile that may be chosen for use by the CF-105.

4.1 External Parameters

By external parameters is meant the kinematic and geometric relations of target and missile. External parameters which may affect launch zones are:

i) missile launch velocity

ii) target velocity

iii) target evasion, in vertical or horizontal plane

iv) altitudes of target and interceptor

v) initial value of missile range

vi) initial value of target aspect

vii) initial value of missile heading at launch

4.2 Internal Parameters

The internal parameters refer more directly to the particular characteristics of the missile. The missiles considered in the study are variants of a constant-bearing course missile, similar to those of the Sparrow family. Velocity and altitude-dependent variables are linearized to simplify the simulation. The aerodynamic behaviour is represented by a second-order transfer function. Basic values for such missile characteristics as drag, lateral acceleration limits, guidance characteristics, control system gains, are similar to those of the Sparrow II missile.

The internal missile parameters which may affect launch zones are:

i) lateral acceleration or g-limits

ii) guidance characteristics such as discriminator pattern and look angle

iii) blind range of guidance

iv) general stability and time lags

v) type of navigation and gains used

vi) whether or not control is effective during boost

vii) drag characteristics of the missile, which depend on its configuration

viii) thrust programme of the missile

ix) radome errors and effects of noise

5.0 POSSIBLE FURTHER DEVELOPMENTS OF STUDY

As outlined above the missile study is to be concerned with:

a) REAC simulation

b) Document Surveys

c) Visits

It may be that as the work progresses it will appear that other methods of investigation may be desirable to supplement the above work such as

d) Direct liaison with other groups interested in specific sections of the missile such as guidance or control.

e) Simulation using hardware

f) Detailed study of specific pieces of hardware

g) Test firings

6.0 This note is to be considered as a general outline of the missile problem for parts (a), (b), and (c) of section 5.0. Detailed descriptions of individual phases of the work will be given as the study crystallizes. No work is contemplated, at the present time, on parts (d), (e), (f), and (g).

PART II

7.0 2-DIMENSIONAL SIMULATION

This part describes work done in February and March of 1956, on the preliminary two-dimensional simulation of missile trajectories. Since it is not known which missile will be eventually used by the CF-105, and since it was desired to keep the time spent on this first phase of the study to a minimum, a very much simplified hypothetical missile was studied , based somewhat on the Sparrow II configuration. Co-altitude attacks on targets of varying speeds (Mach .74 to Mach 2.5) were considered, mainly at altitudes 50,000 ft and 60,000 ft altitude. The only missile internal parameter which was varied to any extent was the lateral acceleration limit.

7.1 In view of the fact that the missile studied may not represent any actual missile, the absolute values of maximum and minimum launch ranges obtained in this work may not be too trustworthy. However the trends in launch zone variation due to variations in target speed, interceptor speed, altitude, and target aspect, should be quite reliable.

8.0 SIMULATION

A block diagram of the missile and kinematic simulator which was set up on the CARDE REAC is given as figure 1.

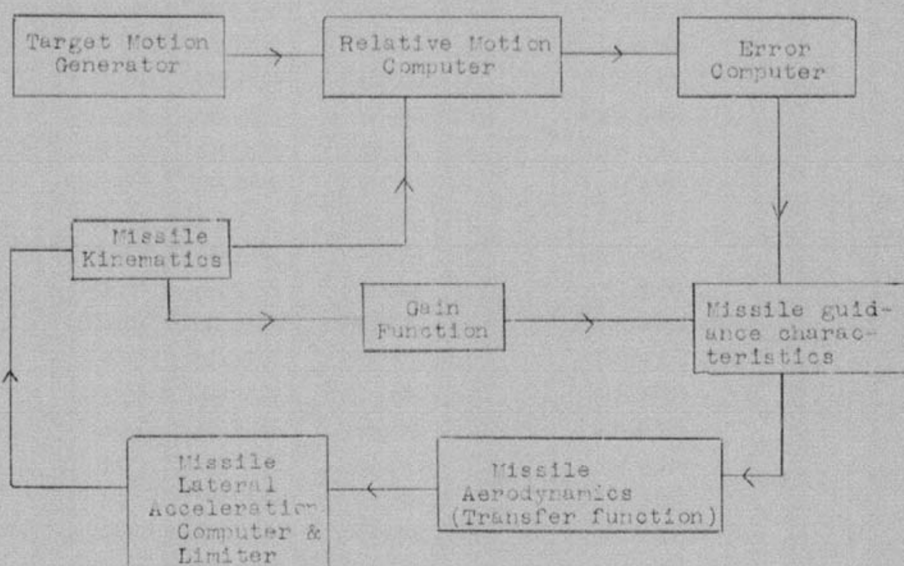


Fig. 1.

8.1 The kinematics were solved in a cartesian coordinate system having the target as origin, and the initial line of sight as the direction of the X axis, with the initial missile position considered to be in the negative X-direction. The Y axis was taken to be at right angles to the X axis, with the Y component of initial target velocity positive. The angles which are used as parameters in defining launch zones are the aspect angle A, of the target: the angle between the initial line of sight and the target velocity vector, and the angle γ , between the initial line of sight and the missile velocity vector at launch. A sketch of the axis system is given as figure 2.

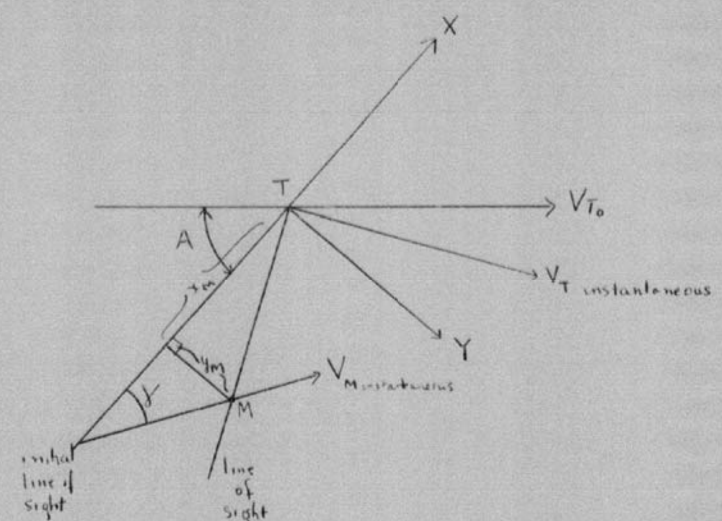


Fig. 2.

8.2 The missile considered in this study followed a constant bearing course; in which the error angle seen by guidance is the angle between the instantaneous line of sight and the initial line of sight. In the coordinate system used this is $\frac{Y}{X}$ using small-angle theory. The guidance and control systems of the missile were similar to those of Sparrow II, using reasonable values for gains and time-constants. The variations of drag and lateral acceleration limit with Mach number and altitude were represented by linear relationships to simplify computation. A detailed description of the simulator including the equations that were solved, and giving the numerical values of parameters used, is given in Reference 3.

9.0 PROCEDURE

The following procedure was used in the trajectory simulation. For given values of target velocity, target lateral acceleration or evasion, missile launch velocity, and aspect angle at launch, runs were made for various values of range and missile heading γ_0 at launch. From the recorded variables, which included acceleration demand of the missile guidance, range, miss distance, range rate, missile velocity, and missile rate of turn, each run was classified as a hit or a miss. No simple straightforward criterion was found for determining whether or not a particular run resulted in a satisfactory trajectory. Consideration was given to missile flight time, miss-distance, closing rate, and the oscillatory character of the missile trajectory as shown by the variation of the missile rate of turn. This procedure used in determination of the angular and range-wise limits to launch zones was essentially the same as that used in a previous study of the Sparrow II missile. (Reference 1). From these results, curves may be drawn depicting launch zones. One type of curve, drawn in cartesian coordinates for a fixed aspect, encloses a region in a two-dimensional space: launch range vs missile heading, in which the missile must be launched for attack to be successful. A second type of plot gives contours of maximum and minimum launch range, for all aspects around the target, with maximum allowable error from the ideal heading at launch, as a parameter.

9.1 The situations which were examined are listed in the following table. The Target Mach number was varied over the whole range of probable values. The interceptor Mach numbers used in most cases were the design combat speeds for the CF 105, which are 0.92 and 1.5.

Missile Launch Mach no. / Target Mach no.	.76	.92	1.2	1.5	1.8
.74 (evasion 2g)	H=50K				
.85 (evasion 2g)		H=40K H=50K		H=50K	
1.2 (evasion $\frac{3}{4}$g)				H=50K	
1.5 (evasion $\frac{3}{4}$g)		H=60K	H=50K	H=40K *H=50K ***H=60K **H=70K	
2.0 (evasion $\frac{1}{2}$g)				H=50K *H=60K **H=70K	H=60K no evasion
2.5 (no evasion)				*H=50K H=60K	**H=60K

In this table, H = altitude,

K = thousand feet.

*Missile lateral g limit was varied.

**Higher lateral g limit only was considered.

***Greater value of discriminator fall-off angle was tried.

10.0 DISCUSSION OF RESULTS

The launch zones obtained for subsonic targets indicate that interceptor Mach numbers of 0.92 and 1.5 are usable, all-round attack being permitted in both cases.

10.1 For supersonic targets, obtainable guidance range will limit seriously the launch zones, especially for front aspects. The following table summarizes the values of course difference which are allowable in the cases considered, if a generous limit to usable guidance range is applied (40,000 ft at all front aspects). These results apply only at 50,000 and 60,000 feet altitude.

Target Mach no. \ Interceptor Mach no.	0.92	1.2	1.5	1.8
1.5	70° - 110°	30°-90°	0°-180°	
2.0			45°-120°	0°-180°
2.5			50°-65°	

Course difference limits against supersonic targets.

10.2 Some work was done for altitude 70,000 feet. Although co-altitude launch zones for this altitude are not applicable as such since it is much above the interceptor's ceiling, such zones may be useful in interpolating for snap-up zones. The launch zones found here at 70,000 feet are very small and the minimum range is very great. This is due to the low g - capability of the missile at this altitude.

10.3 Three factors which have considerable effect on launch zones, especially in so far as minimum range is concerned, are missile lateral acceleration limit, heading error tolerance, and target evasion. Increase in g-limit of 40% produces the same change in launch zone as decrease in the heading error tolerance from 10° to 5°, or as removal of target evasion. Increase of guidance discriminator fall-off angle, which was tried in one case, appears to produce zones a few degrees wider γ-wise, without affecting minimum range.

PART III

11.0 INTRODUCTION

The object of this phase of the study is outlined in Section 3 of Part I of this discussion. This summary is merely to give an indication of the type of work to be done.

12.0 SYSTEM STUDIED

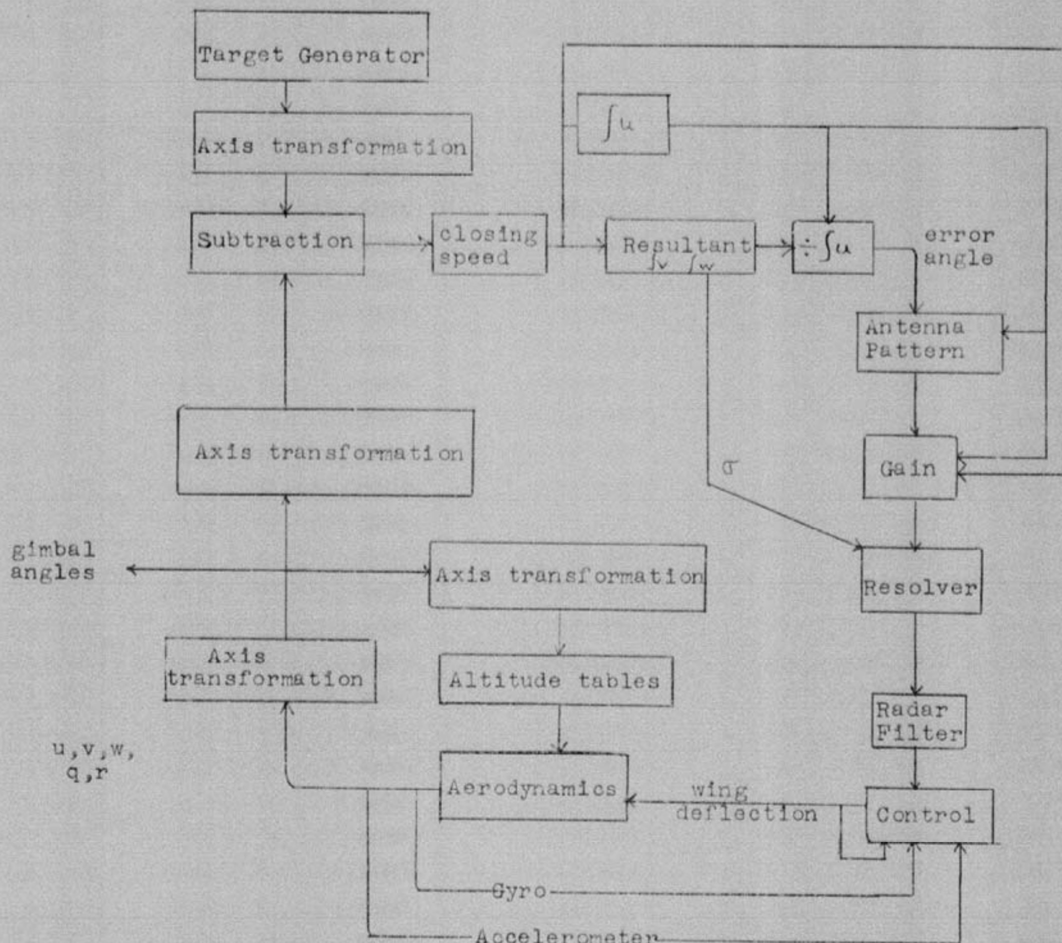
A block diagram of the system to be simulated is shown in Figure 1. Only one channel of the missile control system is depicted whereas a second is to be understood.

13.0 GENERAL SETUP

It has been pointed out in Part I that the 3-D Simulation is more complex than the 2-D and one product of the study should be an indication of the validity of the approximations made in the earlier calculations.

The setup is planned to accommodate any tactical situation with in the following limits.

Target aspect	-	0 to 360 degrees
Fighter lead angle	-	-30 to +50 degrees
Target altitude	-	38,000 to 68,000 feet
Fighter altitude	-	38,000 to 68,000 feet
Target speed	-	0 to Mach 4
Fighter speed	-	Mach 1 to Mach 2.5
Target evasion	-	any practical amount
Fighter pitch up	-	any practical amount
Range	-	- to 40,000 feet



Target Generator
Axis transformation
Subtraction
closing speed
∫u
Resultant
∫v ∫w
÷∫u
error angle
Antenna Pattern
Gain
σ
Axis transformation
gimbal angles
Axis transformation
Resolver
Axis transformation
Altitude tables
Radar Filter
u,v,w, q,r
Aerodynamics
wing deflection
Control
Gyro
Accelerometer

Figure 1

14.0 SCHEDULE OF WORK

Preliminary planning for the simulation began on February 1st, and REAC debugging began on March 19. An initial programme of work was submitted to personnel concerned on March 28. This programme included a number of tests to ensure that the REAC calculations were valid and to establish the soundness of the previous 2-D study. When the machine has been thoroughly checked out a further schedule will be laid down. It is expected that it will not be possible to plan work more than a few days in advance in view of the exploratory nature of the study.

APPENDIX A2

PLACEMENT PROBLEM FOR AIRCRAFT INTERCEPTION

1.0 INTRODUCTION

The nucleus of the CF 105 Weapons Study to be carried out at CARDE, will be the determination of placement diagrams for the CF 105 aircraft, carrying varying armament loads, against specified targets. This subject involves consideration of missile and aircraft characteristics, as well as of the capabilities of the ground environment in which these operate.

1.1 Purpose of Placement Charts

The positioning diagram is a way of showing into what region of space, relative to the target, the ground system must be capable of putting an interceptor in order for the aircraft to launch its weapons. Once this region of space has been determined and the accuracies of the ground environment established the probability of positioning an interceptor so that it may attack a target may be computed.

1.2 The Problem

There are two aspects to the problem that require attention.

a) The determination of placement zones for a number of specified cases.

b) An estimation of how the zones and therefore the placement probabilities are altered as certain basic parameters are varied.

Item (a) will give an indication of the effectiveness that might be expected of the interceptor system. Item (b) will furnish information pertaining to design criteria and enable extrapolations to be made from the basic cases. Each diagram will be drawn for a given set of values of these parameters:

i) Interceptor velocity

ii) Target velocity

iii) Missile launch range and allowable heading error

iv) Course difference of Interceptor and Target

v) Interceptor turn capability

vi) Al Radar characteristics (look angles, allowable lock-on range, scan frequency)

vii) Any restrictions on interceptor heading or flight path

viii) Missile preparation time and fire control computer settling time

ix) Target and Interceptor altitudes

x) Target evasion

2.0 BACKGROUND

Previous studies, at CARDE and elsewhere, have attacked this type of problem by a pencil and paper technique for no target evasion, and making other simplifying assumptions. A description of the method (as employed by F.W. Slingerland) is given in Appendix M of CARDE Technical Memorandum No. 119/55. An application to the particular problem in hand is given in CAO ps/ORS Internal Memorandum No. 55/4 entitled "A Theoretical Assessment of the chance of interception of a Hustler-Hornet by CF-105 or F-102B manned interceptors" by E.L. Leese and S/L H.V. Firneisz.

3.0 OUTLINE OF STUDY

It is proposed to investigate the use of the REAC to obtain positioning diagrams. It is thought that the work would be divided into two stages.

a) Two dimensional plots

b) Three dimensional plots

Definite techniques have not been developed. A suggestion is given in paragraph 4.0 below for a 2-D study, but it is not evident that this method is desirable or even that it is faster than paper and pencil work, especially for a non evading target. No suggestion is yet made for the 3-D study.

In parallel with the study of the application of the REAC to the complete positioning problem it is proposed that an investigation of the extension of paper and pencil techniques by various methods, including the generation of special functions on the REAC as an alternate should be carried out.

Depending on the results obtained, each method will be used where it appears to be most economical and effective.

3.1 Two Dimensional Plots

It is hoped that only a brief look might be taken at this problem to establish the feasibility of the technique and to gain a feel for the problem. If a suitable policy is established, it is proposed to hand over the major portion of this work to Computing Devices of Canada if computer methods appear to be advantageous compared to paper and pencil methods for the 2-D case.

3.2 Three Dimensional Plots

It is thought that CARDE effort should be concentrated on the 3-D aspects of the problem for two main reasons:

a) This problem is relatively new and unexplored. Most fruitful advancement of techniques and knowledge should be expected from this phase of the work, particularly if closely integrated with other study activities.

b) It is expected that in many engagements the target will have an altitude superiority over the CF 105 so that differential altitude attack will be necessary, and be the rule rather than the exception.

4.0 A POSSIBLE 2-D METHOD

A suggestion for attacking the 2-D problem on the REAC is described below. The object of this presentation is more to illustrate the problem than to recommend a method.

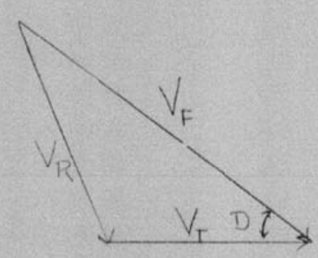


Fig. 1.

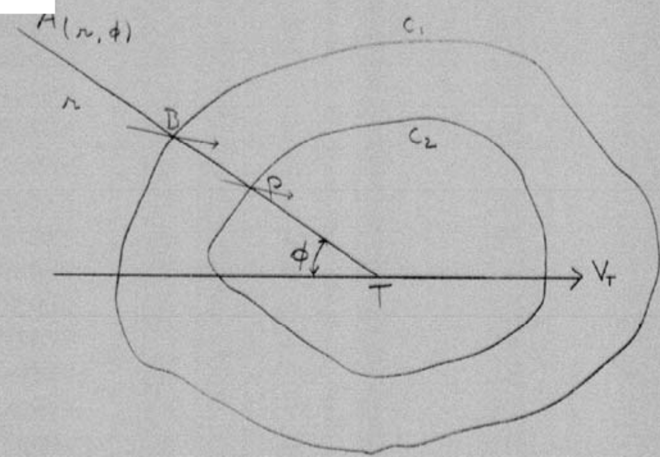


Fig. 2.

With reference to Fig.1 the target has a velocity V_T and the interceptor a velocity V_F. The relative velocity will be V_R and the course difference the angle D. Suppose the interceptor is approaching the target with course difference D and makes AI contact at the point A in Fig.2 which has polar coordinates r and Ø relative to the target. The contours C_1 and C_2 about the target represent the maximum and minimum ranges at which a missile may be fired. At points say B and D on these contours there is an optimum heading relative to the target for firing the missiles and an allowable tolerance about this heading.

The proposed REAC method is to suppose that the aircraft started at point A with the given course difference and under some simple control equation to attempt to obtain a permissible heading on or between the contours C_1 and C_2 to fire the missile. If this is achieved the point A will be plotted as part of a permissible area of approach. Angle Ø will be varied until this zone is obtained for the particular range, which in turn will be varied.

It should be emphasised that, although this method may be workable, there are grave doubts that it has any advantage over paper and pencil methods.

4.1 Governing Factors

The following constraints must be satisfied for a particular run to qualify as permissible.

a) The aircraft lateral acceleration must not exceed a stated value.

b) The angle between the aircraft boresight axis and line of sight to target must not exceed the azimuth or elevation limits of the radar.

c) $\frac{d\,r}{d\,t}$ must not to positive on a load collision course. This limitation may not apply if the aircraft is within the launch zone and has switched over to a lead pursuit mode on the fire control.

d) Possibly items (vii) and (viii) of Section 1.2.

5.0 PARAMETERS

A number of parameters were listed in Section 1.2. A few comments on pertinent aspects of certain of these are given below.

5.1 Detection Range to Target (r)

This should be considered as a prime variable in the problem. Factors which make it desirable to have the results stated for a wide range of values of r is that this quantity depends on the reflecting area of the target. Several values will have to be considered because

a) great uncertainty exists concerning the values to assign to reflecting areas

b) it will change for different targets, of which there may be several

c) detection and effective fighter control may be degraded because of (i) atmospheric conditions (ii) poor equipment operation (iii) E.C.M..

It is thought that at least five values should be considered.

5.2 Ideal Approach Path

It is desired to know the optimum approach path for various attack course differences since it dictates the ideal position to which the G.C.I. must attempt to vector the aircraft. This lies near the centre of the permissible zone. For a non-evading target it is a path such that the interceptor may fly on a straight course and achieve the optimum firing position at maximum launch range.

5.3 Course Difference

This quantity again reflects on G.C.I. methods. At least five values must be considered, these being different for different target/interceptor speed ratios. The following are suggested:

$$\frac{V_T}{V_F} < 1 : D = 180 \text{ to } 60 \text{ by } 30^\circ \text{ increments}$$

$$\frac{V_T}{V_F} > 1 : D = 120 \text{ to } 0 \text{ by } 30^\circ \text{ increments}$$

5.4 Target Velocities

These will lie in a range of Mach 0.8 to Mach 2.5.

5.5 Fighter Velocities

These will lie in a range of Mach 0.8 to Mach 1.8.

5.6 Target Evasion

Basically it is thought that the cases of no evasion, and a steady turn towards and away from the interceptor need to be considered. Some thought may also have to be given to Dog-Leg manoeuvres.

5.7 Altitudes

This parameter will be of interest in the 3-D study. It is thought that altitude differences of zero, and 10,000 to 20,000 feet will be of interest, with target at 50 K, 60 K and 70 K (ft).

The above mentioned parameters pertain to the tactical situation. The parameters listed below are concerned with item (b) of section 1.2 above.

5.8 Interceptor Turn Capabilities

At least three values of this quantity will have to be considered. The range of variation will be specified later.

5.9 Missile Launch Zones

The exact weapon has not been specified as yet for the aircraft so that a number of types must be considered. Also since the aircraft is for future needs the exact missile characteristics should not be tied too rigidly to existing hardware.

With the above statements in mind a program of missile study is underway. It would be most helpful to this study if the method of using launch zone characteristics could be made as flexible as possible.

5.10 AI Look Angle

Probably two values need be considered.

5.11 Restrictions to Flight Path

Certain missiles may require a straight line of flight for a certain time in order to lock on. On the other hand there may be a restriction that the missile's power can only be operative for a limited amount of time.

5.12 It may be noted that some record will be needed of the time required for interception, since this factor bears directly on operational aspects of the problem.

6.0 FIRE CONTROL ASPECTS

The fire control aspects of the problem will require a separate study. It is not clearly understood what problems need investigation nor how they will tie in with the above study. It is thought that the course to be flown will be some sort of lead pursuit or lead collision. How this is to be implemented in a non-coaltitude attack is not known. If decelerating turns or climbs are allowed further complications may arise. Those questions represent a major portion of the whole study. It is thought that some study of this phase of the problem should be done by the group concerned with the placement study so that they may cooperate with whomever is studying fire control and advise both them and the systems group of their views on the subject.

7.0 SHIELDING

A further restriction that may need attention is the problem of missile shielding by the aircraft body which may prevent "lock-on" if this is necessary before launch. This consideration may restrict certain approaches and bank angles. Part of this problem is expected to be considered by "D" Wing.

8.0 EXTENSIONS OF THE PROBLEM

Certain variations on the theme outlined above may be desired by E.C.M. considerations.

APPENDIX A3

LETHALITY STUDIES

1.0 INTRODUCTION

Before considering what might be done in the study of lethality a few of the reasons why this subject is of interest may be reviewed.

a) The fuze-warhead-vulnerability aspect of an attack will dictate the probable success of a weapon system. Erroneous assumptions on this phase of the problem could totally distort an assessment study. This may be seen by considering the following simplified equation for the probable effectiveness Pe of a weapon system.

$$Pe = P_l \times P_k$$

where P_l is the probability of launching a missile and P_k is the kill probability or lethality.

b) Fuze considerations, either pertaining to estimates of the desirability of a particular fuze or to actual development work, requires detailed data on missile warhead lethality since this is the criterion which determines the relative merit of a given fuze system.

c) Lethality contours about a target for a given fuze or warhead may be such that a restricted zone of approach is required. This constraint will be reflected in the allowable positions of launching a missile and this in turn may dictate the manner in which an interception is to be made.

d) Many documents on missile performance give only sketchy accounts of the final phase of a missile attack. Unless this part of the problem is well understood, statements concerning weapon kill probability could be quite misleading.

2.0 ASPECTS OF THE LETHALITY PROBLEM

Several closely related subjects are inherent in a lethality study.

a) Warhead - The direct responsibility to damage or kill a target

b) Fuze - Its functioning determines whether the warhead payload reaches the vital parts of a target

c) Vulnerability - The study of what is needed to kill, or damage a particular target or component

d) Missile ballistics - Determines whether the fuze and warhead reach a suitable position relative to target

e) Engagement studies - Except for actual trials for which only combat offers satisfactory results, the study of the engagement of a target must be done analytically, graphically, or by a simulator or computer.

3.0 AIMS OF STUDY ASSOCIATED WITH THE CF 105 WEAPON SYSTEM

CARDE has not the resources; either staff, knowledge or equipment, to do a thorough lethality study in connection with the CF 105 weapon system. However, because of the importance of the problem as outlined in Section 1.0 and the fact that former studies on similar subjects ignored this phase of the attack and no detailed study of the subject is expected elsewhere in Canada, some attack must be made on the problem. Its aims might be:

a) To assemble a body of knowledge on the state of the art as it exists in allied countries. From this information to give a resumé of what performance may be expected from weapons associated with the CF 105.

b) By studying experimentally or analytically a limited number of special cases, to understand and hence illustrate the problems, pitfalls and hopes that may exist in the realm of lethality. Although limited, this work will give a better grasp of the situation than the blind acceptance of a kill probability figure quoted by a contractor.

4.0 AVENUES OF ATTACK

The following avenues of investigation appear available:

a) Survey of literature
b) Visits
c) Engagement studies
d) Experimental work

4.1 Literature Surveys should be conducted with the following objectives in view:

a) Accomplishing the aims of section 3.0.
b) Obtaining background in preparation for visits.

c) Revision of the work program as more information is available, not only of the group directly concerned, but also the associate phases as outlined in Section 2.0.

4.2 <u>Visits</u> to obtain information on the following subjects should be made:

a) Experimental vulnerability work
b) Theoretical vulnerability work
c) Lethality studies conducted on existing simulators such as at Michigan and project Thor
d) Lethality studies conducted by system groups such as Rand
e) Warhead development
f) Fuzes of specific missiles (Sparrow II, Sparrow III)
g) I.R. Fuzes

4.3 <u>Engagement Studies</u>

A Mark I optical analogue has just been built for "G" Wing and is undergoing initial tests. Although the Mark I analogue was conceived primarily as an instrument to study the analogy of X band target reflection to optical reflection off a mirror-like model, it could with some difficulty be used for engagement studies. However, its complete capabilities in regard to situations that may be studied and the speed of operation are not clearly understood by the author. When this device becomes fully operative, it is desired that a program be laid down which, with due regard to its versatility and available information on allied subjects of Section 2.0, may accomplish the second aim of Section 3.0.

It should be noted that the needs of the fuze section and the CF-105 weapon study are in several respects very similar. An integration of activities should be possible that will be mutually beneficial.

In regard to the Mark II version of the analogue, this instrument is understood to be quite versatile and designed for rapid production of results. However it is felt that this device will not be ready in time to support the present study to any extent. Nonetheless, close liaison should be maintained between interested groups so that the end result will achieve maximum usefulness.

The prospects of doing engagement studies on the REAC were considered some time ago. The formidable equation for a generalized solid cone indicated that the whole of the expanded REAC would be needed.

This would be an extremely cumbersome problem if indeed it could be managed at all. Excessive demands on relay equipment appeared likely.

The possibility of employing the new digital computer exists. However, the implications involved are wholly unknown at present and it is felt that the demands of acquiring techniques on a new tool would prohibit such a study.

4.4 Experimental Work

Experimental work at C.A.R.D.E. in regard to warhead or vulnerability would be governed by (a) Resources, (b) Possible fruitful spheres of investigation, (c) General aims of the establishment in these fields.

It would be hoped that items (a) and (c) above could be established by consultation with Wings B, C and E, and the administration. Item (b) would depend on the outcome of reading and visits.

5.0 SPECIFIC QUESTIONS

In order to assess the possible scope of the study in more detail, and to plan work on the optical analogue and visits, certain information is required.

5.1 Warhead

An outline of available information on the following subjects is needed:

a) Types of warheads that may be used in air-to-air guided missiles.

b) Expected development of these types over the next ten years.

c) Expected advantages or limitations of these types.

d) Characteristics that require further investigation.

e) Special considerations concerning warheads that may be necessary for snap-up attacks.

f) Possible sources of further information.

g) Indication of expected warhead work at C.A.R.D.E., with time scale.

5.2 Fuze

a) Efforts should be continued to obtain information on the fuze system of Sparrow II and Sparrow III and I.R. fuzes.

b) It is desired that an outline be given of what lethality studies are planned.

c) A survey of possible fuze types and warhead combinations that may be possible with future Sparrow or Falcons should be made. This information would serve as a guide in planning the cases to be studied as mentioned in Section 3.0(b). It is probable that information on warheads may be needed before this could be completed.

d) Preparations should be made for visits as outlined in Section 4.2(c), (d), (f) and (g).

5.3 Vulnerability

Literature surveys such as outlined in Section 4.1 should begin. Indication should be given as to:

a) What information is needed on the target aircraft.

b) Possible visits to cover (a) and (b) of Section 4.2.

c) General subjects that the literature survey is to cover, with an indication of how adequate the available material may be.

d) Subjects for which there is little or no information available.

e) What the long range policy on vulnerability studies may be.

5.4 Engagement Studies

An indication is desired as to when the Mark I optical analogue will be ready for use. Based on past experience, the information requested in the above sections, and the capabilities of the Mark I simulator a tentative program should be drawn up to achieve the second aim of Section 3.0. A description should be given of the simulator.

APPENDIX A4

STOWAGE

1.0 Two aspects of missile stowage on the CF 105 interceptor aircraft are of interest:

a) The circumstances under which a missile may be blinded by the interceptor airframe so that it cannot lock-on the target.

b) Possible adverse aerodynamic effects when the missile is placed in the airstream around the aircraft, particularly at supersonic speeds.

2.0 Shielding of Missiles

If a missile must be locked-on the target before launch the tactical situations in which a weapon can be used may be severely limited. This constraint may become excessively severe in a non-coaltitude attack. In fact, this restriction may dictate the type of missile that can be used. A feasible method of attacking this problem would be by the use of models as a simple method of plotting forebidden zones in a plane normal to the axis of the fighter. This procedure may furnish a template which could be used to study the effect of various parameters.

2.1 Parameters which would have to be investigated are:

a) Position of missile on Interceptor

b) Missile angle of look

c) Angle between line of sight to target and interceptor heading

d) Altitude difference between target and interceptor

e) Roll attitude of interceptor

f) Pitch attitude of interceptor

2.2 Sources of Information

a) AVRO

b) DSE

2.3 Specific Problems

If a method using models is employed the actual problems involved are:

a) Construction of model with missiles (say 1/30 scale)

b) Developing technique for using the model

c) Delineating permissible engagement situations as governed by parameters in section 2.1.

The missiles are to be restricted to the Sparrow Family (Sp.II and III, and IR) and Falcons.

3.0 Power

The question exists as to what power would be needed to lower a missile from the airframe and push it forward against the airstream.

4.0 Aerodynamic Effects

Study of the effects of missiles on the airframe may depend on opportunity for adequate model firings. Some investigation of this problem has been done by AVRO.

5.0 Internal Stowage

There is also some doubt as to the effect at supersonic speeds of opening a hole in the airframe if the missiles are internally stowed. It is generally thought that external stowage is not possible.

APPENDIX A5

ASPECTS OF E.C.M.

1.0 INTRODUCTION

It is generally felt that consideration must be given to the possible degradation of the interceptor system by electronic countermeasures. This phase of the problem is quite as important as evasive manoeuvre of the target.

There is appreciable difficulty in attacking this problem because of its complexity, so that other studies of the type to be carried out in regard to the CF 105 system have practically ignored the problem other than saying that it is serious. Any attempt to obtain a quantitative analysis of the problem will therefore have little guidance from other sources. However it seems imperative that such an attempt should be made.

Since the subject is at present so nebulous all that can be done herein is to try to specify broad objectives that the study may hope to accomplish. It is hoped that this may be definite enough to establish the point of view that should be taken in the solution.

2.0 GENERAL ATTITUDE OF STUDY

E.C.M. considerations in connection with the CF 105 weapon study will pertain more to the operational aspects of the problem rather than the actual hardware and mechanisms involved. They will be concerned with estimations of the degradations to be expected and possible methods of alleviating the situation. However such a study cannot proceed without any reference to physical entities, for otherwise a wholly unrealistic view would result.

2.1 The Problem

The object of the study would seem to be to determine:

a) the maximum information necessary to achieve an attack,

b) how this information may be obtained.

The problem as such is associated with information theory, but apart from theoretical considerations of the type that this theory would indicate, there should be participation by personnel studying the placement of the interceptor.

2.2 Areas for Study

There are several areas or phases of E.C.M. that are associated with the problem.

a) Jamming of G.C.I. (including communication link)

b) Jamming of A.I.

c) Jamming of missile guidance

d) Jamming of fuze

e) Effect of chaff on the above four systems

f) Decoys

g) Degradation of radar due to special paints

h) Possible use of homing-on-jammer techniques

2.3 G.C.I.

In regard to the jamming of ground radars some consideration can be given to the following aspects:

a) Vectoring towards the target using only azimuth information. Specific questions in this regard may be

i) How much of the interception can be carried out before it is necessary to know range and height of target?

ii) How is accuracy of azimuth information degraded by the jamming signal?

b) Interception using information gained by triangulation by G.C.I. stations, or by the use of correlation techniques.

c) Possible scan techniques to aid detection.

2.4 A.I.

The same aspects may be considered plus the possibility of I.R. or visual modes to give some indication of range. However there is some indication of possible confusion measures against I.R. Also homing on the jammers may be considered.

2.5 Chaff

A brief consideration of the effect of chaff is given in a Hughes report "Interception Study: Part I", but it is not exhaustive.

2.6 Decoys

The question of decoys is thought to be beyond the scope of the CARDE study.

2.7 Communications

Concerning data links the question arises as to how great a data interval may be tolerated before an attack must be aborted.

3.0 EXPERIMENTAL RESULTS

No extensive amount of experimental work has been done on attempting interceptions in the presence of jamming. However reference should be made to whatever trials have been carried out whenever possible. In addition an effort should be made to carry out more test runs in the face of E.C.M.

4.0 BEST TACTICS

Another approach to the problem is to apply the theory of games technique to the question of the tactical use of armament. The more diversified the interceptor's weapons, both in type and frequencies employed, the more E.C.M. equipment the offensive force must carry, and the more skill is needed for choosing the best method at the right time. In evaluating the situation from this point of view thought would have to be given to the relative lethality of the various weapons and also the fact that jamming is an excellent warning device.

APPENDIX A-6

OPTIMIZATION OF FIGHTER TACTICS

F. W. Slingerland

1.0 INTRODUCTION

This appendix deals with that portion of an airborne interception between fighter scramble and missile launch. Some of the factors governing the success of an interception will be discussed. It will be shown that fighter flight procedures can be optimized only by a combined study of the fighter missile and target.

2.0 CORRECTIVE TURNS

Figure 1 is a simplified diagram of an attack situation. The fighter **F** is attempting a beam attack on a target **T**.

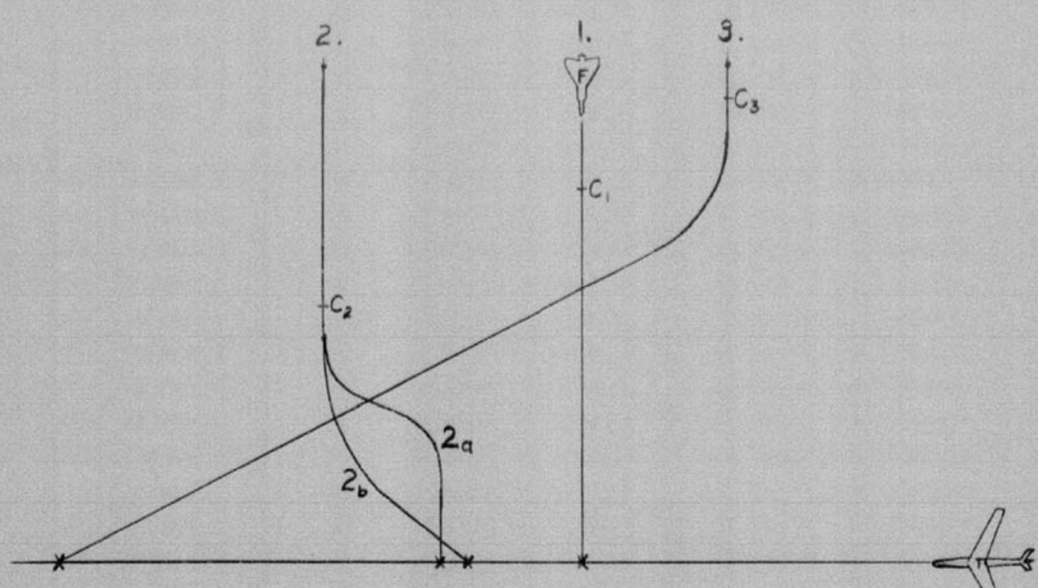


FIGURE 1.

The ideal approach course, marked 1., is such that the fighter obtains A.I. radar contact at C_1, flies straight in, launches its missile at maximum range with perfect aiming and then passes several thousand feet behind the target, well out of range of the target's guns. This ideal course is seldom achieved due to errors in the G.C.I. control phase. G.C.I. control errors have many causes - for example the quantization and inaccuracy of G.C.I. radar information, incorrect wind estimation, G.C.I. controller response time, fighter compass and (auto) pilot steering errors, target manouevres and E.C.M. The greater the G.C.I. vectoring errors the more important it is to optimize fighter tactics. The correction of errors represented by course 2 requires different flight procedures than course 3.

3.0 CONVERSION TO NOSE ATTACKS

If the fighter is vectored too far forward as shown by course 2, two alternatives may be open: (a) the fighter may attempt to turn toward the target, then back, in a zig-zag manoeuvre designed to regain the beam attack position as shown by course 2a. This can only be done if the fighter's turn radius is small compared to A.I. contact range and the distance between courses 1 and 2 is not great. Preliminary calculations indicate that beam conversions are not feasible with the CF 105. With guided missile armament it is usually unnecessary to achieve a beam attack; (b) the fighter must then execute a single-turn conversion to nose attack as shown by course 2b. It is obvious that the tightest possible turn should be pulled, and that fighter deceleration is desirable in order to increase the time available for turning. The fighter therefore pulls to buffet or to structure - or pilot-limited g's. For the CF 105 at high altitude this will give a turn about 3 times as tight as the power-limited turn, together with considerable deceleration. The turn can be further tightened by reducing power, and also extending dive brakes, provided no loss of lift occurs and that the dive brakes either will withstand missile launch turbulence or can be retracted just before launch. The effectiveness of nose conversions is dependent on maximum available lift rather than maximum engine thrust.

As fighter manoeuvrability is increased, larger and larger G.C.I. errors can be tolerated in the forward zone. However, the maximum look angle of the A.I. radar sets an upper limit on the maximum tolerable forward error. If vectored too far ahead, the fighter will not obtain A.I. contact before passing in front of the target and out of the field of view of the A.I. radar. This limitation occurs especially in low altitude beam attacks.

4.0 CONVERSION TO TAIL ATTACK

If the fighter approaches on course 3, the manoeuvres are subject to several limitations and are not as easy to optimize. Consider first a target with less speed than the fighter. The limitations are as follows:

4.1 If the fighter turns too slowly into a tail chase, A.I. contact may be lost during the turn. The attack reverts to the less accurate G.C.I. control with subsequent guidance handover, and considerable time may be lost. This is chiefly a manoeuvre limitation and indicates a need for the tightest available fighter turn.

4.2 If vectored too far back, the fighter may not intercept the bomber until it has penetrated an excessive distance toward its ground target. This limitation argues both for a tight turn and a high speed tail chase, and these two are somewhat mutually exclusive, as before indicated. The relative importance of turn and chase depends on their relative duration and therefore on the fighter's attack course difference. The best solution appears to be a max. g. (structure limited) diving turn, followed by a shallow dive to maintain the highest possible speed consistent with the height loss that can be tolerated. The missile's "jump-up" capability should be borne in mind here. It is possible to launch some missiles in level flight 10,000 ft. below the target without reducing their kill probability. Also, the fighter may dive to more than 10,000 ft. below target and use a decelerating zoom to regain altitude just before launch.

4.3 If the fighter's speed advantage is only slight, the lead angle required to maintain a lead collision course after the initial turn may exceed the maximum look angle of the A.I. radar. With a maximum look angle of 70°, the speed ratio $\frac{V_t}{V_f}$ must be less than sin 70° (= .94) to avoid this.
The limitation is not stringent since it is possible to decrease the amount of the initial turn to retain lock-on and accept slightly higher bomber penetration.

If the fighter has less speed than the target, the above limitations become more severe and others are added:

4.4 There is now a forbidden zone extending from the target's tail to somewhere forward of its beam, in which it is kinematically impossible for the fighter to complete an attack. This is usually the overriding limitation. The fighter must complete its initial turn ahead of this zone. Thus, high rate of turn is desirable. The zone edge is quite sensitive to speed ratios near 1.0. Thus it pays to dive during and after the turn to maintain the maximum available speed, as discussed before.

4.5 A.I. look angle restrictions are more severe with fighter speed disadvantage since the lead angle required to maintain a lead collision course may now be as high as 90°.

5.0 APPROACH SPEED

In general, it is unwise even for a slow fighter to approach a target at V_{max} because of the loss of manoeuvrability involved. For a constant g limit, turn rate is inversely proportional to speed and turn radius directly proportional to the square of speed. For nose conversions the best speed is much lower than V_{max} and usually somewhat lower than the speed for minimum drag. However, this speed is too low for tail conversions because of the excessive dive or long acceleration period required to regain V_{max} during the tail chase. The best approach speed for tail conversions varies inversely with attack course difference. Since it is usually impractical to predict during the G.C.I. phase whether nose or tail conversions will be required, a compromise approach speed must be chosen to give best results for both.

With fighter speed advantage and deep defence coverage the best fighter approach speed appears to be the target's speed. This gives best manoeuvrability consistent with avoidance of the kinematic restrictions resulting from speed ratios $\left(\frac{V_t}{V_f}\right)$ greater than 1.

6.0 OPTIMUM APPROACH ALTITUDE

Most guided missiles are capable of successful kill when launched in level flight several thousand feet below the target. For nose conversions the approach altitude should be as low as possible within the missile's capability, in order to increase fighter manoeuvrability. However, tail conversions may require a dive to V_{max} and unless a pre-launch zoom is feasible, this requires a higher altitude approach. The best compromise altitude is usually below the target.

7.0 OPTIMUM COURSE DIFFERENCE

The best angle between fighter and target courses at A.I. contact is dependent on fighter manoeuvrability, speed ratio and missile fuse and warhead effectiveness. For speed ratios (V_t/V_f) considerably greater than 1 or high fighter manoeuvrability, a head-on attack is optimum kinematically. For speed ratios near 1 a beam attack is best and for ratios less than 1 a tail attack allows greatest G.C.I. errors, though it also allows greater bomber penetration. The above statements are influenced by the variation of the missile's P_K with bomber aspect. Too little is known on this topic to state which attack course difference is preferred by the missile. The assumption to date has been that kill probability is constant at all aspects but this is unlikely.

8.0 TARGET EVASION

Target evasion will probably be initiated as soon as a target detects a fighter locked-on, and will vary depending on the fighter's angular position relative to the target. If the target has a speed advantage, turns away from the fighter are extremely effective. Once the fighter is in the bomber's tail zone and beyond missile range, the attack is aborted.

Turns toward the fighter are effective with speed ratios greater or less than 1. If the fighter can be prevented from entering the launch zone on an acceptable heading before passing behind the target, the attack is either aborted for $\frac{V_t}{V_f} > 1$ or greatly delayed for $\frac{V_t}{V_f} < 1$.

Turns toward can only be countered by increasing fighter manoeuvrability.

9.0 FIRE CONTROL COMPUTER

9.1 Mode: The fire control system may be instrumented to compute any one of a variety of attack courses which are chosen to optimize (a) the chance of successful missile launch and (b) the missile's kill probability. Conditions (a) and (b) are functions of both fighter and missile performance, and the best attack mode will vary with the type of missile used and with speed ratio. Lead collision and lead pursuit modes are the two most commonly used at present. The lead pursuit mode gives inefficient tail conversions for speed ratios of 1 or more. The lead collision mode does not permit utilization of the range width of the missile launch zone. This is required for nose conversions with medium to good fighter manoeuvrability. Under such conditions the conversion can best be performed by flying in to the missile's minimum range before launch in order to gain more time to turn. The disadvantages of the two modes can be avoided by using lead collision steering up to the missile maximum launch range and lead pursuit steering within the launch zone.

9.2 Steering Sensitivity: From the discussion of corrective turns in paragraphs 2 to 4, it appears that the steering signals of the flight control system should be made a function of steering error. If the steering error is large and a nose conversion is indicated, the decelerating (braked?) structure limit turn should be applied. If steering error is large and a tail conversion is indicated, the diving structure limit turn should be applied. For small steering errors in either direction, the usual power limited turns could be applied. Such a variation in turn procedure should be especially useful if large G.C.I. errors exist due to ECM and if the target performs evasive manoeuvres. It is the writer's opinion that in the past too little consideration has been given to evading jamming targets. Our defence system should be optimized against the most likely attack, even if this increases the labours of the analysts.

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APPENDIX B1

DATA AND ASSUMPTIONS

1.0 INTRODUCTION

A review of Section 3 discloses a great deal of indecision and shows that most system parameters are described by ranges of possibilities rather than definite quantities. In view of the amount of effort which CARDE is able to devote to the evaluation of the CF-10C weapons system, it will not be possible to study all combinations with many variants of the various sub-systems: missile, aircraft characteristics, AI radar and fire control, ground environment that might be possible within the general terms of reference defining the interceptor system. The procedure to be adopted is that of establishing one or two basic systems and investigating departures from this basis by varying parameters of interest, one at a time. In some areas sufficient data is available at CARDE, but in many others little or nothing is known.

It is important that the analysis be based on correct assumptions concerning the performance of each sub-system. This is especially true regarding the basic cases which it is hoped will represent the most probable future situation. In choosing a range of values for study of a parameter care must be taken not to multiply the work needlessly. On the other hand, it should be noted that it is often easier and quicker to examine a few extra cases while the work is in progress, than to do such work again after the study has been completed. The disadvantage in having to repeat work is even more pronounced when large automatic computers are involved.

2.0 TARGET CHARACTERISTICS

Data concerning expected target threats for the decade 1960-1970 was requested in a memorandum sent to DAI by D Arm E, 9 November 1955, and the DAI reply has been received. The target characteristics which are used in the kinematic problems of missile trajectory studies and aircraft placement are:

a) Speed as function of altitude (cruising and maximum)

b) Maximum altitude, cruising altitude

c) Load factor g's and minimum turn radius

d) Acceleration or deceleration possible along flight path

e) Climb and dive performance as function of altitude

f) Radar echoing area at various aspects

The main deficiency in this data is concerning echoing areas. This difficult problem will probably form a part of the study, and for this pictures of the actual aircraft will be needed. Lethality studies will also require pictures from which models may be made. Several of the threats are hypothetical and therefore there will be some difficulty in estimating g capabilities, echoing areas and vulnerability.

In the DAI reply a fairly comprehensive discussion is given on E.C.M. which should be sufficient as a guide to E.C.M. studies. There is also an outline of the bombers' possible defensive weapons, which will be needed if the chance of survival of the interceptor is investigated.

The main concentration will be on radar detection and tracking. If an infra-red mode is considered it may be that certain additional information will be needed as requested by specialists in this field.

3.0 MISSILE SYSTEMS

It is essential to have information on missile systems that may be adapted to the CF-105. Before the key problem of interceptor placement can be investigated, a knowledge of the missile launch zones is required. In assessing the capabilities of the CF-105 against the designated threats, details of launch zones (maximum and minimum permissible launch range as function of target aspect, and allowable heading error) are needed for altitudes 30,000 feet to 70,000 feet for as wide a range of target and interceptor velocities as is possible. Other missile characteristics which should be known for the weapons evaluation are:

a) High altitude capability; any limitations on the usability of the missile at high altitudes

b) Supersonic launch: stability problems associated with launching at high Mach number

c) Launch requirements, such as preparation time, lock-on time, restrictions on the time for which the missile may be kept in the ready launch state

d) Kill probability as function of approach angle, altitude, target velocity, miss distance.

3.1 CARDE Missile Study

It has been mentioned that launch zones must be known before the principal problem of aircraft placement may begin. The initial inquiries revealed that information on missile capabilities at the altitude and speeds of interest was not available in Canada. It also became evident that an immediate visit to the U.S. was not possible. In order to ensure that the study proper could commence soon enough that results could be obtained in the time required, CARDE instituted a missile trajectory simulation for high speed high altitude targets. Results of the first part of this study are given in CARDE Technical Letter N-47-2 (Reference 3). These studies provide launch zones of a hypothetical Sparrow family missile for various interceptor and target velocities and altitudes. These are sufficient launch zone data for the initial stages of the aircraft placement study, when the emphasis will be on developing effective analysis techniques. It will be necessary to obtain exact launch zones for the actual missile which is to be carried by the CF-105 for at least one altitude and interceptor/target velocity combination. Results of the CARDE study will then permit estimation of the actual missile launch zones for other target and interceptor velocities.

3.2 Sparrow Missiles

The most recent information available concerning Sparrow II is that given in the brochure dated Nov 1, 1955. This gives launch zones, guidance and lock-on ranges for all aspects at altitudes up to 50,000 feet for subsonic targets and interceptors. No intimation is given of possibility of its use at higher altitudes, nor is any launch zone given for supersonic targets and interceptors. Guidance ranges given against a B-47 type target, while sufficient for subsonic operation, would be at best marginal for the supersonic case.

The only information available for Sparrow III at CARDE is that given in the Brochure of May 15, 1954. Again this is for subsonic target and interceptor velocities only, and at altitudes up to 50,000 feet. Polar diagrams of guidance ranges for modern bombers are not given, though it is thought that these would be greater than those of the active Sparrow II radar.

3.3 Falcon Missile

It is not clear whether any attempt is to be made to evaluate the use of the Falcon with the CF-105 against the probable targets. If this is to be undertaken, information on the behaviour of both the semi-active and IR Falcon against supersonic targets at high altitude will be needed.

3.4 Fuze and Warhead

Very little information is available on any of the fuzing systems, and most of the warheads mentioned are of the fragmenting type. It is felt that this is one part of a missile system which might be changed without fundamentally altering the general concept of the particular weapon, and that future developments may well be along different lines.

4.0 INTERCEPTOR AIRCRAFT CHARACTERISTICS

The interceptor characteristics which must be known for the aircraft placement study are:

a) Load factors as function of altitude and Mach number

b) Best combat speeds

c) Climb rate, and time to height as functions of altitude and Mach number

d) Dynamic behaviour: buffet limits, response time

e) drag characteristics

In order to make a study of missile shielding in the launch position, detail of the anticipated launcher design, and the configuration of the aircraft are required. The detail of the projected launcher design for Sparrow missile is not known.

CARDE has the specification to which the CF-105 aircraft is being built, and the AVRO Brochure giving expected performance of the design to date. It is proposed to use the AVRO estimates of performance as a basis for the study, but to consider variations that might result in future development or in revised estimates of aircraft performance. A summary of the aircraft characteristics is given in Appendix B2.

5.0 AIRCRAFT INTERCEPTION RADAR AND INTEGRATED ELECTRONIC SYSTEM

The performance characteristics of the AI radar and the fire control system which constitute input data to the aircraft placement problem are:

a) Detection range and lock-on range as function of target aspect for the probable targets

b) Look angle in azimuth and elevation

c) Scan pattern and rate

d) Accuracy of range, range rate, and bearing information

e) Modes of operation and type of display

f) Lock-on time

CARDE has not yet seen the Specification Air 7-6 for the integrated electronic system for the CF-105, although most of the applicable part of Air 7-5 has been seen and noted.

6.0 GROUND ENVIRONMENT

CARDE is interested in the ground environment insofar as it affects directly the interceptor placement problem. The characteristics which must be known in this regard are:

a) Accuracy of range information as function of altitude

b) Accuracy of azimuth information

c) Accuracy of altitude information

d) Time required for a fix

e) Navigation accuracy with Tacan or other system

f) Resolution of multiple targets

It is understood that this information will be provided to CARDE by DSE.

APPENDIX B2

ASSUMPTIONS REGARDING TARGETS

The following is a review of the basic parameters assigned to targets considered in the study.

Subsonic Targets

(a) Present day type of subsonic target, at Mach number .85. - This represents a reasonable approximation to the combat speed of various subsonic bombers such as Badger, Bison, etc. It is proposed to consider this target at an altitude of 40,000 feet which represents a mean altitude at which such bombers may appear. It is essential to assign an altitude in order to fix the interceptor characteristics for the placement problem.

Different radar detection contours for AI for the different targets may be used. It is thought necessary to analyse the effect of ECM, by introducing degradation in radar detection range, so that additional shorter range contours of the same shape as the principal ones, will also be considered.

(b) Hypothetical subsonic target. - For this target a Mach number of .85 is still to be assumed to avoid using too many different target speeds. The target is to be considered at 50,000 feet and 60,000 feet. Since this is a hypothetical target, some difficulty may be encountered in estimating radar detection contours.

(c) Evasion of Subsonic Targets. - It is proposed to consider possible evasive action of the subsonic targets at the various altitudes as follows: 2g lateral acceleration at 40,000 feet; 1g at 50,000 ft, and ½g at 60,000 feet. This will be studied mainly as a constant turn applied during the AI phase and the missile phase of the attack. It has been suggested that the following cases be considered:

(i) with no evasion

(ii) with sustained random evasion

(iii) with circular evasion applied only after AI contact

(iv) (ii) above plus (iii).

Another case that may be considered is that of circular evasion applied only some seconds after missile launch. A special case of evasion which will be looked at if time permits is that of target acceleration along the flight path during ground control, AI, or missile phases of the interception.

Supersonic Targets

(a) The supersonic target which appears to be of most interest is one having a Mach number of 2, and which will be considered as non-evading. This will be considered at altitudes of 50,000 feet and 60,000 feet. Since such a target is hypothetical (though possible) the radar detection contour for A.I. will also be hypothetical; this will involve using more than one contour.

(b) Different supersonic target Mach numbers, 1.5 and 2.5, will be considered to a certain extent. The lower velocity target will be considered capable of a 1 g lateral acceleration.

APPENDIX B3

INTERCEPTOR PERFORMANCE

It is proposed to use the current AVRO performance estimates of the production version of the CF-105 with PS 13 engines. The most recent report available at CARDE is that of January, 1956. A summary of some of the more important performance characteristics is given here for convenience.

Take-off Weight with 78% fuel	57,132 lbs
Combat Weight (½ fuel)	49,373 lbs
Wing Loading at Normal Take-off Wt.	45.4 lbs/sq.ft.
Power Loading at Normal Take-off Wt.	1.22 lbs/lb thrust
True Air speed in Level Flight at sea level at Combat Weight	Max.thrust 720 knots Min.thrust 650 knots
at 50,000 feet	Max.thrust 1140 knots
Combat Ceiling at Combat Weight, 500 rpm rate of climb, with maximum thrust at 1.5 Mach number	64,000 feet
Steady Rate of Climb at 50,000 ft, combat weight, maximum thrust, Mach number 1.5	15,000 ft/min.
Time to 50,000 ft. at Mach number 1.5 from engine start at normal Take-off weight	4.0 mins.
Combat Load factor at Combat Weight with maximum thrust at Mach number 1.5 at 50,000 ft., with Sparrow missiles	1.87
Combat radius, High speed Mission with full Internal Fuel	318 miles
Combat radius, subsonic cruise, full Internal Fuel	491 miles

The following table gives maximum g's in level flight corrected for Sparrow missile weights, for the values of interceptor Mach number to be used in the study. In high altitude interceptions turns will be made at g's approaching structural load factors, considerably higher than these power-limited values. The consequent deceleration must be taken into account in computing placement chances.

Altitude \ Mach No.	.92	1.2	1.5	1.8
36,000	2.70	2.88	3.71	3.30
40,000	2.26	2.35	3.07	2.72
45,000	1.76	1.85	2.40	2.16
50,000	1.40	1.46	1.87	1.70
55,000	1.09	1.20	1.51	1.38
60,000	-	-	1.19	1.07

REFERENCES

1. CARDE Technical Memorandum 119/55 (S)

   "A Study to Determine the Effectiveness of the CF-100 Mk 4B Armed with Sparrow II Missiles against a Type 37 Bomber"

2. CARDE Technical Letter N-47-1 (S)

   "U.S.A. Visit"

3. CARDE Technical Letter N-47-2 (S)

   "Launch Zones for a Hypothetical Constant-Bearing Missile"
