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Author J.T. Baker, R.S. Mitchell, Macfarlane **Approved by** **Sheet** Title **of** 118

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PROJECT
CF-105 ASSESSMENT

FIRST QUARTERLY REPORT

Period 1 May to 31 July 1956

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R.S. Mitchell
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-Systems Group

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ERRATA SHEET #2

28

CARDE TECHNICAL LETTER N-47-8
"First Quarterly Report on CF 105
Weapon System Assessment".

Page 28 Lines 9 and 10

"The thrust function f_{11} will then be obtained from

$$f_{11} = \frac{Fne}{(h)} \cdot \frac{aM}{W} \text{"}$$

should read

"The thrust function (2 engines) will then be obtained from

$$f_{11} = 2 \frac{Fne}{(h)} \cdot \frac{aM}{W} \text{"}$$

where Fn_e = net installed maximum thrust with afterburner lit (one engine).

J. J. Baker

Systems Group
6.9.56

[redacted]

ERRATA SHEET

Letters identifying the various barriers (a), (b), (c) and (d) were omitted from the typical placement chart drawn as figure 1. on page 39. The correct labelling is shown below.

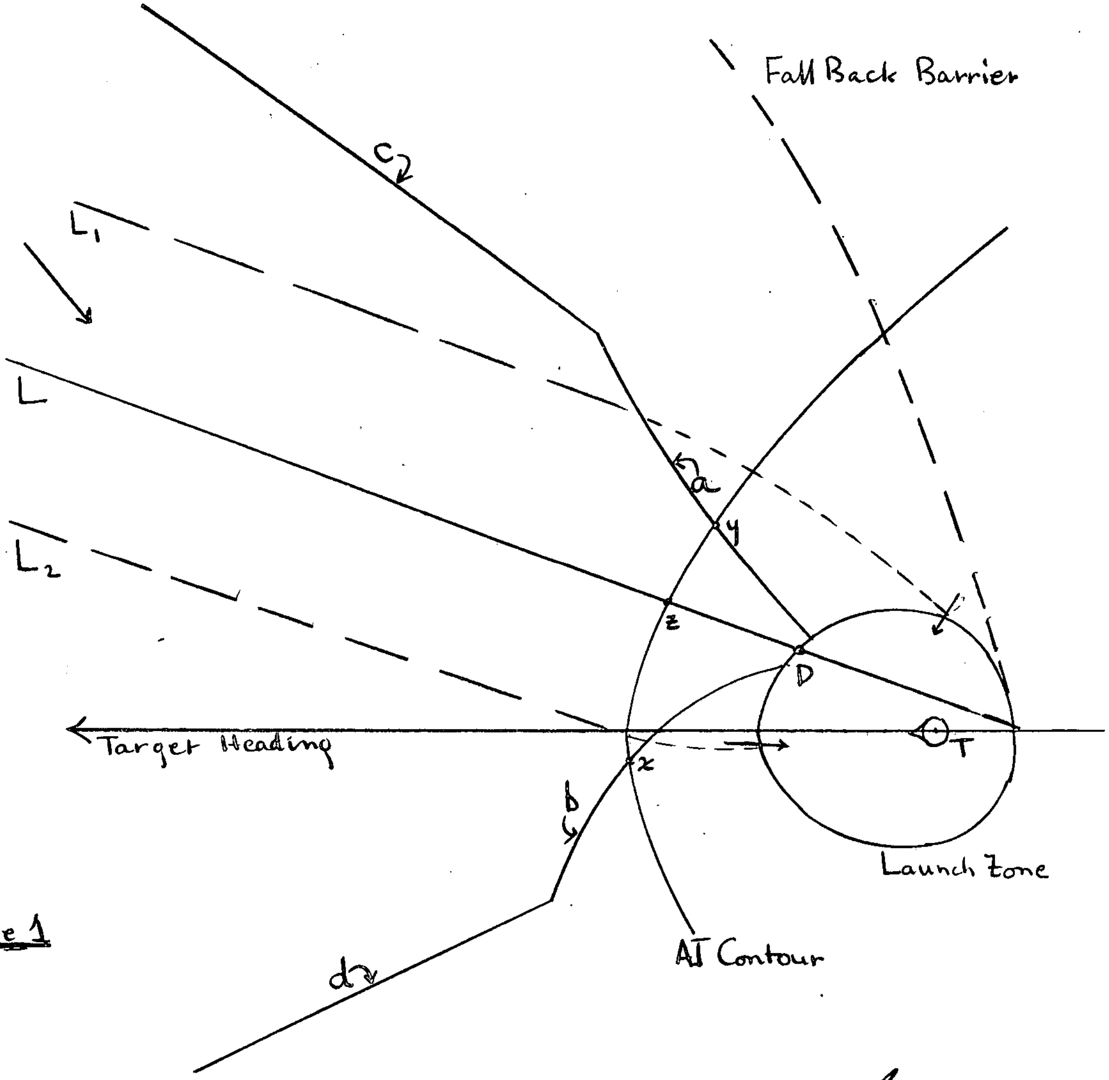

Figure 1

James T. Baker
(J.T. Baker)
Systems Group

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SUMMARY

This technical letter has been issued as an interim progress report on the work being done at CARDE in connection with the CF 105 Weapon System assessment.

The objectives of this study are stated and the methods of approach to the problem are described.

Some fourteen technical appendices dealing with various facets of the work are included. These are not intended to describe completed sections of the assessment, but rather to familiarize the reader with the task and the methods of investigation which have been adopted.

FIRST QUARTERLY REPORT
on
CF 105 WEAPON SYSTEM ASSESSMENT

1. INTRODUCTION

The engagement of high speed targets by supersonic interceptors armed with air-to-air missiles introduces a variety of new problems which cannot be assessed by extrapolation of data arising from experience with conventionally armed subsonic aircraft.

For this reason, CARDE has been requested by the RCAF to carry out an evaluation study of the effectiveness of a supersonic interceptor weapon system based on the AVRO CF-105 aircraft armed with Sparrow II or Sparrow III air-to-air missiles.

The primary objectives of the study as stated by the RCAF are:

(i) To evaluate the combat effectiveness of the system with different types of armament, beginning with the Sparrow series, for probable bomber threats including the Bison, Badger and Bear.

(ii) To investigate the effect of variation in fire control parameters such as A.I. radar range and look angle.

[redacted]

(iii) To establish the minimum acceptable level of aerodynamic performance and to investigate the effect of possible design changes in the aircraft and engine configuration, insofar as these changes affect combat performance.

(iv) To determine the effect of variations in G.C.I. placement accuracy.

(v) To explore possible tactics and suggest optimum modes of attack.

In order to arrive at an accurate assessment of the overall combat effectiveness of this weapon system, the many inter-dependent sub-systems of which it is composed require analysis, first individually and then collectively, so that the relative importance of the principal parameters can be established. Naturally, an exploratory study of this nature is quite involved and certainly time-consuming, if it is to be sufficiently exhaustive to achieve the above-stated objectives. Further, the task is rendered difficult in that very little primary information is available on which to base investigations, as it is evident that the establishment of such data is perhaps the primary object of the study.

The general approach then has been to adopt a range of parameters which should encompass final characteristics, then to conduct an analysis based on these and thus establish their validity and importance in the particular sub-system, as well as their influence on the effectiveness of the system as a whole. In this way overall effectiveness can be established as a function of

[redacted]

the parameters of individual sub-systems and optimum design values indicated.

Although this method is elongated and somewhat tedious, an important compensatory feature lies in the fact that the most critical areas requiring further study are highlighted.

2. INITIATION OF STUDY

CARDE Technical Letter N-47-3, May 56, gives a review of the general interceptor-weapon problem with particular reference to the proposed CF-105 system, and also sets out in some detail a proposal for the prosecution of studies to attain the objectives since enumerated by the RCAF. A directive to initiate the CF-105 Weapon System Assessment Study was received on May 29, 1956 and work has actively continued in accordance with the original program as set out in CARDE Tech. Letter N-47-3, May 4, '56.

3. MANPOWER ALLOCATION

This work is being carried out by specialist sections within the various Wings of CARDE, under the co-ordination and direction of the Systems Group which is generally responsible for the task.

During the period under review, a total of 20 professional personnel have been engaged on the work. The degree of participation was as under:

	Full time	Part time
Systems Group	3	2
G Wing	8	4
B Wing	1	1
C Wing	-	1
TOTAL	12	8

[redacted]

4. GENERAL REVIEW OF PROBLEM

While a study to evaluate the combat effectiveness of the CF 105/Sparrow system may appear capable of break-down into a number of individual problems for indepedent solution, the importance of mutual compatibility of the sub-systems, and determination of vital parameters, will not permit isolated investigation. For this reason, each problem must be studied in proper relation to its place in the integrated system, which necessitates somewhat complex mathematical analysis.

In order to minimise the computation work envisaged, and with a view to substantiating results obtained, it is proposed that several CARDE personnel participating in this study, visit selected organizations in the U.S.A. for discussions on certain aspects of the evaluation; notably to obtain detailed information on the weapons and fire control systems to be used. Trips for this purpose have been planned to commence early in September, when the results of exploratory work, now nearing completion, will indicate more specifically the detailed information which will expedite the later stages of the study.

Generally, the work to date has been hampered by two main factors: lack of basic information and inadequate computing facilities.

As outlined above, steps are being taken to remedy the first item at the most propitious time, and the present REAC facility of this establish-

[redacted] [redacted]

ment is currently being expanded by some 120 percent.

By the end of September the new installation should be in operation, although it may not be possible to fully exploit the expanded facility owing to man-power shortages.

In early October, when it is hoped both additional basic information and REAC capacity will be available, a well balanced and concentrated effort will develop to generate specialized data on which the evaluation study depends.

It is anticipated that the bulk of this work will be complete by December 31, leaving three months for evaluation and preparation of the final report which is required by April 1, 1957.

5. ACTIVITIES MAY-JULY 1956

5.1 Primary Effort

Effort during the three months ended July 31 has been concentrated mainly on the following:

- (a) Seeking out and establishing sources of basic information.
- (b) Placement Problem.
    - (1) Planning REAC circuitry and running unsophisticated probelm cases.
    - (2) Investigating the simplified placement problem.

(c) Furthering missile studies (REAC).

(d) Studies of contributory aspects.

5.2 Information Sources

As previously stated, the study has been hampered by lack of concrete information on several phases of the system. This deficiency can be attributed to several causes; notably the delay in formal notification to commence the study, available data being incomplete or not in a usable form and uncertainty as to where pertinent data could be obtained.

Action has been taken to alleviate the last mentioned bottleneck. A reconnaissance visit was made to Washington D.C. to ascertain the most appropriate organisations in the US to be visited in September with a view to obtaining basic information to further the CARDE Study. A summary report of this visit and proposed itinerary for the September visits is attached. (Appendix A).

Further, direct communication has been established with AVRO Aircraft Ltd., Toronto and N.A.E., (Appendix B) and the necessary clearances are being processed to facilitate direct consultations with R.C.A.

5.3 Placement Problem

5.3.1 Non Evading Target

Experience has shown that the graphical method yields a satisfactory solution to the placement problem when considering the co-planar case of a non-evading target. Work on this aspect has been proceeding with the object of becoming familiar with the simplified problem and gaining an understanding of the effects of parameter variations. The results obtained will be particularized to cases of interest later in the study, when detailed aircraft performance data is available. (Appendix C).

5.3.2 Evading Target

A method has been developed to permit REAC Solution of the placement problem (Appendix D) and the constant speed co-planar case for an evading target is currently being studied on the computer. (Appendix C).

In the course of this exploratory analysis, means by which the simulation could be made less cumbersome and more realistic have presented themselves. Accordingly, effort has been directed towards the development of more sophisticated and realistic techniques. (Appendices E and F).

Appendix F also sets out an alternative graphical method for solution of the above problem.

5.3.3 3 D Placement Problem

The foregoing placement considerations pertain only to co-

[redacted]

planar cases. Ultimately three dimensional investigations must be carried out if more advanced tactics are to be examined, and the placement problem fully explored.

Appendix G deals with a possible method of simulating the 3 D placement problem on the REAC.

5.3.4 The Human Operator

Although the proposed CF 105 system approaches automation, the human element is still present. For this reason a short study has been made to establish a transfer function to simulate pilot response in the REAC studies. These investigations are reported in Appendix H.

5.3.5 AI Acquisition

The probability of correctly placing an interceptor in combat is governed to some extent by the acquisition range of the A.I. radar equipment in the aircraft. This range is itself a variable quantity dependent upon target aspect, size and other factors. Treatment of this subject is given in Appendix I.

5.4 Missile Studies

The 3-D missile problem has been completed. This work is reported in Appendix J.

In the course of this study, and earlier work in two dimensions,

[redacted]

simulation of the missile steering loop was questioned. To investigate the validity of certain assumptions which had been made in connection with this, a separate smaller study was run which is reported in Appendix K.

5.5 ECM Aspects

A preliminary survey of current and anticipated E.C.M. tactics has been carried out with a view to providing a basis on which to obtain information of a more quantitative nature from D.R.T.E. (Appendix L).

To this end a meeting was held at CARDE with a representative of DRTE to discuss the problem and determine the type of information required.

As it is generally felt that ECM and CCM tactics will have a marked influence on the overall effectiveness of the proposed interceptor system, these must be taken into account if a realistic assessment is to be made. Appendix M deals with some operational aspects of jammer homing.

5.6 Fire Control Considerations

Work in this field has been slow in starting mainly as a result of insufficient basic data and a temporary shortage of suitable personnel. However, a program has now been drawn up and it is hoped that a start will be made on this portion of the study at an early date. This

[redacted]

program includes an assessment of the proposed RCA fire control system in relation to the RCAF Specification, Air 7-6, with particular reference to the possibility of incorporating instrumentation of more sophisticated attack modes.

5.7 Lethality

5.7.1 Warhead

A survey of existing and advanced design warheads, suitable for missiles of the CF 105 system, has been completed and suggestions made. This is summarised in Appendix N. The use N of nuclear warheads has not been included in this section of the study.

5.7.2 Fuze

It had been hoped that an optical simulator, which has recently undergone trials at CARDE, may have proved useful in studying fuze action in relation to lethality.

It has now become apparent however, that considerable disagreement exists between the behaviour of light waves reflected from a silvered model, and radar waves reflected from an aircraft. For this reason it has not been possible to establish the fuze triggering point by this method. The problem will be pursued during the next period.

[redacted] [redacted]

5.7.3 Target Vulnerability

Unfortunately, this aspect of the work has not kept pace with the rest of the study during the period under review. A new approach to vulnerability investigations will be taken during the next period when it is hoped that the terminal ballistics of warheads will be examined in relation to target structure to yield quantitative data of a usable nature.

6. FUTURE PROGRAM

During the next period, August 1 to October 31, it is hoped to finalize certain aspects of the study.

Work on the two dimensional placement problem can be completed if reliable information on the aerodynamic performance of the CF 105 is available prior to September 15. This data, notably thrust and drag coefficients, is required so that trajectories of decelerating turns can be drawn on the REAC. These trajectories, or 'Spirals' , will then be used to facilitate the graphical solution of the two dimensional placement problem.

Concurrently, REAC simulation of the three dimensional placement problem will be commenced in order that this investigation may progress as much as possible during this period.

Increased effort will be applied to the fire control, E.C.M. and lethality aspects, so that the results of this work can be integrated and

[redacted] [redacted]

reflected in the later and more sophisticated simulations of the three dimensional placement problem.

The proposed visits in September to U.S. companies and establishments (Appendix A) will constitute an important activity during this period. If the object of this excursion is achieved, much data relevant to the present CF 105/Sparrow System Study will be amassed.

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APPENDIX A

R.S. Mitchell

PROPOSED VISITS TO U.S. ESTABLISHMENTS

As outlined in the first report on the CF-105 study (Ref. No. 1), there is a great need to obtain additional information on several general topics. As a first step in alleviating this situation, an unclassified reconnaissance visit was made to Washington. Several meetings were arranged at various offices (at Buaer and the Pentagon) by the staff of the Defence Research Member (CJS).

The object of these interviews was to first outline what was being attempted in the CF-105 study and then to ascertain where in the U.S. it might be profitable to visit on a classified basis to obtain information which would aid in the prosecution of the study. It was emphasized that there were several kinds of information desired - results of interception-missile studies; methods employed, both analytic and computer techniques; and details of the proposed characteristics of the aircraft and weapon sub-systems. These subjects were discussed under five general areas:

(a) General System Studies

(b) Advanced Missile Studies

(c) Fire Control Studies

(d) Lethality Studies

(e) Interception Trials

It was stressed that, especially regarding missiles, it was necessary to determine what the advanced thinking might be rather than to discuss existing hardware. Details of the various meetings are discussed elsewhere. (Ref. 2.) In the first three fields listed above, it was decided that a visit should be made to the following establishments:

(a) Bell Telephone Labs = Naval Intercept Project. A parametric system study along the lines of the CF-105 assessment.

(b) NADC = Johnsville study, to determine the optimum interceptor-fire control-weapon system for the 1963 era.

(c) Raytheon = Sparrow III missile system (including I.R. version) and the integrated system for the F4H.

(d) R.C.A. = Electronic system for the CF-105.

[redacted]

(e) Mc Donnel = The F4H Aircraft system.

(f) Hughes = Fire control and placement studies.

(g) Ramo-Wooldridge = Interceptor and Missile system studies.

(h) Rand = General system and lethality studies.

(i) Douglas = Sparrow II missile system.

A visit to these establishments is being planned for September by D.R.B. personnel, the majority of whom will be from CARDE.

The object of this visit will be to obtain as much quantitative data as possible. It is hoped that several of these studies may have covered problems which are of concern in the CF-105 study and discussion of their results may save time and labour. It is also necessary to establish as closely as possible what the weapon system characteristics might be for the 1960 era.

To ensure that the maximum benefit be obtained from these visits, several meetings of the CARDE party are planned so that detailed briefings may be given on the various aspects of the problem.

In regard to the subject of lethality, it would seem that the most expeditious course would be to arrange representation on the forthcoming tri-partite conference in October on anti-aircraft lethality. Action is being taken in this regard.

It is felt that the subject of interception trials is better considered by personnel engaged in the Sprint Project, which is concerned with experimental verification of Sparrow II - CF-100 results as indicated in reference three. No definite conclusion has yet been drawn.

REFERENCES

1. CARDE Technical Letter N-47-3

2. CARDE Technical Letter N-47-7

[redacted]

APPENDIX B

B. Cheers

AERODYNAMIC DATA

INTRODUCTION

Ever since the systems study of the CF-105, equipped with internally stowed missiles, was initiated at CARDE in May 1956 there has been a general lack of information on the aircraft characteristics. Accordingly, several D.R.B. personnel paid a visit to AVRO at the beginning of July 1956 with a view to establishing a liaison between the company and DRB. AVRO showed a willingness to cooperate in providing any information which might be required for the CARDE study, and a brief fact-finding visit has already been made, the results of which are given below.

N.A.E. have made some estimates of the aircraft performance characteristics (using AVRO basic data) and, as there are some discrepancies between these and AVRO's own estimates, it is proposed to make the study using both sets of estimates, thus getting upper and lower limits to the performance capabilities of the aircraft, corresponding to AVRO and NAE estimates respectively.

(It must be noted that not all of the information presented as coming from AVRO is yet final or official and must be treated as tentative in nature.)

PRESENT INFORMATION

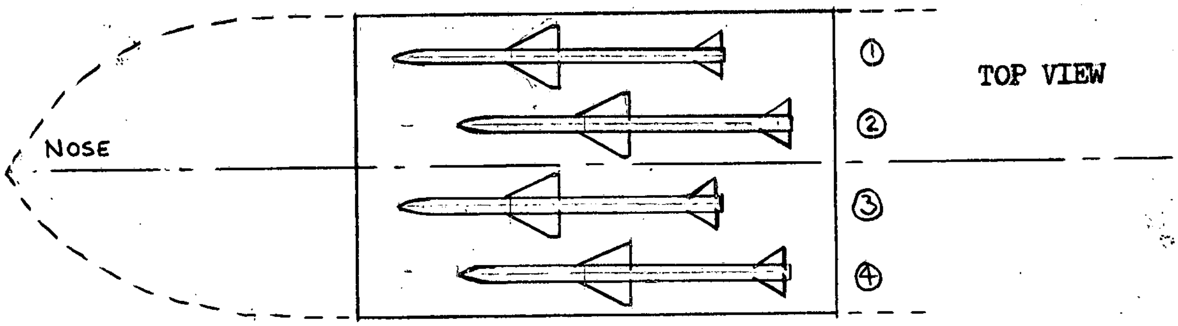
We will now summarize the information so far obtained from AVRO and NAE.

(a) Missile Stowage and Extension Problems

(1) Stowage

The present scheme for stowage is that contained in AVRO report C/ARM2499 published about March 1956 in which 4 Sparrow II missiles are to be carried in the armament bay in the underside of the fuselage. They are staggered to allow space for the wings, and because of insufficient depth in the bay the missiles are carried with their centre-lines on the skin line of the bay. A plastic cover fits over each missile body and is jettisoned at the beginning of missile extension. A diagram showing the positions of the missiles in the bay is given below.

[redacted]



(2) Blinding

AVRO have done some work on the look angle and the blind areas caused by the aircraft nose when the missiles are in the launching position. The graphs of the missile blind regions as provided by AVRO are given in figure B-1. It will be noted that the angles given are measured from the missile datum line which itself is at 3° (nose down) to the aircraft datum. Thus to obtain the effective look angle we need to know the angle of attack of the aircraft under any given conditions. A comprehensive set of graphs of α (trim) for different normal accelerations, (n g), altitudes (h) and CG positions is given in Ext. P/Control/78 and some representative values are given in the table below:-

Mach Number = 1.5 Weight = 47,000 lb.

C.G. at 27% M.A.C.

α Trim (deg)

h \ n(g)	-2	1	2	4	6
40,000	-	1.8	3.8	7.8	11.6
50,000	-	2.9	6.0	-	-
60,000	-	5.3	9.9	-	-

C.G. at 31% M.A.C.

α Trim (deg)

h \ n	-2	1	2	4	6
40,000	-3.9	1.7	3.4	7.1	10.8
50,000	-6.1	2.7	5.6	11.5	17.4
60,000	-9.7	4.5	9.3	-	-

[redacted]

(3) Armament Bay Dimensions

The present dimensions are:

Usable length	184"
Usable width	90"
Usable depth	24"

(4) Effects on Aircraft during missile extension

Wind-tunnel tests at Cornell Aeronautical Laboratory were carried out with Sparrow models in the extended positions and at different positions during the first part of the estimated trajectory after launch, and the effects on aircraft trim were measured. These effects were considered by AVRO to be small and any slight change in trim would be taken into account by the automatic controls. The maximum Mach Number obtained in the tests was 1.23 and it is not yet certain whether further tests with missiles extended at higher Mach Numbers are contemplated.

The limits of the aircraft normal acceleration for extension of the missiles are -1g to + 4g.

Further information will be required on such items as: increased drag due to missile extension, effects of buffet, turns and acceleration on missile launching. There is to be a meeting with AVRO and RCA on these subjects in the middle of August 1956, and it is hoped that some DRB representatives will be present.

(5) Flow fields around the missiles and dispersion effects

No definite information on the flow fields around the missiles and dispersion effects expected is yet available.

(6) Infra-Red Missiles

Very little information regarding the use of I.R. head missiles is available at the present time.

(7) Times for extension and firing of missiles

The proposed timing sequence is as follows:

Wing doors open	½ sec.
Missiles reach fully extended position	1½ secs.
Wing doors close	½ sec.
(as wing doors close missiles are to lock on	½ sec.)
Total time from beginning of extension to lock on	2½ secs.

[redacted] [redacted]

From lock on, intervalometer sends firing signals to the missiles at $\frac{1}{2}$ sec. intervals, so the time taken for all missiles to be fired after lock on is $1\frac{1}{2}$ secs. When all missiles are fired the extensions retract in $\frac{1}{2}$ sec.

Hence total elapsed time doors closed - extension - firing - doors closed is $4\frac{1}{2}$ secs.

(b) Simulation of High-Altitude Performance of the Aircraft

To represent the performance of an aircraft in steady and unsteady manoeuvres in a complete way such that the dynamic characteristics are fully represented, while at the same time taking account of the effects of Mach Number variation, is an almost hopeless task.

It is therefore proposed to set up the simulator in a reasonably simple way by leaving out the dynamic stability almost entirely by assuming that the aircraft obeys orders perfectly as regards normal load factor, bank angle or any other necessary command.

In an interception study we need to take into account the steady and unsteady performance of the aircraft and solve for the motion in 3-dimensions. With the same set-up we may also investigate optimum climb techniques and other unsteady manoeuvres, problems connected with flight near the minimum drag speed and flight above the absolute (steady) ceiling of the aircraft.

A method proposed by R.J. Templin in AE-82 (an internal NAE lab. memo) takes into account all factors likely to be of importance in the above problems in developing the equations of motion in as simple a form as possible for the REAC. Certain assumptions are made in developing the equations and some will restrict the range of application.

In this method, all the aerodynamic characteristics are put into a single "primary" equation, making as few limiting assumptions as possible, so that the equation is of general application. Other assumptions appropriate for the present problem are introduced in "auxiliary" equations only.

The external forces acting on the aircraft are assumed to be gravity, thrust and aerodynamic forces.

The following assumptions are made with reference to these forces:

(1) Gravity force = weight, which is assumed to be essentially constant over the duration of the combat manoeuvres.

(2) Thrust acts in the direction of motion of the aircraft i.e. angles of attack and sideslip are assumed small.

(3) At constant throttle setting and Mach Number, the thrust is assumed to vary directly with atmospheric density. This assumption is true only in the stratosphere ($h > 35,000$ ft).

[redacted]

(4) The resultant aerodynamic forces act in the aircraft plane of symmetry i.e. drag and lift. This is equivalent to assuming that there is no sideslip and no other errors are introduced if the aircraft drag is calculated in "wind-axes".

(5) The aircraft is always trimmed i.e. elevators are set so that $C_m = 0$. This assumption is necessary to avoid the introduction of dynamic characteristics.

"Primary" Equation of Motion

The equation of motion taking all the forces into account is the Total Energy Height Equation which gives the variation of speed and altitude combined.

$$\text{Total energy height } H = h + \frac{V^2}{2g} = h + \frac{a^2M^2}{2g} \qquad (1)$$

where h = altitude in feet
V = velocity in ft/sec.
a = speed of sound (ft/sec)(constant in stratosphere)
M = Mach Number

It can be shown that

$$\frac{dH}{dt} = \frac{dh}{dt} + \frac{a^2}{2g}\frac{d(M^2)}{dt} = \frac{V(T-D)}{W} \qquad (2)$$

where T = thrust in lb. = $\tau C_T \tfrac{1}{2}\rho V^2 S$

D = total drag in lb. = $C_D \tfrac{1}{2}\rho V^2 S$

W = weight (combat) in lb.

τ = fractional throttle setting

C_T = max. thrust coefficient

C_D = total drag coefficient

S = reference area = 1225 sq. ft.

It is assumed that C_D may be split up into

$$C_D = C_{D_0} + K_1C_L + K_2C_L^2$$

where C_{D_0} = drag coefficient at zero lift

[redacted]

$$C_L = \frac{\text{Lift}}{\frac{1}{2}\rho V^2 S}$$

K_1 and K_2 are functions of M only.

Let $n(g) = \frac{L}{W}$ = normal load factor

and $\rho = \rho_0 \sigma(h)$ where σ = relative air-density

ρ_0 = standard air density at sea-level.

Substituting these quantities in equation (2) we get

$$\frac{dh}{dt} + \frac{a^2}{2g}\frac{d(M^2)}{dt} = \left[f_{11}(M)\tau - f_{12}(M)\right]\sigma(h) - f_2(M)n - \frac{f_3(M)}{\sigma(h)}n^2 \qquad (3)$$

where $f_{11} = C_T \tfrac{1}{2}\rho_0 \frac{S}{W} a^3M^3$

$$f_{12} = C_{Do}\,\tfrac{1}{2}\rho_0 \frac{S}{W} a^3M^3$$

$$f_2 = K_1\, aM$$

$$f_3 = \frac{2K_2}{\rho_0\, aM}\left(\frac{W}{S}\right)$$

This equation is fully aerobatic but applies only to the stratosphere.

It is now required to calculate f_{11}, f_{12}, f_2 and f_3 from the known aerodynamic characteristics of the aircraft. These calculations are now being done using both AVRO and NAE estimates.

Auxiliary Equations

To separate h and M from equation (3) we use an equation for $\frac{d^2h}{dt^2}$ and integrate to give $\frac{dh}{dt}$.

[redacted] [redacted]

Case (1) When aircraft is assumed to manoeuvre in a vertical plane only.

With the simplifying assumption that the angle the flight path makes with horizontal (θ) does not exceed 20° or 30° we get

$$\frac{d^2h}{dt^2} = g\,(n - 1)$$

Case (2) Aircraft allowed to turn.

Introducing the bank angle ϕ we get

$$\frac{d^2h}{dt^2} = g(n \cos\phi - 1)$$

The horizontal load factor at right angles to the flight path is given by

$$\frac{d\psi}{dt} = \frac{ng \sin\phi}{V}$$ where ψ is the azimuth angle

Calculation of quantities used in $\frac{dH}{dt}$ equation.

(1) Engine Performance

The maximum installed thrust for the aircraft with PS 13 engines is obtained from the AVRO Monthly Performance Report No. 8 (May 1956).

With nozzle choked and after-burner lit AVRO use the relation

$$F_{n_e} = p_a A_p \left[\left\{ \frac{P_p}{p_a} \cdot \frac{2^{\gamma/\gamma-1}}{(1+\gamma)^{1/\gamma-1}} - 1 \right\}_{\gamma_{HOT}} + \left(\frac{1256}{A_p} - 1 \right) \left\{ \frac{P_s}{p_a} \, \frac{1+\gamma M_s^2}{\left(1+\frac{\gamma-1}{2} M_s^2\right)^{\gamma/\gamma-1}} - 1 \right\} \right]$$

less inlet momentum $\frac{(WV)}{g}$ and spillage drag

where p_a = ambient air pressure

A_p = effective primary nozzle area

P_p = primary nozzle total pressure

[redacted] [redacted]

P_s = secondary total pressure

M_s = secondary Mach Number

The ejector performance is based on a 40" diameter (1256 in^2) secondary shroud with a 60 in^2 bypass inlet area.

It appears that the configuration of the ejector is not yet finalized, the present one being considered is cylindrical, but it is possible that a divergent one might be used. Orenda are doing experiments with about six different types of ejector.

The thrust function f_{11} will then be obtained from

$$f_{11} = \frac{F_{ne}}{\sigma(h)} \frac{aM}{W}$$

Typical values taken from AVRO/MPR/8 are given below:

h = 60,000 feet

M =	1.3	1.5	1.7	1.9	2.1
F_{ne} =	4,600	5,700	6,200	6,600	6,700
$\frac{F_{ne}}{\sigma(h)}$ =	49,000	60,000	66,000	70,000	71,500

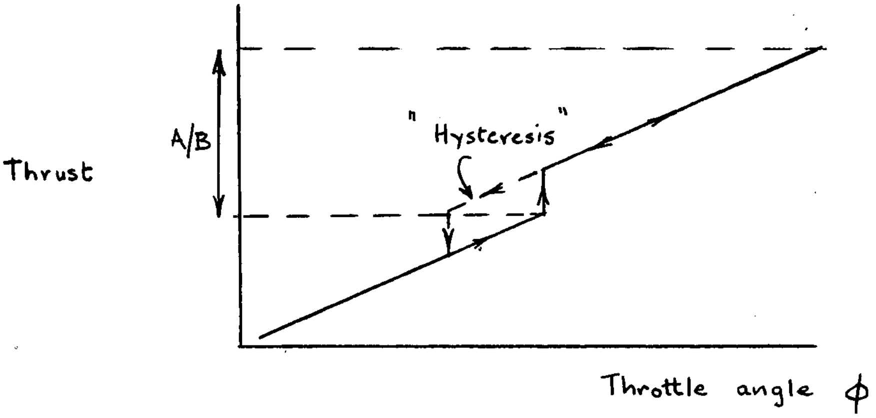
h = 50,000 feet

M =	1.3	1.5	1.7	1.9	2.1
F_{ne} =	7,500	9,100	10,100	10,700	10,900
$\frac{F_{ne}}{\sigma(h)}$ =	49,000	60,000	66,000	70,000	71,500

The fractional throttle setting (τ) is to be chosen to suit any manoeuvre required.

[redacted] [redacted]

A typical graph of thrust vs throttle angle is as shown in the following figure:



The response time of the after-burner is of the order of $\frac{1}{10}$ sec. for the whole reheat range.

PS 13 Relight Altitudes for After-burner and Blow-out Altitudes

(as provided by Orenda)

T. A. S. (Knots)	M	A/B Starting Alt. (feet)	Blow-out Alt. (feet)
200	0.35	45,000	53,000
400	0.70	48,000	56,000
600	1.05	52,000	60,500
800	1.40	57,000	65,500
1000	1.75	62,500	71,500
1200	2.10	69,000	78,000

All these values are for 100% ram efficiency.

For the present CF 105 inlet the ram efficiency is about 95% at M = 1.5

(2) General Information

The combat weight (half fuel) at present as given by AVRO and NAE for a combat radius of 200 miles:-

AVRO	48,843 lb.	MPR/8 (May 1956)
NAE	50,060 lb.	(Jan 1956)

[redacted] [redacted]

Reference area $S = 1225$ sq.ft.

Speed of sound in the stratosphere ($h > 35,000$ ft.)

$= 662$ m.p.h.

$= 971$ ft/sec.

(3) Calculations of C_{D_o}, K_1 and K_2.

$$C_D = C_{D_o} + K_1 C_L + K_2 {C_L}^2$$

$$= \frac{D}{p} \cdot \frac{1}{123,600\ M^2}$$

C_{D_o}, K_1 and K_2 will be obtained from the $C_D - C_L$ curves.

For Mach Numbers up to 1.23 the Cornell wind-tunnel results will be used.

For $M > 1.23$, the extrapolated values as calculated from the formula given in AVRO/MPR/4 will be used. The Drag-Lift-Mach.No. carpets for the most recent C.G. position of 29.5% M.A.C. are to be found in MPR/6 (Mar 56).

It is possible that these estimates may be revised in light of the results of tests now in progress in the NACA Langley Field Unitary Wind-tunnel. The Mach Number range of the tests is 1.6 to 2.0.

$$\frac{D}{p} = \overset{*}{123,600}\ M^2 \Big[\Big\{ C_{D_{min}} + \frac{(C_{L_A} - C_{L_{C_{D min}}})^2}{\pi A e} \Big\}_{\delta = 0} + \underbrace{\Big\{ \Big(\frac{K_2}{a_2} - \frac{2K_1}{a_2} + \frac{1}{\pi A e} \Big)(a_2 \delta)^2 + \Big(\frac{K_2}{a_1} - \frac{1}{\pi A e} \Big)^2 (C_{L_A} - C_{L_{C_{D min}}})(a_2 \delta) \Big\}}_{\text{Trim Drag}} \Big]$$

$$\text{and} \quad -K\delta = \frac{C_{L_A}(c.g. - a.c.) + C_{m_o}}{C_{m_{\delta_{C_L}}}}$$

where D = total drag in lb.

p = ambient pressure lb/in^2

[redacted]

$C_{D_{min}}$ = minimum drag coefficient

C_{L_A} = aircraft lift coefficient

$C_{L_{C_{D_{min}}}}$ = lift coefficient at $C_{D_{min}}$

e = drag efficienty factor ($\delta = o$)

A = aspect ratio = 1.995

a_1 = $\frac{\partial C_{L_A}}{\partial \alpha}$

a_2 = $\frac{\partial C_{L_A}}{\partial \delta}$

δ = control angle

α = angle of attack

c.g. = centre of gravity % M.A.C.

a.c. = aerodynamic centre % M.A.C.

C_{m_o} = pitching moment coefficient at $C_L = o$, $\delta = o$

* The value for this constant is given as 126,800 in the AVRO MPR 4 as it was based on $S = 1253$ sq.ft. However, AVRO are in future going to use $S = 1225 \text{ ft}^2$, giving the constant above, (123,600).

$C_{m_{\delta_{C_L}}}$ = elevator effectiveness at constant C_L

K = non-linearity factor for C_{m_δ}

K_2 = $\dfrac{\text{Lift increment on control}}{\text{Lift increment on wing}}$

[redacted]

The present upper limit of $\frac{L}{p}$ in the AVRO carpets of $\frac{L}{p} - \frac{D}{p} - M$ is 70,000 in.^{2}. At $M = 1.5$ this corresponds to a C_L of 0.25. It is the intention to extend these carpets up to $\frac{L}{p} \approx$ 200,000 in.^{2}. (i.e. at $M = 1.5$ to a C_L of 0.72).

(c) Flight Performance Envelopes

The recent AVRO estimates of maximum normal load factor performance envelopes are contained in Ext. P/Control/78 for altitudes of 0 to 60,000 ft. and for C.G. positions of 27% and 31% M.A.C.

The limitations included are those due to buffet, elevator maximum hinge moment and elevator deflection. The elastic limits are being worked out by AVRO at the present time.

The envelopes for an altitude of 50,000 ft. and C.G. positions at 27% and 31% M.A.C. are given in figures B-2 and B-3.

(d) Aircraft Weight and C.G. Position

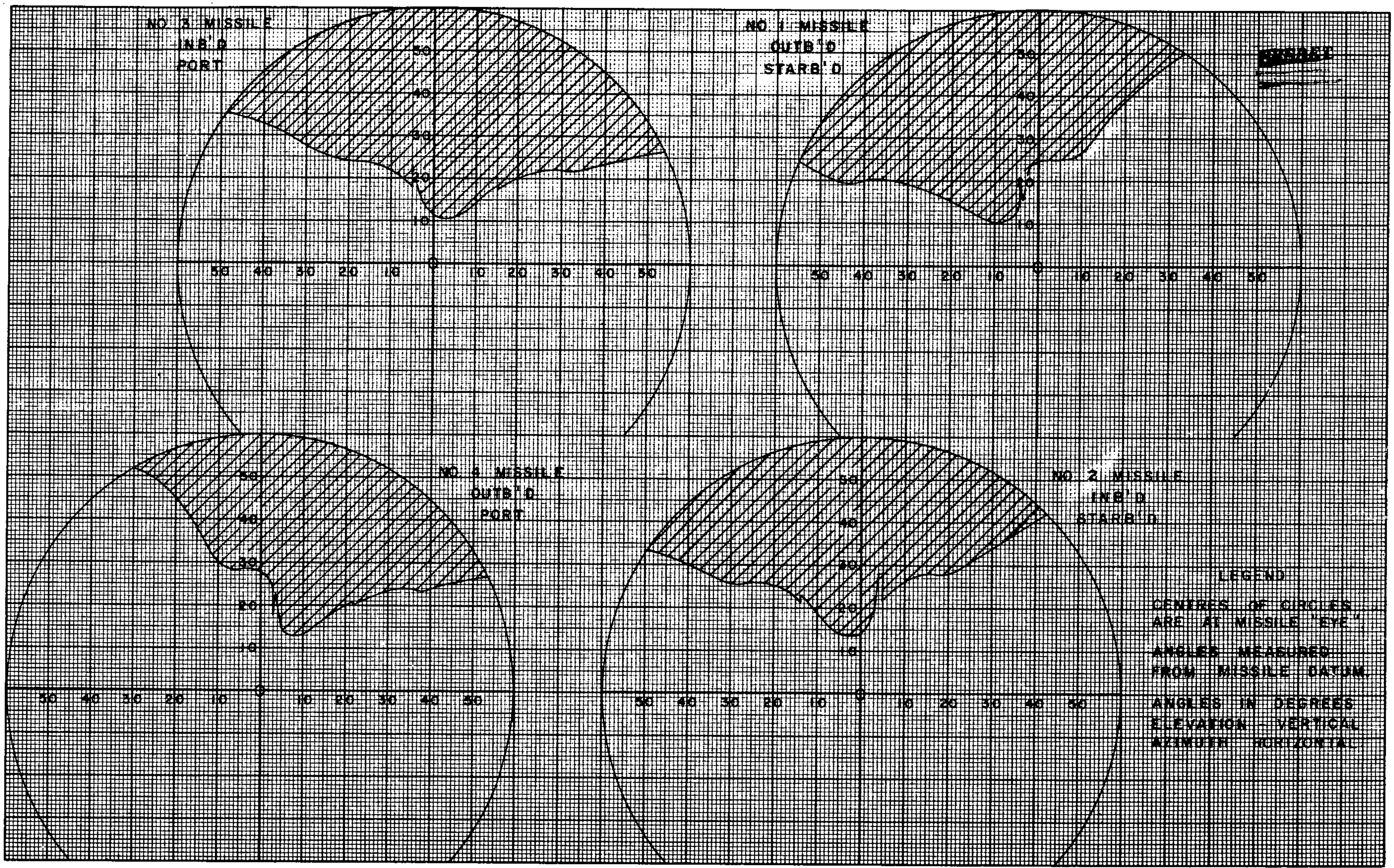
At the present time the empty weight of the aircraft as estimated by AVRO (MPR/8) is

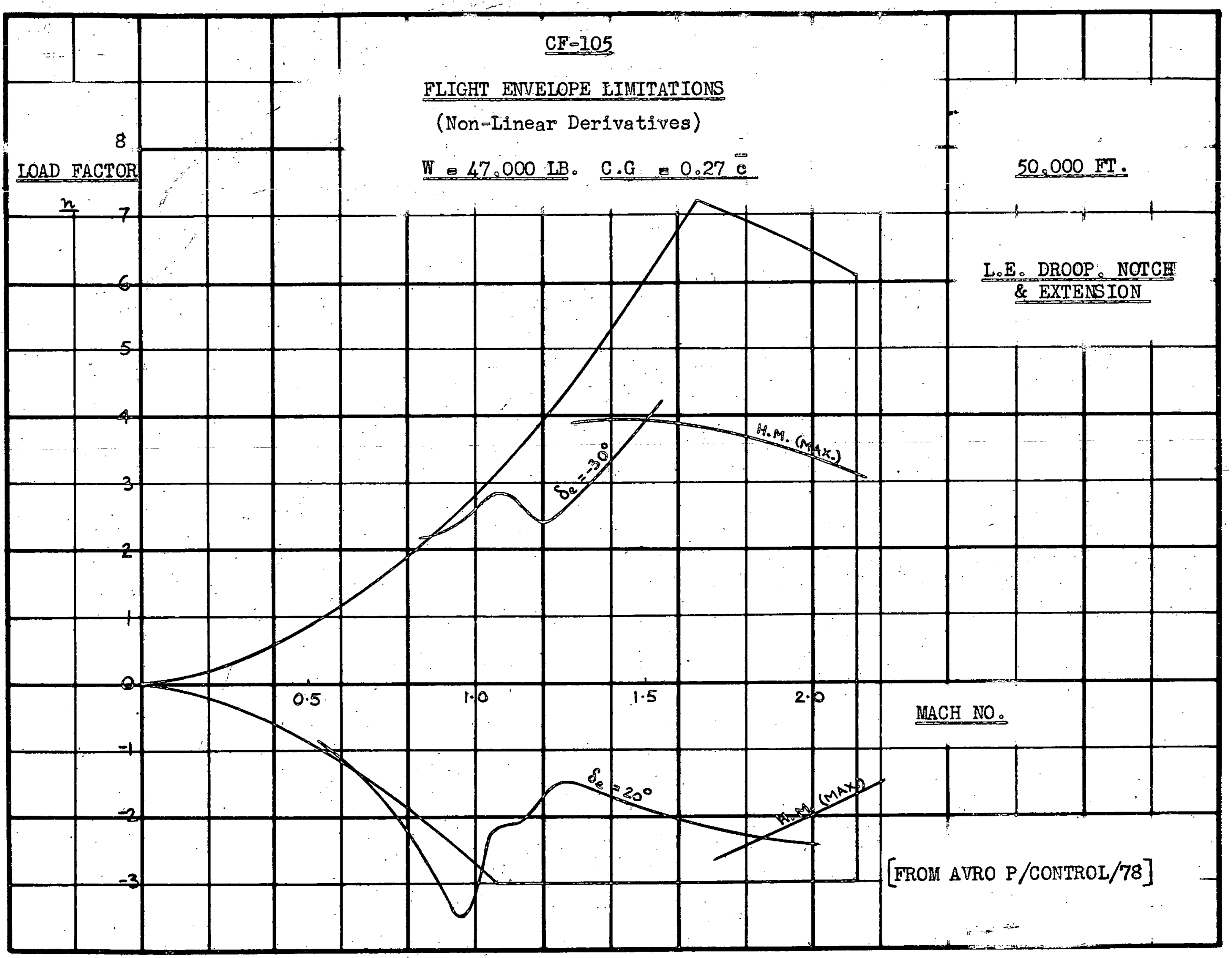
41,566 lb

Fuel scheduling is intended to be used to keep the C.G. at 29.5% M.A.C. for as long as possible during combat. When all the missiles are fired the C.G. will move back another 1½% M.A.C. to the aft-limit of 31% M.A.C.

The C.G. is kept as far aft as possible in order to reduce the elevator angle needed for any required C_L, thereby reducing the elevator drag.

MISSILE BLIND REGIONS





CF-105

FLIGHT ENVELOPE LIMITATIONS

(Non-Linear Derivatives)

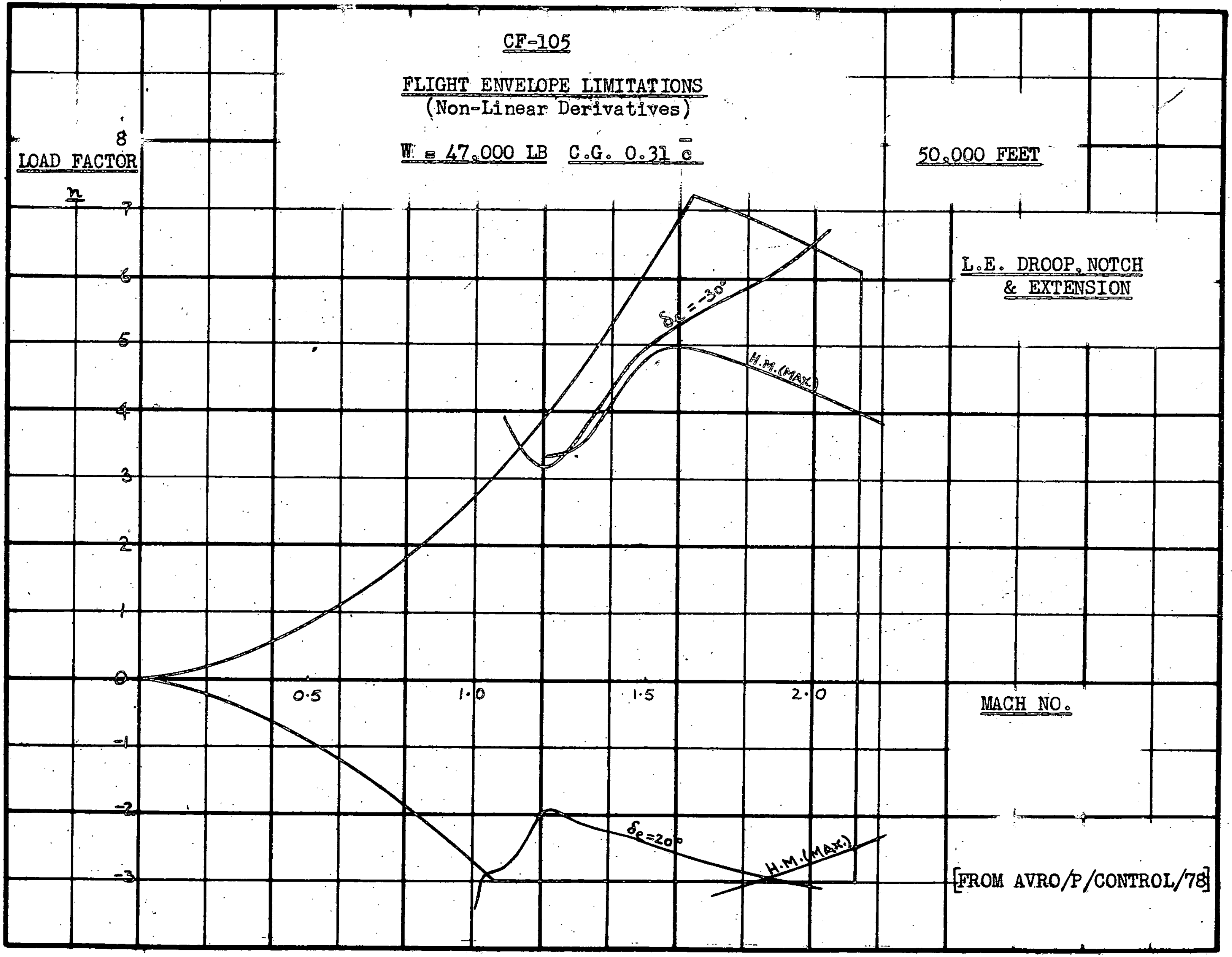
W = 47,000 LB. C.G = 0.27 $\bar{c}$

50,000 FT.

L.E. DROOP, NOTCH & EXTENSION

[FROM AVRO P/CONTROL/78]

Figure B-2



CF-105

FLIGHT ENVELOPE LIMITATIONS
(Non-Linear Derivatives)

W = 47,000 LB C.G. 0.31 $\bar{c}$

50,000 FEET

L.E. DROOP, NOTCH & EXTENSION

[FROM AVRO/P/CONTROL/78]

Figure B-3

[redacted]

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APPENDIX "C"

J. T. MacFarlane

PLACEMENT STUDIES IN PROGRESS

1. The Placement Chart - Manoeuvre Barriers

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

Target Mach Number
Interceptor Mach Number
Initial interceptor course difference relative to target
Target evasion (lateral acceleration)
Interceptor lateral acceleration
AI radar look angle
Missile launch zone (allowable launch heading error, proper launch heading, and allowable launch range; functions of target aspect).

1.2 The system of barriers obtained for one set of values of the parameters may appear as in figure 1. The vector A indicates the initial heading of the interceptor, and T represents target, with the launch zone of the missile drawn around it. The point P on the launch zone is that point at which the missile may be launched with the given initial heading - there is a region along the launch zone for which this heading is usable, when the launch heading error allowance is taken into account. The line L is a relative approach line passing through the offset target, along which the interceptor may progress and arrive at this allowable region of the launch zone without turning. It may thus be called an ideal approach line, and it is along this line which the ground controller is trying to place the interceptor.

1.3 If the original fighter approach line L_1, is behind the correct line L, a turn to starboard must be made if the fighter is to enter the launch zone at a correct heading for some more astern aspect than P. The barrier (a) is the locus of the last points at which the turn may be started for the fighter to reach an allowable launch position. The turn may be started sooner, but not later: in this sense, the locus is a "barrier". A typical trajectory is shown for a fighter progressing in along L_1.

1.4 Similarly, if the original fighter approach line is L_2, ahead of L_1, a port turn must be made to provide the correct final heading of the aircraft when it reaches an allowable launch range at some more forward aspect than P. The barrier for the port turn in figure 1 is (b), and a typical trajectory is shown for a fighter vectored so as to approach along L_2.

1.5 The extension to the rear barrier (a) is (c). The fighter which is approaching at the given course difference, far enough away from L_1 to cross this line, must make a starboard turn before crossing it. This is necessary in order to keep the target in view throughout the turn, and also, in case of fighter speed disadvantage, to avoid passing behind the line (e) which is called a "fall-back" barrier. (The fall-back barrier is a line such that a fighter behind it can never enter the launch zone.)

1.6 The extension to the forward barrier (b) is (d) which is a line below which the fighter will not see the target with its AI radar. The interceptor must make a port turn before reaching this line, in order to keep the target in view.

1.7 Thus the curves (d), (b), (a), and (c), enclose a region in space in which the interceptor must be placed, if its initial heading is A, in order to be able to launch its missiles. A similar zone can be outlined then, for any initial course difference of the fighter relative to the target. Figure (2) shows a typical family of barriers for several different initial course differences, representative values of which are marked on the barrier systems.

[redacted]

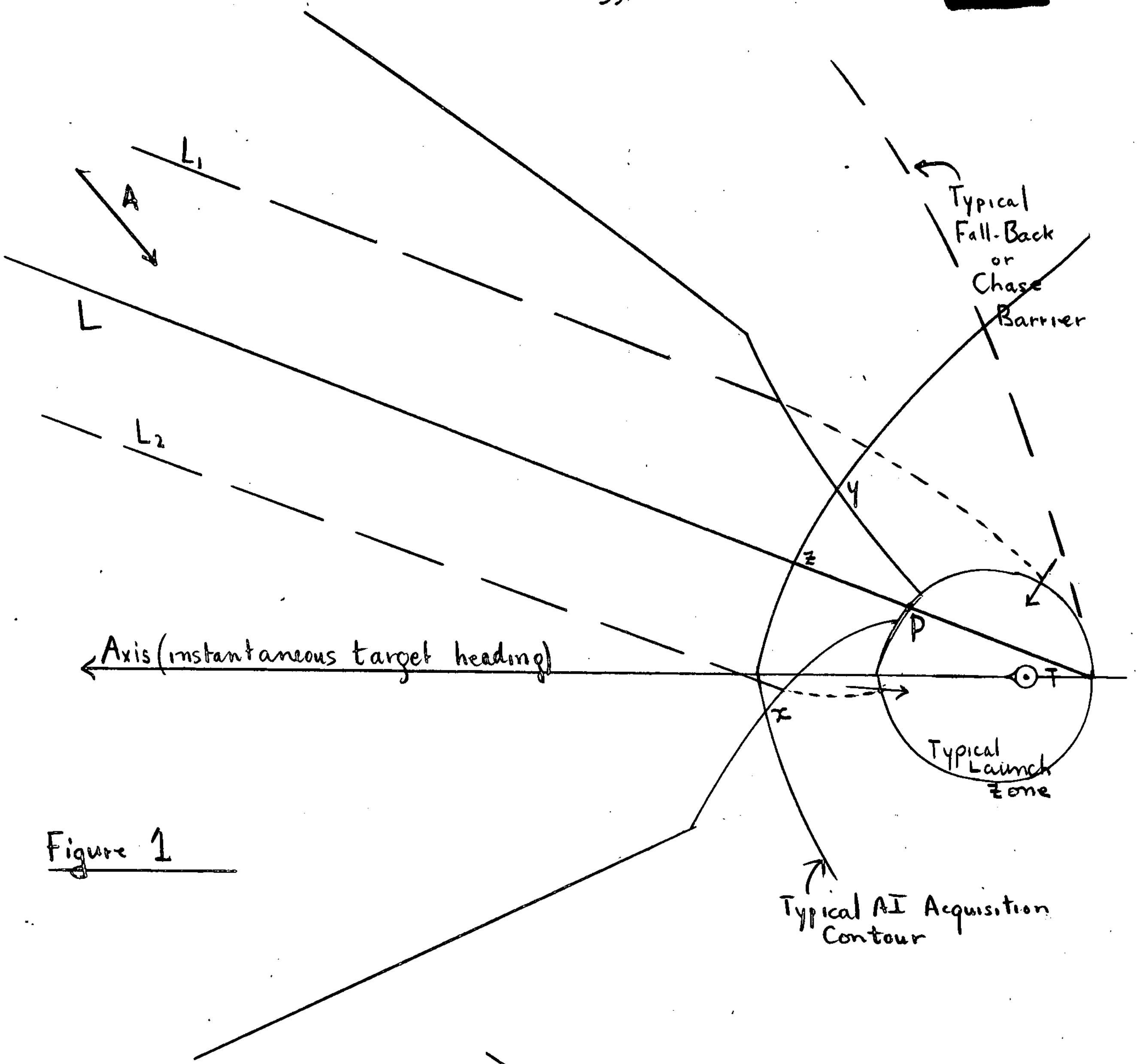


Figure 1

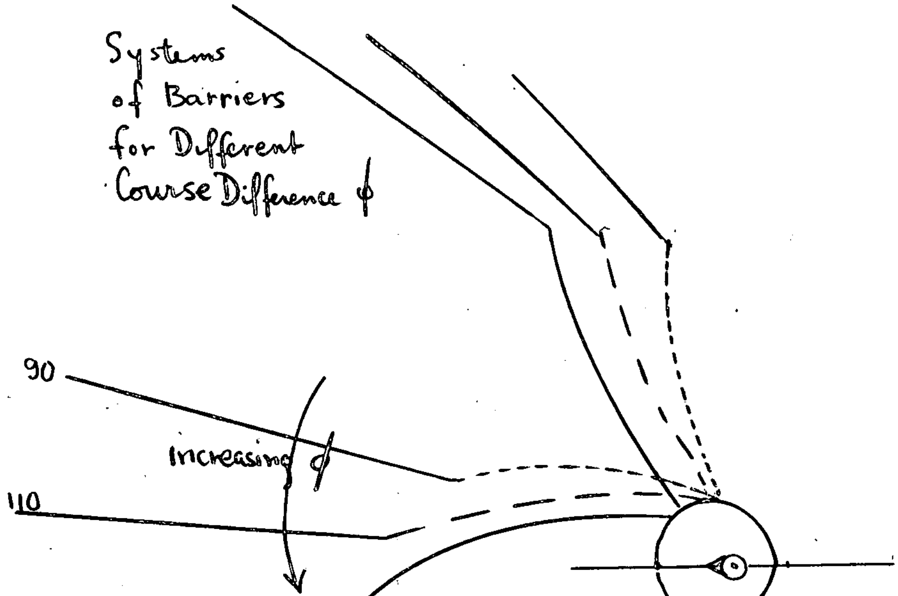


Figure 2

[redacted]

2. Placement Probability

2.1 Although the ground control may roughly position the interceptor for its attack on the target, the final approach run must be made under the guidance of the aircraft's own AI radar; thus the correcting turn can only be made if the target is seen on the AI screen. The turn may be started with the AI in its search mode, or may be delayed until the AI is locked on to the target for automatic tracking, at the discretion of the pilot. Thus the width of the permissible placement zone inside the obtainable AI range determines the required GCI placement accuracy for 100% probability of conversion from approach into attack.

2.2 The procedure for determining the probability of success in conversion is discussed in this paragraph. The AI detection range contour for some arbitrary level of probability of detection is drawn on the kinematic barrier system. A parallel contour, allowing for delay of the operator in recognizing the blip or for delay in its appearance due to the AI scan time, and for pilot reaction time, is drawn closer to the target. The separation of these two contours may represent the relative distance travelled by the fighter in 3 or 6 seconds flight time. Such an AI contour has been drawn in figure 1 to illustrate the method. It cuts the barriers and the ideal approach line at the points x, y, and z. The half-widths xz and zy of the approach zone are measured, and these widths are compared the the standard deviation σ of the G.C.I. placement accuracy. The ratios xy/σ and yz/σ are computed, and from tables of the probability integral, the corresponding probability of placement is found.

3. Studies Underway

3.1 At present kinematic manoeuvre barrier systems are being drawn by the REAC group for the case of an evading target (see Appendix D) and by graphical methods for non-evading targets.

3.2 The missile launch zones being used are those derived in CARDE Technical Letter N-47-2. Since the tactical limits of the actual missile may prove to be different from these values, variations of launch zone have been investigated, and barrier systems drawn for greater maximum launch range and for shorter minimum launch ranges than those given in the Technical Letter. The dependence of placement zone width on launch heading allowance has been studied, with values of 5°, 10° and 15° being used. These effects of variation of launch zone have only been looked at for the non-evading target.

3.3 So far only constant g, constant speed turns of the interceptor have been used; several values of turn rate are used so that the effect of this quantity on the final result can be well understood. The values used vary between 0.66 and 3.0 g's lateral acceleration. Since the lateral acceleration values used are greater than the probable constant speed capabilities of the CF-105 aircraft, the deceleration of the fighter should be taken into account - the effect of this on the shape and location of the manoeuvre barriers will be studied when the aircraft thrust/drag characteristics are known (Appendix B).

[redacted]

3.4 The AI acquisition contours being used are described in Appendix K. Contours for several degrees of radar performance varying from 10 miles to 48 miles on a 5 square metre target have been proposed so that a clear understanding of the variation of conversion probability with this most important parameter will be obtained. Work on the calculation of probabilities has been started for the cases for which kinematic barriers have been drawn. The look angle of the AI radar is another quantity whose effect is being investigated. The basic value used is 70°, with some charts being drawn with a value of 75° to determine the usefulness of increasing this parameter.

3.5 The target which has been considered to date is a Mach 2 bomber flying at 50,000 and 60,000 ft. The interceptor speed used is Mach 1.5; some work has also been done for fighter Mach number 1.8. The target evasion considered is $\frac{1}{2}$ g and 1 g lateral acceleration. Some investigation of the effects of variation of the initiation time of manoeuvre has been made. To date, only circular target turns have been considered.

The work on non-evading targets has included the Mach 2 target at 50,000 and 60,000 ft., and has been extended to a Mach 1.5 target at 50,000 ft.

3.6 The work on placement charts is being reviewed and during the next period it is intended that the following cases will be considered:

Mach 1.5 Target / Mach 1.5 interceptor
Mach .85 Target / Mach 1.5 interceptor
Mach .85 Target / Mach .92 interceptor.

Steady g turns will be used at first.

3.7 The present work is valuable in providing the working group at CARDE with an understanding of the effects of the various parameters; yet the probability values it provides are not usable until the effects of fighter deceleration can be determined. For this reason, computed values of placement probability are not being given at this time.

3.8 A typical barrier system which has been obtained in the course of the study is reproduced as figure 3.3 to illustrate the work which is being done. on this figure the barriers are drawn for the following cases:

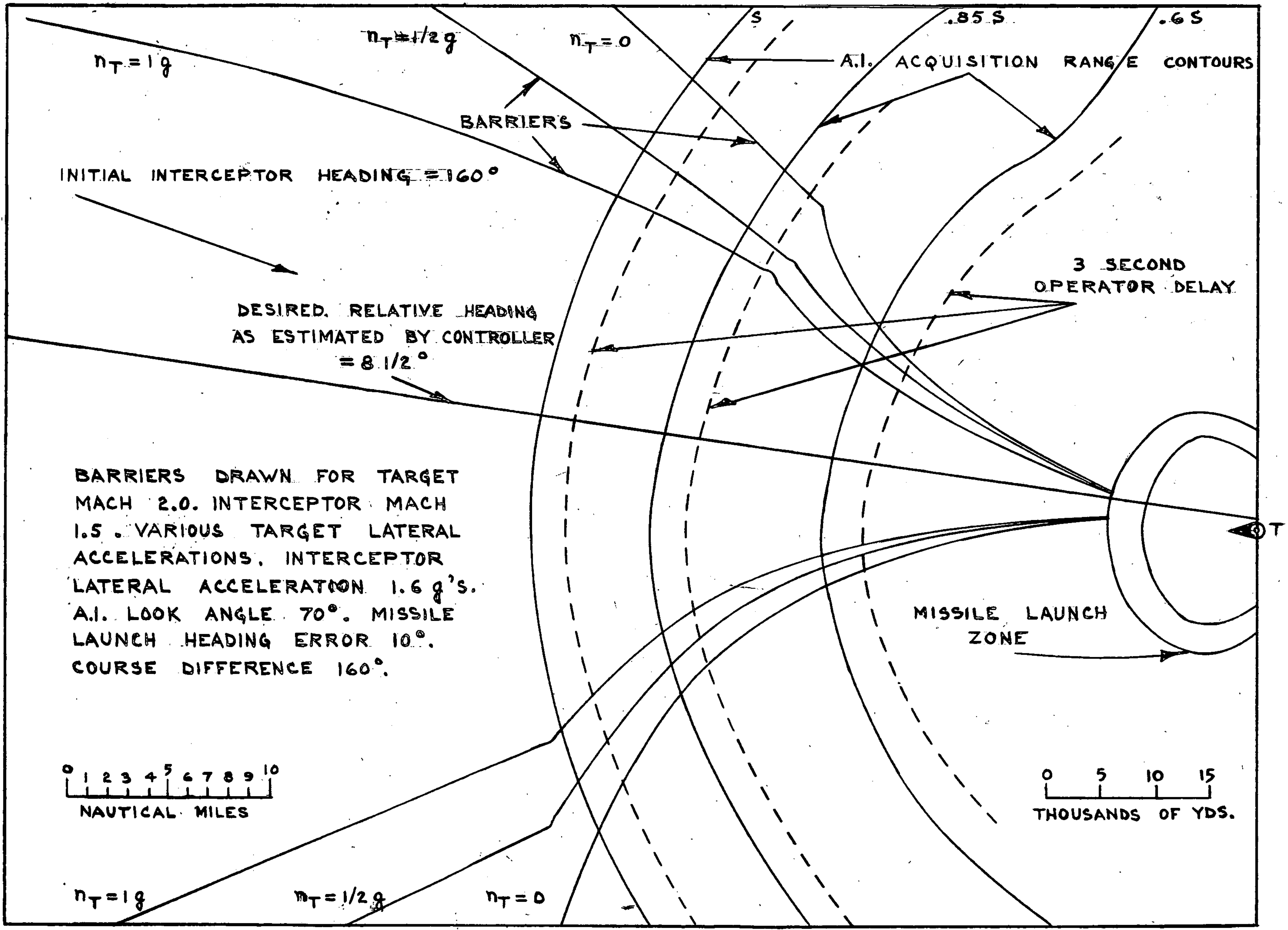
- Target Mach number 2.0
- Interceptor Mach number 1.5
- Interceptor constant speed turn capability = 1.6 g's lateral acceleration, equivalent to 1.9 g's load factor
- Look Angle limit of AI = 70°
- Initial interceptor course difference 160°
- Three values of Target evasion, lateral acceleration = 0, $\frac{1}{2}$ g, 1 g.

Three AI contours are drawn, along with 3-second delayed contours, for the specification range on a medium range delta bomber (see Appendix K) and for .85 and .60 of this range. These contours are drawn in order to show how wide the placement zones may be. Present indications are that

[redacted]

other factors, such as delay of target manoeuvre till AI lock-on, and deceleration of fighter in the turn, will produce narrower zones. Thus this chart should not be used to predict performance of the CF-105, but is given here only to illustrate work which is being done.

3.9 In order to obtain the barrier systems for the evading case, the barriers are drawn separately for the cases where the target is evading towards and away from the interceptor. The region which is common to the two zones thus found, is used as the positioning region for the evading target. This procedure is illustrated in figure 3.4.



BARRIERS DRAWN FOR TARGET MACH 2.0. INTERCEPTOR MACH 1.5. VARIOUS TARGET LATERAL ACCELERATIONS. INTERCEPTOR LATERAL ACCELERATION 1.6 g's. A.I. LOOK ANGLE 70°. MISSILE LAUNCH HEADING ERROR 10°. COURSE DIFFERENCE 160°.

FIGURE 3

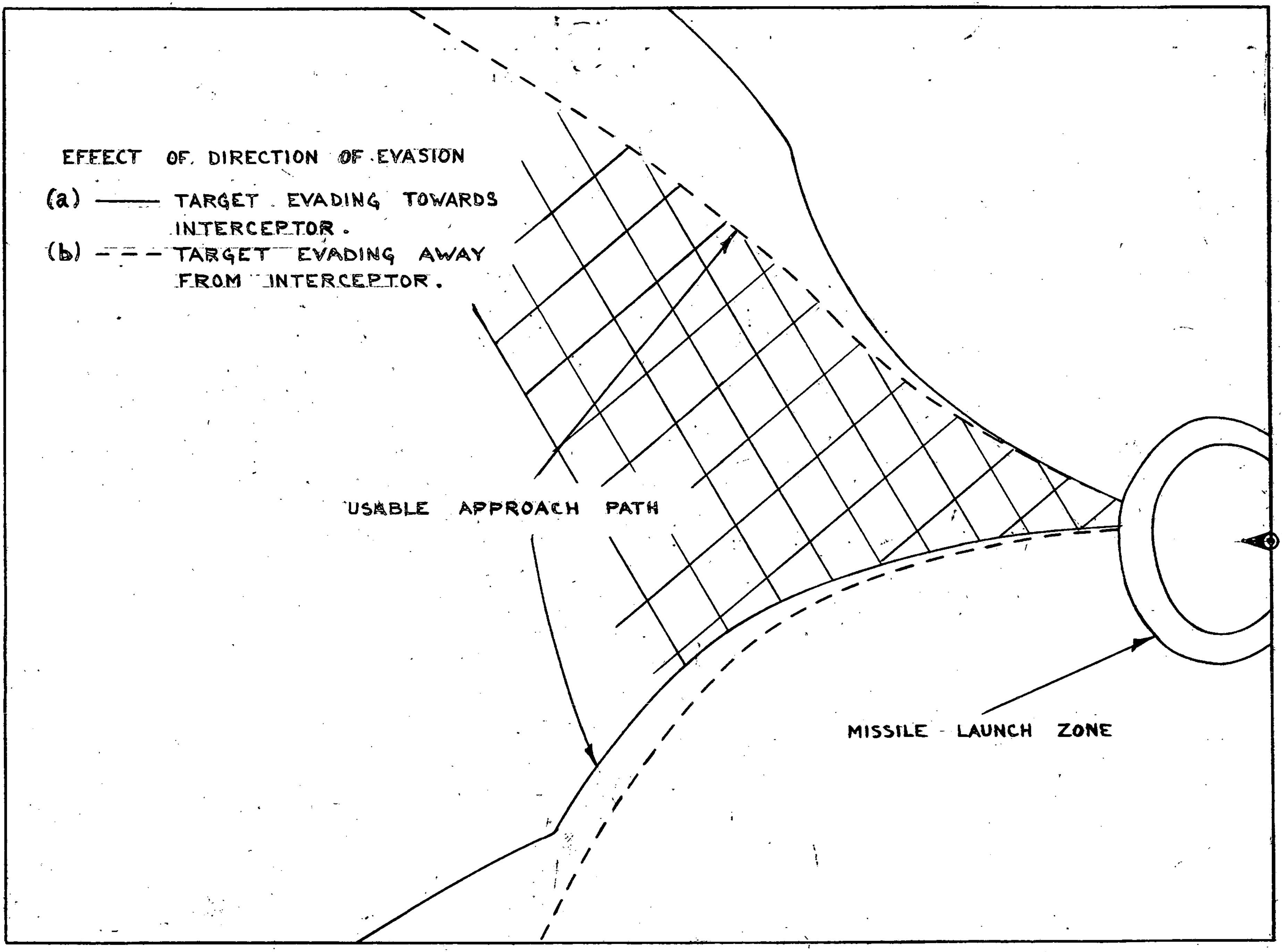

EFFECT OF DIRECTION OF EVASION
(a) —— TARGET EVADING TOWARDS INTERCEPTOR.
(b) - - - TARGET EVADING AWAY FROM INTERCEPTOR.
USABLE APPROACH PATH
MISSILE LAUNCH ZONE
T

FIGURE 4

[redacted]

APPENDIX D

J. Cummins & L.P. Robichaud

CF-105 PLACEMENT PROBLEM FOR AIRCRAFT INTERCEPTION

1.0 INTRODUCTION

This note (or appendix) presents an outline of the work that has been carried out to this date by the G-Wing Analysis Group in connection with the CF-105 placement problem.

The study is still in progress and, although of a preliminary nature, enough work has been done to justify a brief description of the methods used and a summary of the results that have been obtained. A more elaborate presentation will be made in the form of technical letters as the work progresses and as various phases are completed.

2.0 STATEMENT OF THE PROBLEM

The placement problem consists essentially in determining a region of space such that a fighter aircraft starting in a given direction inside that region will be able to position itself in a prescribed launching zone from where it can launch a missile with an error in direction no greater than that for which the missile can correct when launched at that point.

3.0 METHOD

This study presupposes that both the missile launching zone and the allowable heading error are known. The results published in Technical Letter N-47-2 thus provide a basis for the placement problem which reduces then to a comparison between the direction of the interceptor and the allowable heading error inside the launching zone.

The method is then basically one of comparing the fighter terminal conditions with the missile initial conditions as the fighter flies through the missile launching zone.

4.0 ASSUMPTIONS

Some of the parameters involved in this problem were not known with sufficient accuracy or did not seem to influence the solution enough to justify the complications they would introduce.

Therefore some simplifying assumptions were made as follows:

1. The interceptor velocity V_F and the target velocity V_T were assumed constant.

[redacted]

2. An average value was taken for the missile velocity V_m for computing the stick length d and the ideal course difference Γ_i for a given aspect angle A.

3. The transfer function for the aircraft aerodynamics and the pilot response was taken as $\frac{K}{1 + TS}$ in which K = 4 and T = 2 sec., or 4 secs.

4. The target and the fighter were assumed to fly at the same altitude in a horizontal plane.

5. The interceptor was assumed to fly a lead collision course and the equations used are those given in Hughes Aircraft Technical Memorandum No. 339 for their "Universal Computer".

6. Missile seeker contours were used to give further launching zone limitations. These contours were supplied by CARDE Systems Group.

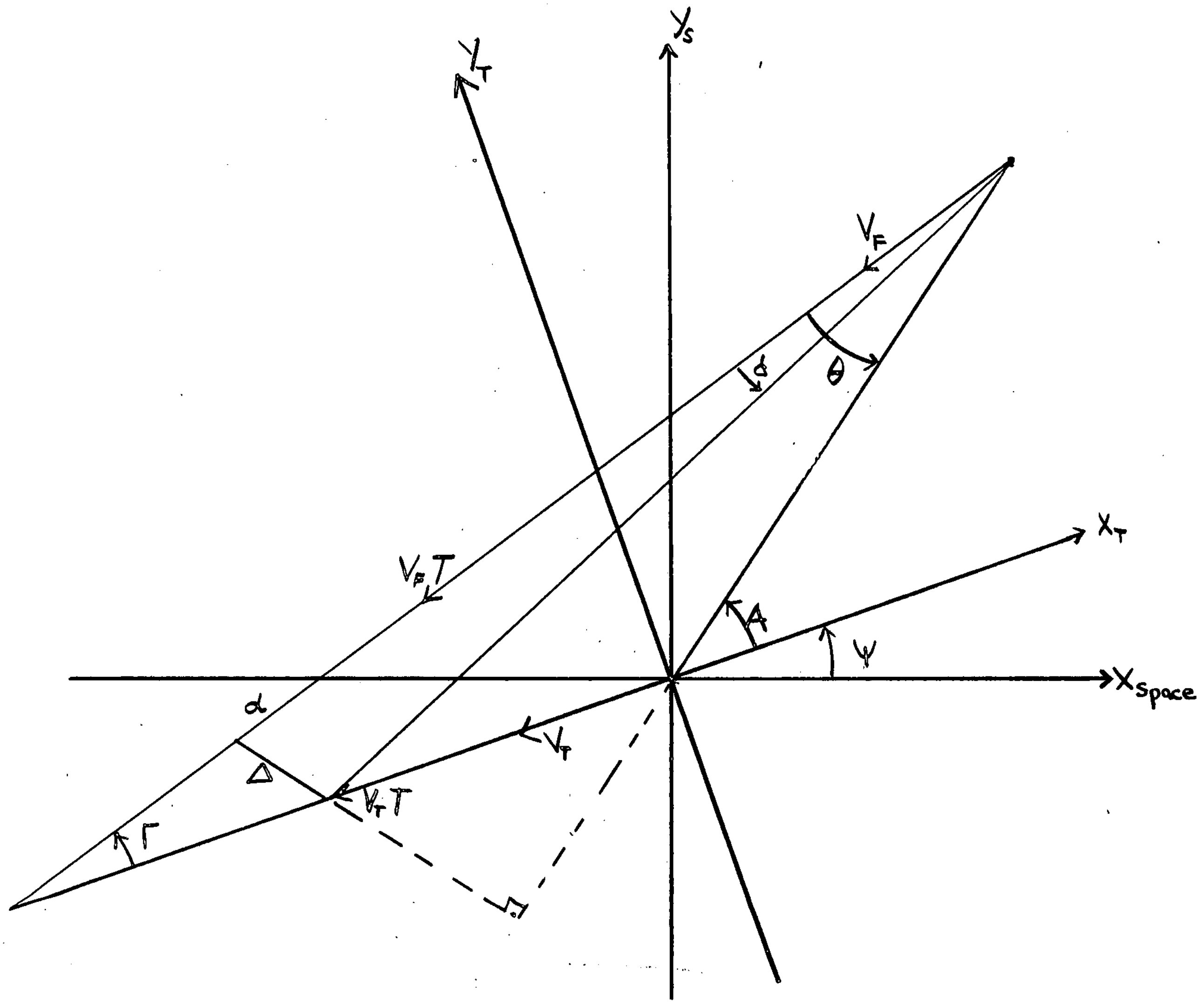
7. The fighter "g" capabilities were also taken as suggested by the Systems Group.

8. The A.I. contour, being an independent problem, was not considered. These contours can be superimposed on the placement diagrams as an additional limitation to the aircraft placement diagram.

[redacted]

5.0 REAC EQUATIONS USED FOR OBTAINING THE PLACEMENT DIAGRAMS

The geometry of the lead collision course is shown in fig. 1.



Legend:

$\dot{\psi}$ is the rate of target evasion.
ψ is the angle made by the negative of the target velocity vector and the x-axis of the fixed frame of reference.
A is the aspect angle.
Γ is the course difference
Δ: the projectile miss if the interceptor and the target were to continue on their present heading.
θ look angle
δ error angle
R range
T time from now until the miss component parallel to the range vector is zero.
V_F Interceptor velocity vector.
V_T Target velocity vector.

[redacted]

The equations that were used to obtain the interceptor trajectory are the following:

$$\dot{R} = V_T \cos A - V_F \cos \Theta$$

$$R (\dot{A} + \mathring{\psi}) = V_F \sin \Theta - V_T \sin A$$

$$\frac{R}{T} = (V_F + \frac{d}{T}) \cos \Theta - V_T \cos A$$

$$\frac{A}{T} = (V_F + \frac{d}{T}) \sin \Theta - V_T \sin A$$

$$\delta = \frac{\Delta}{T} \cdot \frac{1}{V_F + \frac{d}{T}}$$

$$\mathring{\Gamma} + \mathring{\psi} = \frac{K \delta}{1 + TS} \quad \text{in which } K = 4, \quad T = 2 \text{ sec.}$$

$$X_T = R \cos A$$

$$Y_T = R \text{ son } A$$

$\mathring{\Gamma}$ limited to represent 'g' capabilities of aircraft.

The solution of these equations will give the interceptor trajectories when referred to a stationary target.

Although these trajectories are not of interest by themselves for the placement problem, they provide a way of obtaining, by a trial and error process, the barriers enclosing the region of space to be determined. As explained above the method consists essentially in matching the terminal conditions of the interceptor with the initial conditions of the missile. During flight the look angle is monitored to ensure that the accepted limit is not exceeded. This problem involves a large number of parameters that have to be varied in order to form a solid basis for extrapolation for other cases.

The following list shows the cases that have been studied and for which the placement diagrams are available.

[redacted]

TABLE 1

M_T	M_F	d	H	g_T	⊙	g_F	θ_{Limit}	T	target radar limit
2	1.5	10000	50K	½	135°	3	66°	4 sec.	not consid.
"	"	"	"	½	180°	3	"	"	"
"	"	"	"	-½	110	3	"	"	"
"	"	"	"	½	110	3	"	"	"
"	"	"	"	½	160	3	"	"	"
"	"	"	"	½	110	.85	"	"	"
"	"	"	"	½	135	"	"	"	"
"	"	"	"	½	160	"	"	"	"
"	"	"	"	½	180	"	"	"	"
"	"	"	"	½	180	1.6	"	"	"
"	"	"	"	½	160	"	"	"	"
"	"	"	"	½	135	"	"	"	"
"	"	"	"	½	110	"	"	"	"
"	"	"	"	½	135	3	75°	"	"
"	"	"	"	-½	135	1.6	66°	"	"
"	"	"	"	½	200	1.6	"	"	"
"	"	"	"	½	200	3	"	"	"
"	"	"	"	½	225	3	"	"	"
"	"	"	"	-½	135	3	75°	"	"
"	"	"	"	½	110	3	"	"	"
"	"	"	"	½	110	1.6	"	"	"
"	"	"	"	1	110	3	66°	"	"
"	"	"	"	1	160	3	"	"	"
"	"	"	"	1	110	1.6	"	"	"

[redacted]

TABLE I (Cont'd)

M_T	M_F	d	H	g_T	o	g_F	Θ_{Limit}	T	target radar limit
2	1.5	10000	50K	1	160°	1.6	66°	4 sec	not consid.
"	"	"	"	$\frac{1}{2}$	110	"	"	"	150 K
"	"	"	"	$\frac{1}{2}$	160	"	"	"	"
"	"	"	"	$\frac{1}{2}$	160	3	"	2 sec	not consid.
"	"	"	"	$\frac{1}{2}$	160	sm3	"	2 sec	"
"	"	12500	"	$\frac{1}{2}$	160	3	"	4 sec	"
"	"	20000	"	$\frac{1}{2}$	160	3	"	"	"
"	"	10000	"	$\frac{1}{2}$	160	3	"	"	"
"	"	15000	60K	$\frac{1}{2}$	160	2.4	"	"	"
"	"	"	"	$\frac{1}{2}$	110	"	"	"	"
"	"	"	"	$\frac{1}{2}$	135	"	"	"	"
"	"	"	"	$\frac{1}{2}$	180	"	"	"	"
"	"	"	"	$\frac{1}{2}$	200	"	"	"	"
"	"	"	"	$\frac{1}{2}$	225	"	"	"	"
"	"	"	"	$\frac{1}{2}$	250	"	"	"	"
"	"	"	"	$\frac{1}{2}$	250	1.5	"	"	"
"	"	"	"	$\frac{1}{2}$	225	1.5	"	"	"
"	"	"	"	$\frac{1}{2}$	200	1.5	"	"	"

6.0 FUTURE PROGRAM

Work is continuing with attention being directed to effects of altitude change and various target and fighter speed ratios. As soon as details of the aircraft aerodynamics are available a more sophisticated simulation will be attempted. Automatic monitoring circuits are being devised to speed up the work.

It is thought that the present set up will be useful in the early investigation of the fire control problem.

[redacted]

APPENDIX E

CF 105 Analysis Group

IMPROVEMENTS TO THE TWO DIMENSIONAL FIGHTER PLACEMENT PROBLEM

A first stage study of the 2-D placement problem is being run on the REAC. Experience at CARDE and elsewhere shows that large tasks of this sort should be reviewed from time to time to coordinate experience gained in the work and to introduce new concepts arising from the preliminary results. This review has been carried out and it is proposed that the following improvements be undertaken.

1. At present the study is being carried out with an analog of an MG-2 type fire control. This system concentrates on flying a lead collision course at the risk of exceeding the radar look angle. It is thought that the navigation computer may be made to alter its instructions so as to keep the target in view should there be a risk of losing contact, provided such a fire control computer is planned for the CF 105 system.

2. At present the fire control continues to follow the lead collision equation after the fighter has reached the predicted launch point. If the navigation law is converted to lead pursuit at that time, the overall placement chance is improved. This will be included in the simulator if this proves to be a reasonable modification for the CF 105 computer.

3. The present 2-D study incorporates a rather inadequate representation of the CF 105 dynamic performance. When more specific aerodynamic information becomes available it is proposed that a study be made to determine the effect of these characteristics on the interception problem.

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APPENDIX F

T.J. Mentel

THE TWO DIMENSIONAL PLACEMENT PROBLEM

INTRODUCTION

The notes compiled here outline some of the results of an additional theoretical study of the two dimensional placement problem for level flight missile attack. The purpose of this study has been to examine alternative methods of solution to those presently employed. The following topics are presented:

1) A simple graphical procedure for plotting the trajectories of the interceptor.

2) An examination of the corresponding analytical problem.

3) An alternative analog computer set-up.

GENERAL PROBLEM

The interceptor and target are initially assumed to be flying at constant speed, constant heading and at the same (constant) altitude. The interceptor is assumed to be directed in accordance with a lead collision course once the target appears on its radar. When the interceptor approaches to within a certain critical "alert" distance of the target, the latter undertakes evasion tactics. This "alert" distance might be considered to coincide with the interceptor's lock-on range, or it can be simply taken as a circle of some given radius about the target. The maximum value of this radius would be the target's detection distance of the interceptor's radar. For simplicity, only a horizontal turn of constant radius at constant speed is considered for the evasion tactic, although this restriction can be relaxed in a graphical solution which is presented.

It is observed that certain regions in target coordinates from which a successful attack (one pass only) could not have been made under the initial conditions of the non-evading target, may, fortuitously, become regions of possible successful attack on the evading target. These latter regions will be neglected for the reason that the target would be unlikely to manoeuvre in such a way as to advance its own interception, although this may imply some knowledge of the interceptor's armament. The problem, thus, is to determine what portion of those interceptor trajectories which could have lead to a successful attack (within the definition of manoeuvre, look-angle and penetration barriers) had the target not evaded, will still lead to a successful attack on the evading target.

An important consideration which occurs here, is the interpretation to be applied to penetration distance, since the target has presumably gone off or changed course. An alternative criterion would be an engagement time limit for the interceptor, which might be counted from the time of the target's decision

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to evade and which could be based on the afterburner endurance of the interceptor. In this respect, the question occurs whether such endurance, or time-to-launch contours should be based on the extreme trajectories associated with manoeuvre barriers, or on trajectories of shortest length. Since no ambiguity in the time-to-launch values occurs at the manoeuvre barriers themselves, it is suggested that trajectories of the shortest length be used.

An additional question which arises in determining the extreme limits of the placement zones, is whether the interceptor should always be assumed to turn at the instant the target starts turning, or should a delay in its turn be considered (delay in obtaining lock-on) until it reaches a manoeuvre barrier corresponding to the instantaneous course difference. The choice here depends on the importance assigned to the "alert" distance as a distinct parameter; the optimum tactic would certainly be to turn as quickly with the target as possible.

GRAPHICAL SOLUTION

Basic assumptions:

1) Horizontal manoeuvres only (2D problem)

2) All manoeuvres conducted at constant speed (this restriction can be relaxed)

For simplicity, the method is outlined for one initial course difference only. ($\Phi_o = 130^\circ$). The following data is assumed to be known, or calculated:

1) Missile launch boundary with course differences indicated.

2) All manoeuvre and look-angle barriers for the case of no evasion. (For this, the interceptor and target speeds, the interceptor's radius of turn and the maximum allowable look-angle need to be known).

3) An "alert" range defining a distance between the target and interceptor at which the target begins its evasion, and the expected radius of turn of the target.

4) The interceptor's radar lock-on range.

The first step is to construct a diagram incorporating the above data. Such a diagram is shown in figure (1) where the trajectories for constant interceptor heading have been extended from the launch boundary. For illustrative purposes, a circular "alert" range is assumed and the radar lock-on range has been omitted.

If the target did not evade, then an interceptor directed along some path I-M (figure 1) could, at the latest, postpone a corrective turn until it reached point M, at which point it would have to enter into a maximum "g" turn so that, in this case, the complete trajectory would be I-M-A-L. For an evading target, the trajectory A-L is modified. The next step is to construct a second diagram on a separate sheet of paper (where one of the above sheets is translucent so that they may be overlaid) showing the target and interceptor in earth coordinates. Such a diagram is shown in figure (2). The starting point for the trajectories is taken as M or A, whichever occurs first. If M occurs first, as in the particular case chosen, then a circular arc I_m-H can be drawn to represent the subsequent flight. The two diagrams are then overlaid to find the location of A and T_a in earth coordinates. It is noted that these points might have been plotted initially, but the above procedure conveniently establishes the interceptor heading at A. When the target reaches T_a it begins its evasion, so that circles T_a-M and T_a-N can be drawn to represent evasive turns to the right or left respectively. We shall consider a turn to the left.

The law for the guidance of the interceptor is assumed to require a continuation of its maximum rate of turn until such a heading occurs that the interceptor finds itself on a correct lead collision course. Beyond this point, which we denote by P, the interceptor manoeuvres so as to remain continuously on an exact lead collision course. Point P is located in the following manner. We choose a small unit of interceptor turn in earth coordinates, say 5° , and compute the corresponding turn of the target. This is easily done, since the interceptor and target rotations are connected by the relation

$$\Delta\Theta_t = \Delta\Theta_i \frac{V_t R_i}{V_i R_t}$$

where the subscripts i and t stand for interceptor and target, and V and R are the speed and radius of turn. Once the location of the target is marked in earth coordinates, it is superimposed with the first diagram and the new location of the interceptor is plotted in target coordinates. The result of repeating this procedure several times is shown in figures (1) and (2), where the numbered points indicate simultaneous positions of the interceptor and target. Each of these points is associated with a particular value of the course difference Φ, which can be measured directly from figure (2). The point P is reached when these values of course difference first coincide with the corresponding values indicated by the constant heading lines which were extended from the launch boundary in figure (1). A graphical interpolation between two such points (between which P is noted to occur) thus locates the point P.

The following step-wise procedure is used to obtain the trajectories beyond point P. The interceptor is allowed to proceed some small distance (say 2,000 or 3,000 feet) from its location at point P in earth coordinates without changing its heading. The corresponding position of the target is plotted (the target here is assumed to continue its turn, but could be made to change its tactics if desired) and by overlaying the first diagram, the new location of the interceptor in target coordinates is obtained. The proper heading at this new location is obtained by using the lines of constant heading (which give the required course difference) and the next incremental distance covered by the interceptor is taken in this new direction. The process is continued until the interceptor either reaches a launch point or its attack is evidently aborted.

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The time to reach a launch point, from the time of alert of the target, is most easily obtained by noting the degrees of turn of the target, i.e., using figure (2) we can solve,

$$\underset{\text{(A to L)}}{\text{Time}} = \frac{R_t}{V_t}\,\theta_t$$

It is noted that this graphical construction is easily adapted to the case of variable interceptor and target speeds if the relations between speed, rate of turn, and the corresponding accelerations are known. The generalization to take into account finite launch zones is straightforward. An indication of the errors in the construction can be obtained by reworking with smaller increments. The look-angle, at any time, is given by figure (2).

MATHEMATICAL ANALYSIS

Basic assumptions:

1) Horizontal manoeuvres only (2D problem)

2) Constant speeds

3) Circular evasion turn only

4) Ideal missile characteristics (launch boundary, for constant missile flight time, forms a perfect circle).

The objective of the analytical approach to this problem is to obtain, in closed form, an expression for the time-to-launch corresponding to any admissible, initial interceptor placement, and to present criteria from which manoeuvre and look-anle barriers can be constructed. Mathematically, we have a two point boundary value problem with three conditions to be satisfied at each end. These conditions can be considered to involve the location and orientation of the interceptor in target coordinates. In addition, the solution has to account for the intermediate point P, where the rules governing the interceptor's flight are altered, and whose position depends on the location and orientation of the interceptor on the approach side of this point only. In all cases, the lead collision course is based on the linear extrapolation of interceptor and target trajectories.

In order to set the problem up as stated, the final launch situations must be described analytically and included in the problem as additional simultaneous equations. The assumption of a circular launch boundary has been made for this reason. Flight beyond this boundary, which might be converted to lead pursuit, is not considered.

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The first part of this problem, to obtain the location of point P, is solved without difficulty. We start with an interceptor at range R_o, aspect A_o and course difference ϕ_o as shown in figure (3).
Since both interceptor and target are assumed to start turning at this instant, the immediately subsequent flight can be indicated by circular arcs as shown in the figure. The following conditions determine P:

i) $$\text{arc } MP = \frac{V_i}{V_t} \text{ arc } NH$$

which gives $$\theta_{t1} = \frac{V_t R_i}{V_i R_t} \theta_{i1} \qquad (1)$$

ii) $$\underline{PK} = \frac{V_i}{V_t} (\underline{HK} + \underline{X_o})$$

which becomes, in cartesian coordinates,

$$(K_x - B_x)^2 + (K_y - B_y)^2 = \left[\frac{V_i}{V_t}\right]^2 \left[(K - H + X_o \frac{H_y}{R_t})^2 + (K_y - H_y + X_o \frac{H_x}{R_t})^2\right] \qquad (2)$$

iii) $\underline{PK}$ and $\underline{HK}$ tangent to respective circles, from which we obtain,

$$K_x = \frac{H_y B_x (C_x - B_x) + (C_y - B_y)(B_y H_y - H_y - H_x)}{H_y (C_x - B_x) - H_x (C_y - B_y)} \qquad (3)$$

$$K_y = H + \frac{H^2_x}{H_y} - \frac{H_x}{H_y} K_x \qquad (4)$$

The coordinates of points C, P and H are obtained directly from the diagram as,

$$C_x = - D_o \cos A_o + R_i \sin \phi \qquad (5)$$

$$C_y = + D_o \sin A_o + R_i \cos \phi_o + R_t \qquad (6)$$

$$P_x = + C_x - R_i \sin(\phi_o - \theta_{i1}) \qquad (7)$$

$$P_y = + C_y + R_i \cos(\phi - \theta_{i1}) \qquad (8)$$

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$$P_y = + \left[R_i^2 + (P_x - C_x)^2 \right]^{\frac{1}{2}} + C_y$$

$$H_x = + R_t \sin \theta_{t1}$$

$$= + R_t \sin \left[\frac{V_t R_i}{V_i R_t} \theta_{i1} \right] \qquad (9)$$

$$H_y = + R_t \cos \theta_{t1} = + \left[R_t^2 - H_x^2 \right]^{\frac{1}{2}} \qquad (10)$$

Substitution of equations 3 to 10 into equation 2 now yields,

$$F (\theta_{i1} , A_o , D_o , \Phi_o) = 0 \qquad (11)$$

It is noted at this stage, that not only does an explicit expression for θ_{i1} appear unobtainable, but the present formulation results in a multi-valued transcendental equation. (The multi-valuedness results from the presence (mathematically) of two lead collision courses for any point, both of which may imply a launch point in future time, or one in future and one in past time). Once equation (11) has been computed, the values of D_1, A_1 and Φ_1 are given by

$$D_1 = \left[(H_x - P_x)^2 + (H_y - P_y)^2 \right]^{\frac{1}{2}}$$

$$A_1 = \sin^{-1} \left[\frac{P_x \quad H_x}{D_1} \right] - \frac{V_t R_i}{V_i R_t} \theta_{i1}$$

$$\Phi_1 = \Phi_o - \theta_{i1} \left[1 - \frac{V_t R_i}{V_i R_t} \right]$$

The distance X_o for the ideal case of zero heading error is given by,

$$X_o = V_t t_m \left[\frac{V_m}{V_i} - 1 \right]$$

The differential equation governing the motion for the final phase of the interception can be derived in several ways. One formulation, for example, is to eliminate the course difference ϕ and the computed time-to-launch t^*, to obtain,

$$R(1 - V_t) \sin A + R^2 V_i (\mathring{A} + \mathring{\Theta}_t) =$$

$$t_m \; (V_m - V_i) \left[\frac{V_t}{V_i} \cos A \; (\sin A - \cos A) - \frac{\dot{R}}{V_i} (\sin A - \cos A)\right]$$

$$\left[\frac{V_t}{V_i} \sin A - \frac{R}{V_i} (\mathring{A}_t + \mathring{\Theta}_t)\right]^2 - \left[\frac{V_t}{V_i} \cos A - \frac{\mathring{R}}{V_i}\right]^2 = 1$$

Except on making certain assumptions, such as restricting the range or variation of R, an attempt to reduce these highly non-linear expressions was not successful. Alternative formulations were attempted, in which the statement of the kinematic conditions was altered so as to enable different combinations of variables to be used, but equations amenable to direct quadrature were not obtained. The possibility of using a linearized geometry by assuming a trajectory slightly perturbed from the ideal trajectory was also considered, but found impracticable due to the large amount of target manoeuvre being considered. Further analysis on this problem was therefore withheld pending alternative developments.

ALTERNATIVE ANALOG COMPUTER SET-UP

The present technique used to determine the placement zones involves "flying" the interceptor from a range of initial placements and noting the eventual success or failure of each flight. It would be useful to eliminate this trial and error procedure by some more direct method. One possible approach, which has been suggested, is to fly the interceptor backwards from known launch positions, and at the same time, use closed form solutions for part of the trajectory to obtain final results directly. The possible defects, which still may be listed against this procedure are:

1) If the depth of the launch zone is taken into account, an early determination of the extreme trajectories may be difficult owing to the great variety of final launch positions.

2) The location of the transition point P becomes arbitrary, so that in plotting results for all P, superfluous data may be obtained.

3) The variation in the look-angle is by-passed in the section of the trajectory where the closed form solution is used, so that additional instrumentation is required to check this parameter.

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It is not possible, at this time, to assess fully the first of the above items. The second item means a possible redundancy in some plots, but the additional solution time involved is expected to be negligible. The third item means additional computer equipment to check the look-angle variation.

The following mathematical description has been tentatively suggested for this "reversed" analysis. We define the following specific times:

$t = t_o$ (interceptor attains lock-on)

$t = t_1$ (interceptor at transition point P)

$t = t_2$ (interceptor at launch point)

Equations for the period $t_1 \leqslant t \leqslant t_2$ (see figure 4)

The cartesian components of the range (line of sight) are,

$$R_x - R_{x1} = \int_0^t \left[V_i \cos\alpha + R_t \cos\beta \right] dt$$

$$R_y - R_{y1} = \int_0^t \left[V_i \sin\alpha + R_t \sin\beta \right] dt$$

where

$$\beta = \beta_1 + \dot{\beta}(t - t_1)$$

The look-angle is given by

$$l_a = \frac{\pi}{2} - \alpha - \gamma$$

where

$$\tan\gamma = \frac{R_y}{R_x}$$

The final equation ascribes the property of the lead collision course,

$$\frac{V_t\ t_m(V_m - V_i)}{R} = \sin\gamma \left[V_i \cos\alpha - V_t \cos\beta \right] + \cos\gamma \left[V_i \sin\alpha - V_t \cos\beta \right]$$

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Equations for the period $t_o \leqslant t \leqslant t_1$ (see figure 5)

The cartesian components of the range are now written,

$$R_x = C_x - R_i \sin(\Phi_o - \theta_i) - R_i \cos\left[\frac{V_t R_i}{V_i R_t} \theta_i\right]$$

$$R_y = C_y + R_i \cos(\Phi_o - \theta_i) - R_i \sin\left[\frac{V_t R_i}{V_t R_i} \theta_i\right]$$

where

$$\theta_i = \dot{\alpha}_{max.} (t - t_o)$$

One choice for the third equation is

$$R_o = f(A_o)$$

which may describe either the lock-on or alert range. In this case we solve for

$$\theta_i = \theta_{io} ,$$

and obtain the required initial course difference, which the computer can be set up to plot versus A_o. A second choice for the third equation is,

$$l_a = (l_a)_{max} = \frac{\pi}{2} - \theta'_{io} - \gamma'_o$$

in which case the degrees of interceptor turn (flying backwards) required to lose radar contact are obtained. The criterion

$$\theta'_{io} \geqslant \theta_{io}$$

can then be used to delete automatically those initial placements associated with excessive look-angle. An alternative check of the look-angle can be made on noting that,

$$\dot{l}_a = -\dot{\alpha} - \dot{\gamma}$$

which can be used to construct

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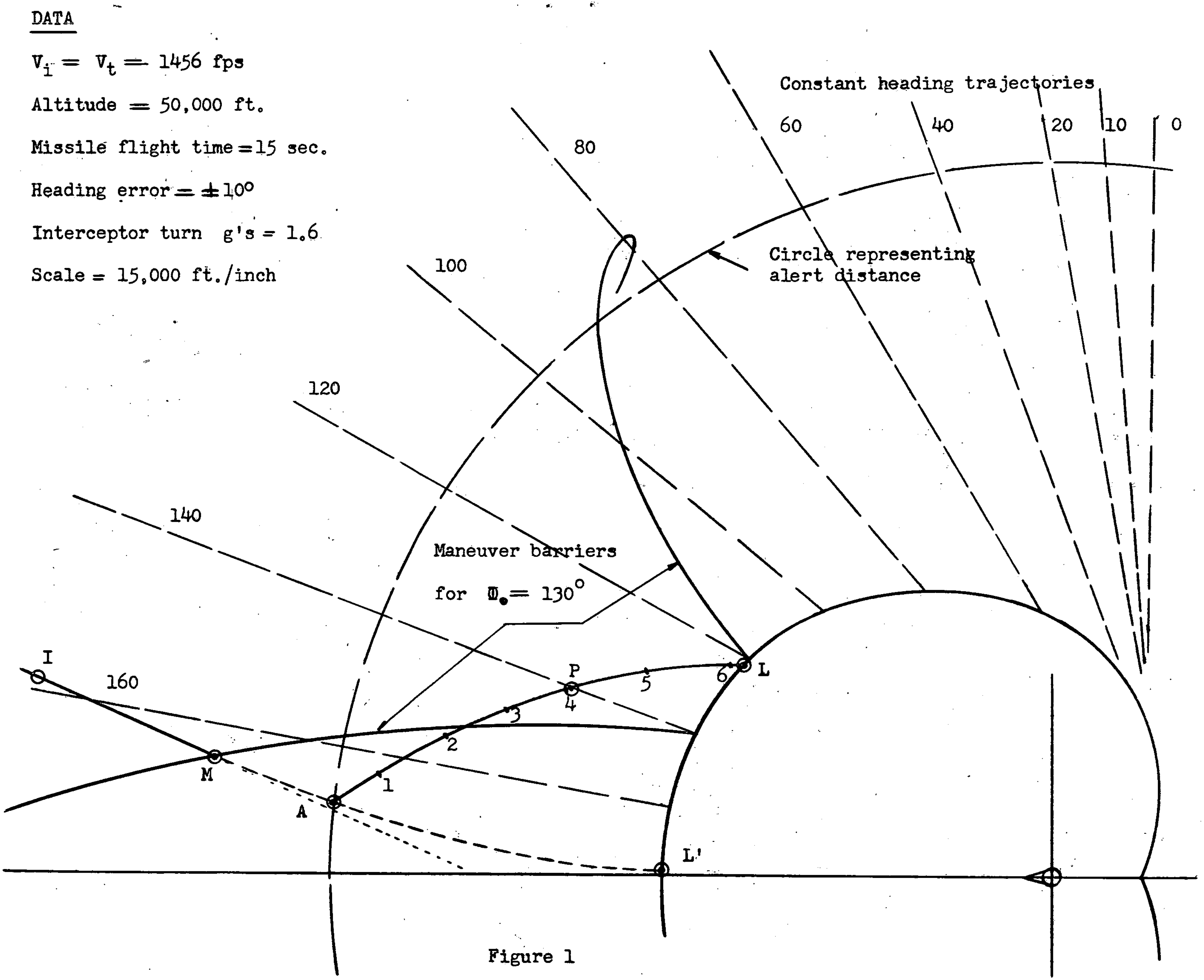
$$\frac{V_t \sin A - V_i \sin(l_{a\ max})}{\dot{\alpha}} \leq R_1$$

as a criterion for the occurrence of an extremum in the look-angle variation during the period

$$t_o \leq t \leq t_1$$

If an extremum is indicated, then its value could be plotted. This latter formulation requires R to be a monotonic function of time for the period considered. A more detailed description of this entire procedure is in preparation.

Some consideration was also given to the use of alternative criteria in the generation of the steering signal for the interceptor. The criterion presently employed is based on the solution of a certain "miss" distance and involves a continuous evaluation of a time-to-launch parameter t^*. A possible alternative formulation would be the direct solution for the required course difference (by the elimination of t^*) which at the same time would yield the aspect angle, thus permitting consideration of preferred launch aspects. This study is being continued.



DATA

$V_i = V_t = 1456$ fps

Altitude = 50,000 ft.

Missile flight time = 15 sec.

Heading error = ±10°

Interceptor turn g's = 1.6

Scale = 15,000 ft./inch

Figure 1

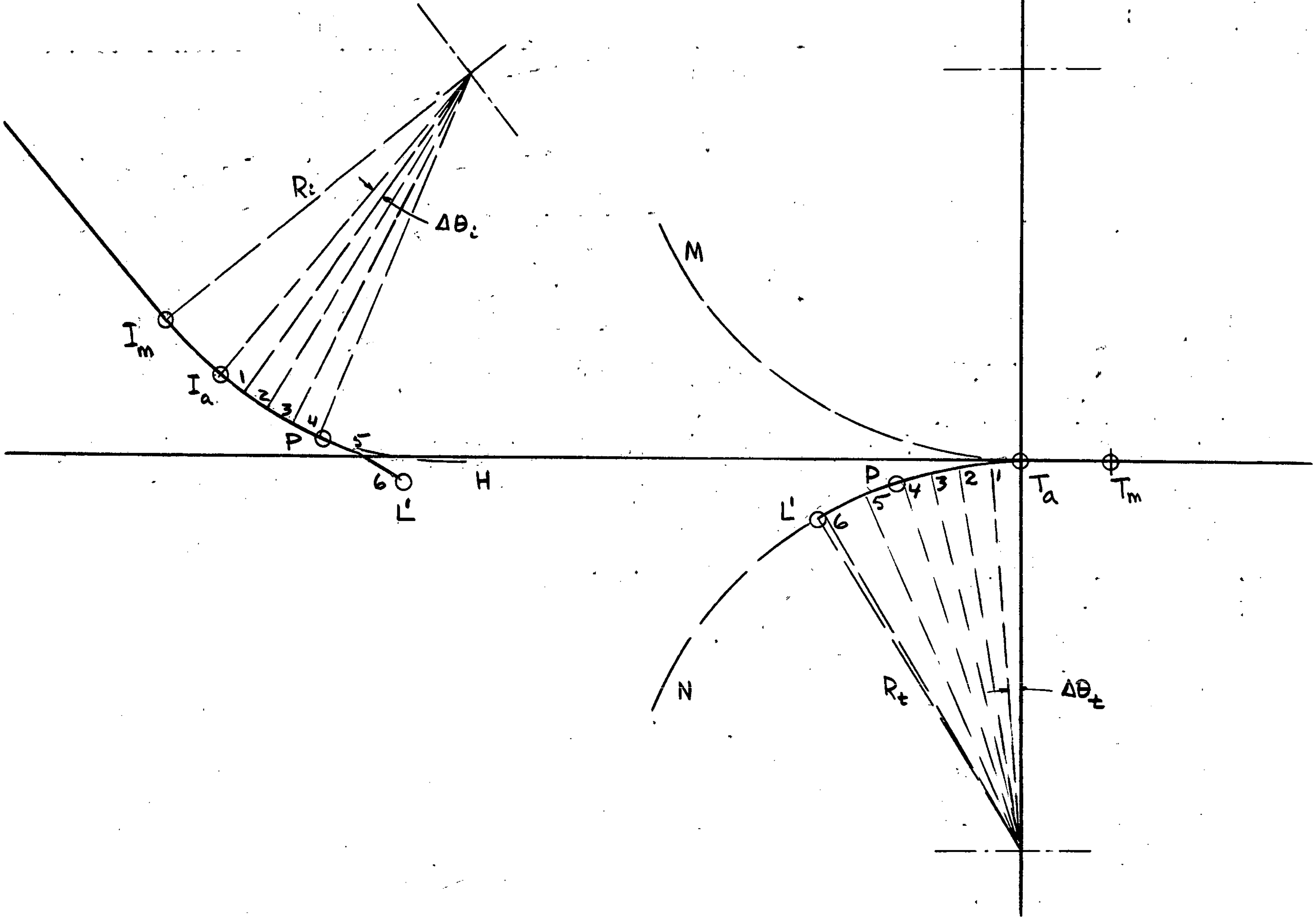


Figure 2

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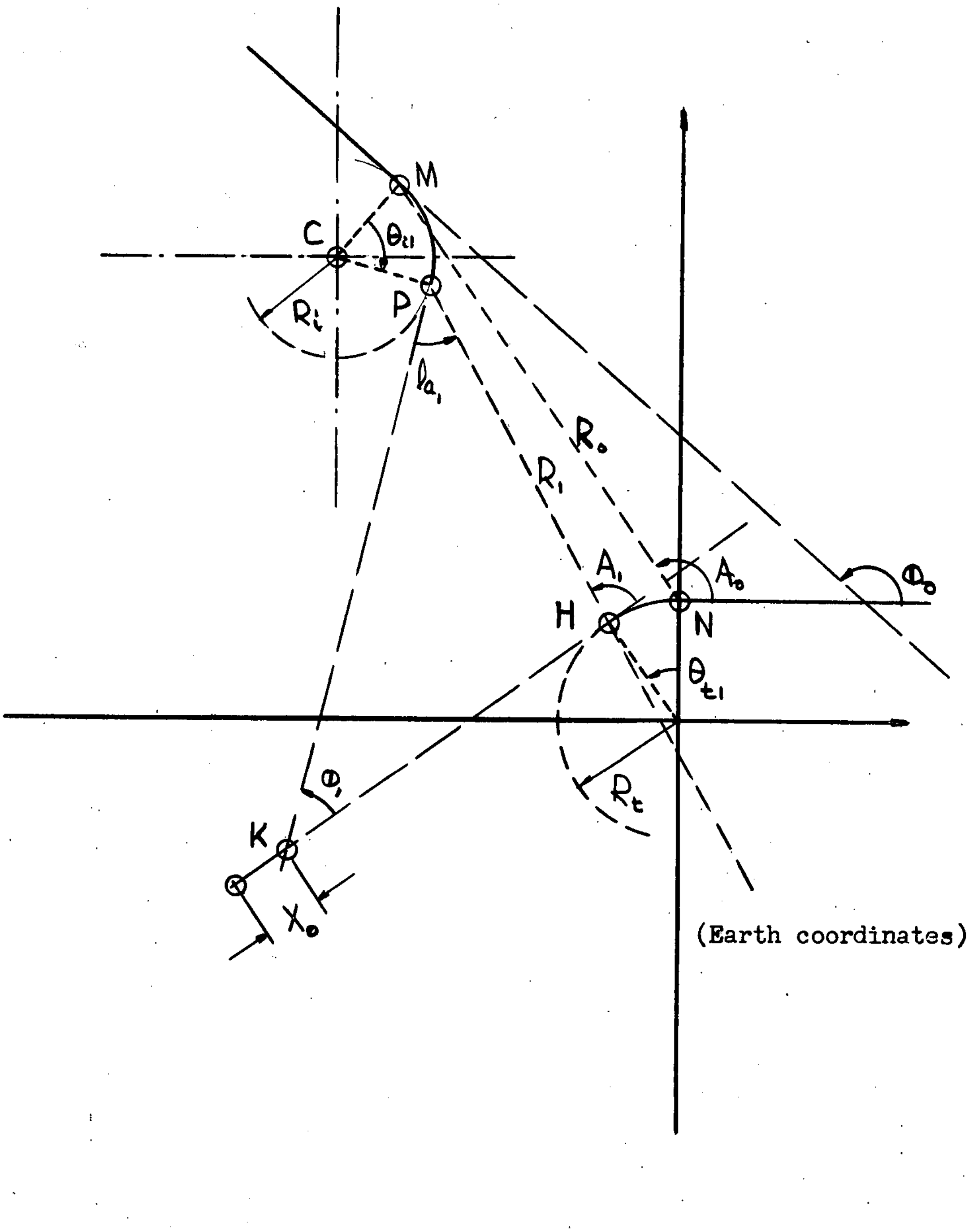

Figure 3

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For period

$t_1 \leqslant t \leqslant t_2$

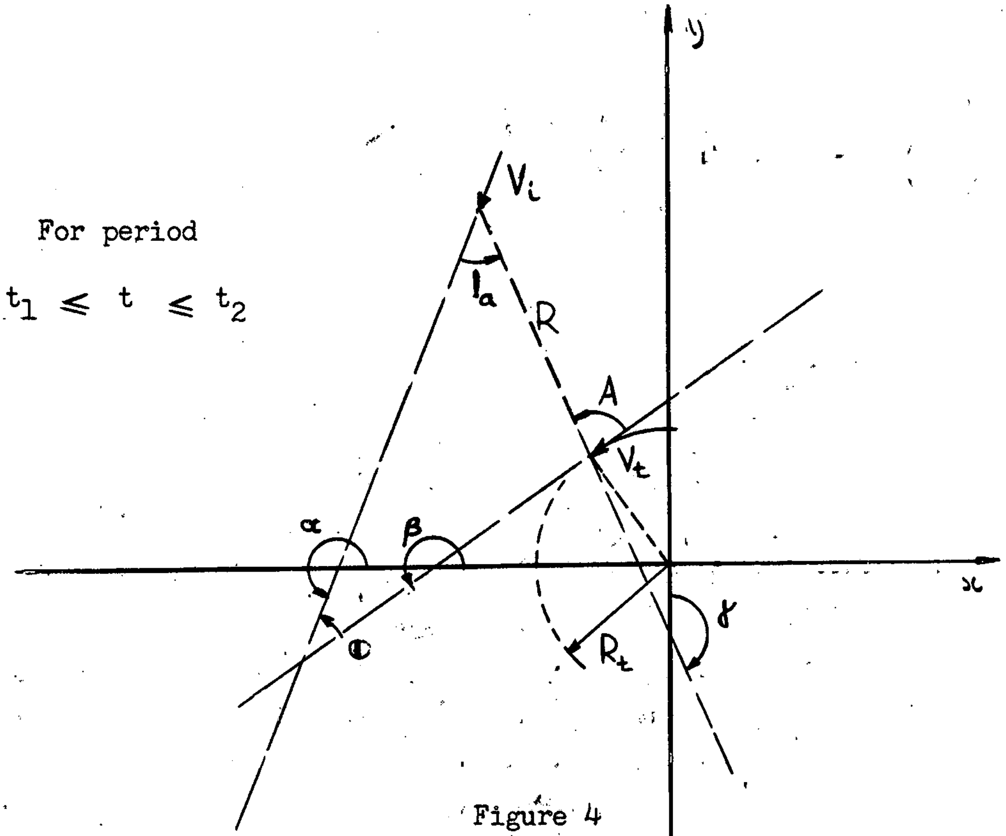

Figure 4

For period

$t_o \leqslant t \leqslant t_1$

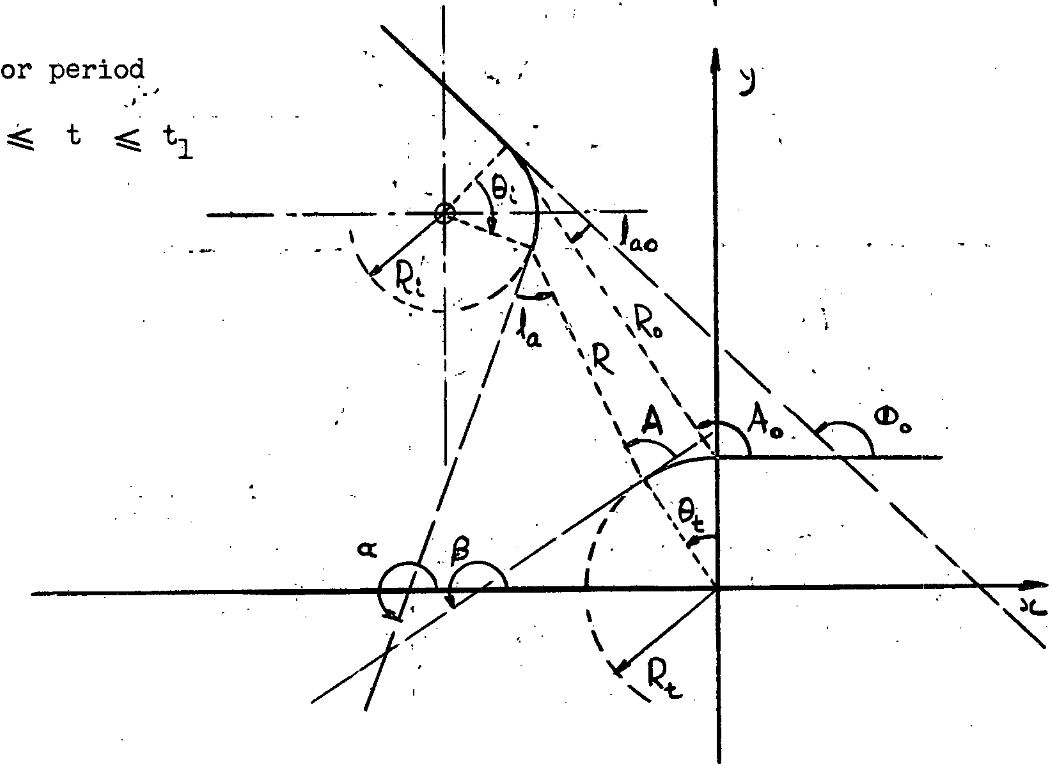

Figure 5

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APPENDIX G

C. Wilson

STUDY OF THE PLACEMENT PROBLEM IN THREE DIMENSIONS

Generally, a fighter will not remain in one horizontal plane during the initial stages of attack run on a bomber. Preferably it will execute diving or climbing turns, or deliberately fly at a lower altitude than its target and launch missiles from below in order to obtain the advantages of extra manoeuvrability and speed. To assess the merits of fighter tactics of this nature, it is necessary to take vertical components of velocity and height difference into account in some way. As simulation of fighter and target motions in three dimensions becomes complex the problem must first be studied in two dimensions and these results used, together with approximations, to simplify the representation in three dimensions.

As a result of insufficient data on the CF 105, consideration of the 3 D problem has been restricted to preparation of a partial REAC set-up which may be extended when aerodynamic data is available.

The coordinate system used to define the fighter's position and velocity relative to the target are shown in Fig. 1.

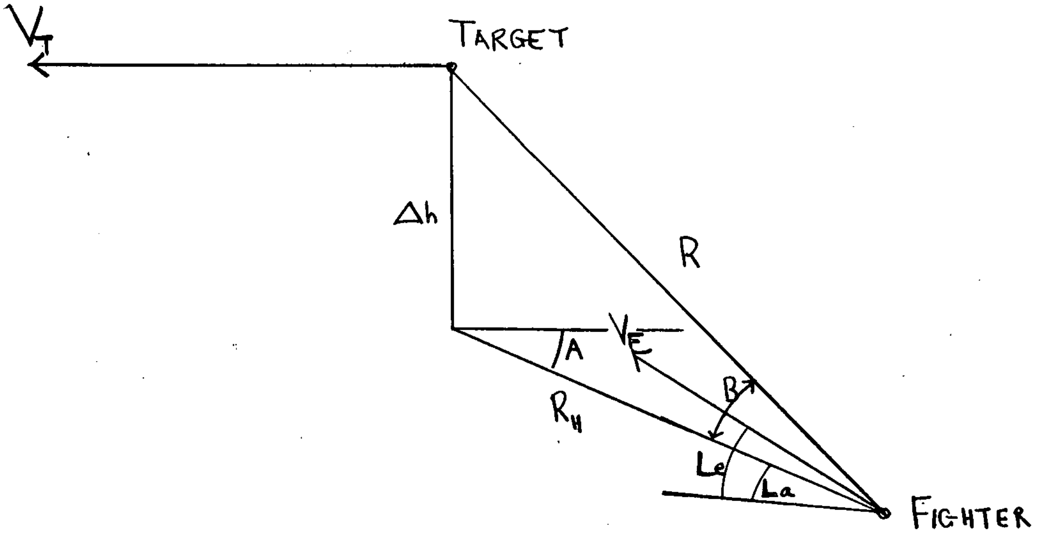

Fig. 1.

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$\underline{V}_f$ and $\underline{V}_t$ are the vector velocities of the fighter and target; the target is flying at height h above the fighter; L_e, the inclination of the fighter's velocity to the horizontal is assumed to be a small angle i.e. $-20^\circ < L_e < 20^\circ$.

The orientation of the fighter in terms of L_a, L_e, and bank angle must be obtained from its roll rate p_f and pitch rate q_f (Yaw is assumed to be zero), by an Euler transformation and integration. If $\underline{R}$ is the position vector of the fighter relating to the target, then

$$\dot{\underline{R}} = \underline{V}_f - \underline{V}_t$$

The method of navigation used in the Hughes Aircraft Universal Computer* has been adopted. If both fighter and target were to fly with constant velocity for a time T and a missile were fired so as to have travelled a distance $\underline{F}$ relative to the fighter at the end of this time, the position vector $\underline{M}$ of the missile relative to the target would then be given by

$$\underline{M} = \underline{R} + \dot{\underline{R}}T + \underline{F}$$

The Universal Computer uses this equation to determine the heading errors to be corrected for a lead-collision course by assuming that the component of $\underline{M}$ in the direction of the line of sight is zero. i.e.

$$M.R = 0$$

Hence obtaining a value for time-to-go T and using the other two components of $\underline{M}$ to provide azimuth and elevation steering instructions.

The vector quantities in these equations have to be resolved into their components in a suitable coordinate system for REAC solution of the equations. The block diagram of Figure 2 shows in outline how the problem can be set up, with the inclusion of some features which will be discussed below.

The fighter's fire-control radar measures range R, relative velocity along the line-of-sight $\dot{R}$, and the rate of rotation of the line-of-sight. In effect the radar resolves the velocities etc. along and perpendicular to the line-of-sight. A simulation has been drawn up which uses the same components, imitating the actual airborne system as closely as possible.

An alternative method has been considered for its simplicity. All vectors can be projected onto a horizontal plane, and the problem solved as if in two dimensions. A horizontal steering signal and time-to-go would be derived from the geometry in this plane. At the same time height difference, relative vertical velocity, and a vertical steering, instruction can be obtained from a separate computation. It seems likely that any differences between the

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* Tech. Memo. 339 - Hughes Aircraft Co.

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results of these two methods would be small except when, simultaneously, B is a large angle ($> 30^\circ$) (see Fig. 1) and there is a significant elevation heading error. Under such circumstances the chance of a successful attack is not high.

With the simulation of Figure 2 fighter tactics can be tried by programming the computer appropriately. A procedure which is simple enough to be useful in an aircraft, e.g. conversion from lead-collision to lead-pursuit, as discussed above, or variation of thrust with closing velocity, can be easily mechanized.

If at any time during an attack the fighter's position and heading are suitable for successful missile launch then the fighter was clearly in an allowable placement zone originally. Thus the boundaries of these zones can be determined by a trial and error process. A missile launch zone computer is necessary to determine whether the attack runs are successful or not. The ideal fighter heading in terms of optimum values of L_a and L_e, $L_a(opt)$ and $L_e(opt)$, can be obtained from the equations given. Permissible azimuth heading errors at launch have been determined for some particular cases *, but insufficient information is available about permissible heading errors in the general case in three dimensions. However it is proposed that the effect of gravity drop of the missile be neglected, and the permissible heading error be assumed symmetrical about the ideal heading. The launch zone computer can then take the form of Figure 3, where the actual heading error, which is approximately equal to:

$$\left[(L_e - L_e(opt))^2 + (L_a - L_a(opt))^2\right]^{\frac{1}{2}}$$

is compared with the permissible heading error, ΔL, which is a function of range R, aspect angle, A, and height, h.

Gravity drop may be taken into account by changing the value of $L_e(opt)$ appropriately, still assuming that the launch zone is symmetrical about the revised ideal heading. $L_e(opt)$ may have to be increased by as much as 5° when firing missiles at maximum range.

Look-angle limits of the antennae of the aircraft's fire control radar and of the missile's guidance radar place a restriction on fighter manoeuvres. For this reason the azimuth and elevation angles of the fire control radar must be monitored throughout the simulation, so that gimbal lock can be detected. At the same time the look angles of the missile radars must be monitored with particular reference to screening of the field of view by the fighter's structure. The fire control radar must be locked on to the target throughout a successful attack run and the missile radar must be locked on at the time it is launched. If the fighter flies in such a way that lock-on is lost the attack must be counted a failure.

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* CARDE Tech. Letters N-47-2 and N-47-4

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It has been suggested that an over-riding steering signal should be provided whenever the fire control radar is on the point of losing the target from its field of view. The fighter would turn to retain lock-on to the target, and resume normal navigation at a later stage of the attack if possible. If, when the missile launch time approaches, the missile is not able to lock on to the target because of screening by the airframe, the fighter must pitch up, or manoeuvre in some other way, to correct its attitude suitably. Any advantages to be gained from specific procedures designed to retain lock-on can be determined by trial and error on the computer.

A useful study of possible tactics for the CF 105 can be made by means of a REAC simulation in three dimensions. At present a variety of attack procedures have been suggested, but no evaluation of their applicability has been made. Such an evaluation can be most economically made by simulation on an analog computer.

The following programme is suggested, divided into two main classes:

i) The fighter manoeuvres so as to correct horizontal and vertical heading errors simultaneously.

ii) The fighter corrects horizontal heading errors without reference to vertical errors until a short time before launch when it pitches up, and relies on the missile's jump-up capability to make up any height difference. With this framework the effects of the following tactics will be studied.

(a) Approach with various altitude differences from zero to about 10,000 - 15,000 ft. below the target (missile jump-up capability is about 10,000 ft.).

(b) Variation of fighter thrust with aspect angle A. Fighter speed should be high when the target is flying away, but kept lower for greater manoeuvrability when the target is approaching. This variation is probably best implemented by making thrust a function of closing speed

(c) Shallow diving turns for the most rapid correction of horizontal errors, provided that the fighter does not fall more than 10,000 - 15,000 ft. below the target.

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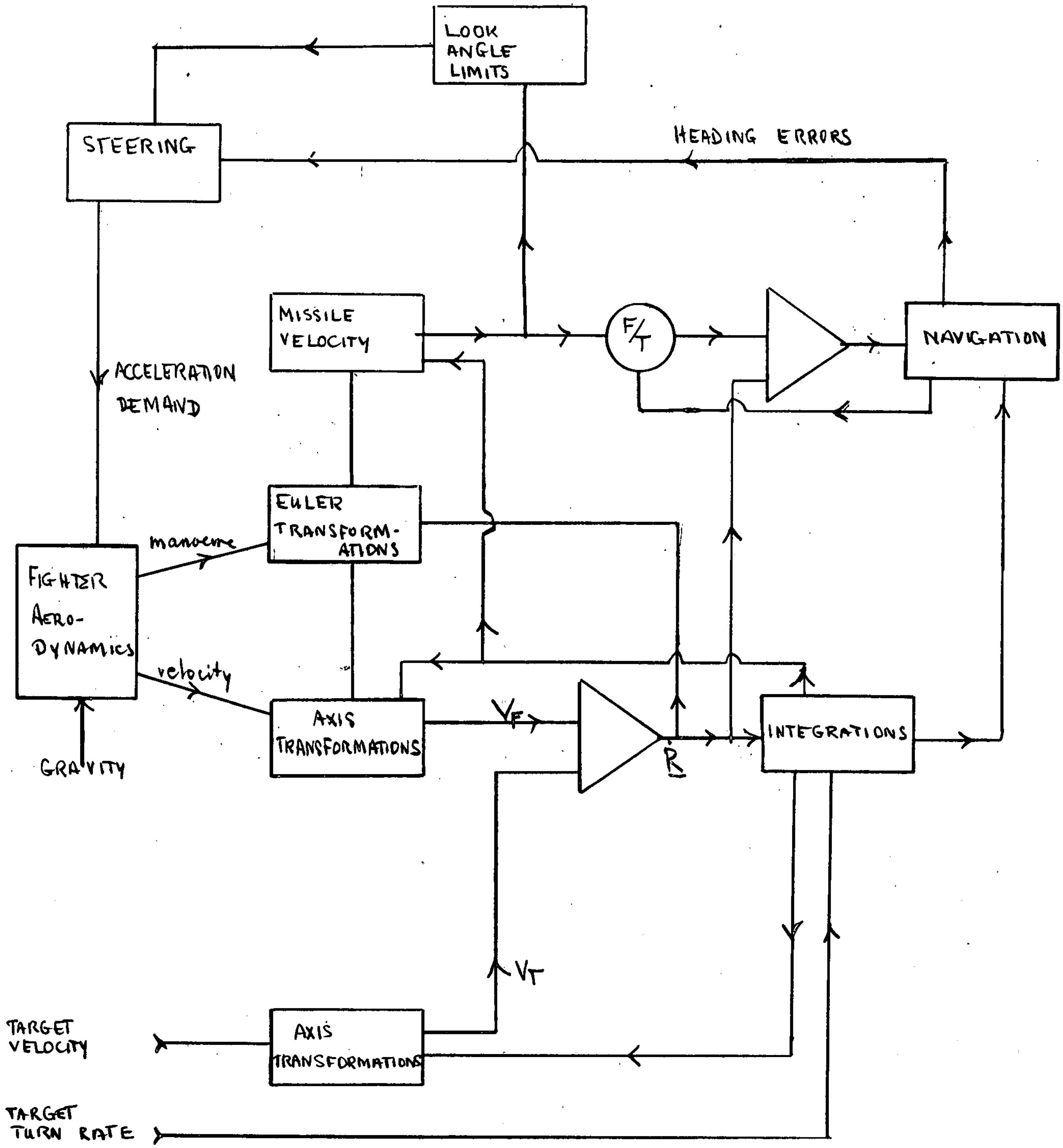

FIGURE 2   BLOCK DIAGRAM OF KINEMATIC SIMULATOR

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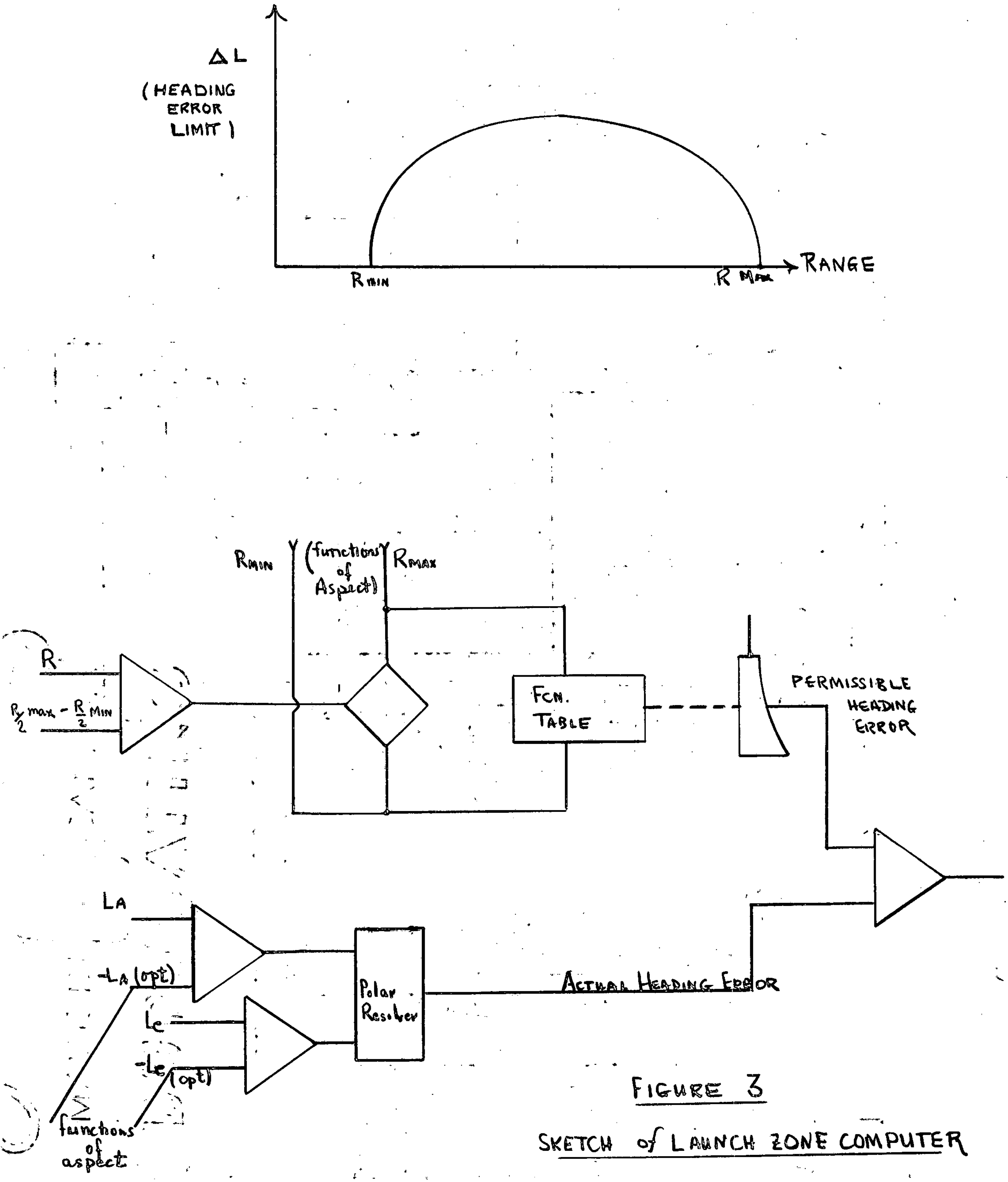

FIGURE 3

SKETCH of LAUNCH ZONE COMPUTER

[redacted]

[redacted]

APPENDIX ~~J~~ H

CF 105 Analysis Group

TRANSFER FUNCTION OF A HUMAN

In analog computer studies involving a human operator an increase in the accuracy of simulation may be obtained by inserting a transfer function representing a human's response. Information (1,2) is scarce but an attempt is made to synthesize the transfer function using the smallest possible number of components.

The response of a human to a "step" input is obtained from data (3) showing the velocities attained by a person's hand when he is asked to move it as rapidly as possible between two points. When motion is initiated by visual or aural means there is a constant reaction time of between 0.1 and 0.5 secs., depending upon the stimulus, in which no motion occurs. The complete step response of a human for a typical delay of 0.17 secs. (4), on a 20x time scale is shown in fig. 1.

The step response may be considered as a pure delay followed by another network to give the required amplitude response. A 4 root linear delay network, using 2 integrators and 2 amplifiers, may be synthesized by utilizing readily available data (5). The transfer function of the delay network is

$$-\frac{S^2 - 1.76S + 1.138}{S^2 + 1.76S + 1.138}$$

The remainder of the response may be obtained from the transfer function

$$-\frac{.49S^2 - .090S - .198}{S^3 + 1.75S^2 + 1.02S + .198}$$

whose step function response is

$$1 + 0.9\epsilon^{-\frac{11}{20}t} - 1.9\epsilon^{-\frac{12}{20}t}\left(1 + \frac{12}{20}t\right)$$

The fit obtained is shown in fig.1. If a more accurate fit is desired more amplifiers may be used. A $\sin^2$ impulse response filter (6) produces a better fit but involves terms in S^7 and is excluded on this account.

The above transfer functions assume that a human's response is linear. However, since there is a limit on the velocity attainable for arm movements it has been suggested that a diode limiter could be inserted into the transfer function to limit the rate at which steady-state response is reached for large demands. It is expected that an improved fit would result.

[redacted]

[redacted]

It is suggested that information on pilot response for the F102 may be available from the Air Force Flight Test Center, Edwards, Calif. This information should be applicable to the CF 105.

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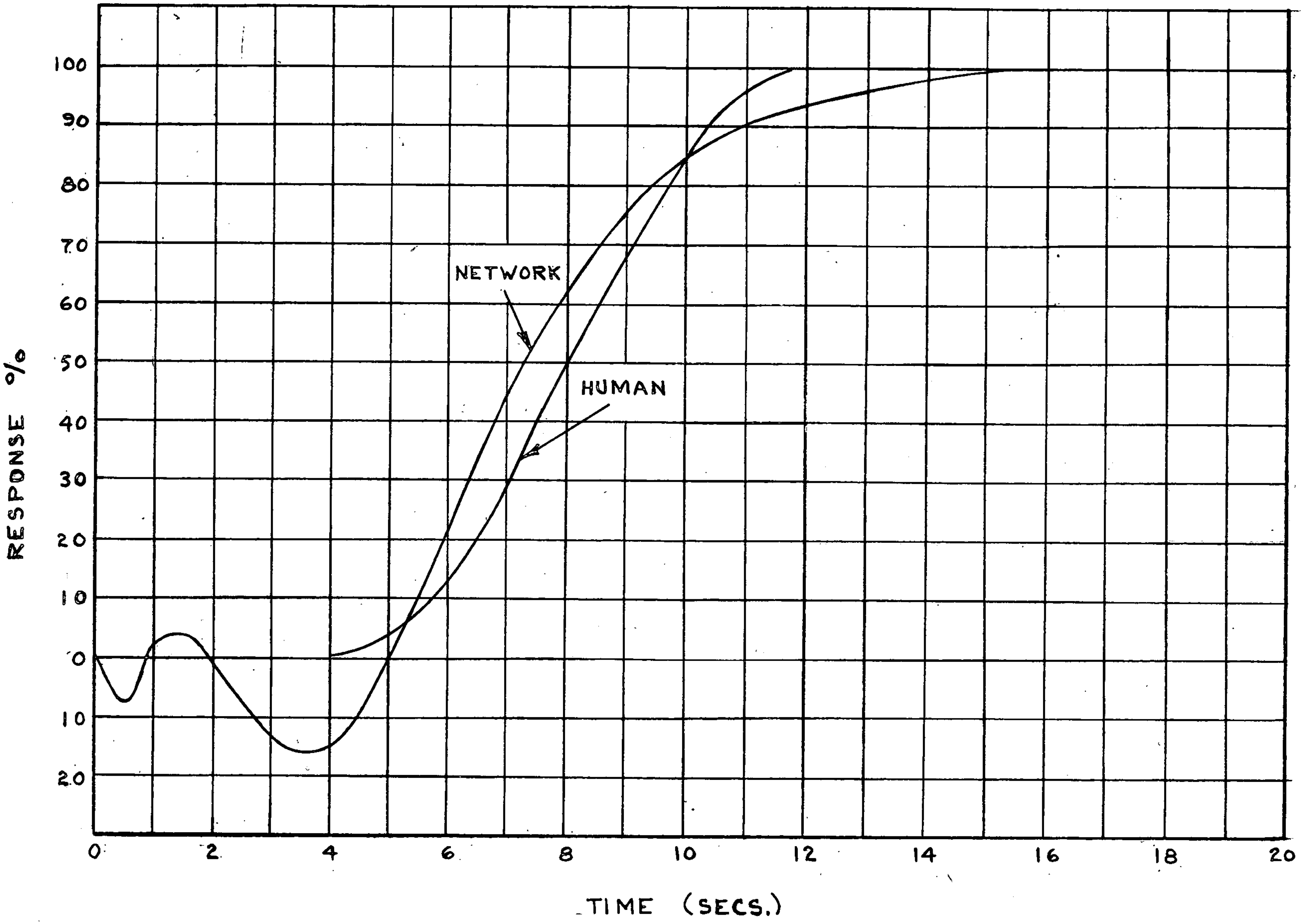


CALCULATED AND APPROXIMATED RESPONSES

FIGURE 1

[redacted]

[redacted]

APPENDIX I

J. T. MacFarlane

A.I. ACQUISITION

1. Calculation of placement probability for an interceptor requires knowledge of the available acquisition range of the A.I. radar. This quantity varies with aspect for a given target, and is different of course for different targets.

2. The RCAF Specification Air 7-6 states a range of 25 nautical miles for 80% probability of detection of a target having 5 square meters reflection area. This figure was used in computing expected acquisition range as a function of aspect for three targets: a subsonic swept-wing bomber, a delta-winged medium bomber, and a supersonic straight-winged bomber.

3. The reflection area values used for computing A.I. radar range on a swept-wing aircraft are those for the B.52 aircraft given in University of Michigan reports on Radar Cross Sections. These values were derived theoretically rather than from actual measurement. The reflection area values used for the delta-winged aircraft are those for the AVRO Vulcan medium bomber, taken from RRE published reports. Reflection area values used to represent a straight-winged supersonic aircraft were estimated by analogy with those given for representative straight-winged aircraft such as the B-45 and the Canberra, adjusted to the probable size of a long-range aircraft. (See references 1, 2, 3.)

Any sharp peaks which may actually exist on radar reflection area contours have been reduced or eliminated since such peaks, if only a few degrees wide, are of no use in positioning a fighter aircraft by ground control because of the obtainable accuracy in placement, and the variability in the position of these long range peaks due to pitch and yaw of the target and interceptor.

4. Polar graphs of expected acquisition range for these targets have been drawn and are reproduced as figures 1, 2 and 3. Contours are given for various degrees of radar performance, as tabulated:

S	The Range required in RCAF Specification.
1.92S	Range proposed by RCA for final development.
1.28S	Range proposed for the degraded system by RCA.
0.85S	Range obtainable on a medium-swept-wing bomber (B47) rather than the heavy type (B52); a 6 db degradation of the specification.
0.6S	Range obtainable by the present MG-2 fire control system on a B-52 type target.
0.4S	This may represent range obtainable under severe degradation due to ECM conditions or poor maintenance of the equipment.

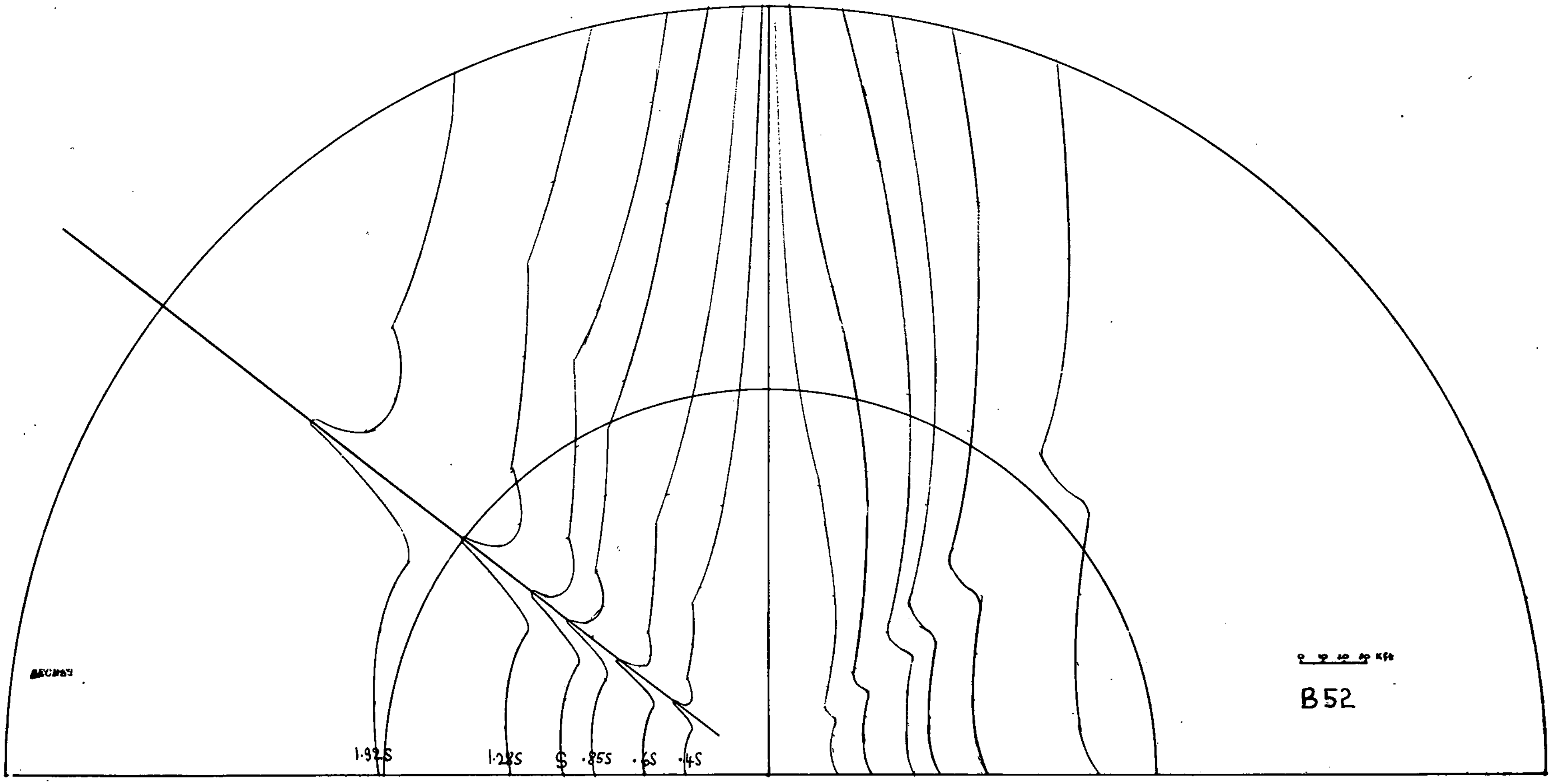
[redacted]

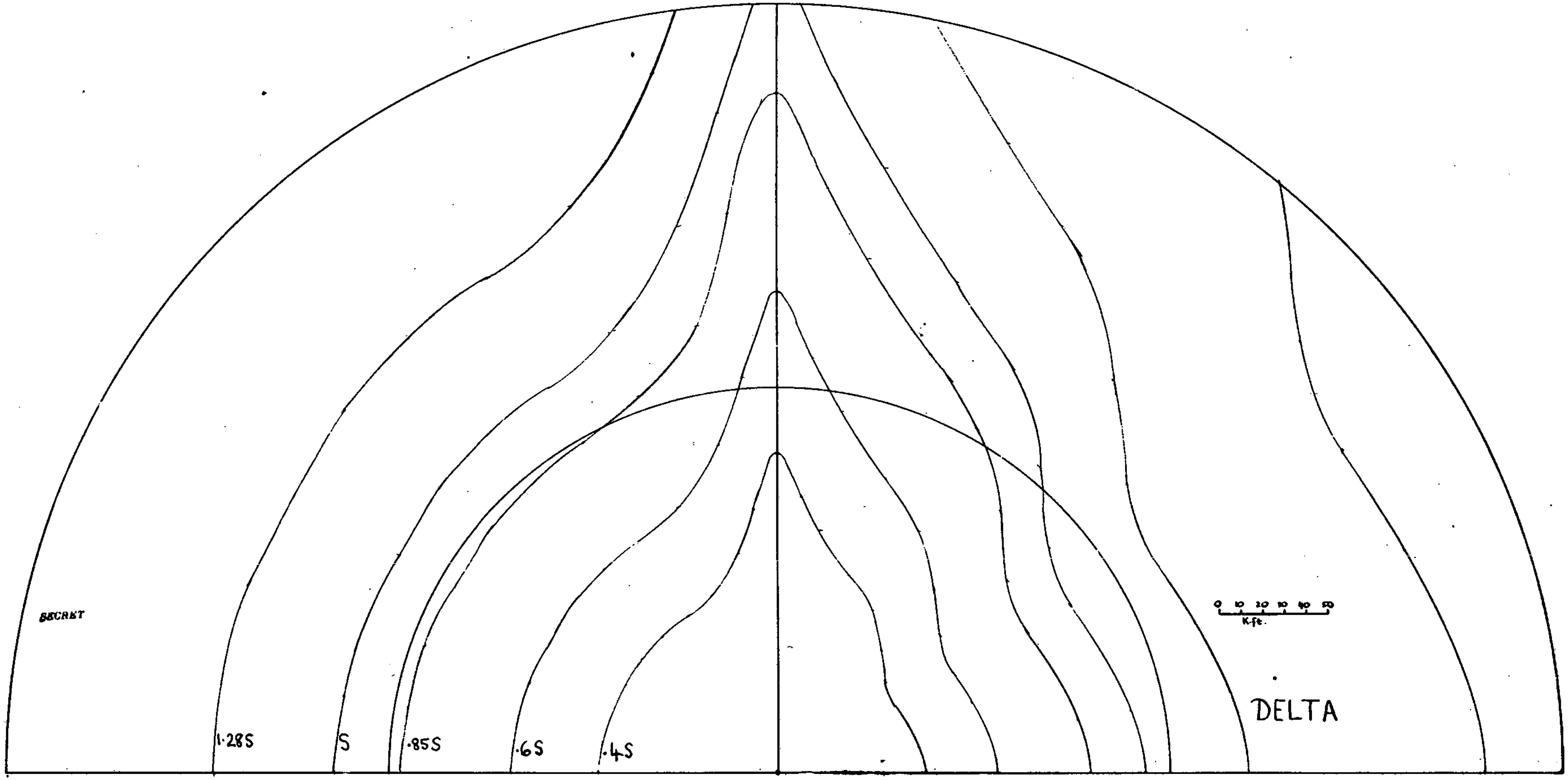
5. Semicircles are drawn on the graphs to indicate the 30 n.m. lock-on range which is required by the specification, and the 60 n.m. max. range of the search presentation.

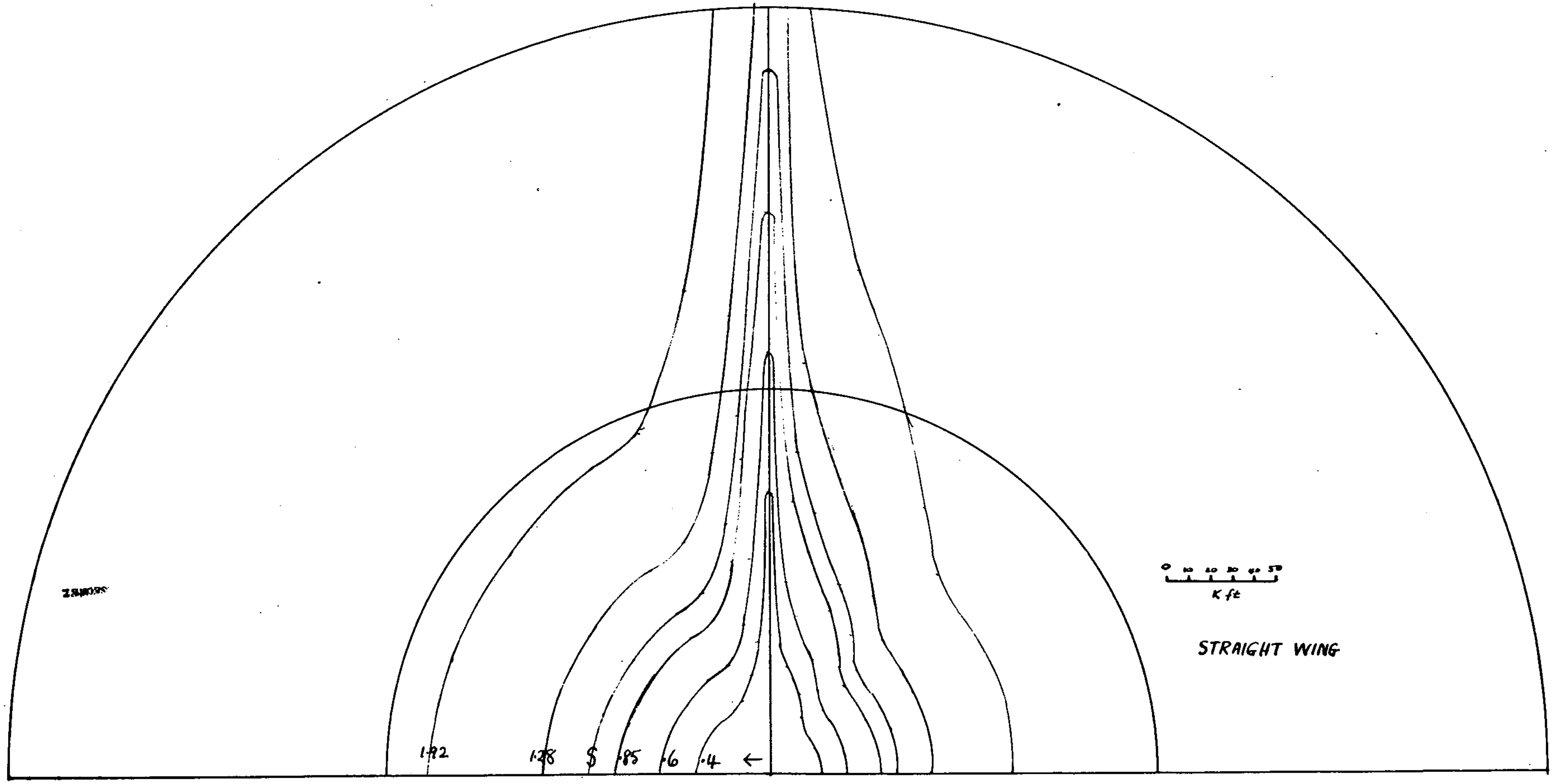
Reference 1. University of Michigan Report 2260-1-T.
Studies in Radar Cross Sections XV (DRB # 56/2003)

2. RRE Memos 1078, 1015.

3. NRL Memorandum Report 116.
B-45 Reflection Areas.


1·92S
1·28S
S
·85S
·6S
·4S
0 10 20 30 KFt
B52


SECRET
1·28S
S
·85S
·6S
·4S
0 10 20 30 40 50
K-ft.
DELTA


1.92
1.28
$
.85
.6
.4
←
0 10 20 30 40 50
K ft
STRAIGHT WING

[redacted]

APPENDIX J

CF-105 Analysis Group

THREE-DIMENSIONAL MISSILE LAUNCH ZONES

A REAC study was undertaken to examine the performance in three dimensions of a missile similar to Sparrow II. A block diagram of the computer set-up used was given in CARDE Technical Letter N-47-4, page 43. The simulation included the effect of varying range on the guidance signal. Since a missile launched at supersonic speed will have a longer aerodynamic range than the same missile launched at subsonic speed, the variation of guidance characteristics with range will be extremely important. As originally set up, the simulator used values of radar gain given in Sparrow II progress reports for 1951 and 1952. It was found that in order to produce a useful weapon the gain had to be increased by 6 db. In regard to a change such as this, it must be stressed that the simulation either before or after the change cannot be regarded as an exact representation of Sparrow II. The only check which may be used is the comparison of launch zones obtained for coplanar cases with those published for the current Sparrow II.

Using the constant bearing missile simulator about one thousand trajectories were flown to determine missile performance and charts were prepared for the cases shown in Table I below. It is to be noted that nine variables must be considered.

- Target speed, altitude, heading, and manoeuvre
- Fighter speed, altitude, heading, and manoeuvre
- Range at launch.

If all combinations of only three values of each of these variables were used there would be about 20,000 trajectories to run. It is thus apparent that the 3-D study was far from comprehensive.

Some results of the simulation will be useful in planning further work. It was found that a full representation of the Sparrow II gimbal system is not required, and a more effective computing technique for the radar discriminator characteristic was developed. The results showed that in the case where the fighter pitches up to the line of sight at launch, the launch zone obtained is the same as an equivalent co-altitude attack carried out at fighter altitude. Thus a considerable part of a complete 3-D study may be replaced by 2-D calculations.

The results of the study have been published in CARDE Technical Letter N-47-4 in which the following conclusions were drawn:-

1. It is established that accurate simulation of the radar discriminator characteristic is essential for launch zone studies.

[redacted] [redacted]

2. The experience gained suggested certain REAC set-up improvements which will be incorporated in future 3-D launch zone studies. (See above).

3. It appears that 3-D results can be extrapolated from 2-D results in the case where the fighter is pitched up through an angle equal to the angle of sight.

TABLE I

Summary of cases considered in launch zone study

Aspect-Degrees	Angle of Sight-Degrees	Pitch-up Angle-Degrees	Target Altitude-ft.
0	0	0	55,000
45			
90			
135			
0	10	0	55,000
45			
90			
135			
45	20	0	55,000
90			
45	0	0	48,000
90			
135			
45	20	20	55,000

Aspect = angle between line of sight and negative target axis projected into the horizontal plane.

Angle of Sight = angle between the horizontal and the fighter velocity vector.

[redacted]

APPENDIX K

J.Y. Caron & A.P. Paris

ANALYSIS OF THE SPARROW II STEERING LOOP

An analysis of the Sparrow II steering loop i.e., the portion of the system relating acceleration achieved to acceleration demanded, has been made. The report on this analysis has been completed and will be published shortly in the form of a technical letter. A block diagram of the steering loop is shown in figure 1.

The main purpose of the analysis was to obtain second order differential equations to approximate the relatively complicated steering loop and to check the stability of the missile at high altitudes. This approximate form of the steering loop is important for trajectory analysis and it is felt that the approximate forms as obtained can be used, with somewhat more confidence, than those used in the past.

The control and aerodynamic data were obtained from the most recent Douglas reports on hand. The control and aerodynamic transfer functions were simulated on a REAC, on a one-tenth time scale. The second order approximations of the steering loop were obtained from step and frequency responses of the simulation. The aerodynamics used will be called type 1. A table of equivalent gains, damping factors and resonant frequencies for the second order approximations is given in figure 2 over the range of altitudes and Mach numbers considered.

The results showed that the steering loop was stable at high altitudes even in the presence of wing limiting. The g-capabilities, for the aerodynamic coefficients used (type 1), were about 60% higher than estimates obtained from more recent information. This newer set of aerodynamics will be called type 2. The more conservative g-capabilities are apparently more realistic than those found in the study. Figure 3 gives a comparison of the g-capabilities while figure 4 gives a comparison of the step responses, for types 1 and 2 aerodynamics.

CURRENT WORK

The Sparrow II two-dimensional simulation for trajectory analyses is presently on the REAC. Work has begun to study the effects of various parameters on missile system effectiveness.

A systematic study is now underway to study the deleterious effects of g-limits and guidance discriminator characteristics.

[redacted] [redacted]

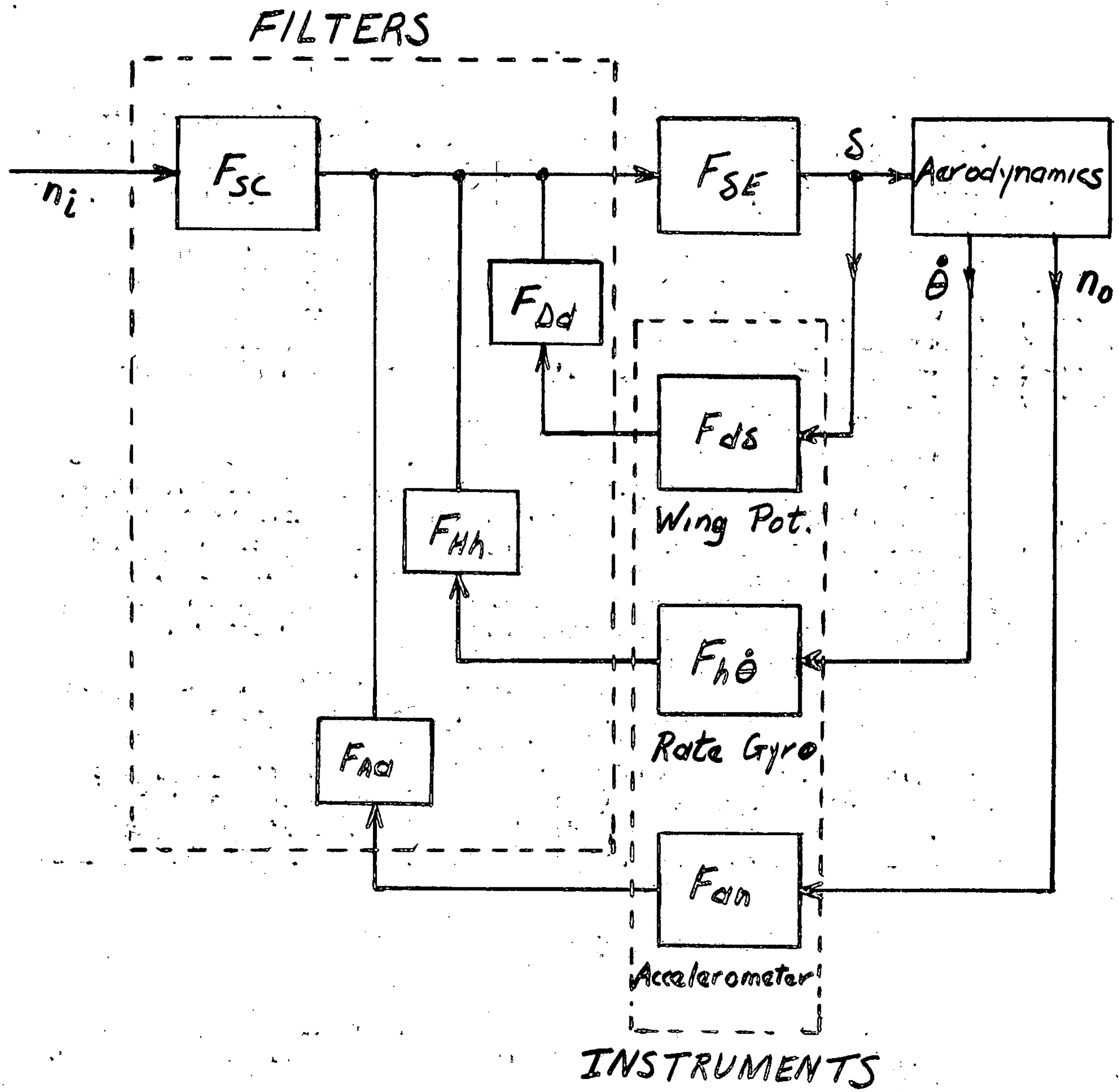


Fig 1 - BLOCK DIAGRAM

[redacted]

Altitude	Mach no.	From Step Response			From Frequency Response		
		K	Wn	ζ	K	Wn	ζ
5,000'	1.5	1.04	19	.29			
	2.0	1.14	21	.31			
	2.5	1.16	23	.31			
30,000'	1.5	1.05	14	.40		12	.5
	2.0	1.07	16	.42			
	2.5	1.08	18	.44			
50,000'	1.5	0.90	10	.53		7.2	.6
	2.0	0.91	10.5	.55		8.2	.45
	2.5	0.93	11	.57		9.2	.5
70,000'	1.5	0.67	7.1	0.7	.7	5	.6
	2.0	0.68	7.2	0.7			
	2.5	0.69	7.5	0.7			

Fig - 2

[redacted]

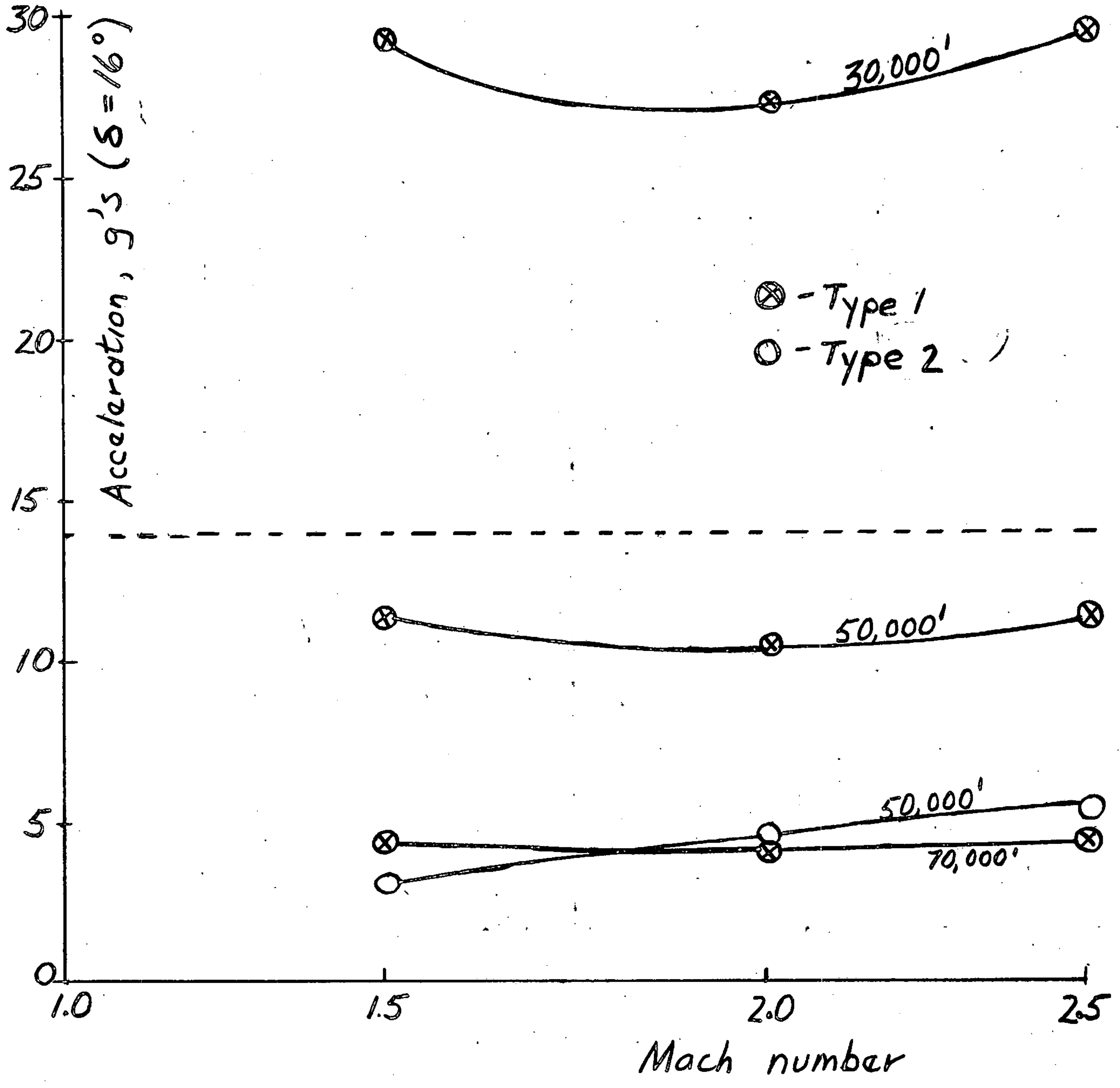


Fig. 3 - "g" Capabilities

[redacted]

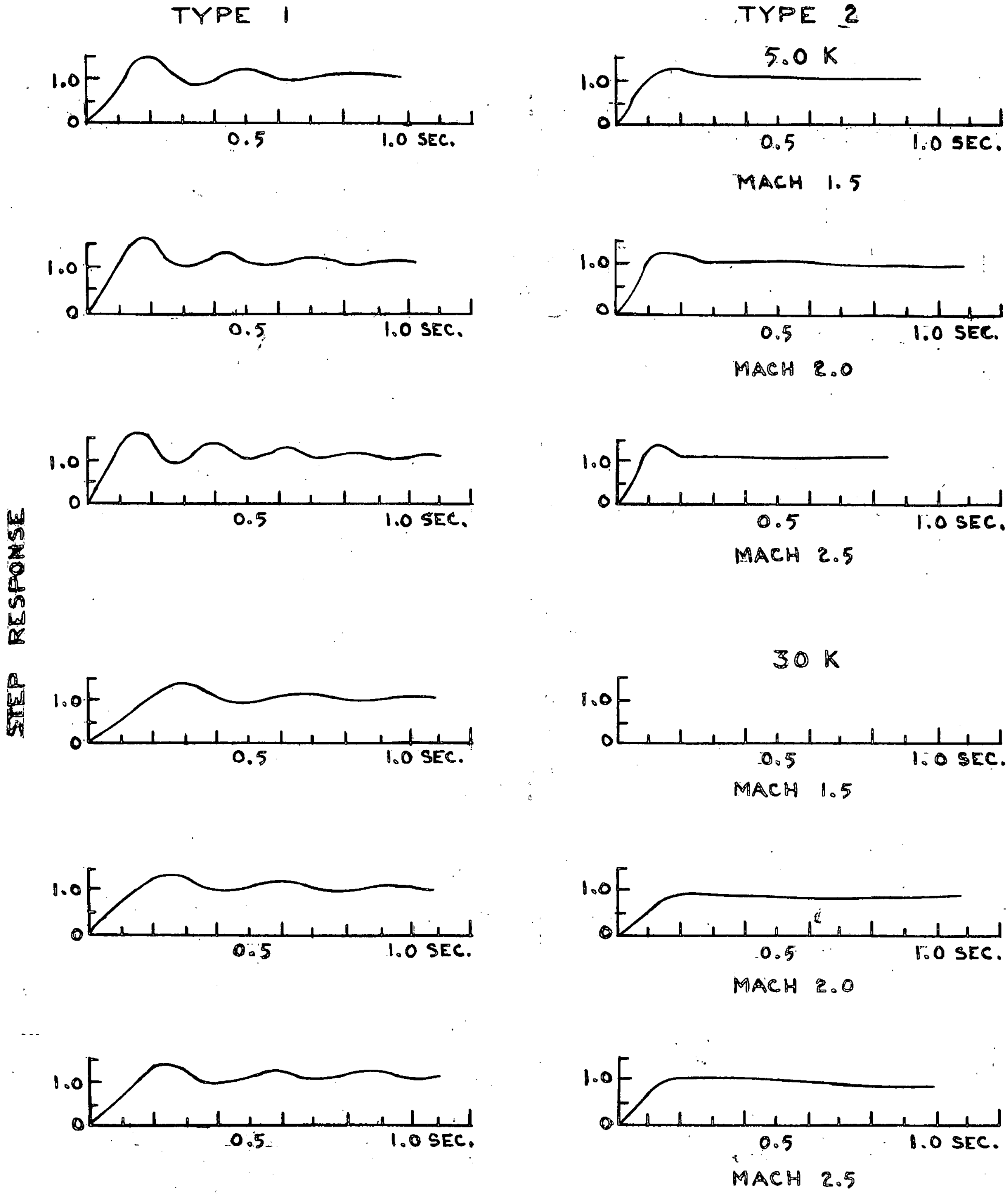


FIGURE 4

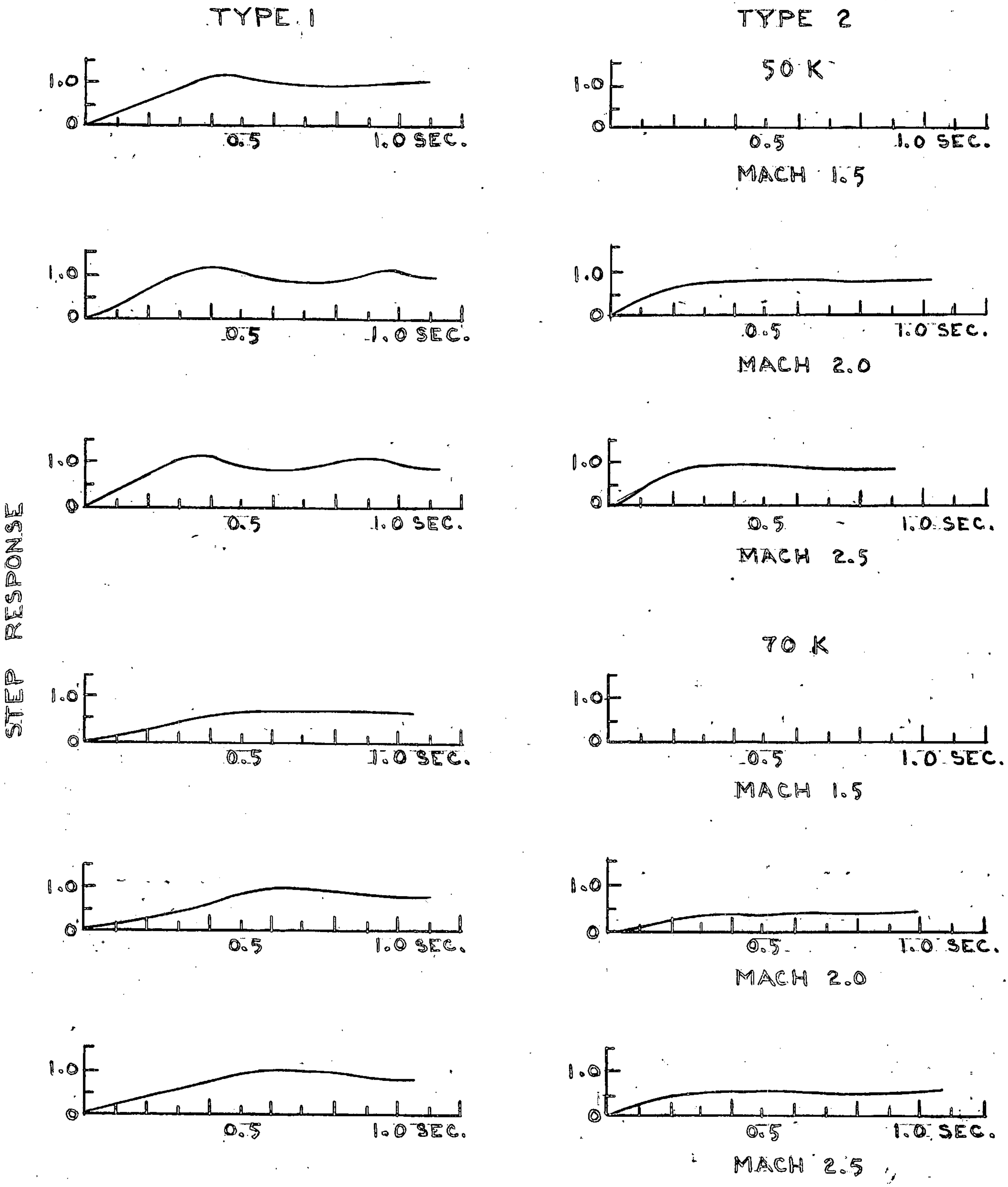


FIGURE 4
(CONTINUATION)

[redacted]

APPENDIX E

J.T. Baker

ELECTRONIC COUNTERMEASURE ASPECTS

PRELIMINARY SURVEY

INTRODUCTION

Although the CF-105 manned interceptor is the prime vehicle in the integrated weapon system under consideration, it forms only part of a complex fighting instrument which is almost totally dependent on radar and radio link equipment for its functional efficiency.

It is apparent, therefore, that countermeasures applied to impair or disrupt the efficient functioning of any of the various sub-systems of this composite weapon system could seriously reduce its effectiveness as an instrument of destruction.

OBJECT

The object of this paper is to examine electronic countermeasure techniques, both current and future, and to discuss the probable degradation of the proposed CF-105 Weapon System as a result of their use against this system under combat conditions.

BRIEF DESCRIPTION OF THE CF-105 WEAPON SYSTEM

This weapon system is based on the use of a manned interceptor, the AVRO CF-105, armed with Sparrow II or III air-to-air guided missiles.

It is intended that this combination of vehicle and sub-vehicle be directed by ground controlled interception equipment to the target zone, within which the interceptor's own air intercept radar equipment is capable of "locking-on" to the target. Information obtained from the A.I. radar is then processed within the aircraft, permitting the missile payload to be launched effectively against the target at the correct time.

In order to achieve this desirable tactical situation, early warning of the enemy's approach and subsequent movements within the defended area have to be provided by radar and other equipment located on the ground, which naturally forms part of the overall weapon system.

SUB-SYSTEMS VULNERABLE TO E.C.M.

It is evident that the following sub-systems are vulnerable to active electronic countermeasures such as jamming:

(i) Early Warning Search Radar.

[redacted]

(ii) Ground Controlled Interception Radar.

(iii) Ground-air/Air-ground radio link.

(iv) Air Intercept radar in aircraft.

(v) Missile Guidance.

(vi) Missile Fuze.

In addition, passive E.C.M. techniques could also be employed to disrupt or reduce the efficiency of these six sub-systems.

Such techniques include:

(a) The use of skin paint capable of absorbing radar energy.

(b) The use of "Window" or free balloons to create false reflecting surfaces.

(c) The use of "Blinkers" to disguise the size and disposition of the attacking formations.

(d) The launching of parasite decoys.

In the absence of defensive counter-counter-measure equipment, all six sub-systems are highly vulnerable to current countermeasure techniques aside from improved techniques likely to be in service use by the enemy during the period 1960-1965. However, counter-countermeasure techniques can be employed with a certain degree of success and work is being continuously carried out in this field to reduce or eliminate the effectiveness of known or projected enemy ECM equipment.

ACTIVE E.C.M.

(A) Jamming

As the name suggests, this simply consists of radiating a signal of sufficient strength to "drown" the return signal on which the defensive radar depends for measurement of range, angular position and other data. For this to be effective the enemy must previously know, or be able to determine, the frequency in use and carry apparatus capable of radiating a signal of reasonable strength on or over a band in which it lies.

The most elementary form of such E.C.M. equipment consists of a receiver which is used to detect and analize transmissions from the defence radar, and a tunable transmitter, together with a suitable aerial system, to provide the required jamming signal. However, this technique is of doubtful value against ground based early warning and GCI equipment where unrestricted space and abundant power supplies permit the use of diversity transmission and reception. Pursued to the limit, an attacking aircraft could not economically carry sufficient spot jammers to obliterate all signals.

[redacted]

Furthermore, the use of such apparatus tends to enhance the early warning capability of the defence radar and, while denying range and height measurements, it does not prevent measurement of azimuth bearing, from which position in two dimensions can be determined with complimentary bearing information obtained from an associated defence radar.

While the effectiveness of spot jamming against such installations is questionable, this technique can present serious problems if it is employed against airborne radar equipment where weight, space, and power restrictions tend to limit the amount of counter E.C.M. devices that can be installed. However, if exact operating frequencies are not known to the enemy, and the apparatus is used only at the last possible moment in the combat cycle, the task of effectively applying E.C.M. becomes difficult.

Although these spot jamming techniques, which have now been developed to the stage of being almost fully automatic, constitute a threat, advances in the art of barrage jamming are far more serious.

Comparatively recently, a travelling wave vacuum tube known as the "Carcinotron", was developed commercially in France. Unfortunately the design details of this tube were freely available to the world before its enormous potentialities as a backward wave oscillator with wide band capabilities, were realised by the western powers.

The advent of this tube has revolutionized the technique of barrage jamming in that it is capable of delivering comparatively high power while being electronically swept in a random fashion over relatively wide frequency ranges.

Considerable work has been carried out in the United Kingdom using these tubes, as a result of which, experimental airborne barrage jammers have been successfully demonstrated recently against the Canadian Pine Tree Line. Ref: "Operation Bracket".

Work in this field is progressing with the object of developing light-weight carcinotron jammers to cover all usable radar bands, and it is likely that jammers of this type will be available for service use by 1960.

While Counter-counter-measure techniques have been developed which frustrate wide band jamming directed against ground-based stations, there is no doubt that "Carcinotron" jammers constitute a serious potential ECM threat to radar equipment at the present time, and continued advances in the design of this type of ECM equipment will necessitate the application of great ingenuity if worthwhile C.C.M. apparatus, particularly for airborne use, is to be developed.

It must be assumed that the U.S.S.R. had free access to all available design data on the Carcinotron during the early stages of its development, and, having recognized its potentialities, they have pressed on with advanced development of the tube itself and barrage jamming apparatus based on it.

[redacted]

If this assumption is correct, the Soviet Union will probably have equipment capable of jamming the frequency range 500-10,000 mc/s in service use by 1960. By 1965 this frequency range may well have been extended to 30,000-40,000 mc/s.

(B) Generation of False Signals

This form of E.C.M. is somewhat more subtle than "brute force" jamming. In its active form, the technique consists of determining the frequency and other signal characteristics of the defence radar transmissions, and, after modification by means of suitable apparatus, re-transmitting a series of false return signals. These cause erroneous position information to be generated after reception by the defence radar, but are sufficiently 'genuine' as to not arouse suspicion.

ECM of this type presents a considerable threat to tracking radar equipments and if not successfully countered, could be the cause of many frustrated interceptions.

Naturally, equipment necessary to originate this form of ECM successfully is relatively complex and more space and weight consuming than straight-forward jammers, so it is not likely to be employed as commonly as other types. However, the application of an effective counter-countermeasure is rendered difficult by the basic ingenuity of the technique which lies in the fact that, if properly applied, it is not obvious.

PASSIVE E.C.M.

Effective ECM techniques are known which depend only on the power radiated from the defence radar for their operation.

Perhaps the most common of these practices, known as "Window" consists of releasing quantities of metal foil dipoles from the enemy aircraft. Relatively small patches of this 'chaff' can constitute a large equivalent reflecting area to radar transmissions, particularly if the dimensions of the individual pieces bear a suitable relationship to the wavelength of the defence radar transmissions.

This technique is not new, and is known to be practiced by the Soviet air force. However, until comparatively recently, its use has been limited to partial screening of the formation by the creation of false echoes when chaff is discharged into the slip stream. Under these conditions, radar carried by fighter aircraft or missiles, approaching from astern, could be temporarily disabled, but advances in techniques, particularly C.W. doppler radar, have greatly reduced the effectiveness of slip stream ejected "window". However, work is being directed towards the development of chaff projectors which will allow the attacking aircraft to sow patches of chaff ahead of them through which they will fly. While still ineffective against C.W. doppler radar, this practice will seriously effect pulse type radars, even if equipped for leading edge tracking.

[redacted]

One application of this technique could be the premature firing of proximity fuzed missiles and possibly the temporary disablement of AI radars and some missile seekers. However, an inherent drawback to window created by any means, lies in the fact that sophisticated speed measuring radar equipment can quickly detect that the echo it creates is not that of a relatively fast-moving target.

A technique that does produce echoes which have all the characteristics of those originating from an aircraft, involves towing a banner of reflective material astern of the aircraft, but the advantages of possible protection from attack have to be weighed against the inherent hazards of "target towing".

The release of free balloons covered with reflective material is another known practice which is worthy of mention. Released in sufficient numbers, these have a considerable nuisance value by originating misleading clutter which reduces the efficiency of defence radars.

Parasite decoys launched from an attacking bomber force are a refined version of the above-mentioned passive devices. These missiles are specifically designed to exhibit the reflective properties of bomber aircraft and skillfully used, can cause serious confusion to defence radars.

Another practiced means of misleading the defence is the employment of corner reflectors or blinkers by the enemy force. These devices produce marked increases in the reflected power, and if located skillfully, can yield very misleading information on the true positions of the attacking aircraft, as well as hamper the operation of AI's and seekers by means of the glint they produce.

A potentially serious passive ECM threat lies in the development of a relatively new technique based on the use of Radar absorbent paint. This coating, when applied to the skin of an aircraft, has the property of partially absorbing electro-magnetic energy which falls upon its surface. By using such coating material the effective reflective area of a given aircraft is noticeably reduced and consequently the effectiveness of defence radar suffers. Although research work in this field is still progressing, the art has been developed to the point where 25% to 50% reduction in maximum detection range can be anticipated during the period 1960-1965.

Coatings of this type tend to become more efficient at the higher frequencies, and for this reason airborne fire control radar operating on wavelengths of 10 cm or less may well suffer considerable degradation. A simple counter-counter-measure to this technique has not as yet presented itself, aside from the possible compromise of using lower frequencies and/or greatly increased power in the defence radar transmissions.

[redacted]

INFRA RED COUNTERMEASURES

Although somewhat outside the scope of this paper, it is felt that passing reference should be made to some techniques which have been developed to countermeasure seekers and fuzes whose operation is based on the use of infra-red detectors.

At the present time most infra-red devices of this type are actuated by the heat associated with the exhaust or jet stream of aircraft. To protect bombers from weapons equipped with I.R. detectors, considerable effort has been fruitfully expended to reduce these sources of heat, and to create hot spots some distance astern of the target aircraft.

It has been found that the exhaust stream from jet aircraft can be cooled sufficiently to countermeasure most known I.R. fuze and seeker devices currently in use with relatively small losses in engine efficiency. Further, by using chemical additives in the fuel, hot spots with desirable characteristics, can be created some distance down the jet stream rendering the aircraft itself relatively invisible.

CF 105 WEAPON SYSTEM V"S ECM

The foregoing is intended as an introductory discussion on the status of electronic countermeasures in general. It is now proposed to examine the ECM picture in relation to the CF 105 Weapon System in particular.

It must be borne in mind however, that great uncertainties shroud any estimates of the effectiveness of ECM and CCM as the art is constantly in a state of flux and depends to a large extent on the comparative ingenuities of research workers on each side of the Iron Curtain.

The overall weapon system will now be reviewed in relation to ECM vulnerability, sub-system by sub-system, in the following order:

Ground Environment

CF-105 Interceptor

Missile

GROUND ENVIRONMENT

This can be broken down into -

(a) Distant Early Warning or First Detection of Target

(b) Tracking of Target within defended area

(c) Communications to Interceptor in flight.

[redacted]

[redacted]

(a) Distant Early Warning

Initial warning of an approaching hostile force is not essentially a part of the integrated weapon system under consideration. However, passing reference is made to the Distant Early Warning Fence, because, if operating efficiently, it will forewarn GCI Stations and facilitate the acquisition of the raid as it approaches the perimeter of the defended area.

(b) Tracking of Target - G.C.I.

Once the hostile force approaches within maximum acquisition range of the G.C.I. radar, its position and height can be continuously plotted provided this equipment is not countermeasured.

The apparatus in current use, and also new installations which should be operational during the period 1960-65, will probably operate in P, L and S bands, all of which are susceptible to barrage jamming, window, and other ECM techniques. However, considerable doubt exists concerning the probability that such tactics would be employed except in the case of very large attacks, as the hostile force would be faced with jamming more than one installation at once, each possibly consisting of several frequencies, and would still not deny accurate information on azimuth bearing from each station. Aside from this, the use of active ECM at such an early stage of an attack would undoubtedly warn the defence of the enemy's presence, were they not already aware of it. For the same reason the use of passive devices such as corner reflectors and window are likely to be kept in reserve until the attack has developed to a more dangerous stage from the enemy point of view.

(c) Communications to Interceptor in Flight

These will probably consist of RT and data links in the VHF and UHF bands which can be jammed. However, if the frequencies of such links are constantly changed and transmissions limited to extremely short periods, the enemy could hardly rely on preventing vital information being passed to the interceptor when airborne. Furthermore, if necessary, it would be quite feasible to make use of relatively high power broadcasting stations for this purpose.

CF 105 INTERCEPTOR

Perhaps the most logical recipient for ECM would be the radar installation of the interceptor itself. Once a fighter is approaching the hostile force it is obvious to the enemy that its presence is known and that a critical stage in the attack has been reached.

Unimpaired, the interceptor's AI radar will, sooner or later, 'lock-on' to the target and continuously supply range and bearing information which will allow it to make a successful guided missile attack, and although the enemy could still avert disaster by countermeasuring the missiles themselves, it

[redacted]

[redacted]

does not seem probable that they would pass up an opportunity of aborting the attack. Attempts to apply ECM to the AI radar of the interceptor must therefore be expected.

The AI radar of the CF 105 could possibly be of the AN/APG-37 series operating in X-band, and if this is the case it is potentially vulnerable to a variety of known electronic countermeasures. In its basic form it is certainly vulnerable to barrage jamming, window, corner reflectors etc. However, in view of the extreme vulnerability of such apparatus, and its importance in the overall system, considerable effort has gone into the development of CCM devices and it would appear that by 1958 to 1960 the susceptibility of these radars will have been somewhat reduced. To this end circuits have been developed to permit pulse-edge tracking. Such circuits permit the tracking of the leading or trailing edge of the pulse depending on the direction of approach. This technique counters the use of window, provided it is dispersed astern, as it prevents the radar unlocking from the target echo and relocking on to the much stronger echo of the chaff burst. However, with advances in the dispensing of chaff which permit it to be sown ahead of the aircraft, leading edge circuitry is of little avail while the aircraft is flying through the cloud. Under these conditions inaccuracies of several hundred feet may exist in the target's true position if it takes evasive action while obscured.

In order to counter this advance in window techniques, AMTI for the search portion and doppler circuitry for the tracking portion of the AI radar have been under development, but, it is unlikely that AI radars of the pulse type will be capable of countering advanced window techniques before 1958-1960. Even then, the results may be very disappointing, and it would seem that the only real solution lies in the development of a highly sophisticated AI radar embodying advanced pulse doppler or possibly CW techniques.

The tracking portion of an AN/APG-37 AI set also appears vulnerable to blinkers. This ECM practice consists of employing suitable reflectors, or repeaters, to produce glint and thus mislead the radar concerning the true position of the target by causing an erratic motion of the apparent centre of the echo. Counter circuitry to deal with this form of ECM is, however, in advanced stages of development, although it is not yet clear that it will provide a complete solution.

Decoys used to saturate the defences could well constitute a serious hazard to interceptor A.I. effectiveness from 1960 on. These craft can be made to exhibit identical characteristics to a manned bomber, from the radar point of view, and for this reason there is no effective countermeasure to their employment aside from systematic destruction. It is anticipated that decoy-carrying aircraft will, in fact, form part of a hostile force on any serious mission and that such tactics may well achieve a 2/1 dilution of the defence if employed judiciously.

Barrage jamming of the AI radar is almost certain to be practiced unless an effective device is developed which will permit the interceptor and its missiles to home on the source. By 1960-65 it is probable that the Soviet Air Force will have carcinotron jammers covering X-band and possibly beyond, in service use, and so far no suitable countermeasure to wide band jamming of AI equipment has been perfected.

MISSILE

It is not yet clear which missile system will form the offensive armament of the CF 105 interceptor. For this reason both Sparrow II and Sparrow III systems will be examined in relation to possible electronic countermeasures.

(a) Sparrow II - Seeker

As far as is known, this system is based on the use of the AN/DPN-21 seeker. This pulse type equipment operates in "K" band with a peak transmitted power of 50 K.W. and as with the aircraft AI radar, such equipment is basically susceptible to most known forms of E.C.M. However, the incorporation of counter E.C.M. circuitry is a far more serious problem in the case of a missile seeker, owing to the extremely tight limitations on space, weight and power available for extra components.

While a fully active missile seeker offers great advantages in many aspects of aerial combat, its relatively high susceptibility to various forms of E.C.M. make the chances of reaping the fruits of these advantages doubtful. Unless elaborate counter-ECM devices can be incorporated, the successful guidance of a missile can be aborted by barrage jamming, window, the use of corner reflectors, repeaters and decoys just to list some of the known ECM techniques which will no doubt be used by a hostile bomber to protect itself from an imminent missile attack.

The degree to which E.C.M. considerations have influenced the design of these seekers cannot be assessed until more detailed information is available. If, however, serious consideration is to be given to the use of Sparrow II missiles, a thorough study of their susceptibility to E.C.M. cannot be recommended too strongly.

Sparrow II - Fuze

Sufficient details of the Sparrow II fuzing system are not at present available for any worthwhile comment on their performance in the presence of E.C.M.

(b) Sparrow III

Sparrow III guidance is initiated by means of a semi-active continuous wave seeker which offers marked advantages in overcoming some forms of E.C.M.

[redacted]

[redacted]

First of all, such a seeker is basically invulnerable to present and future window techniques. This alone is a feature which should not be overlooked. Aside from this however, capability against barrage jamming is being improved as well as a means to defeat such devices as corner reflectors and repeaters, both aircraft mounted and towed.

As far as is known, warhead fuzing of this missile is accomplished by use of target seeker signals fed to suitable circuitry. If this is the case, it would appear that successful fuzing in the face of E.C.M. is not beyond the bounds of possibility.

CONCLUSIONS

To prepare a realistic analysis of enemy ECM tactics likely to be encountered during the period 1960-1965 is not an easy task. It is even more difficult to forecast accurately the degradation which a given weapon, such as the CF 105 system, will suffer under prevailing ECM conditions even when these are known. However, during the period 1960-1965, the following countermeasure techniques should be available to the enemy and appear the most likely to be tactically employed against the CF 105 Weapon System.

Barrage jamming

Window or chaff in various forms

Use of decoy missiles

Use of blinkers

For small specific raids, it seems unlikely that attempts will be made to countermeasure G.C.I. stations by means of active jamming or even the use of chaff. The use of a limited number of decoys is possible with the object of distracting attention from the main force. However, a small force of this sort is more likely to depend on each aircraft defending itself as and when it is attacked.

A large near saturation raid may well be proceeded by area chaff-sowing craft and enter the defended zone using supplementary chaff and barrage jamming; decoys would probably be used to complete saturation. Individual aircraft will no doubt be equipped with chaff projectors, blinkers and barrage jammers for self protection against interceptor AI and guided missile radars.

It is felt that the weakest link in the CF 105-Sparrow II System lies in the susceptibility of the proposed A.I. radar, missile seeker radar and fuze to the above-mentioned forms of ECM. The equipments concerned appear to have little or no capability if subjected to advanced chaff techniques or barrage jamming.

It is suggested that a system using a combination of Sparrow III and the CF 105 with a sophisticated A.I., each equipped with jammer homers may suffer far less degradation, as the CW semi-active seeker should be virtually immune to chaff techniques and has development potential as regards freedom from other forms of E.C.M.

It is therefore considered that the potentialities of the CF 105-Sparrow III system using a sophisticated A.I. radar be thoroughly examined in view of the considerable E.C.M. threat which will exist during the period 1960-1965.

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APPENDIX M

F.W. Slingerland

OPERATIONAL STUDY OF AN AIRBORNE JAMMER HOMER

1. INTRODUCTION

On February 15, 1956, CARDE was asked by DRTE to investigate the tactical aspects of an airborne homer for use against airborne jammers, in order to determine the optimum specifications for the homer. In particular, CARDE was asked to specify the azimuth and elevation coverage of the homer, and to suggest procedures for its operational use. The homer is to operate in L band initially, and derives azimuth and elevation information by amplitude comparison of the signals received from two pairs of fixed antennae whose beam axes diverge from the nose of the homing aircraft.

The following is a condensed report on the investigation, which will be described fully in a forthcoming Operational Research Group Internal Memorandum.

2. ASSUMPTIONS

2.1 Jammer Characteristics

The jammer under consideration will operate in L band at a minimum power of 1 watt per megacycle with a radiation pattern approximated by a hemisphere below the jamming aircraft. Jamming may be continuous, responsive, or programmed.

2.2 Homer Range

The homer is expected to acquire the jammer at ranges up to 150 n.m.

2.3 Aircraft

The homer is to be fitted to the CF-100 and the CF-105. Fighter speeds will be approximately Mach .8 at 40,000 feet for the CF-100 and either Mach .9 or 1.5 at 50,000 feet for the CF-105. Representative targets are:

a) Bison or Badger type bomber with a combat speed of approximately Mach .85 at 40,000 feet.

b) Hustler-Hornet type, with cruising speed of Mach .95 at 60,000 ft. and single 20-minute dash capability of Mach 2 at 60,000 feet.

c) Hypothetical bomber-cruising at Mach 2 at 65,000 feet.

[redacted]

Targets (b) and (c) are not expected to appear during the operational life of the CF-100.

2.4 G.C.I. Information

It is assumed that a typical bomber formation is a more or less circular "bunch" of aircraft with overall dimensions between 25 and 100 n.m. It is estimated that G.C.I. can dead reckon the position of such a formation to about ± 30 n.m. and its direction to ± 30°.

3. HOMING PROCEDURES

Interceptor courses were plotted for three different navigation methods. All three begin as follows. The fighter locates a jammer on the homer indicator, turns until the jammer is dead ahead, and flies this course while watching for drift in the azimuth indication. From this common beginning, the three methods proceed as follows:

Method One:

The constant bearing course is flown until the azimuth indication drifts by 5°. The first turn is then calculated and immediately made. This turn is determined by dividing a reference number by the time required to build up the azimuth drift. The reference number is derived from a rough estimate of jammer range but does not require knowledge of jammer speed or direction. After the turn, the fighter again flies straight until the drift again builds to 5° once more makes turn. For these subsequent turns, the original reference number is multiplied by the amount of the previous turn in degrees over 100, and divided by the time required for the drift to build up. This continues until interception.

Method Two:

The fighter initially turns to put the jammer dead ahead, then watches the drift. When a drift of 2° is indicated (i.e. about the least perceptible drift above noise) the fighter makes a 10° turn. This procedure is followed until interception.

Method Three:

The first turn is calculated and executed in the same manner as Method One; however, subsequent turns are made when a drift indication of 3° is obtained, and all these turns are 10°.

The direction of the turn in all cases is such that the fighter leads the jammer (i.e. a drift to the right calls for a turn to the right).

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4. RESULTS

4.1 Trajectories

Following the above procedure, the trajectories of an interceptor and jammer were plotted for various combinations of the following parameters:

a) Interceptor speed, V_f
b) Jammer speed, V_t
c) Homer acquisition range, R_o
d) Initial angle off target track Θ_o
e) 30% errors in range estimation
f) Target evasive tactics.

Representative trajectories are shown in Figures 1 to 5. Figure 1 illustrates CF-105 homing trajectories against a subsonic bomber; Figures 2 and 3 those against a Mach 2 bomber. Figures 4 and 5 indicate the homer lead angle required during the flights of Figures 4 and 5.

4.2 Homing Accuracy

All homing methods produce minimum aircraft separations in the order of $1\frac{1}{2}$ miles. This figure would be increased somewhat in homing against multiple jammers. The ability to discriminate between jammers involves both human and technical problems and can be answered finally only by experimental homing flight trials. These are proposed for inclusion in Project Sprint.

5. DISCUSSION

5.1 Comparison of Homing Methods

It is evident from the trajectories that at low Θ_o there is little to choose between the various homing procedures. Method 1 is ruled out since it requires continuous calculation by the navigator, with no apparent advantage over methods 2 and 3. Method 3 is preferred to Method 1 for the following reasons:

a) It gives faster response at high Θ_o. This is particularly important since there is then a maximum Θ beyond which an interception is kinematically impossible. Slow turns onto a collision course cause Θ to increase beyond the kinematic limit. The navigation constant of Method 2 might be increased, but there is danger of oscillation at low Θ_o.

[redacted]

b) It provides some idea of target direction, since the initial turn is related to θ_0.

c) There is less tendency to chase azimuth rate noise caused by fighter yaw or shifts in the apparent jamming centre of a formation. Method 2 could possibly be improved in this respect by reducing the navigation constant, but this would retard its already slow response at high θ_0.

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are here stated with little or no explanation. They will be discussed in full in the O.R.G. Memo.

6.1 It appears possible to achieve a collision course on a group of jammers, and home to a position acceptable for missile launch.

6.2 Homing Method 3 is preferable to Methods 1 and 2.

6.3 Coverage

a) The long-range angular coverage of the azimuth antennae should be ± 65 az. by ± 10° el. An azimuth accuracy of ± 5° is acceptable provided azimuth indications are not range-sensitive, since the homing procedures are concerned more with azimuth rate than with azimuth.

b) The elevation antennae should have a long range coverage of ± 50° az. by ± 10° el. Elevation accuracy should be better than 1°. To minimise the effect of ground returns, elevation angles between 0 and -1° should be disregarded.

6.4 Homer Display

a) It is recommended that azimuth and elevation be displayed simultaneously on a C.R.O. This can be achieved with a single wide band amplifier and four local oscillators.

b) Manual gain control should be provided.

c) The navigator should be given an audio presentation of all modulation on the received jamming signals.

6.5 Flight Procedures

a) To reduce azimuth rate noise, homing should be carried out with autopilot set on "heading hold" during straight courses.

b) Turns should be executed at maximum rate.

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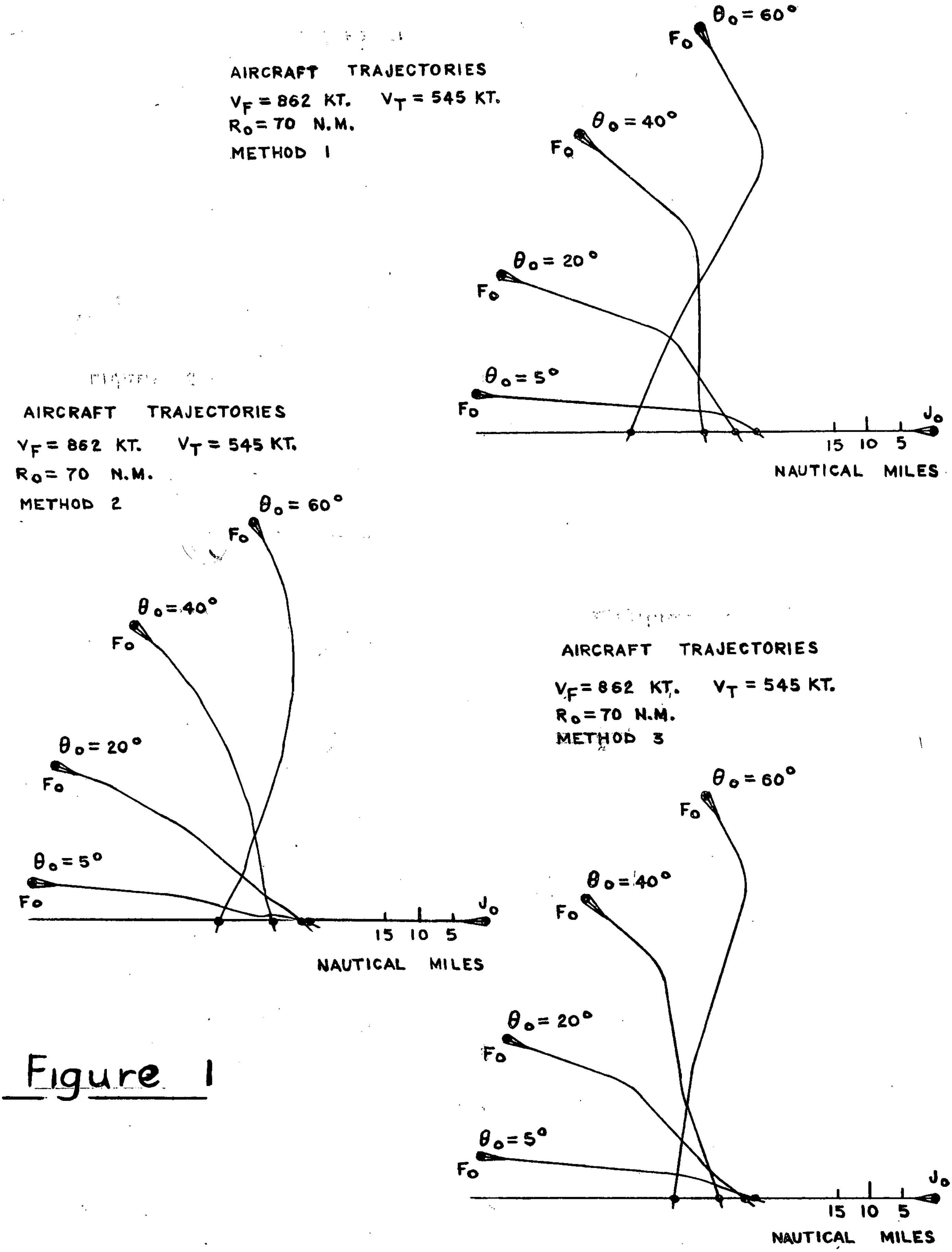


Figure 1

FIGURE 2

AIRCRAFT TRAJECTORIES

$V_F = 862$ KT. $V_T = 1150$ KT.

$R_0 = 150$ N.M.

METHOD 2

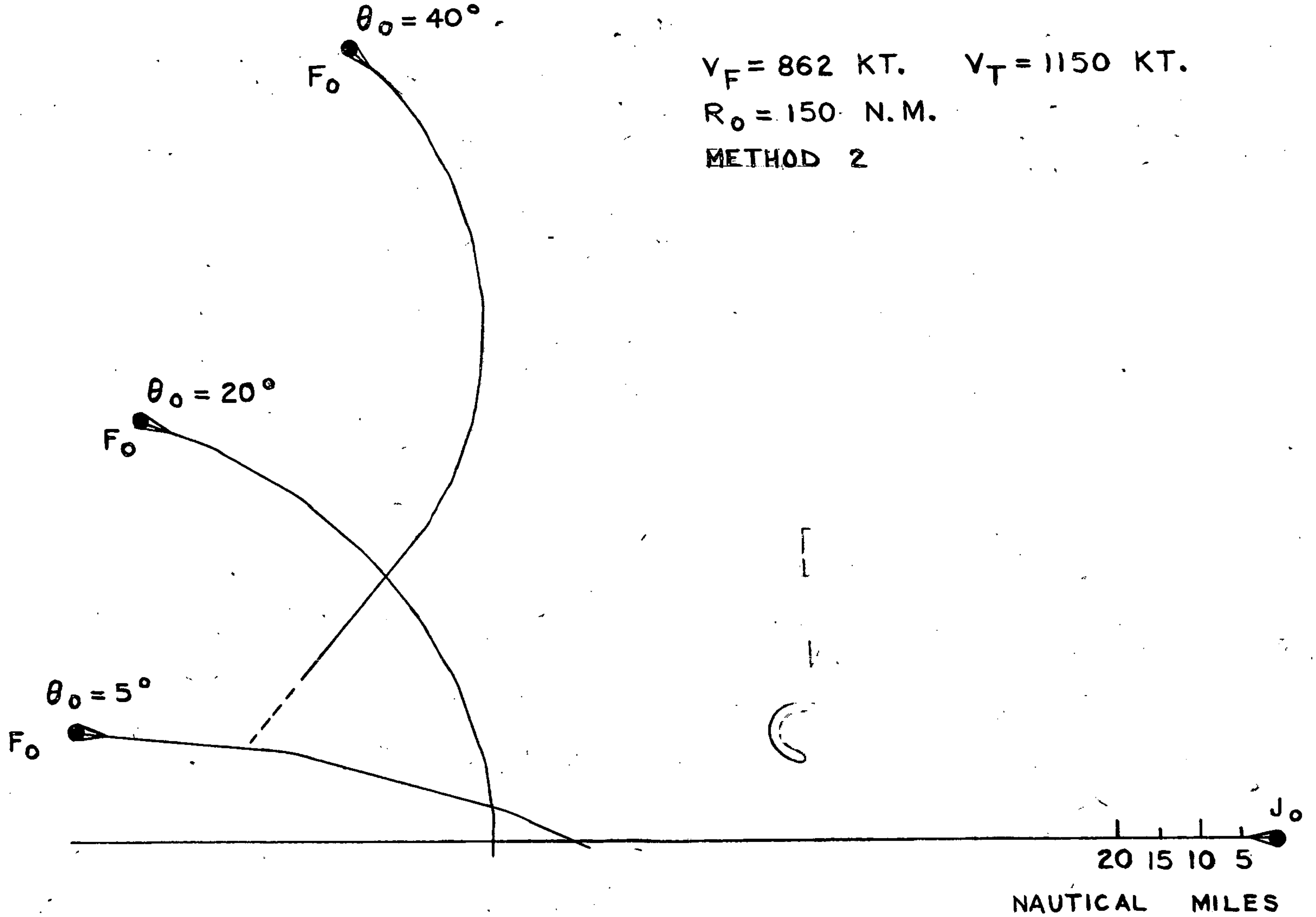


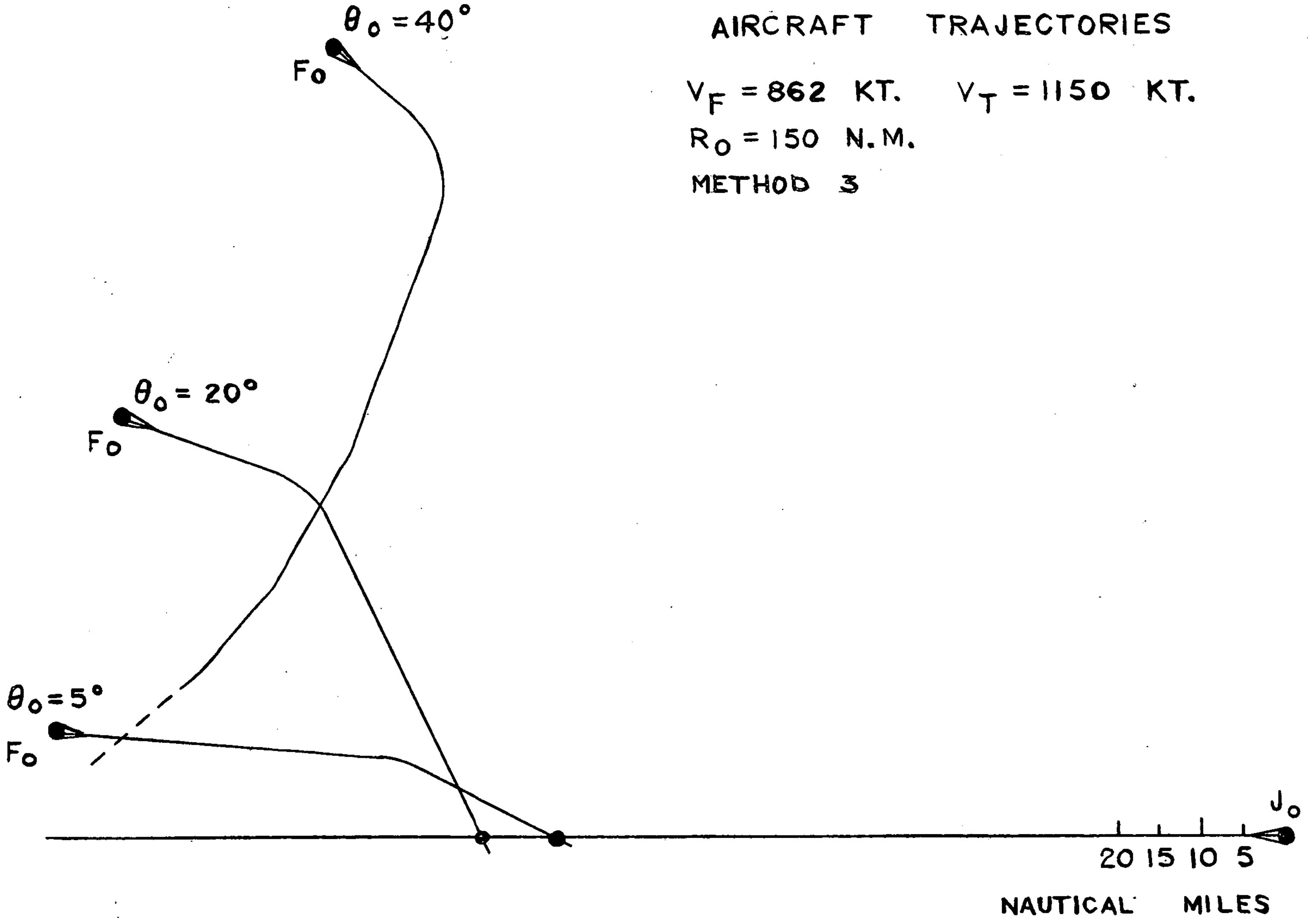
FIGURE 3

AIRCRAFT TRAJECTORIES

$V_F = 862$ KT. $V_T = 1150$ KT.

$R_O = 150$ N.M.

METHOD 3



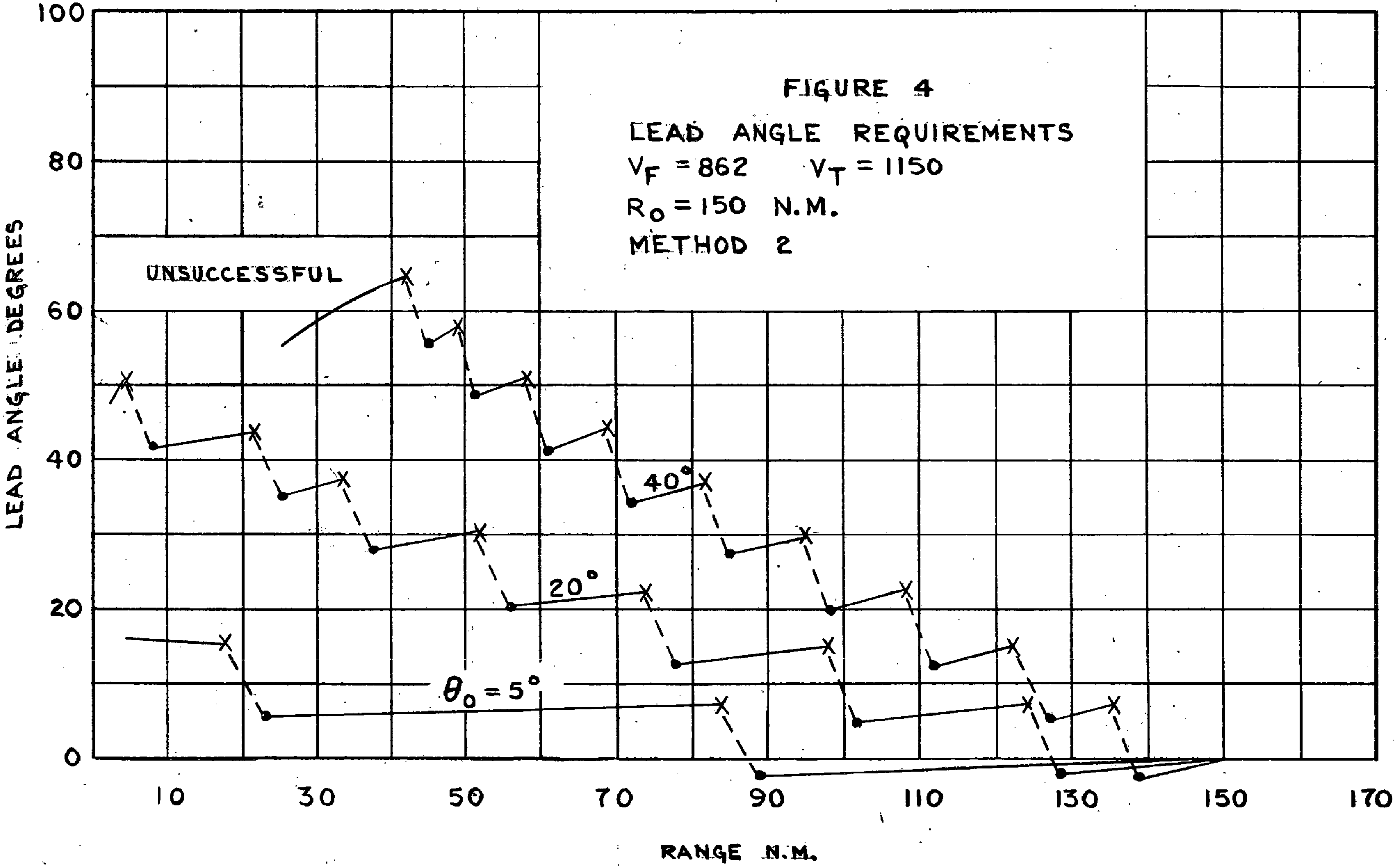


FIGURE 4

LEAD ANGLE REQUIREMENTS

$V_F = 862$ $V_T = 1150$

$R_O = 150$ N.M.

METHOD 2

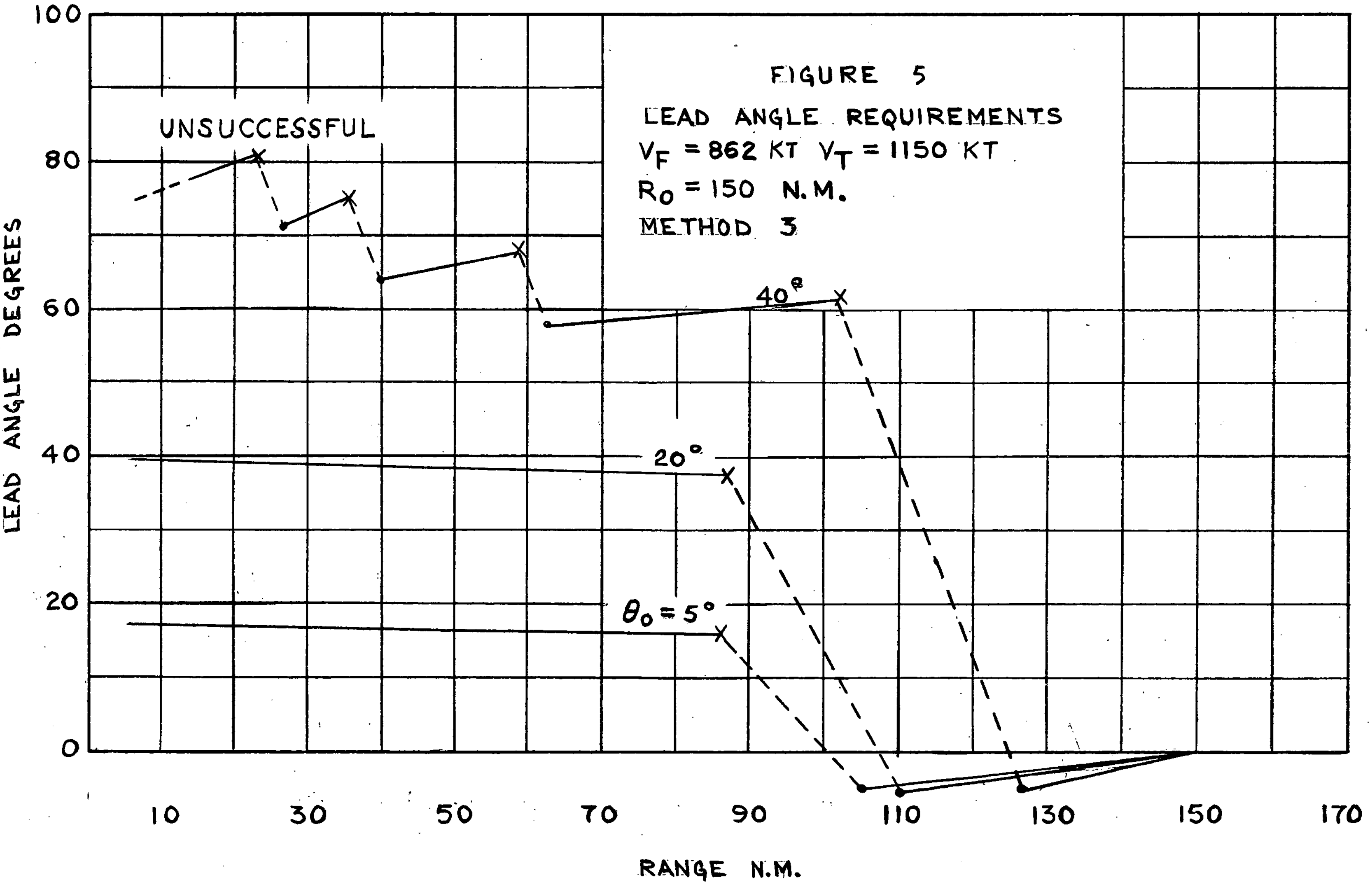


FIGURE 5

LEAD ANGLE REQUIREMENTS
$V_F = 862$ KT $V_T = 1150$ KT
$R_O = 150$ N.M.
METHOD 3

APPENDIX N

G. R. Walker

WARHEADS FOR GUIDED MISSILES FOR CF-105 FIGHTER SYSTEM

ABSTRACT

For the guided missile armament of the CF-105 fighter to attack heavy bombers, the ring (continuous rod) warhead appears to be the best choice, with the cluster (sub projectile) warhead perhaps equally good. Both are at present in the development stage. However, both show promise of being effective against most of the aircraft structure and of giving immediate kills.

Shaped charge warheads are not feasible because of size and weight limitations. Fragment warheads are effective only against small and widely scattered components, most of which are duplicated, and they give only slow kills except within the blast region. Blast warheads are less severe than fragments with respect to fuze requirements, but are less effective than ring or cluster warheads.

1. INTRODUCTION

The armament for the CF-105 fighter aircraft will include guided missiles whose main purpose is to defeat enemy bombers. In order to progress rationally with the overall design of aircraft and missile, it is desirable to foresee the optimum type of warhead likely to be available for these missiles. Unfortunately no clear-cut choice can be made; two types appear about equally promising. This document aims to discuss types which are being developed, to relate their design features to the assumptions stated below, and to summarize the factors which will ultimately be the basis of choice. It is not easy to deal definitively with this question because warhead types must be considered for use even though they and/or the associated fuzes, are still under development.

The following assumptions will be made:

(a) Missiles are required for service use soon after 1960, minor modifications and improvements being acceptable until 1965.

(b) Missile diameter is about 8 inches and weight is about 70 pounds.

(c) Missile speed at burst may be in the range Mach 1.15 to 2.5, depending principally on engagement distance.

(d) Target to be defeated is a medium or heavy bomber flying at 40,000 to 60,000 feet with speeds from Mach 0.85 to 2.5.

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A great fund of relevant data and expert opinions are contained in the report of the last tri-partite conference (Ref. 1). Unfortunately, however, there is available little information of more recent date on either of the two warhead types which seem most favorable for the CF-105 weapons system. The problem discussed in this Appendix is treated more fully in Ref. 2.

2. TYPES OF WARHEADS

The types of warheads considered promising for guided missiles are: fragment, blast, shaped charge, ring and cluster.

A fragmenting warhead consists of steel backed by explosive. On detonation of the warhead the steel breaks into fragments driven at a high velocity and capable of lethal damage to certain components of the target.

A blast warhead consists of explosive supported by a minimum weight of structural materials. It defeats a target, if exploded sufficiently near, by crushing large areas of structure or by gust (Ref. 1, p.203).

A shaped-charge warhead consists of a number of shaped liners, usually cones of aluminum, aimed to throw their jets into a limited solid angle about the missile. The particles from these jets travel at very high velocity, and damage aircraft structure by mass fragment-effect or by causing vaporific explosion.

A ring (or continuous-rod) warhead consists of long rods placed axially in two layers around the central explosive, and welded together at the ends. On detonation these unfold like a concertina to form one endless ring, which damages by cutting aircraft structure.

A cluster (or sub-projectile) warhead contains many sub-missiles which are ejected from the main warhead. These sub-projectiles are each separately fuzed to detonate a small explosive charge after penetration of the initial target skin, or a larger explosive charge during penetration.

3. FIRST GENERATION WARHEADS

The first generation of G.M. have fragmenting or blast warheads, since these could be designed to meet early completion deadlines. Their effectiveness is less by an order of magnitude compared with those now being developed.

For attack of an enemy bomber in the decade 1960 to 1970, the fragmenting warhead is effective against only a few components, all relatively small and widely scattered. Furthermore, on a heavy bomber all vulnerable components are duplicated and/or heavily armored. For example, at least 4 out of 6 engines or 2 out of 2 pilots must be killed to give an "A"* kill.

* - Category A damage. The aircraft will be out of control within 5 minutes.

[redacted]

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Both require a high level of fragment energy, as essential aircrew are given armor protection. Most other bomber components may be considered practically invulnerable. For example, fuel tanks will be covered to reduce effectiveness of fragment flash in causing fuel ignition, and air stream is effective in extinguishing fire in a well-designed wing, especially at high altitude. Fuel lines where possible, will run through the interior of tanks, or be located to take advantage of the protection of structural members.

For a fragmenting warhead, it is virtually impossible to get "K"** kills unless the target lies within the blast contour. Where the emphasis is on early kills, this contour can be enlarged by increasing the weight of explosive filling at the expense of fragmenting metal. For such a blast warhead the belief is widely held that the "K" kill probability is approximately equal to that of "A" kills for a fragmenting warhead of equal total weight. In addition to the bonus of killing earlier, the blast warhead requires a less sophisticated fuze, since the payload is effective over a much larger portion of the bomber.

** - Category K damage - The aircraft will fall out of control immediately.

4. SHAPED-CHARGE WARHEAD

A shaped-charge warhead appears hopeless for a missile of diameter 8 inches. The maximum cone diameter possible in each circular bank would be much too small and the space for explosive entirely inadequate, even if space were not required between cone base and missile skin to permit jet formation, and if space were not required for adequate initiation of each cone.

5. RING (OR CONTINUOUS ROD) WARHEAD

The ring warhead appears to be the best choice for the CF-105 weapon system. Successful trials have been conducted with warhead diameters from 5 to 24 inches, the smaller ones with solid filling and the larger ones annular. Rod sizes used are 3/16 x 3/16, 3/16 x 1/4, and 1/4 x 1/4, with lengths from 15 to 48 inches. Initial velocities have been in the range 3500 - 6000 ft/sec. depending on the charge-to-metal ratio.

The warhead consists of long rods placed axially in two layers around the central explosive. One layer is biased just the rod width, and all ends are welded together in pairs, inner and outer. On detonation the rods remain joined in an endless ring while unfolding concertina fashion, and give uninterrupted cuts through target structure. For defeat of a target element it is not necessary to achieve perforation by the ring element, but rather partial penetration accompanied by spalling and scabbing from the rear along with cracking through at the point of impact.

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A fuselage is defeated by a continuous cut half-way around, and this is relatively easy to achieve on modern bombers which use the stressed-skin type of construction, as there are no heavy spars but only light ribs close to the skin. Defeating the fuselage anywhere except at the extreme ends gives a "K" kill.

The wings of most modern bombers also have the stressed-skin type of construction, and are defeated by a continuous cut chordwise across either top or bottom. This is achieved as easily as on the fuselage for strikes which do not hit an engine or a wheel well cap, provided only that the direction of approach (i.e. warhead burst) is not in or near the plane of the wing. However, the possibility cannot be ruled out that some wings will have the B-29 type of construction, with one heavy and one lighter spar beam to carry the load. These must be severed (at least 75 percent) to cause wing failure. The B-29 wing is defeated if incidence is near normal by a 1/4-in. square section at 4000 ft/sec. Defeat of a wing anywhere within the outermost engine gives a "K" kill.

The following approximate figures indicate roughly what might be expected for a ring warhead of the CF-105 weapon system:

Diameter	8 in.
Weight of rod	35 lb.
Weight of H.E. filling	25 lb.
End fittings, etc.	10 lb.
Total weight	70 lb.
Rod size	1/4 x 1/4 in.
Rod velocity, initial	4500 ft/sec.
Length of ring, full	175 ft.
Radius of ring, full	28 ft.

In practice the ring from such a warhead breaks into rod pairs on attaining a radius of about 20 feet. However, these rod pairs will still be oriented to form a broken circle and will possess appreciable lethality out to about 40 feet or more.

An alternative warhead might be similar to the above, except as follows:

Weight of rod	37 lb.
Weight of H.E. filling	23 lb.
Rod size	3/16 x 3/16 in.
Rod velocity, initial	4000 ft/sec.
Length of ring, full	330 ft.
Radius of ring, full	52 ft.

[redacted] [redacted]

This alternative would be preferable for the attack of bombers with stressed-skin wings. It may even be attractive for the attack of bombers with B-29 type wings, as the extra effectiveness against fuselage would tend to compensate for lack of lethality against wings. The lighter rod would appear especially attractive if guidance errors are large, if most attacks are made such that the missile closes on its target within 60° from ahead or astern, and if the target is a supersonic bomber with long fuselage and short tough wings.

The fuze required for a ring warhead is similar to that of Velvet Glove, a V.T. fuze with a constant forward-looking angle of 70 to 80 degrees. The delay device need not be complicated as the ring is effective almost anywhere on the target.

6. CLUSTER (OR SUB-PROJECTILE) WARHEAD

For the CF-105 weapon system, the cluster warhead shows promise as an alternative, should the ring warhead fail to live up to expectations. A cluster warhead contains many sub-projectiles, each separately fuzed to detonate a small explosive charge after penetration of the initial target skin, or a larger explosive charge during penetration.

For a warhead of diameter 8 inches, it is practical to use a stabilized sub-projectile to achieve penetration, hence only about 1.5 pounds H.E. filling is required. About 14 to 18 sub-projectiles could be assembled in one warhead. They are ejected at a velocity of only one hundred feet per second, more or less, and at a small angle to the missile axis; hence the main fuze must function at a great distance before reaching target intersection to allow the sub-projectiles to spread out sufficiently.

Such sub-projectiles will penetrate an 1/8 inch stationary 24 ST aluminum target plate at 80 degrees from the normal. With a moving target the direction of penetration would be the relative velocity vector, which is equivalent to penetration by a yawed projectile. For supersonic targets the angle of "yaw" will cover a wide range. To penetrate the wing skin of a modern stressed-skin bomber (for one typical bomber it varies from 3/16 to 5/8 inch) at large angles of attack by a "yawed" projectile is not an attractive proposition. Fuze design for such difficult penetration conditions is also a major problem, and has not yet been achieved. However, some progress is being made in providing stabilized sub-projectiles with a D.A. (direct acting) fuze which has a suitable delay.

Design of a fuze for the cluster warhead has not yet been undertaken, as far as can be ascertained.

7. CONCLUSIONS

Two types of warhead show about equal promise for the guided missile armament of the CF-105, ring (or continuous-rod) warhead, and cluster (or sub-projectile) warhead. Both seem entirely feasible, with the reservations noted below. For both types most "A" kills are also "K" kills.

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Both types are more effective against a wing of the B-47 type as compared with the B-29 wing, although the thicker skin of the B-47 wing increases the penetration difficulty of the sub-projectile, especially for "yawed" sub-projectiles. For attack at large angles (to the normal) satisfactory performance has not been proven for either type. The lethality of the cluster falls off at high altitude, whereas that of the ring presumably does not. The fuze for the ring warhead is in existence (Ref. 1, p.309) whereas that for the cluster is in the earliest stages of development. However, the cluster is much less sensitive to fuzing errors. For the cluster there is a bonus lethality if the target aircraft is part of a formation; a sub-projectile is just as lethal over large or small distances, and the relatively small chance of hitting a more distant aircraft is compensated by the presence of several aircraft targets. The ring is especially effective against supersonic aircraft if they have long fuselage and short, tough wings. Sub-projectiles would be relatively less effective if foamed-plastic or other fillings are adopted, as intimated in Ref. 1, p. 202.

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