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ARROW WEAPON SYSTEM CO-ORDINATING CONTRACTOR REPORT No. 10 THE MATHEMATICAL MODEL

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ARROW WEAPON SYSTEM

CO-ORDINATING CONTRACTOR

REPORT NO. 10

18 SEPTEMBER 1958

THE MATHEMATICAL MODEL OF THE ARROW 2 WEAPON SYSTEM

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AVRO AIRCRAFT LIMITED

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THE MATHEMATICAL MODEL OF THE ARROW 2 WEAPON SYSTEM

FOREWORD

A/AWS has stated that a requirement exists for a mathematical model of the operation of the Arrow 2, for the following purposes:-

1. To determine the theoretical potential of the Weapon System,
2. To indicate suspect areas and influence the flight test program accordingly,
3. To form a basis for evaluation of the Weapon System.

The following terms of reference for an immediate study program have been laid down:-

a. Single interceptor versus single target will be considered, multiple interception studies being considered too complex for the initial program,

b. The model will commence at target acquisition by the ground environment,

c. The model will terminate at the completion of the missile phase,

d. Both clear and ECM environments will be considered, the greater emphasis being placed on ECM,

e. The results of the Arrow Weapon System demonstration and the predictions of the model shall be shown to be in statistical agreement,

f. The 1961 weapon system shall have priority over studies of the ultimate system.

This document sets out a program of digital and analog simulations to meet these requirements.

It may be noted in respect of item (d) that ECM is expected to be the normal environment by 1961. It is appreciated that the specification to which Astra I was designed did not state this but merely required the provision of

FOREWORD (Cont'd)

certain CCM facilities. However, to be realistic the greatest weight must be placed on ECM conditions in evaluating the system, and it is the view of the RCAF that clear environment is of interest in this program for development work only.

INTRODUCTION

The program proposed here relates to the Arrow 2 weapon system which comprises:-

Arrow 2 airframe

~~Astra I airborne radar and integrated electronic system~~ (out)

Iroquois Series 2 engines

~~Sparrow 2 Mk. 1~~ or Genie Armament

A ground environment, which should initially be representative of the conditions that may be expected at Cold Lake for the test program.

Early phases of the program will consider the version of the airborne system that will enter service in 1961, and by postulating a ground environment that is capable of being reproduced or simulated at Cold Lake, direct comparison can be made between model and test results. The work will be extended later to cover the fully developed Arrow 2 system and a ground environment that is more representative of the actual operational system. The program will not include assessment of major developments of the system, although it will be possible to adapt the model to cope with such developments. At any time that an assessment of this kind appears desirable, A/AWS will initiate a request to the contractors, who will then discuss it between themselves and present cost estimates. Where necessary, specific contracts will be raised to cover these additional studies.

INTRODUCTION (Cont'd)

The Model will be constructed basically from studies which will be used in the normal course of systems development. However, some extensions and additions to the existing and presently planned studies will be required to meet the objectives of the program. It is considered that this should be essentially a contractor program; however, it is clear that inputs from government agencies will be needed for setting up certain phases of the model and for supplying the values of a number of parameters throughout the program, and that the program must be monitored by a government agency. It is generally accepted that CARDE should be this agency. Mutually acceptable details will be arranged between A/AWS, CARDE and the contractors. It is further considered that CARDE should participate in the program by carrying out the associated weapon lethality studies.

The program envisaged consists of a group of ten studies which are linked together in suitable combinations under the general heading of study no. 11, by matching of outputs and inputs. A breakdown of the program is given in Table I at the end of this document. Each of these studies is an entity in itself and most of them will be used as independent tools for the development and optimisation of various components of the weapon system. The prime motivation for linking the studies in the manner proposed is to fulfill the purposes of the mathematical model as stated in (1)(2) and (3) in the foreword.

It is essential that consideration be given throughout the program to the effects of weapon system component reliability. This will probably be more effectively introduced within the individual studies, by applying factors to account for the reliability of the components required to function during the phase, rather than by using overall factors applied to the final answers.

It is proposed that the program be extended to include a real-time simulation of the entire system which will integrate the essential features of the other studies into a single model. This will enable human operators to be introduced into the complete system and will also allow the investigation of problems, such as the effect on system capability under ECM conditions of extending GCI guidance into the A.I. phase. This study is complementary to the rest of the program and is shown as such in the table. Its main purpose is to check the results of the evaluation carried out using the component studies; it is not an alternative approach.

The following advantages accrue from adopting the "block" approach to the mathematical model.

(i) Use may be made of programs which are primarily intended for systems development. In several cases these programs are either completely written or nearly so, and it is hoped that several others may be derived from these by relatively simple modifications.

(ii) Considerably increased flexibility is obtained, due to the greater ease of making changes to the model.

(iii) Since parts of the model are already in existence results will be available with the minimum delay.

(iv) Economy of operation is achieved by running parts of the program only, when specific features of the system are to be studied. Further economy stems from the ability to combine the results of several modes of operation of the system in one phase with those of several modes in another, without

INTRODUCTION (Cont'd)

(iv) having to re-run each phase in each combination.

(v) The breakdown results in the program being brought within the capacity of the computational equipment that is expected to be available, while still retaining a level of detail commensurate with the requirements.

In the discussion of the items in the program, given below, the outputs required from studies which feed into other parts of the program are set out in some detail. As the program progresses it may become apparent that certain of the parameters quoted are unimportant. In this event these parameters may be omitted from the presentation of results, subject to discussion and agreement. The statement of details as given below should be taken as indicative rather than contractually binding. In certain cases the requirements for compatibility between the component blocks of the model will necessitate additional information being supplied from programs which are covered either by existing contracts or by contracts at present under negotiation. In these cases it may be necessary to revise the contracts to provide for this.

A typical list of topics on which information will be supplied by government agencies is given in Appendix A. Need-to-know in these areas of analysis will be arranged where required to further the effective implementation of this proposal. To facilitate program planning proceedings will be instituted immediately to enable this information to be released as soon as possible.

Wherever possible in this program the results of studies carried out by government agencies should be used. In particular CARDE's evaluation of the AI phase in the automatic mode should be examined to determine the applicability of the results.

ARROW MID-COURSE GUIDANCE STUDIES

1. Automatic Operation Under Close Control

This study will utilize a model, at present being programmed at Avro for digital computation, in which the GCI radar is simulated by random sampling techniques, and the midcourse guidance calculated according to the procedures used by SAGE. In the present model the target tracking processes are based on clear environment.

For the initial phase of the program, in which the validity of the model is to be demonstrated by correlation with the results of the integrated flight test program, it will be necessary to replace the ground environment in the model by "Test Environments" which are capable of being reproduced at Cold Lake. These environments will be postulated by Avro, after consultation with the RCAF, and should be such as to require the minimum of modifications to the present model, while still being realistic in terms of the capability of the facilities of Cold Lake. However, it is appreciated that extensive revisions to the present model may be necessary to introduce the environment corresponding to the ECM situation.

Once the validity of the model has been established by direct comparison with flight tests, it can be put to its intended use. This is to determine the capability of the weapon system against actual enemy targets, under operational conditions. For this phase of the program the postulated test ground environments will be replaced by operational environments which correctly represent the procedures expected to be used in all modes of operation. It should be noted that this may not necessarily be SAGE.

1. Automatic Operation Under Close Control (Cont'd)

The study requires as input, tables of expected A.I. detection range as a function of aspect angle for eaoh target considered, and the corresponding range of interceptor-target course differences from which successful attacks may be made. These tables will be obtained as output from the A.I. phase studies to be described below, and are used in the present program to determine whether a particular run results in success or failure. Interceptor performance will be calculated, using the basic equations of motion, from stored performance data. Engine thrust will be derived initially from data supplied by Orenda Engines Ltd. Drag will be initially based on best estimates. Both will be modified in accordance with flight results as they become available.

For each set of initial conditions a large number of runs must be carried out, since the program makes considerable use of random sampling to simulate quantities whose exact values are indeterminate. The probability of successful attack is then derived by statistical analysis of the results.

The program as written corresponds to the final version of the complete system, in which all the automatic features are installed and functioning. Many of these features will be absent from the system that will enter service in 1961 and from the system to be tested at Cold Lake, and it is a matter of great urgency that the model be adapted to enable these systems be studied as soon as possible.

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The study of the test system will constitute the first part of study no. 2 and will be started as soon as full information is available.

Output:- (a) Distribution of target and interceptor tracking errors - position and velocity.

(b) Distributions of the interceptor placement errors relative to the target.

(c) Distributions of the interceptor heading errors relative to the desired approach to the target.

(d) Probability of successful attack.

(e) Analysis of various interceptor and ground environment quantities of interest in systems development studies.

2. Manual Operation Under Close Control

(i) Interim System (1961)

In study no. 1 the interceptor is assumed to be steered automatically by the AFCS coupler, acting on heading commands received via data link. Approximations are made to simulate the properties of the automatic control system.

The 1961 system will have neither data link nor automatic steering, and other automatic features will be absent from the airborne system and from both test and operational ground environments. The heading commands generated by the ground computer will be relayed to the pilot verbally by the intercept director. The pilot will then attempt to correct the heading by control stick steering. The approximations used in No. 1 for the response of the aircraft to heading commands will not apply here,

(i) Interim System (1961) (Cont'd)

since the pilot's response characteristics are not the same as those of the AFCS coupler. The delays in the system, being due to different causes, will also be different.

To enable this mode of operation to be studied it will be necessary to conduct simulator studies to measure pilot response over a wide range of conditions. In this way it should be possible to obtain suitable approximations to account for the aircraft's behaviour during heading corrections, and use may then be made of the model developed for study no. 1 with suitable modifications to account for changes in the mode of operation.

Again, the initial emphasis will be placed on evaluating the system under test conditions for comparison with the I.F.T.P. The output required is the same as for study no. 1.

(ii) Final System

In later work using this model it will be desirable to consider the fully developed system, in which data link and other automatic features are fitted, but using manual steering. For this type of operation the required heading, as computed by the ground environment, will be displayed to the pilot, who will then use control stick steering to correct the interceptor's course.

To simulate this condition, the same model will be used as for study no. 1, but similar approximations to those introduced in 2 (i) to account for pilot response will be used in computing the interceptor path.

Again the output is the same as for no. 1.

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3. Midcourse Guidance - Broadcast Control

In this mode of operation the guidance commands are calculated in the air by means of the navigation computer. The ground environment supplies data on the position, heading and velocity of the target. The interceptor's own position coordinates relative to a common frame of reference are subtracted and the course required for collision with the target is computed. Complete details required for writing a model will be made available; it is anticipated that some parts of programs No. 1 and 2 can be carried over, and that those parts which do not apply directly can be used after fairly simple modifications.

Steering in this mode may be either manual or automatic, and both must therefore be considered.

The output of the study will be similar to No. 1.

A.I. PHASE STUDIES

4. Digital Simulation of Automatic and Manual Operation

It is anticipated that both automatic and manual modes of operation will be studied by means of a digital computer program which has been written and programmed at Avro and will shortly be ready for use. This program applies directly only to the automatic mode, since it is based on the rigidly defined steering properties of the AFCS coupler. However, it is thought that by making a study of the responses of a human pilot under widely representative conditions, it should be possible to derive an "equivalent" coupler, and in this way the program may be adapted for studying manually steered attacks. This study of human response characteristics will be described below under study no. 10.

The approximations implicit in the study, insofar as they affect inputs required from other parts of the program, are enumerated below.

(a) System Response

A very simple approximation has been used for this which will be the output of studies not included in the program.

(b) Radar Ranges

Several contours are input to the program to define various aspects of radar performance. These may be functions of aspect angle, closing rate, altitude differential, radar scan pattern and ECM type, where present. The use of these ranges in the A.I. phase program implies that exact ranges for detection, lock-on, etc., can be defined. In fact, these events have varying cumulative probabilities of occurrence with range, and the ranges quoted are defined by a specific choice of probability.

(b) Radar Ranges (Cont'd)

(i) A.I. Detection Defined for the clear environment and for all ECM types.

(ii) A.I. Lock-on In the clear environment this will normally occur at a given delay after A.I. detection. Information on this delay will by supplied by RCA. In ECM conditions A.I. lock-on is not necessarily related to A.I. detection and study No. 6 below will specify a clear range contour, as a function of the ECM type, where the interceptor can lock-on regardless of jamming. Study No. 6 will also define the steering procedure, if any, to be used in each environment between detection and either lock-on or the selection of the best CCM mode.

(iii) Loss of A.I. Lock-on After A.I. lock-on, the relative motion of the target and interceptor may be such that an aspect is reached where the range exceeds that required to maintain lock-on. A hysteresis effect is expected so that this range considerably exceeds the lock-on range. This effect has been incorporated in the program and a separate study by RCA may be required to provide this data.

(iv) Missile Seeker Lock-on Output of Study No. 7.

(v) Cumulative Probability of Detection An analysis may be introduced which will allow the variation of cumulative probability of target detection with range to be taken into account in evaluating the conversion probability.

The outputs of studies nos. 7 and 8 are input to this study as the criteria for the success of an attack. When the computer program is used for a 'multiple run', for each course difference it will find the limiting aspect angles on a given detection contour from which successful attack is possible.

The detection contour is automatically varied up to the maximum A.I. range and down to the minimum missile range, so that the limiting aspect angles form a marginal conversion boundary. The 'multiple run' facility will produce these boundaries for initial course differences all round the clock in one computer run.

The given detection contour corresponds to a certain cumulative probability of detection, as already stated, and a probability of successful conversion from this detection contour may be defined as the probability of placement by the midcourse guidance in the region between the limiting aspect angles, the success region. Detection contours corresponding to other cumulative probabilities may be placed on the marginal conversion boundary to give further conversion probabilities from the midcourse study, and by associating each conversion probability with the cumulative probability of detection having occured at that contour, the conversion probability for one approach lane is found, independent of where target detection occurs.

(c) Manual Override at Limits of A.I. Scan

Perfect tracking of the target by the A.I. antenna is assumed, until the maximum antenna look angles or angular rates in either plane of freedom are exceeded, when the A.I. radar loses the target. It is assumed that

(c) Manual Override at Limits of A.I. Scan (Cont'd)

if the spot representing the target approaches the edge of the navigator's 'B' scope the pilot will override the automatic steering and attempt to keep track of the target through verbal commands from the navigator, and this has been simulated in the program. Study No. 10 will be used for a quantitative check of this.

(d) Steering Mode

Several steering modes are provided in the program and two mechanisations for the snap up attack. The basic steering mode in the clear environment is lead collision. Under ECM conditions a CCM mode will be provided, the inputs required from study No. 6 being:

(i) The sequence of modes for steering without range information,

(ii) The value of range to be used in fixed range steering modes, and

(iii) The radar clear range.

(e) Passive Ranging (Range Keeping)

In the CCM mode the weapons may be released on range information provided by passive ranging methods or they may only be released when the radar clear range has been reached. Passive ranging however may be substantially in error when target manoeuvres are present. No simulation of the accuracy of passive ranging is presently included in the program, the true range being used.

Output:- (a) Success domains of course difference against aspect angle corresponding to various combinations of

Target type, speed, altitude and evasive manoeuvre
Interceptor speed and altitude
A.I. lock-on range
E.C.M.

These may be input to the midcourse guidance studies, nos. 1, 2, and 3.

(b) Various items of interceptor performance as required for system development studies.

5. Analog Simulation of Automatic and Manual Operation in Clear Environment

In this study system noise, radome aberrations, random computer errors and target scintillation effects will be introduced into a model in which the dynamic motion of the aircraft and the feedback characteristics of the electronic system are represented and inter-related.

The purpose of this study is to check the effects of these quantities, which, particularly in respect of their interrelation, are more suitably examined by analog rather than digital methods. The simulation will be used to study the variation in the "success-domains" determined by the digital program No. 4, due to these effects. Part of study no. 6 below, will serve the same purpose for the ECM environment.

Programs No. 4 and 5 and are considered to be complementary and not a duplication of effort. The determination of success domains is a process of trial and error in which the initial relative geometry of interceptor and target is varied systematically to find the limiting conditions from which an attack may be successfully initiated. To carry out this process for all the cases that will be required, in terms of target type and altitude, evasive manoeuvre, ECM, interceptor speed and altitude, initial course difference, type of attack, etc., will be a major undertaking. To attempt to do it by means of a program in which random variations are permitted, would increase the magnitude of the task many fold, due to the necessity for statistical sampling.

5. Analog Simulation of Automatic and Manual Operation in Clear Environment (Cont'd)

On the other hand it is not sufficient merely to use the digital analysis without a parallel study of the effects of quantities which are either omitted or approximated in study no. 4.

For these reasons it is considered that both digital and analog studies of the A.I. phase are essential parts of the program.

It is not possible at present to specify the output of the analog simulations, since the inputs that may be required to other parts of the program will be largely determined by a comparison of the digital and analog results.

6. Analog Simulation of Automatic and Manual Operation in ECM Environment

It is clear that in an ECM environment the automatic tracking facilities of the Astra system must be largely abandoned and the decision-making capabilities of both members of the crew utilized as fully as possible. This study should therefore be conducted by use of a simulator in which the loop is closed by human operators. Statistical analysis of a suitable number of trials may then be combined with a theoretical approach to indicate the optimum procedure and the expected results of its application. It is important in carrying out the simulator program to include the use of flight test personnel actively engaged in the Arrow program.

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A detailed proposal has been made by RCA for a study requiring 120 man-months of effort. This will cover all expected types of ECM. The output of the study that is required for use in other parts of this program is given below. Since the primary purpose of the study was for system development, additional studies beyond the scope of the original proposal will be required.

In later phases of the program this study will also be used to provide a check on the results of the digital evaluation of the A.I. phase under ECM conditions, as indicated in Study No. 5.

Output:- (a) Conditions under which both range and angular information may be obtained.

(b) Accuracy of information under all conditions, for all types of ECM likely to be encountered.

(c) When ECM is used continuously from long range

(i) Detection range and delay before lock-on, where this is possible, as functions of aspect angle, altitude differential, closing rate and scan pattern, for all targets and all ECM types. The detection ranges should correspond to some agreed cumulative probability of detection.

(ii) The optimum procedure for application of CCM facilities and the delay involved in selecting the best operational mode. Clearly this delay will be a function of the type of ECM encountered.

(iii) The degree to which the aircraft can, or should, be steered manually, by joint pilot - Obs/A.I. action, during the period from detection to either lock-on or selection of the best CCM mode.

Output:- (Cont'd)

(iv) The amount of steering information that may be expected and the steering modes that will be available.

(v) The conditions under which automatic steering will be possible.

(d) When ECM is used from A.I. lock-on only

(i) The optimum procedure for application of CCM facilities and the delay in selecting the best mode.

(ii) The degree to which the aircraft can, or should, be steered by joint pilot - Obs/A.I. action during the period from detection to either lock-on or selection of the best CCM mode. (Note: This may not be the same as for (c) (iii)).

(iii) The amount of steering information to be expected and the steering modes available.

(iv) The conditions under which automatic steering will be possible.

(v) The conditions under which spotlight operation will be possible.

(vi) The clear range in cases where normally only angular information is available. This should be given as a function of aspect angle, altitude differential, and closing rate for all targets and types of ECM.

MISSILE STUDIES

7. Evaluation of Sparrow 2 Performance Capabilities

Analog and digital methods will be used to determine the capability of the missile against expected types of target. These studies will include the effects of:-

- Missile dynamics
- Aerodynamic and hydraulic limitations on range
- Seeker characteristics
- Radome aberrations
- Target characteristics
- Target scintillation and glint
- Missile computer errors
- System noise
- Transient effects of the launch conditions
- K-Band ECM

Both co-altitude and altitude-difference cases will be considered, and for the latter, studies should include cases where steering errors exist in azimuth and elevation planes both individually and simultaneously. The complete flight envelope of the Arrow should be covered, from sea-level to 65,000 ft. and from high subsonic speeds to M = 2.0. However, the initial studies should concentrate on the high altitude, supersonic launch capability of the 1961 system.

7. Evaluation of Sparrow 2 Performance Capabilities (Cont'd)

The results of these simulations should be correlated with data obtained from tests using actual missiles. Analysis of the results of the captive missile program at Pt. Mugu will be required to determine missile lock-on characteristics, and continuation programs should aim to use targets that are more representative of the type expected to be encountered by the Arrow.

Output:-

(a) Lock-on range as a function of aspect angle and closing rate for all targets. Both normal operation, with range and angle-slaving, and operation under ECM conditions where range-slaving is not possible will be considered.

(b) Miss vector as a function of aspect angle, angular firing error, launch range, closing rate, target altitude and evasive manoeuvre, altitude separation between interceptor and target, and countermeasures.

(c) Maximum and minimum launch ranges, as functions of aspect angle, closing rate, target altitude, and altitude separation between interceptor and target. The effect of seeker range restrictions should be included.

(d) Azimuth and elevation components of allowable steering error as functions of aspect angle, target altitude, and altitude separation.

(e) Contours of constant P_K, to be obtained by synthesis of the results of this study with those of study no. 9, below.

8. Evaluation of Genie (MB-1) Capability

The Genie rocket has been selected as the alternative armament to the Sparrow 2 missile, and a study will therefore be carried out as part of this program to evaluate the capability of this weapon.

It will first be necessary to obtain full information on the various versions of Genie from the manufacturers and other sources. Digital computer methods will then be used to establish the effects on the flight characteristics and miss distance of:-

Projectile aerodynamics
Thrust variation
Launch dispersion
Target altitude and altitude differential
Evasive manoeuvres

Both co-altitude and altitude difference cases will studied, covering the complete flight envelope of the Arrow. Again the initial emphasis should be on the high altitude supersonic launch capability of the 1961 system. The study will determine, in conjunction with lethality studies, which do not lie within the scope of this program, the accuracy requirements for the launch conditions in order that an acceptable kill probability is obtained.

Output:- (a) Miss distance and kill probability as a function of aspect angle, angular firing error, launch range, closing rate, target altitude and evasive manoeuvres, and altitude separation between interceptor and target.

(b) Acceptable tolerances on launch range and angular firing error.

9. Evaluation of Fuze and Warhead Lethality for Sparrow 2

Since the contractors have no responsibility for the lethality of missile it may well be argued that this study is outside the scope of the program and that the evaluation should lead simply to the determination of probable miss distance. While this is true as far as the correlation of model and flight test results is concerned, it is clear that in the final analysis the quantity of interest is the ability of the complete system to destroy enemy raiders, and to this end it is essential that the P_K associated with the warhead should be introduced.

This study will be carried out by CARDE, using the results of study no. 7 above as input. For the test program it will only be necessary to consider the conditions under which it is intended to fire armed missiles. The greater part of the study will be the evaluation of kill probabilities against all expected enemy threats, in all attack situations.

Output:- Single shot probability of kill corresponding to launch within the allowable firing zone, for all expected targets under all expected conditions.

OTHER STUDIES

10. Study of Aircrew Response

This study, which should be planned in oonsultation with specialists in human engineering, is needed to determine the manner in which a pilot may be expected to steer the airoraft under the following conditions:-

a) When he is simply required to turn to a specified heading, with no knowledge of the geometry of the attack.

b) When he is required to turn to a specified heading, knowing the range or time remaining to weapon launch,

c) When he is required to steer according to the fire control steering dot presentation, with no knowledge of range or time to go.

d) When he steers according to the fire control presentation, with full information on range and time to go.

e) When he steers according to verbal instructions from the Obs/A.I. with no other information.

Of these situations, (a) relates to study No. 2

(b) to No. 3

(c) to No. 4 under ECM conditions

(d) to No. 4 under clear conditions, and

(e) to No. 4 under ECM conditions, prior to selection of the optimum mode.

The study should also determine the combined behaviour of the aircrew in the situation, corresponding to broadcast mode operation, where the Obs/A.I. receives verbal information about the target, which he inserts manually into the navigation computer, the output of the computer being either displayed to the pilot or transmitted verbally by the Obs./A.I.

10. Study of Aircrew Responses (Cont'd)

Although the information is required in slightly different forms, in all cases the study should determine the response characteristics of the aircrew under varying conditions of speed, altitude and demanded correction. For midcourse studies it will be sufficient to express the results in terms of the time required to make a heading correction as a function of the magnitude of the correction. For A.I. phase studies the output should be in the form of an equivalent steering loop gain and filter. Some preliminary consideration will be required to determine whether it is possible to produce an analysis in this form.

Output:- (a) Time required to make a heading correction, as a function of speed, altitude, magnitude of correction and time-to-go (for midoourse studies).

(b) Gain of an equivalent automatic system as a function of speed, altitude, magnitude of error and either time-to-go or range (for A.I. Phase studies).

(c) The ranges over which variations in these quantities may be expected.

11. EVALUATION OF ENTIRE WEAPON SYSTEM

The overall evaluation of the system using the models described above is given here as a separate study, although in actual fact it does not exist as such. In reality the links between the various phases of the mission are written into the models themselves and are accomplished in one of two ways.

a) From studies nos. 7 and 8 the allowable launch zones for the armament are determined and these are input to study no. 4 the digital analysis of the A.I. phase. A postulated A.I. detection contour, corresponding to the type of target, ECM conditions, etc. is also input to this study. For each initial target-interceptor course difference, study no. 4 then determines, by a process of trial and error, the limiting aspect angles at which detection may occur for conversion to a launch position to be possible. The output is then given in the form of "success zones" in the plane of course difference - aspect angle. If the values of these two quantities at A.I. detection place the interceptor within such a zone, it can then successfully convert and launch its armament.

The success zones are then input, together with the corresponding A.I. detection contours, into the appropriate midcourse guidance study No. 1,2 or 3. These studies trace the complete history of target and interceptor during the period that the interceptor is subject to ground control, and determine the point at which A.I. detection may be expected to occur. At this point the true values of course difference and aspect angle are evaluated, and by comparison with the success zone the success or failure of the run is determined. Random variations are allowed to occur from run to run, and statistical analysis of a large number of runs for the same initial conditions gives the overall probability of

11. EVALUATION OF THE ENTIRE WEAPON SYSTEM (Cont'd)

successful midcourse guidance, A.I. phase conversion and missile launch.

Finally, the results of Study No. 9 are used to obtain a probability of kill value from this overall probability of missile launch.

b) An alternative procedure is to input only the A.I. detection contour into the midcourse guidance program. For each of a large number of runs, the midcourse placement errors at A.I. detection are evaluated. These are then analysed to give a statistical distribution in terms of the mean and standard deviation of the error in placing the interceptor relative to the target.

Missile launch zones are input to the A.I. phase study as before, but now this study determines the width and location of the approach lane of the interceptor relative to the target, from which successful conversion is possible. By superimposing on this lane the distribution of midcourse placement probability, the overall probability of midcourse guidance followed by successful conversion in the terminal phase is evaluated. The probability of kill is derived in the same way as before.

Of these two procedures the first is preferred, since it enables considerable economy in computer operation to be achieved by evaluating the midcourse program against the results from a number of A.I. phase studies at the same time. Thus the success zones for the terminal phase against various types of target, with various types of A.I. phase ECM, using various terminal evasive manoeuvres may all be input to the midcourse program simultaneously. By associating the appropriate A.I. detection contour with each, this study then determines successively the success or failure of each of them in each run. It is also considered preferable that the studies should be linked by actual numbers, as in the first method, rather than by probabilities, as in the second.

COMPLEMENTARY STUDY

12. Real-Time Simulation of the Complete System

In this study a cockpit simulator in conjunction with analog computation is used to simulate the aircraft and is linked via analog-digital and digital-analog conversion equipment to a digital computer which simulates the target path and the ground environment. The program for this will draw upon several of the preceding studies, although considerable revision of the ground environment simulations will be required to enable them to operate in real time. Wherever possible simplifications based on the results of the earlier studies will be introduced.

By simulating the complete system in this way it will be possible to examine the problems associated with operating a oomplex airborne system in conjunction with a complex ground environment in the proper time scale and sequenoe of events and in controlled laboratory conditions. This will enable oonsideration to be given to several problems which cannot be studied by means of the "block" approach. Of these the most important is the additional system capability that may be made available under ECM conditions by oontinuing the ground control into the A.I. phase. Even in the situation where the ground radars are jammed it is possible that the ground controller has better information on the target than is supplied by the A.I., this being particularly true when deception jamming is used against the A.I. Under such conditions the overall positioning probability may be improved by the ground controller continuing to give information to the interceptor after A.I. oontaot has been made. A similar problem is that of the interceptor attempting to attack a quiet target in the presence of jamming decoys. To study such problems it is essential to place both aircrew

12. Real-Time Simulation of the Complete System (Cont'd)

and controller in as close as possible a simulation of the true situation, and examine their combined behaviour in real-time operation. Clearly, the ground controller must be presented with the output of the ground computer at the same time as the pilot sees the fire control presentation from his A.I.

Another important problem which is not suitable for consideration other than in real-time is that of fuel management. As has been shown in this document, the evaluation of P_K is more readily and economically achieved by working back from the missile phase, through the A.I. phase, to the mid-course guidance. It is obvious that it is not possible to vary the aircraft weight systematically in such a procedure, and although it would be possible to do so in each phase separately, there would be no means available for linking the phases together in respect of fuel.

Being the nearest possible approach to actual hardware, this model will also afford a conclusive check on the correctness of the results obtained by the block approach. It will have additional uses for aircrew familiarisation and in studying operational techniques in general.

There is, however, no question of this model replacing the rest of the program and being used alone for carrying out the evaluation. The cost of operating the simulation, as well as the difficulty of obtaining simultaneous serviceability on all components, makes it an unsuitable procedure for direct evaluation of the system. Furthermore, the use of random quantities in so many parts of the model means that a very large number of runs of any particular case would have to be made in order to obtain a complete assessment of every phase of operation. However, by virtue of the completeness of the simulation, it represents a most important complement to the other studies in the program.

It is appreciated that there will be items of capital expenditure involved in setting up this model; in particular the purchase of analog-digital and digital-analog conversion equipment will be required. The contractors are requested to present cost estimates for such equipment in order that contracts may be raised.

CONCLUSION

An outline has been presented of a program for developing the mathematical model as a synthesis of a group of studies that will also be used by the contractors for systems development. These studies are for the most part either in existence at present or planned for initiation in the near future, and it is considered that when linked together by proper matching of outputs and inputs, as indicated above, they should be suitable for the purposes of evaluation required of the mathematical model.

This program, and the division of responsibilities shown in Table I, have been discussed with Avro, RCA and Canadair. In the course of discussions it has become apparent that:-

a) Considerable information is required, principally from RCAF sources, to enable the simulated environment at Cold Lake to be formulated in such a manner as to be representative of the 1961 operational environment.

b) Improved communications between the United States and Canada are needed so that this work may be pursued in an adequate manner. Specifically, the requirement exists for contractors' representatives to be authorized to carry classified documents across the border for discussion and transmission.

c) Certain items of capital expenditure will be required to enable the program to be carried out in its entirety.

CONCLUSION (Cont'd)

The contractors have submitted a statement of the topics on which information is required; this is given in Appendix A. Arrangements are being made to make this information available. A similar statement of the equipment required to implement the program should be submitted for consideration.

Negotiations are in progress to set up simplified communications between U.S. and Canadian contractors. However, final details have yet to be worked out.

This document represents the views of A/AWS on the manner in which the mathematical model shall be constructed.

APPENDIX A

INFORMATION REQUIRED BY THE CONTRACTORS IN SUPPORT OF THE MATHEMATICAL MODEL

The oontractors have submitted a request for information on the topics listed below, to assist them in setting up the mathematical model. Where this information is available, arrangements will be made for it to be supplied by the appropriate government agencies.

GROUND ENVIRONMENT

1) GCI Radar

(a) Details of the radar network envisaged for 1961 in respect of:-

Location of stations.

Type of installation and capability (i.e. early warning, tracking, height - finding etc.) at each station.

Quality of radar data (distributions of random and systematic error, blip/scan ratio, noise).

(b) Information as above on the proposed extensions and developments of the network, with the dates into service of such modifications.

2) Data Processing

(a) If SAGE is not operational when the Arrow enters service, the following information is required for the alternative ground environment:-

Operational procedures for detection and identification of enemy aircraft, interceptor assignment and scramble. Procedures for radar data processing, transmission and integration. Interrelation with U.S. facilities.

2) Data Processing (Cont'd)

Procedures for midcourse direction and control of interceptors. The manner in which information is passed between ground and air, the form in which it is given and the frequency of transmission. Placement accuracy. Methods used for interceptor tracking. Frequency and reliability of meteorological information and the manner in which it is used in correcting for wind effects.

(b) Proposed modifications and developments of these procedures, with expected dates, prior to the introduction of SAGE.

(c) SAGE:

Expected date into service in Canada.

Operational and mathematical specifications, including differences between U.S. and Canadian versions. These specifications should cover the operation of the system in all modes, including E.C.M., and should detail any differences between initial and final versions.

Location of SAGE installations and boundaries of the sectors to be defended.

Links, if any, between Canadian and U.S. sectors.

RCAF CONCEPT OF OPERATIONS

1) Interception Procedures

Proposed locations of Arrow air bases, with possible alternatives.

Number of aircraft at each base.

Tactical procedures, including considerations of marshalling point, area coverage and cross coverage by aircraft from different stations, mid-course guidance philosophies (i.e. direct cut-off, offset point, co-altitude, snap-up and climbing turn attacks).

Application rate, in terms of the separation between aircraft required for radar resolution.

2) Target Characteristics

Details of the performance of enemy aircraft to be intercepted by the Arrow.

Should include speed, altitude, manoeuvreability and expected confusion and evasion Manoeuvres.

Size and radar cross section of expected threats.

Probable form of enemy attack, including number of aircraft, type of formation, direction of attack.

Complete characteristics of stand-off bombs.

3) Arrow Armament

Sparrow 2. Details of the types of warhead and fuze to be used, with the associated lethality characteristics against the expected targets.

Outline of policy on Sparrow development programs.

What plans exist for armament other than Sparrow 2.

Is there an operational requirement for Genie. If so, what characteristics should be used in systems studies with this weapon.

ECM

For both 1961 and developed versions of broadcast control and for SAGE, information is required on:-

The types of ECM to be expected and their effects on the capability

ECM (Cont'd)

of GCI radars. This should be given in terms of:-

(a) Conditions under which full azimuth and range information may be obtained. Detection range and range for close-control.

(b) Accuracy of information under all conditions. This should be expressed in terms of the distributions of systematic and random errors in azimuth and range (where applicable) for each type of ECM.

(c) Clear range in cases where normally only azimuth information is available. This may be a function of the type of target and the angle between the radar line of sight and the target's heading as well as of the type of ECM.

(d) Accuracy of height finding, given in terms of the distributions of systematic and random errors.

(e) Ability to distinguish interceptor (beacon) returns.

(f) IFF procedures and their reliability.

The modifications required to the procedures for target tracking and data processing.

The modifications required to the midcourse guidance procedures.

TABLE I

SUMMARY OF PROGRAM

STUDY NUMBER	SUBJECT	TYPE OF COMPUTER	CONTRACTOR
1	Automatic Operation in Midcourse (Close Control)	Digital	Avro
2	Manual Operation in Midcourse (Close Control)	Digital	Avro
3	Midcourse Operation (Broadcast Control)	Digital	Avro
4	A.I. Phase Automatic and Manual	Digital	Avro
5	A.I. Phase, Automatic and Manual Clear Environment	Analog	RCA
6	A.I. Phase, Automatic and Manual. ECM Environment	Analog	RCA
7	Evaluation of Sparrow 2 Capability	(Digital (Analog	Canadair
8	Evaluation of Genie Capability	Digital	Avro
9	Evaluation of Warhead Lethality		CARDE
10	Simulation of Crew Response.	Analog	Avro RCA
11	The overall evaluation of the entire weapon system is obtained by taking studies 1 to 10 together in appropriate combinations.		
	Complementary Study		
12	Simulation of the Complete System in real-time	Combined analog-Digital Simulation	Avro