MODIFICATION OF THE BLUERAX II TERRAIN FOLLOWING MODEL TO INCORPORATE RAD (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI J D HEARRELL
UNCLASSIFIED MAR 88 AFIT/GST/ENS/88M-5
A MODIFICATION OF THE BLUE MAX II
TERRAIN FOLLOWING MODEL
TO INCORPORATE RADAR DETECTION

THESIS

Jeffrey D. Hearrell
Captain, USAF

AFIT/GST/ENS/88M-5

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio
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Presented to the Faculty of the School of Engineering of the Air Force Institute of Technology
Air University
In partial Fulf\'llment of the Requirements for the Degree of Master of Science in Operations Research

Jeffrey D. Hearrell
Captain, USAF

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Preface

The purpose of this study was to determine if radar cross section affects results generated by a post-processor routine that uses information from the flight path created by the BLUEMAX II model.

I would like to thank my sponsor: Mr. Frank Campanile, ASD/ENSSE, for proposing an idea that was workable. Thanks to Dr. Vittal Pyati, chairman of my thesis committee and to Lt. Col. Tom Schuppe, Operational Sciences faculty, for their help and guidance, a special thank-you to Mr. David Richart also of ASD/ENSSE, for the considerable time and effort he spent with me, and to the men and women of ASD/ENSSE who put up with me for the last six months.

My deepest gratitude however, goes to my wife, Elizabeth, for her encouragement and understanding while enduring the hardships AFIT places on a family and finally to my son, Rudy who is probably quite happy that the house is back to normal.

Jeffrey D. Hearrell
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The objective of this thesis was to show that introducing radar detection characteristics into one of the post-processors to BLUEMAX II, a terrain following/terrain avoidance model, would decrease the number of detections by radar against a target. Additionally, it sought to decrease computer (CPU) run time.

The objectives were met through the writing and implementation of two programs, DETECT and MAXMIN. A third program, TFTAEXP, was modified. The radar parameters used in program DETECT approximate the parameters of a tracking radar; the radar cross section values and the flight path that was used were provided by ASD/ENSSE. Results of several runs were compared to a base model that is currently in use at the Air Force Studies and Analysis Office, Washington D.C. and by ASD/ENSSE, Wright-Patterson AFB, Ohio.
1. Introduction

1.1 Overview

The survivability of aircraft in a hostile environment is of high importance to the Air Force. The Aeronautical Systems Division Systems (ASD) Analysis Division (ASD/ENSS), Wright-Patterson AFB, has a number of elaborate and specialized computer simulation models to evaluate individual physical properties whose values determine the characteristics or behavior of an aircraft. One such attribute is the aircraft's terrain following capabilities as it flies near the ground or past a specific target in the presence of ground based defenses. BLUEMAX II, and the SHOTOP post-processor family of models, are a set of simulation models designed specifically to generate a flight path for the purposes of studying an aircraft's terrain following capability and exposure to ground threat.

There are two major limitations to the present simulation models. First, the erroneous assumption is made by a post-processor routine that once an aircraft comes over a horizon and within line of sight, it will be detected by ground based threat such as surface-to-air (SAM) radar sites. Additionally, not incorporated is radar detection, radar cross section (RCS), chaff countermeasure...
expenditures, nor an aircraft's self-screening jamming ability in this particular model. Drawbacks of the present simulation model occur when the data is analyzed in post-processor routines. Although this is not a severe limitation for large RCS aircraft, it is a limitation for vehicles with a small RCS.

If the question of radar cross section vs. detection by the SAM radar is raised, then an extensive and complicated detection model is brought into use, such as AAA Gun Simulation or ESAMS (16:1). Some high fidelity detection models can get cumbersome and expensive to use. What ASD does not have is a computer simulation model that incorporates both terrain following-terrain avoidance features and radar detection. This situation exists because the Systems Analysis Division has in the past decoupled the two functions.

A solution is to group unwanted radar echos (ground or radar clutter (7:10), self screening jammers, radar cross section, and chaff countermeasures into fundamental, elementary, post-processing routines that do not resort to large and cumbersome algorithms. By keeping the algorithms as simple as possible large blocks of time can be saved while still retaining enough fidelity to study pertinent low altitude penetration problems.

Ch. I - 2
1.2 Problem Statement

The current ASD/ENSS family of models does not have one which compares an aircraft's radar cross section to the detection capabilities of specific surface-to-air radars as the aircraft maneuvers along a flight path generated by the BLUEMAX II flight path generator. Such a radar detection capability integrated into the BLUEMAX II would allow ASD/ENSS to obtain basic information from a single program, rather than going through the time consuming process of loading a number of elaborate and different programs. It is felt that in many instances, this level of fidelity is sufficient.

1.3 Objective

The objective of this thesis is to determine if radar cross section affects results generated by post-processors, which use information from the flight path created by the BLUEMAX II model. It will examine the benefits of adding radar detection algorithms to the BLUEMAX II flight path generator model and its post-processing routines to improve the fidelity of the results and to bring the model closer to the real world. Of concern is the detection of an air vehicle by radar under the current circumstance of line-of-sight vs. actual detection distance of the target in question by radar. The real down range distance of the air vehicle under study is provided at specific points in time.
but the current post-processors calculate detection of the vehicle at that point when the vehicle comes within line-of-sight of the radar. The addition of radar detection FORTRAN routines which use a radar range equation coupled with the radar cross section of the target vehicle, should show a considerable difference when compared to line-of-sight distance when the vehicle has a small radar cross section such as a reconnaissance drone, cruise missile, or fighter. Further, the results from the added routines should indicate a possible change in the number of potential Soviet lock-ons when later run through the SHOTOP post-processor. It should ultimately reflect a certain degree of increased survivability for the aircraft. In the process of enhancing this model, a concomitant goal will be to make the low altitude penetration model more computationally efficient, as well as more credible.

1.4 Specific Subobjective

A specific subobjective is to incorporate radar cross section (RCS) tables, provided by the Mission Effectiveness Branch (ASD/ENSSE) as a function of azimuth and elevation angle of the aircraft during the flight path. Since the number of data points can become extremely large, the dimensions of the RCS tables will be reduced while still illustrating the difference in aircraft signatures as seen from the front, rear, top, bottom, and sides.
1.5 Limitations

The current procedure followed is to examine the line-of-sight contour from all aspect angles of the target (see definition in Ch II). In order to examine the RCS impacts of a target vehicle, the vehicle must first be run through BLUEMAX II to generate a desired path. Then a model such as ALARM86 (Advanced Low Altitude Radar Model) with approximately 15,500 lines of code, would be used to evaluate the ability of the (radar) system to detect the target (16:9). Much time and expense is spent in this sequence. If a FORTRAN code which evaluates a representative number of angles for RCS were incorporated in the BLUEMAX II model, then computation time could be decreased by as much as 50% and still yield reliable results.

Historically, the earliest descriptions of a target were in terms of a single cross-sectional area value. This quantity was usually some type of average cross section over the aspect angles which the system designer considered most probable (7:36). As time went on, the demands upon radar systems and operators increased. The requirements, coupled with advances in electronics, allowed radar systems to account for targets with variable cross sections. For the purposes of this thesis, and to keep computer operations as basic and fast as possible, the historical approach, as
mentioned by Meyer, of average cross section by sector will be used. However, the sector can be as fine as required. For example, at microwave frequencies the frontal radar cross section of an unmanned missile might be set specifically at .5 square meters, for a small fighter 2 square meters, and for a cargo plane 100 square meters (15:48). Similarly, the RCS from the other aspects can be defined.

1.6 Assumptions

A flight path generated by BLUEMAX II without any radar cross section routine will be used to test the accuracy of the new FORTRAN routines. This will be considered in more detail in Ch. 4. No defensive maneuvers will be considered. Validation will be a comparison to the existing BLUEMAX II computer model and its post-processor software. No human operator will intervene once the program has begun.

1.7 General Approach

The computer language FORTRAN 77 will be used to design the post-processing routines and evaluate the effectiveness of the aircraft with radar detection routines incorporated. The current model will be explained in Chapter III. Comparison to the currently running model will be used to check the accuracy of the results produced by the new routines.
1.8 Sequence of Presentation

Chapter II presents objectives, background material, and explanations that pertain to radar detection. Chapter III reviews the rationale behind the development of the FORTRAN routines applicable to this investigation. Chapter IV will present the refined data obtained from the current BLUEMAX II and its post-processors with and then compare it with the new FORTRAN routines. The final chapter will present conclusions and recommendations for further analysis.
2. Background

2.1 Overview

Terms essential to the topic of radar detection will be defined. Radar range equations and computer routines used will be kept simple. Whenever practical, constants will be substituted for variables, thus promoting speed and efficiency of the computer.

2.2 Definitions

Azimuth

The longitudinal angle or horizontal width made by the radar beam. At other than an angle of zero degrees, radar to target, see Figure 1 below, the azimuth angle is called the Traverse angle. For the purposes of this thesis, the azimuth angle will be used due to the low altitude of the target vehicle with the ground.

Elevation

The latitudinal or vertical angle made by the radar beam; the elevation angle corresponds with the horizontal plane of the radar and a straight line between the radar and the target aircraft.
Figure 2.1 Azimuth Angle and Traverse Angle

**Free Space**

An area devoid of objects that reflect electromagnetic radiation. This is an idealization never realized in practice.

**Ground Clutter**

"The random reflection of the electromagnetic energy from leaves, water, the ground, and almost any man-made object" (toomy:83). ENSSE will provide required ground clutter data for the flight path generated by BLUEMAX II (richart:discussions)
Model, Computer Simulation

'A simulation model is a particular type of mathematical model of a system' (2:10). 'In its broadest sense, computer simulation is the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer' (10:6).

Model, Simulation, BLUEMAX II

A realistic model, in use by the Aeronautical Systems Division, Wright-Patterson AFB. BLUEMAX II is an aircraft flight path generator developed by Fairchild Republic Co. It generates a description of the aircraft's status at short time intervals (presently .5 sec.) that is suitable for input into other models (i.e. ESAMS or TAC REPELLE) which analyze the survivability and effectiveness of the aircraft (6:Users Manual).

Multipath Effects

The unwanted reflected echo from a radar that tracks a target at low elevation angles. The first reflection is from the target itself, the second echo reflects directly from the earth. Both combined result in an error in the measurement of elevation (15:172).
Radar Range Equation

The detection range of a radar is the maximum distance at which a target of given size can be detected within certain limits of confidence or reliability or the maximum distance a radar can 'see' clearly (11).

...[it] is primarily a function of three parameters:

1) transmitted power, 2) antenna gain, and 3) receiver sensitivity. Increasing the transmitted power will increase the radiated energy which, in turn will result in a stronger target return. The antenna gain is a measure of the radiated energy in the direction of the target as compared to uniform radiated energy. Receiver sensitivity is a measure of the capability of the receiver in detecting target returns (5:1.4).

The distance or range to a target is determined by measuring the time \( T_r \) taken by an electromagnetic pulse to travel to the air vehicle and return, divided by 2 for a round trip.

\[
\text{Range} = \frac{C \cdot T_r}{2}
\]  

(2.1)

where

\( C = \text{Speed of light, } 3 \times 10^8 \text{ (m/s)} \)

\( T_r = \text{Time, } 2 \times 10^{-6} \text{ (\mu sec)} \)
For the pulse rate: "...the rate at which pulses may be transmitted is determined by the longest range at which targets are expected (15:2). This is also called the unambiguous radar range or a range in which clear distinction between a target and the pulse or between targets is assured. Thus unambiguous range is:

\[
R_{unam} = \left( \frac{C}{2 \text{ PRF}} \right) * (5.3996580 \times 10^{-4})
\]  

where

\( C \) = Speed of light, \( 3 \times 10^8 \) (m/s)

Correction factor

= \( 5.3996580 \times 10^{-4} \) (nmi)

PRF = The pulse rate of the transmitter (MHz)

The radar range equation relates the detection range of a radar to the attributes of the transmitter, receiver, antenna, target, and environment.

\[
R_{max} = \left( \frac{P \cdot G \cdot A_e \cdot \sigma}{(4\pi)^2 \cdot S_{min}} \right)^{\frac{1}{4}}
\]

\( R_{max} \) = the detection range of the radar (nmi)
\( P \) = the maximum transmitting power of the radar (watt)
\( A_e \) = the effective aperture of the antenna (m²), it includes:

\( G \) = the gain of the antenna (dB)

\( \Lambda \) = the wavelength of the radar (m)
TFTAEXP.FOR

A FORTRAN program written to work as a post-processor routine in combination with BLUEMAX II. It evaluates the occurrence of line of sight between a radar site and an air vehicle. As a target vehicle moves along a terrain following or terrain avoidance flight path, created by BLUEMAX II, it calculates whether or not detection occurred.

2.3 Additional Parameters

Antenna Gain

An antenna, for instance a steel rod or aerial, is an instrument that intercepts or transmits an electromagnetic waves. If the aerial is replaced by a parabola shaped dish that focuses transmitted energy, then gain is simply a measure of how much focusing is being accomplished (17:9). The antenna as a receiver is much the same. The larger the parabola the more power that is received, thus this amplification is also called gain. Further, 'One of the basic principles of antenna theory is that of reciprocity, which states that the properties of an antenna are the same whether it is used for transmission or reception' (3:170).
Antenna Effective Aperture

This is merely the area of the parabolic antenna that is effective in intercepting an electromagnetic pulse. "... [the area] when multiplied by the power density of an incoming wave gives the power intercepted by an antenna in a receiving mode" (11). The power is usually in watts, and the area is in meters$^2$

Radar Cross Section (RCS):

The radar cross section of a target is the (fictional) area intercepting that amount of power which, when scattered equally in all directions, produces an echo at the radar equal to that from the target; or in other terms (15:33).

\[
RCS = \frac{\text{power reflected / unit toward source}}{\text{solid angle}} / \text{incident power density/4π} \quad (2.4)
\]

Further, it is defined as "... a measure of the electromagnetic energy intercepted and reradiated at the same wavelength by any object" (17:72).

Sensitivity Analysis

"An attempt to study the manner in which the values of the decision variables in a mathematical model change as the parameters of the model change" (18:52).

Signal to Noise Ratio (S/N)

The ratio is in terms of a signal that is to be amplified to that of the random noise that either
enters the receiving aperture of the antenna or is created internally by the electronics. The internal or receiver noise is generated from the thermal excitement of electrons.

**Target**

A target aircraft may be considered as comprising a large number of independent objects that scatter energy in all directions (15:38).

**Terrain Avoidance**

An altitude flown, through mountainous or irregular land, to avoid terrain terrain features (5:10-11). See Figure 2.3 for a physical view.

**Terrain Following**

The need to maintain a reference height plus some safety factor above the terrain (5:10-15). See Figure 2.4 for a geometrical representation.

**Transmitted Power**

This is the time average transmitter power in watts.

2.4 Validation

Validation for this thesis will consist of contrasting the modified penetration model results with those of a base or standard model. The base model is one which is currently in use by the Air Force.
Figure 2.3 Clearance Plane for Terrain Avoidance

Figure 2.4 Terrain Following Geometry
3. - **Method**

3.1 **Overview**

This chapter introduces solution techniques: Various techniques are enumerated and a discussion on particular methods is given while each is rejected and one is ultimately chosen to incorporate radar detection into a BLUEMAX II a low altitude penetration model. As part of the approach certain simplified assumptions are made which will be clarified in the course of the discussion. Included will be short explanations on how BLUEMAX II generates a flight path and a full discussion on the modifications to a major program that interprets the results from BLUEMAX II.

3.2 **Approach**

There are two possible approaches that can be followed in creating a combined program. One method is to use an existing radar detection computer code such as ENGAG3D, by the Northrop Corp (1:1), or search for another similar specialized code. The alternative is to write a series of fundamental FORTRAN routines tailored to the BLUEMAX II.

There are advantages and disadvantages to each approach. Using the Northrop program, or one similar, eliminates the need to write a major amount of code. However, a disadvantage is that the program itself is extremely large and designed only to study the radar cross section of an aircraft and its various geometries as it
approaches a SAMs' radar. Another disadvantage is that ENSSE is not analyzing the detection process in detail. It is only trying to obtain an adequate representation for the part radar cross section plays in aircraft's flight along the BLUEMAX II generated flight path as it moves toward a fixed point. Therefore, a computer code designed around detailed detection criteria is not necessary.

An advantage to a program written for the BLUEMAX II penetration model is that it is sufficient to use a minimum number or even one specific radar cross section value to characterize a weapon system. As mentioned in Ch. I, the RCS tables might be a median signal head on, one average signal from the top and one from the bottom, and one from either side or can be more detailed, if warranted. For a very quick, rough look, a single parameter of 1 square meter is generally used, i.e., a spherical RCS. This makes the model BLUEMAX II an efficient tool for parametrics and sensitivity analysis without changing its purpose.

Finally, since the BLUEMAX II deals with surface-to-air missile threats, only the RF (radio frequency) portion of the electromagnetic spectrum is used when dealing with radar, i.e., the infrared threat will not be addressed.
3.3 **Optimum Approach**

An approach that seemed best was to write the radar cross section FORTRAN code as post processing routines to be called whenever desired. This not only saves time, but is easier to assimilate. The following procedures were studied before choosing the final required level of complexity.

3.3.1 **Stage 1**

In its present form, Radar Cross Section has not been considered in BLUEMAX II, a computer model that generates either a terrain avoidance flight path or a terrain following flight path for air vehicles.

There are three levels of sophistication which can be obtained in developing a radar detection model. The most elementary is one which gives the air vehicle a single nominal value for its radar cross section (RCS). Given a particular radar's capability, the radar range equation can provide the distance the radar can detect or 'see' a target accurately. The following radar range equation can be used:

\[
R_{\text{max}} = 11.72 \left( \frac{P_t G^2 \lambda^2 \sigma}{F B S/N} \right)^{\frac{1}{4}}
\]  
(3.1)

where

- \( R_{\text{max}} \) = the detection range of the radar (n miles),
- \( \sigma \) = the radar cross section of the target vehicle (m²),
- \( P_t \) = the maximum transmitting power of the radar (watts),
- \( G \) = the gain of the antenna (dB).
\[
\begin{align*}
\text{Lambda} &= \text{the radar wavelength (meters, m)}, \\
F &= \text{the receiver noise figure (dB)}, \\
B &= \text{the bandwidth of the radar (Hz)}, \\
S/N &= \text{the signal to noise ratio (dB)}, \\
11.72 &= \text{a useful form of the radar equation that converts R}_{\text{max}} \text{ to statute miles}, \\
\text{and} \\
\text{all values are assumed to be in standard temperature and pressure (STP)}.
\end{align*}
\]

There are a number of different more complex ways this equation can be expressed. For the purposes of determining the effects of radar cross section on the detection results arrived at from BLUEMAX II, this form would be adequate. The assumption made is to use elementary radar, setting each of its values constant. We can see from Equation (3.1) that by doing this, \( \sigma \), the radar cross section of the target, becomes the determining factor on just how far radar can detect. If this particular kind of radar, with set values and constant \( \sigma \), can detect a target at a maximum of 25 miles for the given RCS, then the solution to the problem of detection is simple. If the target is beyond the radars 25 nautical mile limit it can not be seen. Within 25 miles, and with no obstruction in the way, the target can be detected. This level of sophistication will be bypassed since a similar approach, using line of sight between target and
radar, is used and therefore not enough new information for comparison purposes can be obtained.

3.3.2 Stage 2

The second level of sophistication development concerns the fact that the aircraft does not have a single uniform radar cross section. Rather, the RCS varies depending upon the relative bearing or the angle between the vehicle and the tracking radar site when both are in the same horizontal plane. At this point in the development there are two dimensions to consider, azimuth or azimuth with elevation see figure 3.1. When we consider the azimuth angle we have an increase in the level of sophistication over just a calculation of distance as mentioned in stage 1. Consider the azimuth angle first since only the relative bearing is the determining factor.
Elevation Angle: Maximum of ± 90° of pitch

Azimuth Angle: Maximum of + 0° to 180°.
Assume Symmetry for RCS, i.e.,
0° to 180° = 181° to 360°

Figure 3.1. Azimuth & Elevation Depicted
Relative bearing is an angular measurement from the nose of the plane to the tracking radar site (see figure 2.2). The determination of relative bearing comes by knowing the vehicle heading and knowing the true bearing of the defensive site or sites. Then, the relative bearing is equal to true bearing minus the vehicle heading. Or, from the true bearing, the true heading of the aircraft and then the relative bearing of the aircraft can be calculated.

As an illustration, if we know both the position of an aircraft and the radar site, and we also know the heading of the aircraft, then relative bearing can be calculated. Assume the true heading of the aircraft is due north and the site is due east. The relative bearing and true bearing (both the same because the plane is heading due north) to the site from the nose of the aircraft is 90 degrees. If, on the other hand the aircraft is heading due east and a radar site is 90 degrees off the nose of the vehicle then true bearing, as read from a compass to the site, is 180 degrees. The relative bearing from the nose of the aircraft remains the same at 90 degrees. As far as the RCS of the aircraft is concerned, as presented to the radar site, they are the same. At this point, the real heading of the aircraft is not important since the RCS value of the particular target can be obtained from a table using the relative bearing angle. Based upon this value, the calculation for the proper radar detection range is made.
using the radar range equation. This determined angle, of course, is called the azimuth angle, or as we've been showing, the relative bearing angle. At the end of the last example, the relative bearing was 90 degrees, this is the azimuth angle. Note, this procedure is only determining the angles between a vehicle and a radar site. Then radar cross section values for a given air vehicle, which have already been determined, are provided to the analyst before running the BLUEMAX II model. This information will be copied into a computer file to be accessed according to the azimuth angle.

Thus, if radar is off at 45 degrees from the nose of the aircraft the RCS value that corresponds to this 45 degree azimuth point would be used. Given this azimuth angle, the RCS value, $\sigma$, might be 2.1 meter$^{-2}$ and given a second different azimuth angle at a later point in the flight path the angle would change as would the apparent $\sigma$ value. In this way the varying azimuth angles of the moving aircraft would cause differing RCS values when detected by the radar, which in turn influences the actual detection range of the radar as can easily be seen in Equation (3.1).

There are routines already established that take into account the flight path data generated in BLUEMAX II, and calculate the azimuth. They are not however, in BLUEMAX II.
They are located in a post-processor routine which uses the BLUEMAX II output.

The azimuth calculations are accomplished by the Terrain Following Terrain Avoidance Exposure (TFTAEXP) FORTRAN program in two functions called RELABR, short for relative angle bearing, and TCRSE, which is true course. These functions determine the relative bearing or azimuth from vehicle nose to radar site. To do this job TFTAEXP draws information from a number of sources. It uses the flight path information from BLUEMAX II, which has its own unique internal X, Y, Z coordinates system, and it uses information from an external file which was initially the route data input file. When brought together, these pieces of data provide an azimuth angle. At this level of sophistication, BLUEMAX II in combination with TFTAEXP will provide sufficient information to determine the azimuth angle.

To be even more accurate and still efficiently determine if varying the radar cross section of an air vehicle, when run through a post-processor routine for BLUEMAX II, will reduce the number of potential detections a
third stage of sophistication must be obtained, i.e., combining the azimuth and elevation angles.

3.3.3 Stage 3

The third level of sophistication takes into account the elevation angle of the aircraft, refer to figure 3.1. Now, not only is the target vehicle examined at all angles in the horizontal plane, but also the slight pitch of the plane. The pitch of the plane being a comparison of a horizontal line running through the plane, front to rear, to its angle to the earth. The banking angles of the target vehicle will not be examined. In developing the program for incorporating RCS into present models, two assumptions are made.

The first of these two assumption concerns the horizontal plane of the target vehicle. It is assumed that both the left and right half of the vehicle are symmetrical. With this assumption we can reduce the azimuth angle from 360 degrees to 0 through 180 degrees. If an angle equals 185°, then we subtract from 360° and use 175°. This reduces by 50% the computer memory required for the azimuth array, and will reduce some calculations as will be shown later in the discussion on program DETECT.

The other assumption referred to the elevation angle. Since the target vehicle is in a terrain following or terrain avoidance flight path, its elevation above the
ground will usually be under 500 feet. Therefore it has been determined that the elevation angle will be the angle from the radar site to the nose of the target vehicle.

For instance, a target 10 miles away, 500 feet above the ground would have an elevation angle of approximately one half degree. At one mile, the elevation angle is approximately five degrees, but also at one mile, with no obstructions in the way, detection is practically assured. Therefore error, introduced by calculating the elevation angle this way will have little effect on detection of an aircraft based on RCS. It must be emphasized that radar cross section is being tied in to reduce detection range, since detection range in the current model starts when the target is within line of sight of the radar.

Suffice to say, as with determination of azimuth there is already software available that will do the elevation angle calculations and moreover it is already built into the TFTAEXP program. With minor changes the accessible software will calculate the elevation angle of the target with respect to the radar. Initial input values for BLUEMAX II are position of the radar and position of the aircraft (altitude as well as latitude and longitude). Since the elevation angle is based upon radar parameters, we must also input the height of the radar and elevation of the terrain that surrounds the radar. Terrain information comes from the defense Map Agency in the form of digital terrain data.
To get a precise determination for where the radar is located, all values are with respect to the center of the earth, then radar refraction algorithms are used to come up with an elevation angle to the target. The elevation angle assumes a radar refraction angle using a $\frac{4}{3}$ earth's effective radius.

3.4 Supporting Information

Proper azimuth angle and the proper elevation angle can now be calculated. With this data, a prepared table can be consulted to find the corresponding radar cross section. With the RCS value at hand and, given the characteristics of the radar, a radar detection range can be calculated.

There is one more operation performed by the TFTAEXP program that works in conjunction with radar detection, and although not addressed directly, it should be brought to the readers attention. This operation is called Terrain Masking, which simply means that the hills and terrain around the radar site are taken into account. If the elevation angle, or altitude, of the target is greater than that of the terrain in front of the radar, a potential detection exists.

At this point, there are a couple of approaches that can be followed to include the new radar calculations. One is to construct a table of ranges to be accessed as needed. This means that a target's radar cross section must be
manually converted to range values. Another is to make this calculation on line - real time, and a third technique is to have built into the program one nominal radar cross section or range value for whichever air vehicle is being examined. In Merrill Skolnik's Introduction to Radar Systems page 41, a discussion is presented concerning average RCS vs. a large number of values. The discussion revolves around the fact that '... the radar cross section of an aircraft is difficult to specify concisely.' But that, '... a single value of cross section is sometimes given for specific aircraft targets for use in computing the radar equation.' This value '... when substituted into the radar equation assures that the computed range agrees with the experimentally measured range (12)." This is the basis for the development of the radar cross section program. A maximum RCS using a maximum RCS value, regardless of aircraft was chosen. By orientation the radar and TFTAEXP can never detect the aircraft beyond a certain range. This then becomes a maximum radar range. If the aircraft is beyond this range no calculation for detection need be made. Further, there are some minimum value where the radar can always detect the aircraft. With these upper and
lower bounds, the area between will be used for making
calculations.

One major radar detection program called DETECT, and a
smaller program called MAXMIN were designed. The TFTAEXP
analysis program was also modified.

Program Development

The current model BLUEMAX II uses two programs as post-
processors in the determination of detection. These are
TFTAEXP, the Terrain Following Terrain Avoidance Exposure
program, and SHOTOP which is short for Shot Opportunity.
TFTAEXP evaluates if a target can be seen, and upon making
this determination it creates a record of detections and no
detections, l's and 0's respectively. SHOTOP further
processes this data by analyzing the record and determines
potential lock on points by a specific type of SAM.

BLUEMAX II generates the flight path using digital
terrain data provided by the Defense Map Agency. This is
the sole, but ultimately important, purpose of BLUEMAX II.
Once a flight path is created and saved a second program,
TFTAEXP is brought into use. Its sole objective is to
determine the line of sight or lack of, between a target
vehicle and one of more radar sites. It does so by
indicating a '1' for detection and a '0' for no detection.
SHOTOP is the third program called into use to analyze and
yield a probability that detection occurred long enough to
allow a SAM to be fired. It also indicates the probability

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of kill based upon the number of detections. Although referred to later, the program uses real world parameters and since some of these parameters may be sensitive SHOTOP will not be used in the analysis. As mentioned, TFTAEXP creates an array where '1' is an indication of a detection, and a '0' indicates no detection. This is accomplished by looking at each point on the route in .5 second increments. and also by looking at each point, in .05 nmile increments from the radar site out to the target. (Hereafter the term route will refer to the flight path the target vehicle follows. The term radial will refer to a line of points from the radar site out to the target, see Fig. 1)

Program DETECT has been formed to interact directly with TFTAEXP. SHOTOP will be mentioned only indirectly hereafter.

3.5 Program DETECT

Program DETECT has two primary subroutines and two secondary routines (Appendix A). The program allows the operator to choose between three options. Use the constraints and values built into the program, access external data then run the program, or build a data file internally and then run the program. The data base referred to is a two dimensional array of radar cross sections. As mentioned previously, earlier RCS data will be provided to the systems analyst with the data then being
mainframe, option number 1 is deleted. Only options two and three will be referred to hereafter.

Figure 3.2  BLUEMAX II Generated Flight Path with Radar Sites
entered into the computer based upon elevation-azimuth coordinates. A PC (personal computer) version allows the use of all three options however, when tied into a VAX

Regardless of which of the two procedure is used, once a radar cross section file is made available program DETECT calls upon subroutine RMAX. This subroutine accesses the RCS file to read it, one value at a time. Each value is sent to another subroutine RANGE where the actual radar detection range, based on the RCS value is calculated. Upon returning to RMAX the value is written to its own separate file for use by TFTAEXP at a latter time.

This is the basic operation of program DETECT, with the end result being an array of radar detection ranges, based upon a target's radar cross section, for use by TFTAEXP, as well as a decrease in Computer processing time (CPU). After creating this program the next step is a modification of the analysis done by TFTAEXP.

3.6 Program TFTAEXP

The TFTAEXP program in itself is approximately 1200 lines long, but in order to accomplish its function it must access a digital terrain data input file which contains literally hundreds of thousands of bits of data (see Ch. 4 for segments of the referenced TFTAEXP program). Most of the modifications appear in the main program buried within a
series of nested loops that follow, point by point, the flight path created by BLUEMAX II. (refer to Figure 3.2). The original idea of this loop was to determine if the target vehicle was within line of sight of the radar based upon target distance, the terrain masking angle, and the maximum effective range of a radar.

The planned modifications will use existing subroutines for the azimuth and elevation angles of the air vehicle. Then, supplanting the original line of sight determination with range values for a particular radar, these values are compared to the target distance. In theory, there should be a reduction in the number of detections if the RCS is small enough.

In order to increase the efficiency of this new routine it was decided to use the existing maximum radar range routine which was already built into TFTAEXP and create a number of new routines. To make the existing range compatible with the radar values used in program DETECT it would have to be manually changed in the radar site data input file (12). To do this, the maximum radar range had to be found from all the values calculated by program DETECT. Then, the maximum radar range and existing range are set equal to one another. A small program was written (see Appendix B) to examine and determine this value, and was added to the end of TFTAEXP to be called when needed. Efficiency and time savings result from only calling this
subroutine once during execution. Thereafter, the values returned will be used for comparison to the actual target range to determine whether to proceed with further calculations in TFTAEXP or to immediately increment to another point on a radial or the flight path. In conjunction with $R_{\text{max}}$, equation 3.1, if RCS decreases beyond a certain point, based on distance, the range the radar can use for detection gets smaller or the SAM radar can't see as far, refer to Figure 3.3 on the next page and the following examples.

The baseline in Figure 3.2 is case-B with the targets true position 15 n miles from the radar and radar pointing at this actual target. If $\sigma$, the radar cross section of the target vehicle, is such that the distance of the air vehicle is within $R_{\text{max}}$, from Eq. 3.1, then there is a potential for detection and calculations would be done in TFTAEXP. This refers to case-B on the periphery of the radars range, or case-C. If on the other hand, as in case-A, there is a reduced $\sigma$, smaller than presented in case-B, then from Eq. 3.1 it can be seen that as $\sigma$ is decreased the apparent radar detection range $R_{\text{max}}$ is also decreased. Thus it appears to the radar that no target is within detection range. For detection to occur the target would have to be much closer than it actually is and so for all intents and purposes the target is beyond detection range as indicated by case-A near point 'I'. Since the target can't be seen,
the program increments to the next point in the flight path. Case-C is the opposite. \( \sigma \) has been increased. Again, it can be seen from Eq 3.1 that if \( \sigma \) is increased, the maximum detection range has to increase. This gives the appearance of complete detection or a vehicle closer in.

In other words, if \( \sigma_2 \leq \sigma_1 \), the vehicle would have to be at or near the 'I' in case-C before detection could occur. If \( \sigma_1 \leq \sigma_2 \), the target could be as far away as the position indicated near the 'I' in case-A for detection to still occur.

If the detection range of the SAM is as far as case-B, and the target is either completely beyond the radars range, or the RCS presents the indicated appearance of being beyond detection, then detection or masking is not of concern, and
the next point is incremented. In other words, if the air
vehicle is not in a detectable range no further calculations
are made, and TFTAEXP increments or loops to the next point
in the flight path. A similar situation holds for minimum
distance. If the SAM radar always pick up the target
vehicle within say, one mile, then calculations are ended
for this point.

The area in between max and min is where azimuth and
elevation is checked and analyzed. TFTAEXP uses the angles,
draws data from the Defense Map Agency digital terrain
files, and then starts comparing results from these
calculations to points of terrain under the flight path and
along the radial, see Figure 3.2. If there is a hill or
some other obstruction in the way the SAM radar has to look
up over its crest. Once the angle (mask) gets larger than
the angle where the plane is located, the radar will be
unable to see the aircraft. evaluation is stopped.

When TFTAEXP is finished it has created a file of 1's
and 0's for a specific route. The 1's and 0's refer to
possible detection or no detection based upon the type of
radar and SAM in use. It is at this point that the analysis
will be done on the effectiveness of incorporating RCS into
the current BLUEMAX II flight path generating model. By
comparing output data from the programs now in use by the
Air Force to the output data generated with the use of RCS,
we will see if there is a benefit to incorporating radar
detection in BLUEMAX II.
4. Results

4.1 Overview

This chapter presents the results that were obtained when program DETECT was used along with the modified post-processor TFTAEXP (terrain following terrain avoidance exposure). It discusses the control program with no modifications, and some of its variations; and with each control is paired a modified program that contains the radar detection enhancements. The radar cross section for discrete azimuth and elevation angles were provided by ASD/ENSSE.

4.2 Refined Data

The control program was TFTAEXP in the original form that is currently in use by the Air Force Studies and Analysis Office in Washington, and ASD/ENS at Wright-Patterson AFB. In its fundamental form, TFTAEXP uses a maximum radar range, or for the purposes of this thesis, an imaginary range. This maximum range, in real world situations is usually paired with a surface-to-air (SAM) missile site. Thus, as explained in Ch. 3, beyond this maximum point there is no detection; and between this point and some arbitrary minimum range there is always detection. Figure 4.1 is a sample of a radar site data file for one of the three variations and the parameters that can be varied. This particular set of values shown in Figure 4.1 will be
used in only one control run and with only one run that includes radar detection.

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where

Col a = 1 for terrain following, 2 for terrain avoidance,
- b = the number of the site, with up to 90 sites
- c = latitude of the site in degrees,
  - c.1 = minutes,
  - c.2 = seconds,
- d = longitude of the site in degrees,
  - d.1 = minutes,
  - d.2 = seconds,
- e = height of the radar above the terrain (m),
- f = maximum detectable range of the SAM radar (nmiles),
Col g = minimum detectable range of the SAM radar (nmiles).

Figure 4.1. Sample Sitelist Data File -- Minimum Range

In all cases for both the control program and the enhanced program the height of the radar, 10 meters, never varied. It was kept at a constant 10 meters above the ground, i.e., Column 'e' in Figure 4.1.

Since TFTAEXP already had a maximum and minimum range built in, Col's. 'f' & 'g' in Figure 4.1, valid results could only be gathered when the maximum range was adjusted.
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**Figure 4.2. Radar Cross Sections with Corresponding Radar Ranges -- Control Group**

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Figure 4.3.

Radar Cross Sections with Corresponding Radar Ranges -- Control Group -- Figure 4.2 -- Divided by a Factor of 10

Row 10
7.15 8.50 10.11 11.49 13.66 15.12 14.15 12.27
10.51 8.84 7.68
Row 11
17.98 17.98 17.98 17.98 17.98 17.98 17.98 17.98
17.98 17.98 17.98

Figure 4.3 is the same data as in Figure 4.1 but divided by a factor of 10. It would represent a target with a considerably smaller RCS.
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</tbody>
</table>

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Figure 4.4. Radar Cross sections with Corresponding Radar Ranges -- Control Group - Figure 4.2 - Multiplied by a Factor of 10

shown in Figure 4.2, but multiplied by a factor of 10. It would represent a target that was considerably larger than the standard target vehicle.

Observe that in Figures 4.2, 4.3, and 4.4 there are two tables. The first or uppermost table is the radar cross section of the vehicle in meters squared. The lower table is the maximum range value in which the radar can actually detect something, based upon a radar cross section and equation 3.1. Notice that the maximum range in Figure 4.1 is 21.4 n miles in column 'f'. This maximum range, rounded off, corresponds directly with the maximum RCS in Figure 4.3 positions (1,1) through (1,11) and a maximum range of 21.38 in the lower table in the same positions, (1,1) through (1,11).

Each radar cross section value in the top table corresponds exactly and by position to a radar range in the lower table. For example in Figure 4.2 position (6,4) in the upper table equates to a range of 9.14 n miles or

(Figure 4.4 cont.)

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<th>Row1</th>
<th>22.61</th>
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<th>31.97</th>
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<td>56.85</td>
</tr>
</tbody>
</table>
position (6,4) in table 2. Similarly position (10,7) in the upper portion equates to a radar range of 25.16 nmiles, or position (10,7) in the lower portion. Note that the range is proportional to $\sigma^m$ power and so as the RCS of this vehicle increases from one value to a higher value, the radar detection range also increases, from approximately 9.14 nmiles to 25.16 nmiles.

This can be easily shown by the following, using equation 3.1, and by calculating an equivalent value for the radar parameters used in Appendix A with:

- $P_t = 1 \times 10^6$ (watts),
- $G = 1 \times 10^3$ (dB),
- $\lambda = 9.993 \times 10^{-3}$ (m),
- $F = 10$ (dB),
- $B = 6 \times 10^5$ (Hz),
- $S/N = 31.6$ (dB),
- $1.1507 = a$ conversion from statute miles to nautical miles,

and:

$$ R_{\max} = (5.61)(1.1507)(\sigma)^m, \quad (4.1) $$
$$ R_{\max} = 6.4595(\sigma)^m = R_0(\sigma)^m. \quad (4.2) $$

Then, when $\sigma$ equals $4m^2$, $R_{\max}$ is equal to 9.135 nmiles; when $\sigma$ increases to $230m^2$, $R_{\max}$ will equal 25.155 nmiles.

As was discussed briefly in Ch. 3, these tables play a vital part, and program DETECT is used to assist in entering or building the RCS values. For this thesis the radar cross section for discrete azimuth and elevation angles were provided. Program Detect then enhances this output by creating a separate file of ranges that complement the RCS.
values. Program TFTAEXP then accesses the range data for use in various comparisons.

4.3 Program Operation

Figures 4.5, 4.6, 4.7, 4.8, 4.9, 4.11 represent portions of TFTAEXP. Since these are the only parts that were modified, only these sections of TFTAEXP will be discussed. Further, only interactive parts will be discussed, areas such as the addition of comments, common statements, and dimension statements will not be covered. The outlined or bracketed areas in the following figures indicate changes that were made so that TFTAEXP could accept and use the radar detection enhancements. The first operation done, prior to all others in TFTAEXP, is to call a newly added subroutine, MAXMIN, and can be seen in Figure 4.5 at the second bracket.

Figure 4.6, Subroutine MAXMIN, was added to the end of TFTAEXP and has two purposes. The first, and by far the most important, is the process of accessing the radar range value file. This file was created by subroutine BUILD in program DETECT. MAXMIN reads all the range values it finds and puts them into a temporary array for later use.
C THIS PROGRAM IS UNCLASSIFIED
PROGRAM TFTAEXP

Dimension El(12), Az(12)
C These two dimensions are set up to equal the same
dimensions of the radar range array, by Elevation and
Azimuth, in degrees.
TFLAG=.TRUE.
CALL CPUTIM(TFLAG)

CALL MAXMIN(IRow, ICol)
Do 3 I = 1, IRow
   Write(6,*) 'Enter in the elevation angles in your
array'
   Read(5,*) El(I)
   Continue
3   EL(12)=999.
Do 4 J = 1, ICol
   Write(6,*) 'Enter in the Az angles in your array'
   Read(5,*) Az(J)
4   Continue
AZ(12)=999.
C These two do loops provide reference points between
C this program
C and the temp. array of radar range values.
C DLAT = 50.5
C DLON = 10.5
   WRITE (6,*) 'ENTER CENTRAL COORDINATES, LAT, LON
(69.0, 34.0) : '
   READ (5,*) DLAT, DLON

: Change, Changes or Additions
   Made to TFTAEXP

Figure 4.5. CALL Subroutine MAXMIN, Initiation of
Radar Range Enhancements
Subroutine MAXMIN (IRow, ICol)
IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
COMMON /MXMN/ TLOOK(11,11), DMAX, DMIN
Open (20, File= 'LOOK', Status = 'Old')
Open (31, File= 'MAX', Status = 'new')
Open (32, File= 'MIN', Status = 'new')
Write(6,*) 'Enter in the * of Rows and Columns '
Read(5,*) IRow, ICol
Do 11 I = 1, IRow
   Read(20,*) (tLOOK(I,J), J = 1, ICol)
11 Continue
   c This will build a temporary array of radar detection range values
   DMAX = 0.0
   DMin = 9999.0
   Do 22 I = 1, IRow
      Do 21 J = 1, ICol
         If (tLOOK(I,J) .GT. DMAX) Then
            DMAX = tLOOK(I,J)
         End If
21 Continue
   22 Continue
   Do 24 I = 1, IRow
      Do 23 J = 1, ICol
         If (tLOOK(I,J) .LT. DMIN) Then
            DMIN = tLOOK(I,J)
         End If
23 Continue
24 Continue
   c Write(31,20) DMAX
   c Write(31,*); DMAX
   c Write(32,20) DMIN
   c Write(32,*);DMIN
   Write(6,*) 'MAXimum radar detection range is = ', DMAX
   Write(6,*)
   Write(6,*); 'Minimum radar detection range is = ', DMIN
c20 Format(10(1x,F10.2))
return
End

Figure 4.6. Subroutine MAXMIN
INPUT FILES
C  FCR043.DAT = SITE DATA INPUT FILE
C  FOR045.DAT = ROUTE DATA INPUT FILE
C  FOR022.DAT = DIGITAL TERRAIN DATA INPUT FILE
C  OUTPUT FILES ARE AS FOLLOWS:
C  FOR024.DAT = ERROR OUTPUT FILE
C  FOR025.DAT = LINE OF SIGHT OUTPUT FILE
C
DO 271 NZ = 1, NS
DO 149 I = 1, NB
RDANM(I) = -999.
149 CONTINUE
DO 270 NP = 1, NB
DRD(NP) = DISTAN(SLAR(NZ), SLOR(NZ), RTLAR(NP),
RTLOR(NP), R2NM)
IF (DRD(NP) .GT. DMAX) Then
LIOS1(NZ,NP) = 0
Go to 270
EndIf
If target is outside range of radar then line of sight is 0.
IF (DRD(NP) .GT. EFRNG(NZ)) THEN
LIOS1(NZ,NP) = 0
GO TO 270
ENDIF
410 IF (DRD(NP) .LT. RNGMIN(NZ)) THEN
LIOS1(NZ,NP) = 0
GO TO 270
1
C Checking elevation angle now
TRD = DRD(NP)
TARALT = FLTALT(NP) / CFAC
VEANG(NP) = ELANG(TARALT, ANTZ(NZ), TRD/(DB60 * RAD))
ELVANG = -VEANG(NP) * RAD
Do 1400 I = 1, IRow
II=I+1
If ((ELVANG .GE. EL(I)) .AND. (ELVANG .LT. EL(II)))
Then
ELRow = I
GO TO 1401
ENDIF
1400 Continue
1401 CONTINUE
Write(6,*) 'ElRow is ', ElRow
TRBRNG = TCRSE(RTLAR(NP), RTLOR(NP), SLAR(NZ),
SLOR(NZ), DRD(NP))
ACHDG = HDG(NP)*RAD
AZMUTH = RELABR(ACHDG, TRBRNG)
CONTINUED ON NEXT PAGE
Figure 4.7 cont.

```plaintext
If (AZMUTH .GT. DB180) Then
    AZMUTH = DB360 - AZMUTH
EndIf
Do 1420 J = 1, ICol
    JJ = J + 1
    If (((AZMUTH .GE. AZ(J)).AND.(AZMUTH .LT. AZ(JJ)))) Then
        AzCol = J
        Go to 1421
    End If
1420 Continue
1421 CONTINUE
Write(6,*) 'AzCol is ', AzCol
WRITE(6,*) 'AZMUTH IS ', AZMUTH
If ((LOOK(ELROW, AZCOL) .LT. DRD(NP))) THEN
    LIOS1(NZ, NP) = 0
    Go to 270
EndIf
```

Figure 4.7. Radar Range Enhancements to Program TFTAEXP

The second duty for subroutine MAXMIN is to examine this array of radar ranges to determine a maximum and a minimum range. The maximum and minimum values that were found and number of rows and columns to be used in the temporary array are then passed back to the main program. These values are then used in the code show in Figure 4.7.

Figure 4.7 depicts the heart of the radar detection additions. In the introduction to this figure it is indicated that the input files are radar site data, route
data generated from BLUEMAX II, and the Defense Map Agency's Digital Terrain Data which will all be used from here on out in the program. The most important of the two output files is the 'Line of Sight Output File.' This is the file that will record detections or no detections through the use of 1's and 0's. Next comes the drivers for the loops of the main program, just above line 149. NS is the number of SAM sites that this post-processor can manage with the maximum number being 90 for one run. NB is the number of points, in 0.5 second increments from the start of the target vehicles route to the end. Each time the vehicle increments one point, each and every radar site is examined. Just prior to the first bracketed series of lines in Figure 4.7 is DRD(NP) = ... DRD(NP) is the actual, calculated, distance along a radial, from the radar site to the target aircraft. It calls the function DISTAN, Figure 4.8.

```
FUNCTION DISTAN(AIPLAR, AIPLOR, AFPLAR, AFPLOR, R2NM)
IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
C DISTANCE IN NM IS CALCULATED
DISTAN = ACOS(SIN(AIPLAR)*SIN(AFPLAR)+COS(AIPLAR)*COS(AFPLAR-AIPLOR)) * R2NM
RETURN
END
```

Figure 4.8. Function DISTAN

DISTAN makes the calculation which are in radians. The radians are then multiplied by a conversion factor into nautical miles and returned to DRD(NP). In DRD(NP), NF is
the number of a particular point along the route; NP increments from one to NB. The first bracketed series of lines begins the radar detection additions, and it is here at this first set that the greatest time savings in computer processing will happen.

If the actual target range is greater than the maximum range that a radar can detect, or DRD(NP) > MAX, the program loops immediately back up to 'DO 270 NP = 1, NB.' By looping back up to the 'DO 270' statement all preceding calculations for the entire program are stopped for this particular point, NB. This means that elevation angles, masking angles, azimuth angles, terrain coordinates, and elevation parameters do not have to be processed. This saves valuable computer processing time. Similarly, if the target is less than the maximum radar range an identical procedure is done for minimum range. The procedure is to check the minimum range of the target vs. the minimum range of the radar. A best guess was made and set the minimum range at two nautical miles, see Figure 4.1 column 'g'. If the target is within the two mile limit then all the same calculations are stopped as with the maximum range check point; and a loop back up to 'DO 270' is executed with an increment to the next point. Should the target vehicle be between maximum and minimum range then the following procedures will take place.
FUNCTION ELANG (A, H, RHO)
IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
C THIS FUNCTION GENERATES RADAR REFRACTION ELEVATION
C ANGLE TANGENT.
C HEIGHT
C OF POINT(A) - ALCM OR DIRT ABOVE MSL IN METERS - AND
C RADAR HORN(H)
C ABOVE MSL IN METERS ARE NEEDED. ALSO NEEDED IS GREAT
C CIRCLE DISTANCE IN RADIANS(RHO) FROM RADAR TO POINT
C ON EARTH AT
C SL UNDER POINT OF INTEREST.
C AUTHOR: DAVE RICHART
C RE = 6378204.0 * 4. / 3.
C RE = 8504272.0
DP75 = DBLE(.75)
RHO = RHO * DP75
A1 = (RE + A) * (DCOS(RHOP)) - RE - H
A2 = (RE + A) * (DSIN(RHOP))
ELANG = DATAN2 (A1, A2)
C TELANG = A1 / A2
RETURN
END

FUNCTION TELANG (A, H, RHO)
IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
C THIS FUNCTION GENERATES RADAR REFRACTION ELEVATION
C ANGLE TANGENT.
C HEIGHT
C OF POINT(A) - ALCM OR DIRT ABOVE MSL IN METERS - AND
C RADAR
C HORN(H)
C ABOVE MSL IN METERS ARE NEEDED. ALSO NEEDED IS GREAT
C CIRCLE DISTANCE IN RADIANS(RHO) FROM RADAR TO POINT ON
C EARTH AT
C SL UNDER POINT OF INTEREST.
C AUTHOR: DAVE RICHART
C RE = 6378204.0 * 4. / 3.
C RE = 8504272.0
DP75 = DBLE(.75)
RHO = RHO * DP75
A1 = (RE + A) * (DCOS(RHOP)) - RE - H
A2 = (RE + A) * (DSIN(RHOP))
ELANG = DATAN2 (A1, A2)
C TELANG = A1 / A2
RETURN
END

Figure 4.9. Function ELANG or Elevation Angle Calculations
First the vehicle angle or elevation angle is calculated through \( \text{VEANG}(\text{NP}) \). \( \text{VEANG} \) calls the function \( \text{ELANG} \), Figure 4.9, and an elevation angle is determined. Depending upon an operator's preference, two provisions for calculating angles are provided for in this function. The first is the \( \text{ELANG} \), elevation angle, which gives an angle in radians, and the second is \( \text{TELANG} \), tangent angle, which provides for the tangent of the angle. \( \text{ELANG} \) was used. The radian value from \( \text{ELANG} \) is passed back up to \( \text{VEANG}(\text{NP}) \) for the particular point in question, and then is converted into degrees by the conversion factor \( \text{RAD} \). \( \text{RAD} \) is defined earlier in the program as:

\[
\theta^\circ = \text{rad} \cdot \frac{180}{\pi}
\]

where \( \theta^\circ \) is the angle in question, in degrees.

The next step is to compare this elevation angle for the target with one of the elevation angles read in right after the CALL MAXMIN procedure in Figure 4.5. What the program does is look for an elevation angle that matches an angle on the array, see Figure 4.10. For instance:

If \( \text{ELVANG} = 39^\circ \) then the default is to \( 30^\circ \).

If \( \text{ELVANG} = 59^\circ \) the default is still to \( 30^\circ \).

If \( \text{ELVANG} \) is between \( 60^\circ \) through \( 70^\circ \) the default is to \( 60^\circ \).
Figure 4.10. Elevation & Azimuth Angles, with Corresponding Range Values

FUNCTION RELABR(VHDG,TRBRNG)
IMPLICIT DOUBLE PRECISION (A-H), (O-Z)
C DETERMINES RELATIVE BEARING FROM VEHICLE NOSE TO SITE
DB0=0.
DB360=360.
TRBRNG=TRBRNG+DB360
RELBER=TRBRNG-VHDG
123 IF(RELBER .GT. DB360) THEN
    RELBER = RELBER - DB360
    GO TO 123
ENDIF
124 IF(RELBER .LT. DB0) THEN
    RELBER = RELBER + DB360
    GO TO 124
ENDIF
RELABR=RELBER
RETURN
END

Figure 4.11. Function RELABR or Relative Bearing
It is important to note that the row position, not the actual elevation angle, is remembered by the program. A similar situation exists for the azimuth angle. The azimuth is determined from function RELABR, Figure 4.11.

Once the azimuth angle is found, it too is compared to one of the azimuth angles that were read in to TFTAEXP. Again, keep in mind, that the comparison of azimuth angles yields a column position, not an angle.

Once the row position and column position are generated we have an ordered pair of subscripts that can be used to locate and process a value in the temporary array of radar range values. For instance, in Figure 4.4 in the lower table, an ordered pair of (5,6) would yield a range of approximately 44.49 nautical miles. This all important range, as mentioned in Ch. 3, is the maximum distance the radar can detect an object. It is based upon the radar cross section of the target for whichever surface faces the radar. Then, the array range, TLOOK(ELROW, AZCOL) in Figure 4.7 is compared with the actual target range, DRD(NP). If this range is less than the actual target range we again loop up to 'DO 270 ...' and increment to the next point. In all cases, when target range is greater than maximum radar range, when target range is less than minimum reaction range or radar range, or when the derived radar cross section range indicates the target is undetectable then the
recording as to detection or no detection is a zero. That is, line of sight between radar and target for this particular point on the route is set equal to zero. If none of the options above occur, that is, if the line of sight equals one, then and only then will the program continue.

4.4 Refined Output

It is helpful to be able to visualize just what the flight path looks like when one talks about the line of sight output file. Figure 4.12.a shows the terrain avoidance flight path that was generated by BLUEMAX II. Figure 4.12.b shows the same flight path but with the terrain contours. The arrows seen in Figure 4.12.a indicate a large change in direction or azimuth angle as seen by the separate radar sites. The slight off sets of contours overlaid on the figure from 4.12.a are due to different data bases being used. Figure 4.12.a uses Defense Map agency coordinates, while Figure 4.12.b uses World Map coordinates. The target craft starts at 69° North and 34° East, near the top center of the figure. It went in a southerly direction ending at a point near 69° North and 34° East. The North-South indicator crosses are six nautical miles apart, so the flight path covers almost exactly 30 nautical miles. The path first started out over a body of water, passed a small island where two radar sites were located, cross over a straight between the island and the mainland where a third radar site
was located, and finished on the mainland some 30 nautical miles south of where it started. Although not indicated on Figure 4.12.a, there is elevated terrain which tended to mask the target from the radar at certain times.
Figure 4.12.a Flight Path Generated by BLUEXAN II
Figure 4.12.b Flight Path Generated by BLUEMAX II
with Contours Added
Figure 4.13 is a portion of an output line of sight file for the unmodified TFTAEXP post-processor. This output file, and all others referred to will refer to the same generated flight path pictured in Figure 4.12.a & b.

<table>
<thead>
<tr>
<th>a. b--c--d--e. f--g--h--i.</th>
<th>j.</th>
<th>k-</th>
<th>m-</th>
</tr>
</thead>
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</table>

where

Line a = a route point in 0.5 sec increments,
' b-c-d-e = degrees, minutes, seconds, 1/10's,
' f-g-h-i = degrees, minutes, seconds, 1/10's,
' j = heading.

Line k, l, m = indicators of detection or no detection by SAM radar,
  k - site 1 or S1 in Figure 4.12.a & b,
  l - site 2 or S2 in Figure 4.12.a & b,
  m - site 3 or S3 in Figure 4.12.a & b.

'1' is a detection by radar,
'0' is no detection by radar.
### Figure 4.14. Comparison of Output Detection Results Between the Enhanced & Unenhanced Versions of TFTAEXP

<table>
<thead>
<tr>
<th>SERIES A</th>
<th>SERIES B</th>
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<tr>
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</tbody>
</table>

Ch. IV - 63
Of prime interest are lines k, 1, and m. It is these lines that are used for comparison between an unenhanced and enhanced versions of TFTAEXP. Figure 4.14 is an extract of Figure 4.13 with just lines k, 1, and m for two runs of TFTAEXP. It is a representation of all six runs that were made using the flight path in Figure 4.12.

Series 'A' column 1 shows results for sites one, two and three at the start of the flight path for the base or standard program; the maximum SAM range set equal to a 38.02 nautical mile line-of-sight range. The second column of results depicts when radar detection was used. One can see from all the zeros for site three of column 2 line 'm' that due to azimuth and elevation angles of the target, it initially goes unnoticed by site three. It is not until time increment 158.5, Series A column 2, that site three finally detects the vehicle. Series 'B' in Figure 4.13 is another set of comparison, later in the same run, with primary emphasis on site three. The detections for both versions at site three started at time increment 158.5 (shown in Series 'A') and concluded at increment 206.0 as indicated. Note that in Series 'B', for the unenhanced version (ref. to column 1), detection for site three picks up again at increment number 209.0, continues to 212.5 and stops. Then it picks back up one more time at 218.5 and concludes for the rest of the program, at 232.5 (not shown). The importance is that for the enhanced radar version.
Series 'B' column 2, after detection for site 3 started and ended, between 158.5 and 206.0, there were no other detections. The total number of detections for the standard or base model with no radar enhancements, for site number three, was 182. The total for the upgraded version with radar were just 96 detections. This is a decrease in detection of approximately 52%.

For sites one and two evaluation results were negligible. In fact, they were identical to one another for the enhanced and unenhanced versions. This is not due to program problems, rather it is due to the close proximity of the flight path to the SAM site and the terrain. For instance, (refer to Figure 4.12.a) along latitude 69.18N which is the cross or indicator marker directly below site one, the azimuth angle of the target vehicle is approximately 60° for site one and 73° for site two. This produces a radar cross section of approximately 4m² and a maximum range of about nine miles for both sites. Noting that the distance between Latitude indicators is six nautical miles, detection should occur for both, but occurs for only site one. Site two is about six nautical miles from this point and detection doesn't occur. The results for site two indicate a ridge or hill blocks any southern exposure by the site for anything below latitude 69.22N. This can be seen in Figure 4.12.b. So, with or without radar capability, target detection from site two will be
non-existent. A similar case holds true for site one above 69.18N, and the results are identical for enhanced and unenhanced. Site one is on the back side of the island and either on the water or in a cove. Although the target is well within radar range, the terrain on the island blocks any detection; it's not until the target moves up over or around the obstruction that detection occurs. This happens a little bit below 69.18N and lasts until 69.14 at which point the target disappears from sight due to the terrain, for the rest of the flight path. The nearness of flight path to SAM site and the characteristics of the terrain affected the data output. Only Site three, which was far enough away from the flight path, showed a change in detections. The change however was over 50%. Table 4.1 shows how the addition of a radar capability affected the detection of one of the sites, while terrain and the close proximity of the flight path to Sites one and two caused detection to be identical, with or without RCS added.
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<td>1  2  3</td>
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<td><strong>Base Model</strong></td>
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<tr>
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<td>155 0</td>
<td>112 155 49</td>
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<tr>
<td>0</td>
<td>4 96</td>
<td>0 4 96</td>
</tr>
<tr>
<td>0</td>
<td>0 0</td>
<td>0 0 8</td>
</tr>
<tr>
<td>0</td>
<td>0 0</td>
<td>0 0 29</td>
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<tr>
<td>112</td>
<td>159 96</td>
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### Table 4.1

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<td>112</td>
<td>159 95</td>
<td>112 159 182</td>
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5. Conclusions

5.1 Overview

The objective of this project was to determine if radar cross section affects results generated by post-processors, which use information from BLUEMAX II. This chapter presents the results of the study. One is that radar detection does affect end product results from BLUEMAX II. Another is a reduction or decrease in the CPU time, and finally in shot opportunity.

5.2 Results

When TFTAEXP does not use the addition of radar detection capabilities, i.e., when flight path or terrain effects outweigh radar detection characteristics, then there is no apparent change between either version of TFTAEXP.

However, when radar is used by the program, there is a significant indication of reduction in the number of detections. This fact is shown and discussed in Ch. 4; there was a 50% reduction for radar site three in the number of detections for the enhanced version over the base or standard version. This 50% reduction occurred in all three variations: the base version, the base version increased by a factor of 10, and the base version decreased by a factor of ten. Further, there were indications of a 30% to 50% reduction in computation time, based on the CPU time that
was indicated on the computer monitor at the end of each test run. This percentage is at best only an estimate due to the time share basis with which the computer runs, therefore an accurate measure of CPU time is difficult to assess. However, the indicated CPU time for the radar capable version was about 275 seconds for each run, while the base model version was over 500 seconds.

A good measure of merit would be to look at the number of detections in 0.5 increments that allow for a SAM lock-on. If, to confirm tracking and lock-on, a SAM site requires 25 continuous 0.5 time increments of detection then site three had three such periods as indicated in Table 4.1. With the radar enhanced version this was reduced down to one such period. Notice in Figure 4.14 under Series A column 2, the radar enhanced version shows only detection from Site two while the base model shows tracking and detection from sites two and three. Thus a reduction in detection means reduced shot opportunities, and ultimately, a more survivable run.

Based upon work done, the ultimate conclusion for this project is that a radar cross section addition does indeed affect output results enough so further study is warranted.
5.3 Recommendations

Future follow-ons to this thesis might address some of the following topics and approaches to further reducing radar detection and tracking.

1. The addition of an on board self screening jammer and stand-off jammer if electronic countermeasures are available for a particular target vehicle. The jammers should perform better when the vehicle's RCS is reduced.

2. The ability to analyze detection or tracking due to ground clutter. Use of a simple radar detection equation for clutter such as the following:

\[
R_c = \frac{\sigma_t \text{ (SCV)}}{\Theta_m \left( \frac{R_s}{\sigma_c (S/C)_{min}} \right)}
\]

where

- \(\sigma_t\) = Targets radar cross section (m²)
- SCV = Sub-clutter visibility (≈ 20 to 30 dB)
- \(\Theta_m\) = Radar bandwidth (in azimuth angle, ≈ 1.0° to 1.4°)
- \(R_s\) = Radar range resolution, ≈ \(\frac{\gamma C}{2}\)
  with:
  - \(\gamma\) as the pulse width and ≈ 0.3 to 0.7 μ sec.
  - \(C\) as the speed of light.
- \(\sigma_c\) = Back-scatter coefficient (-30 to -40 dB)
- S/C_{min} = Signal to clutter (noise ratio) required for detection, (11 to 15 dB)

3. The addition of chaff bundles to the target vehicle, which would be expended as a function of threat radar type.
For instance:

a. chaff vs. radar type 1, expend 2 bundles,
b. chaff vs. radar type 2, expend 3 bundles,
c. chaff vs. radar type 3, expend 0 bundles.  
(No capability, hence no degrade)

Also, since the # of chaff bundles is finite we must keep track of the overall number of bundles that can expended, and are expended. When a bundle is ejected we degrade the single shot probability of kill, Pk's, of the missile. When we run out of chaff we must suffer higher Pk's.

4. Include infrared (IR) threat. Then we can determine the number of chaff and flares that can be loaded to give the highest vehicle protection from a survivability point of view.

5. Include the effects of radar warning receivers (RWR) and missile warning systems (MWS). The RWR can help avoid defenses and the MWS could dispense chaff and flares optimally and perform well executed defensive maneuvers.

The same restrictions that were mentioned in Ch 1. of this thesis, that of limiting data for the algorithms, would also apply to ground clutter, chaff countermeasures, and self screening jammers. Basic radar equations should be used with the minimum amount of data to attain desired results. Further, an examination of the time required to do some of these routines should be accomplished. The initial goal is to show proof of concept, but once this is done then
The second goal is to make the program efficient by finding alternative ways of speeding the routines and calculations.


11. Pyati, Dr. V. P. Class notes from EENG 5.73, Electronic Warfare. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, July 1986.


16. SURVIVAL Model Brochure. The Survivability-Vulnerability Information Analysis Center, operated by Booz-Allen & Hamilton Inc. AFWAL/FIES/SURVIAC Wright-Patterson AFB, OH


Appendix A: Program Detect

The following is a close approximation of the FORTRAN code used on a VAX mainframe. This particular version can be used on a PC (personal computer). There are two differences between this and the VAX version. Line 3, SLARGE, is an MS-DOS Macro command telling the computer to use a full 256K of memory. Default for this particular FORTRAN Compiler is 64K of memory. The second difference starts with line 88 and the response on line 89. Both of these lines and all subsequent applicable lines that follow the response for '3' are not accessed by the VAX. Note: where every line numbers are missing, some deletions for printing this appendix were required.

1 Program DETECT
2 c (saved under RCS9.for)
3 SLARGE
4 c SLARGE increases the memory limit for arrays past 64k
5 c This program will add radar detection capability to
6 c the BLUEMAX ground path generating program.
7
8 REAL Sigma, Ae, Bndwth, Clite, F, Freq, Gain, Htrdr,
9 + Pekpwr, P1, PRF, SN, Tau, Wavin, TgtRng, NoisdB
10 +
11 INTEGER Answr, ROW, COL
12 COMMON /Bl/ Ae, Bndwth, Clite, F, Freq, Gain, Htrdr,
13 + P1, PRF, SN, Tau, Wavin, Pekpwr
14
15
Ae : Antenna effective aperture, in meters sq watts.
Bndwth: Bandwidth of the radar, in MHz ~ 1.2/Tau.
Clite : The speed of light, 161,875 n.miles/sec, or 2.998925E8 meters/sec.
F : Receiver noise figure, usually from 1.0 to ~ 30 dB.
Freq : Radar frequency in Hz.
Gain : Gain of the antenna in dB's.
Htrdr : The height of the ground radar in feet.
Pekpwr : Peak transmitted power of the antenna, in watts.
PRF : No. of Pulses Repeated Per Second decibels usually in Hertz (Hz)
RdrRng: The detection range of a radar unit.
Runamb: The maximum radar to target range, with no ambiguity, for one interpulse period. Usually used for more than one target. Ex: Rmax=C/(2*PRF) the max range For a PRF of 1kHz, Runamb=161,875/(2*1000)=81 n.miles.
Sigma : The radar cross section of the target, in meters sq.
SN : The Signal to Noise Ratio in dB's.
Tau : The pulse width or pulse duration, usually in microseconds.
Wavln : The radar wavelength in meters.
Wavln = Clite/Freq

```c
44 Ae = 0.
46 Bndwth = 0.
47 Clite = 2.9979D+8
48 c Write(*,*) 'Enter in the receiver generated noise figure in dBs'
49 c Read(*,*) NoisdB
50 c F = 10.**((NoisdB/10.)
51 c F = 10.
52 c Write(*,*) 'Enter in the receiver frequency'
53 c Read(*,*) Freq
54 c Freq = 30.00D+9
55 c Write(*,*) 'Enter in the antenna gain in dB's'
56 c Read(*,*) GaindB
57 c Gain = 10.**((GaindB/10.)
58 Gain = 1.0D+3
59 c Write(*,*) 'Enter in the height of the radar in feet'
60 c Read(*,*) Htrdr
61 Htrdr = 0.
62 c Write(*,*) 'Enter in the receivers peak power'
63 c Read(*,*) Pekpwr
64 Pekpwr = 1.0D+5
65 Pi = .31415927D+1
66 c Write(*,*) 'Enter in the Pulse Repetition Frequency'
```
Appendix A - 76
67 c Read(*,*) PRF
68 PRF = 1.0D+4
69 c Write(*,*) 'Enter in the Signal to Noise ration in dB''s '
70 c Read(*,*) SNdB
71 c SN = 10.**(SNdB/10.)
72 c Write(*,*) 'Enter in the pulse width, 'Tau'', in scientific notation
73 c Write(*,*) 'i.e., 2 micro seconds is 2.0D-6. D for double precision
74 c Read(*,*) Tau
75 c Write(*,*) 'Enter in the pulse width, 'Tau'', in scientific notation
76 c Tau = 2.0D-6
77 Wavln = Clte/Freq
78 Runam = (Clte/(2.* PRF)) * .00053995680
79 Runamb = Runam * 1.1507
80 c Converts from meters/sec to nmiles/sec:m/s*km/m*smi/km*smi
81 Write(*,*) 'Do you want to build an array of Radar Cross Section data? Type 1 then return'
82 Write(*,*) 'Do you want to use the existing RCS array?'
83 Write(*,*) 'Then type 2'
84 Write(*,*) 'Do you want to use the constants in this program?'
85 Write(*,*) 'Type 3'
86 Read(*,*) ANSWR
87 If (ANSWR .EQ. 1) Then
88 Write(*,*) 'Enter in the size of the array for your Radar Cross Sections. Type in the # of Rows first'
89 Write(*,*) 'then the # of columns.'
90 Read(*,*) ROW,COL
91 Write(*,*) 'The # of rows columns are = ', ROW, COL
92 Write(*,*) Call BUILD (ROW,COL)
93 Else If (ANSWR .EQ. 2) Then
94 Write(*,*) 'Enter in the dimensions of the external array that will be used. Type in the # of Rows first then the # of columns.'
95 Read(*,*) Row, Col
96 Write(*,*) 'The # of rows columns are = ', Row, Col
97 Go to 10
98 Else If (ANSWR .EQ. 3) Then
99 Go to 10
100 End If
101 Write(*,*) 'To continue type 1, to quit type 2'

Appendix A - 77
Read (*,*) Think
If (Think .EQ. 1) Then
    Go to 10
Else If (Think .EQ. 2) Then
    Go to 430
End If
CALL RMAX (Answr, ROW, COL, Runamb)
STOP
end of program detect
430 END

***********************************************************
500 SUBROUTINE RMAX (Answr, ROW, COL, Runamb)
INTEGER ROW, COL, Answr, Compar(100,100)
REAL tSigma(100,100), Sigma, TgtRng, RdrRng(100,100)
tSigma is for a temporary Sigma
If (ANSWR .EQ. 3) Then
    Go to 510
Else If (ANSWR .EQ. 1 OR ANSWR .EQ. 2) Then
    Go to 520
End If
510 Write(*,*) 'Please enter the Average Radar Cross Section'
Write(*,*) 'for your target'
Read(*,*) Sigma
No format, else you would have to type
in the number exactly as a format statement
specified (what a pain in the ass).
N=1
I=1
Write(*,650) Sigma
Call RANGE(RdrRng(N,I), Sigma, TgtRng, N, I)
Write(*,652) RdrRng(N,I), Runamb, Sigma
If (RdrRng(N,I) .LT. TgtRng) Then
    Write(*,*) 'Target can not be seen for this single RCS
value'
Else If (RdrRng(N,I) .GE. TgtRng) Then
    Write(*,*) 'Target is in probably within range of the
Write(*,*) 'radar and may be detectable.'
End If
Write(*,*) 'The unambiguous range of the radar is ',Runamb
RETURN
520 OPEN(60, FILE='TEST', STATUS='Old')
Write(*,*) 'I am now at 520 '
Write(*,*) 'SR RMAX ..... ROW & COL are = ', ROW, COL
RETURN
Do 530 N=1,ROW
READ(60,655) (tSigma(N,I), I=1,COL)
Continue

This Do-loop saves the RCS var's 'N & I', from BUILD, in the array DIMENSION tSigma, in essence it is loading up a temp. array.

Do 640 N=1,ROW
   Do 630 I=1,Col
      Sigma = tSigma(N,I)
      Write(*,*) 'I am now at line 540~~~~~~~~~~~~~~START ~~~~'
      Now tSigma is being read, set equal to Sigma, and passed into the Range subroutine for the RdrRng equation to work on. Then they're sent to the Check subroutine and the result is put into another array for storage.
      Call RANGE(RdrRng(N,I), Sigma, TgtRng, N, I)
      Write(*,*) 'I am going into Check now'
      Call CHECK(RdrRng(N,I), N, I, Compar, TgtRng)
   Continue
Write(*,*) 'I am now at line 563'
Do 645 N=1,ROW
   Write(60,680) (Compar(N,I), I=1,Col)
   Write(*,*) 'I am now above line * 645 '
Continue

COMPAR data is being written to Unit 60. In this case data from the array COMPAR, created in the Check subroutine, is being written to file 60 in format 680. This puts the l's and o's at the end of the array of radar cross sections.

OPEN(70, File='Look', Status= 'NEW')
Do 649 N = 1,Row
   Write(60,656) N, (RdrRng(N,I),I=1,Col)
   Write(70,655) (RdrRng(N,I),I=1,Col)
   Write(*,*) 'I am now above line * 649 '
Continue
Format (lx,'The value you have entered is ',lx,F15.4)
Format (lx,'The radar range ',F7.2,/, 'Runam is ',F7.2,
     +lx,' and Sigma is ',F7.2/)
Format (10(lx,F6.2))
format 655 has to be the same as format 870
Format (lx,'Row',I3,/,10(lx,F6.2))
Format (10(lx,I6))
CLOSE(70)
end of subroutine RMAX
RETURN
END
Subroutine RANGE(RdrRng, Sigma, TgtRng, N, I)

REAL Sigma, Ae, Bndwth, Clite, F, Freq, Gain, Htrdr, Pekpwr, Pi, PRF, SN, Tau, Wavln, TgtRng

COMMON /B/
Ae, Bndwth, Clite, F, Freq, Gain, Htrdr, Pekpwr, Pi, PRF, SN, Tau, Wavln

WRITE(*,*) 'Wavelength = .............', Wavln
WRITE(*,*) 'Gain is .................', Gain
WRITE(*,*) 'Noise figure F = .........', F
WRITE(*,*) 'This is Tau ............', Tau

Bndwth = 1.2/Tau
WRITE(*,*) 'Bandwidth = .............', Bndwth
WRITE(*,*) 'Signal to Noise ratio = ', SN
WRITE(*,*) 'Sigma is equal to = ', Sigma

700 WRITE(*,*) 'I am now at line 700'
RdrRng = (Pekpwr)*(Gain**2)*(Wavln**2)*(Sigma)/
+ (F*Bndwth*SN)
RdrRng = 11.72 * (RdrRng**.25))
RdrRng = RdrRng * 1.1507

Converts from stmiiles to nmiles.

720 WRITE(*,*) 'I am now at line 720 RdrRng = ', RdrRng

Converts from stmiiles to nmiles.

750 TgtRng = 50.

End of subroutine RANGE
RETURN
END

Subroutine CHECK(RdrRng, N, I, Compar, TgtRng)

INTEGER COMPAR(100,100)
WRITE(*,*) 'What are the Ns and Is down here? ', N, I
IF (RdrRng .LT. TgtRng) THEN
  COMPAR(N,I) = 0
END
Else If (RdrRng .GE. TgtRng) Then
    COMPAR(N,I)=I
End If

Write(*,*) 'I am leaving check now'
RETURN
END

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Subroutine BUILD (ROW,COL)

This program will allow you to build an array of Radar Cross Section Values that will be called in for later use. Subroutine AVRCS is average RCS for aspect angles near nose-on for the T-38. In the Dimension stmt the rows and columns, respectively, can be changed to reflect larger or smaller arrays. Make sure to change the read and write stmts.

REAL AVRCS(100,100)
INTEGER Row, Col
OPEN(50,File ='TEST',Status='NEW')
Write(*,*) 'SR Build where ROW and COL are = ', Row, COL
Use unit 50 to read RCS data into an array; for use at a later time

Write(*,*) 'Prepare to enter in the data for your array,'
Write(*,*) 'Enter in your first Row of numbers, hit return,'
Write(*,*) 'then continue until you' re finished. The'
Write(*,*) 'program will give you the system prompt when'
Write(*,*) 'all the figures have been entered.'

Do 800 N = 1,ROW
Read(*,*) (AVRCS (N,I), I = 1,COL)
Write(50,870) (AVRCS(N,I), I = 1,COL)
Write(*,*)
Continue
N = 1.ROW is the # of rows
I = 1.COL is the # of columns

Do 830 N = 1.ROW
    Write(*,875) N, (AVRCS(N,I), I = 1, COL)
    Write(*,870) (AVRCS(N,I), I = 1, COL)
830 Continue

This loop is writing the data to the screen for a final check.

Write(*,*)
Write(*,**) 'Is this data ok? If not restart and retype'
Write(*,**) 'it in, or better still call up the newly'
Write(*,**) 'created file and edit with any text editor.'
Write(*,**)

Format(10(1x,F6.2))
format 870 has to be the same as format 655

Format(1x,'Row ',13,/,10(1x,F6.2))
* Warning -- Invalid format, Error 1200
CLOSE (50)

Closes the array and end of subroutine BUILD
END

******************************************************************************
Appendix B: Program Maxmin

The following is a copy of the program that was attached to the terrain following terrain avoidance exposure program (TFTAEXP). There have been no changes. The purpose of Maxmin is to read the radar range array file and evaluate the maximum radar range value.

```
1 #Large
2     Real LOOK(100,100), tLOOK(100,100), max, min.
3     Integer Row, Col
4     Open(20, file='LOOK', Status='old')
5     Open(21, file='max', Status='new')
6     Open(22, file='min', Status='new')
7     Write(*,*) 'Enter in the * of rows and columns'
8     Read(*,*) row, col
9     Do 11 I = 1, row
10    Read(20,20) (tLOOK J; J = 1, col)
11    continue
12    c this builds a temp array of radar detection range values
13    max = 0
14    min = 9999
15    Do 22 I = 1, row
16       Do 21 J = 1, col
17          If ( tLOOK(I,J) .GT. MAX) THEN
18             MAX = tLOOK(I,J)
19          End If
20    21 continue
21    22 continue
22    23
23    24 Do 24 I = 1, row
24       Do 23 J = 1, col
25          If ( tLOOK(I,J) .LT. Min) Then
26             Min = tLook(I,J)
27          End If
27    23 continue
28    24 continue
23    24
24    Write(21,20) max
25    Write(22,20) min
26    Write(*,*) 'Maximum radar detection range is ', Max
```
Write(*,*) 'Minimum radar detection range is ', Min
Write(*,*)
Write(*,*) 'What value would you like to see, enter '
Write(*,*) 'in the row and column.'
read(*,*) Row, Col
Write(*,*) 'The number is ', tLOOK(row.col)
Format(10(1x,f6.2))
stop
end
Vita

Jeffrey D. Hearrell

Captain Jeffrey D. Hearrell was born in Oceanside, California, on 13 January 1953. In 1971 he graduated from high school in Madison, Connecticut, and soon thereafter joined the United States Navy. After receiving an honorable discharge in 1977 he attended the University of Northern Colorado from which he received a Bachelors Degree in Physics. In 1982 he was commissioned in the United States Air Force. Upon commissioning, he was assigned to Edwards AFB, California where he worked in program management until June of 1983 at which time he was assigned as the Director of Intelligence for Edwards. In 1986 he entered the Air Force Institute of Technology where he received a Masters Degree in Strategic and Tactical Operations Research.

Permanent address: 5127 Honeyleaf Way
Dayton, Ohio 45424
A Modification of the BLUEMAX II Terrain Following Model to Incorporate Radar Detection

Hearrell, Jeffrey D., Captain, USAP

This thesis presents a method of including radar detection characteristics in a terrain following/terrain avoidance model, BLUEMAX II. It demonstrates that radar detection affects the output of a post-processor to BLUEMAX II by reducing potential detections. It also reduces computer run time. Comparison was to the base model, BLUEMAX II, which is currently in use by the Studies and Analysis Office, Washington, D.C.
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