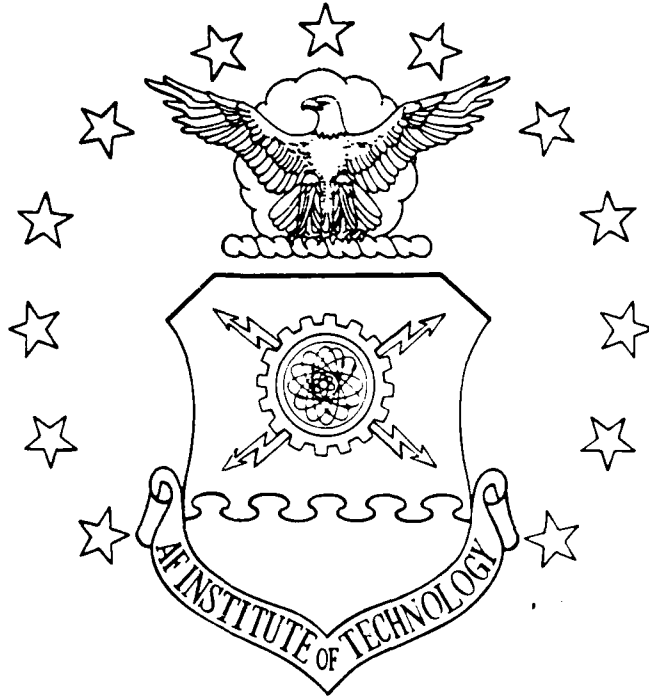MICROCOPY RESOLUTION TEST CHART

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A MODIFICATION OF THE BLUEMAX II

TERRAIN FOLLOWING MODEL

TO INCORPORATE RADAR DETECTION

THESIS

Jeffrey D. Hearrell
Captain, USAF

AFIT/GST/ENS/88M-5

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DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Jeffrey D. Hearrell

Captain, USAF

March 1988

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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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AFIT/GST/ENS/88M-5

Abstract

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.

A MODIFICATION OF THE BLUEMAX II TERRAIN FOLLOWING MODEL TO INCORPORATE RADAR DETECTION

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.

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.
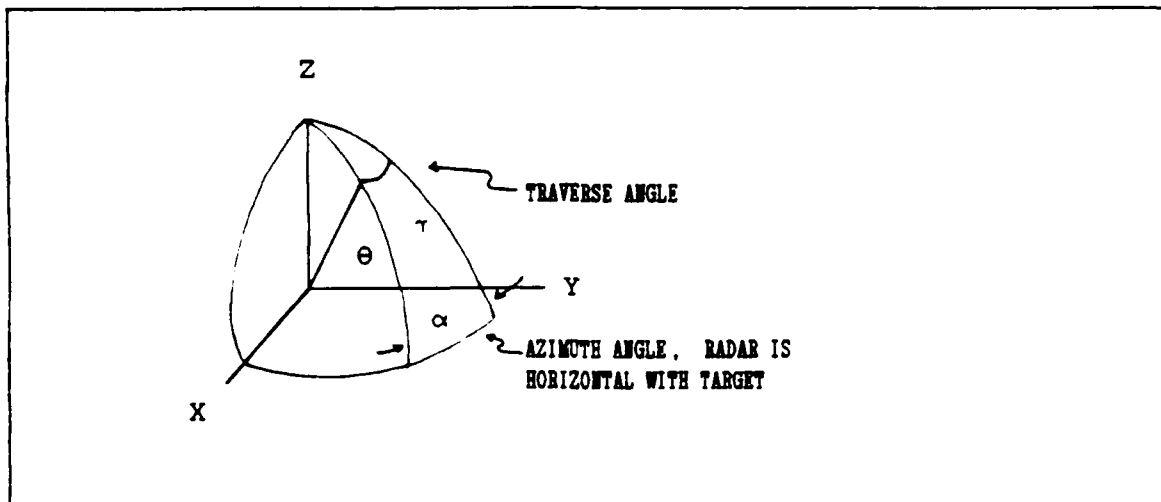
Figure 2.1   Azimuth Angle and Traverse Angle

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 REPELLER) 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 directi n 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 'Tr' taken by an electromagnetic pulse to travel to the air vehicle and return, divided by 2 for a round trip.

$$\text{Range} = \boxed{\frac{C\ Tr}{2}} \tag{2.1}$$

where

C = Speed of light, 3×10^8 (m/s)

Tr = Time, 2×10^{-8} (μsec)

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:

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

(2.2)

where

C = Speed of light, 3×10^8 (m/s)

Correction factor

 = 5.3996580×10^{-4} (nmiles)

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.

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

(2.3)

Rmax = the detection range of the radar (nmiles)
P = the maximum transmitting power of the radar (watts)
Ae = the effective aperture of the antenna (m²), it includes:
    G = the gain of the antenna (dB)
    Lambda = the radar wavelength (m)

<u>TFTAEXP.FOR</u>

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   <u>Additional Parameters</u>

<u>Antenna Gain</u>

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)",

$$RCS = \frac{\begin{array}{l}\text{power reflected / unit}\\ \text{toward source / solid angle}\end{array}}{\text{incident power density}/4\pi} \qquad (2.4)$$

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.
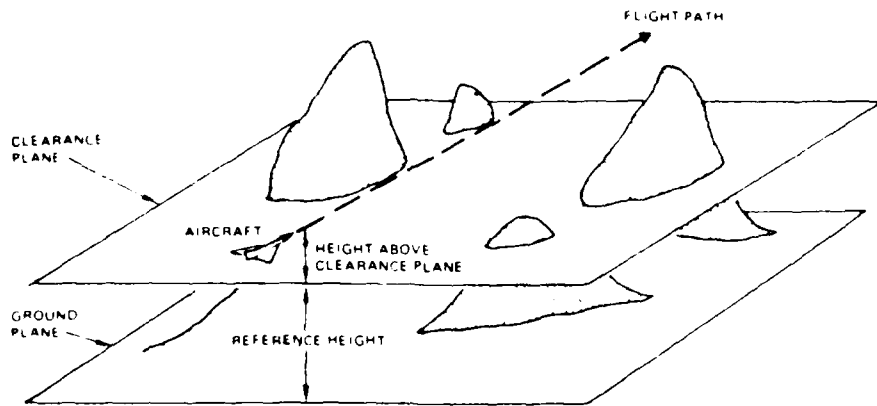
Figure 2.3 Clearance Plane for Terrain Avoidance
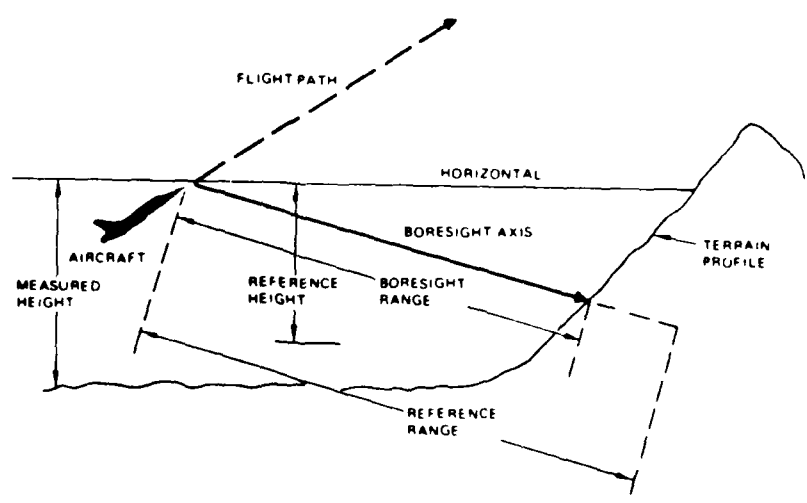
Figure 2.4 Terrain Following Geometry

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:

$$R_{max} = 11.72 \left[\frac{Pt\ G^2\ Lambda^2\ \sigma}{F\ B\ S/N} \right]^{\frac{1}{4}} \qquad (3.1)$$

where

R_{max} = the detection range of the radar (nmiles),
σ = the radar cross section of the target vehicle (m^2),
Pt = the maximum transmitting power of the radar (watts),
G = the gain of the antenna (dB),

```
Lambda  =  the radar wavelength (meters, m),
F       =  the receiver noise figure (dB),
B       =  the bandwidth of the radar (Hz),
S/N     =  the signal to noise ratio (dB),
11.72   =  a useful form of the radar equation that
           converts $R_{max}$ to statute miles,
```
and
```
all values are assumed to be in standard temperature
and pressure(STP).
```

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, σ, 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 σ, 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 - 0° to ± 90°

AZIMUTH ANGLE - 0° to + 180°

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°
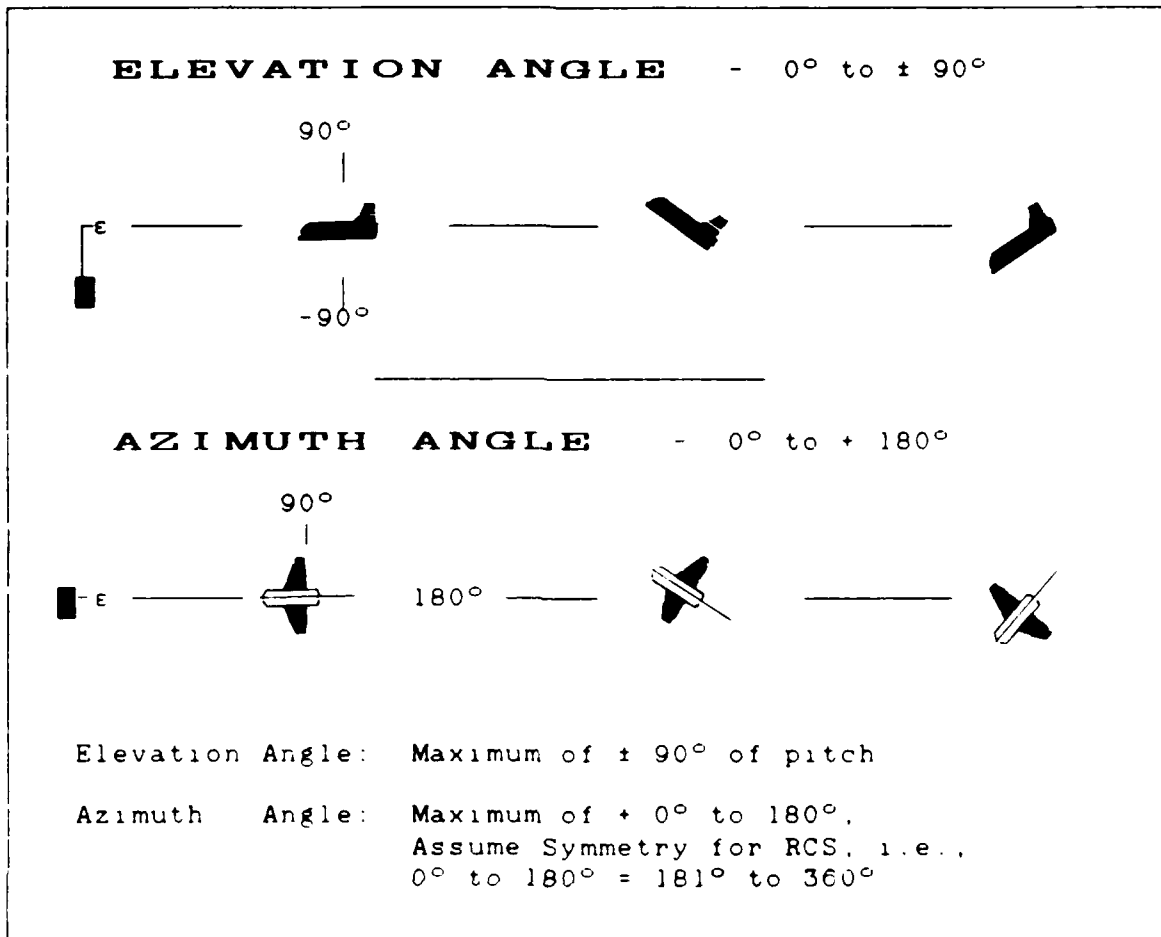
Figure 3.1. Azimuth & Elevation Depicted

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, σ, 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 σ

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 (12).

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 4/3 earths

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, 1'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

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.
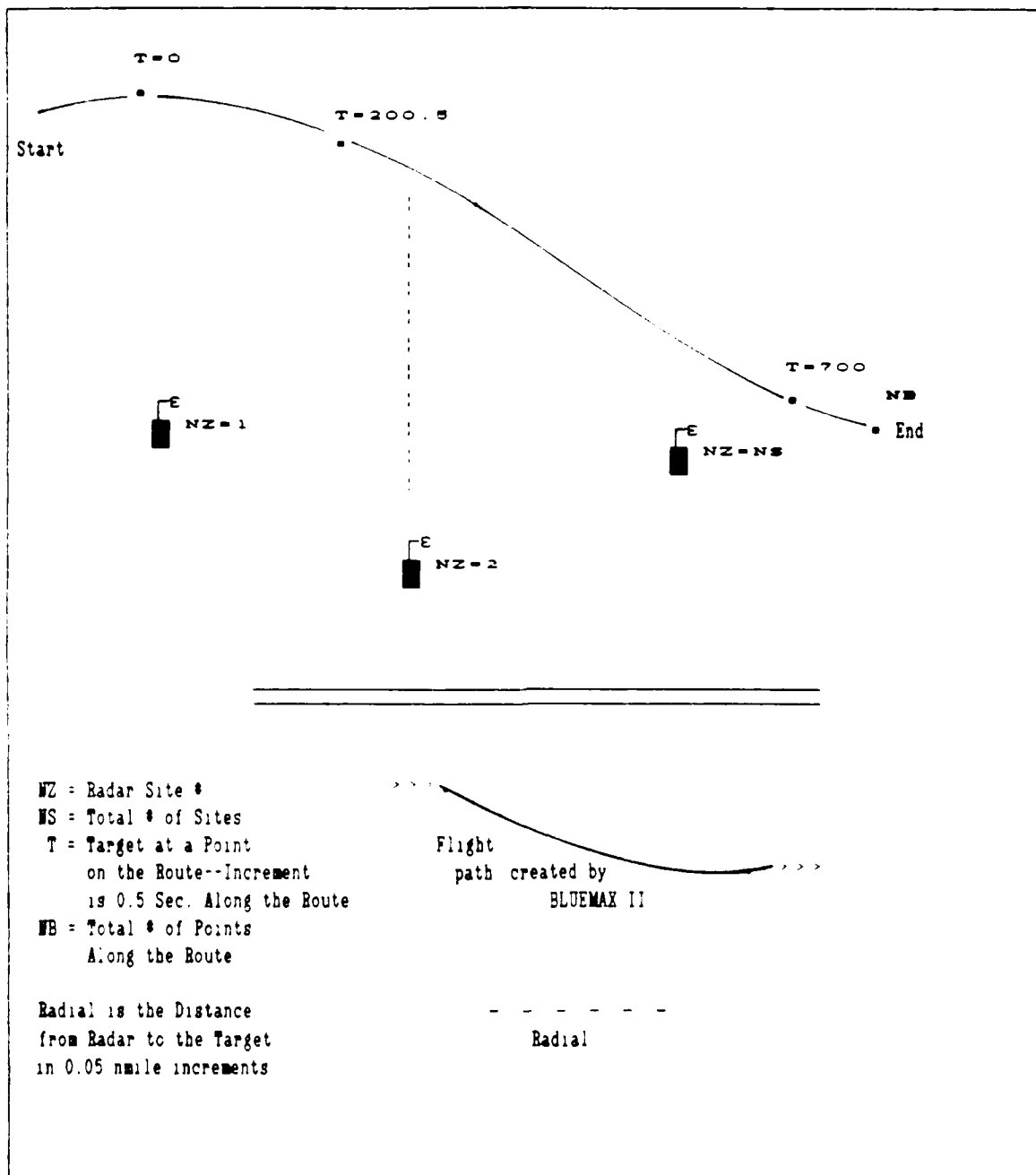
Figure 3.2   BLUEMAX II Generated Flight Path
with Radar Sites

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 targets 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 an other. 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_{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 nmiles from the radar and radar pointing at
this actual target. If sigma, σ, the radar cross section of
the target vehicle, is such that the distance of the air
vehicle is within R_{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 σ, smaller than presented in case-B,
then from Eq. 3.1 it can be seen that as σ is decreased the
apparent radar detection range R_{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, σ has been increased. Again, it can
be seen from Eq 3.1 that if σ 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 $\sigma_A \leq \sigma_s$ the vehicle would have to be
at or near the `I` in case-C before detection could occur.
If $\sigma_C \geq \sigma_s$ the target could be as far away as the position
indicated near the `I` in case-A for detection to still
occur.
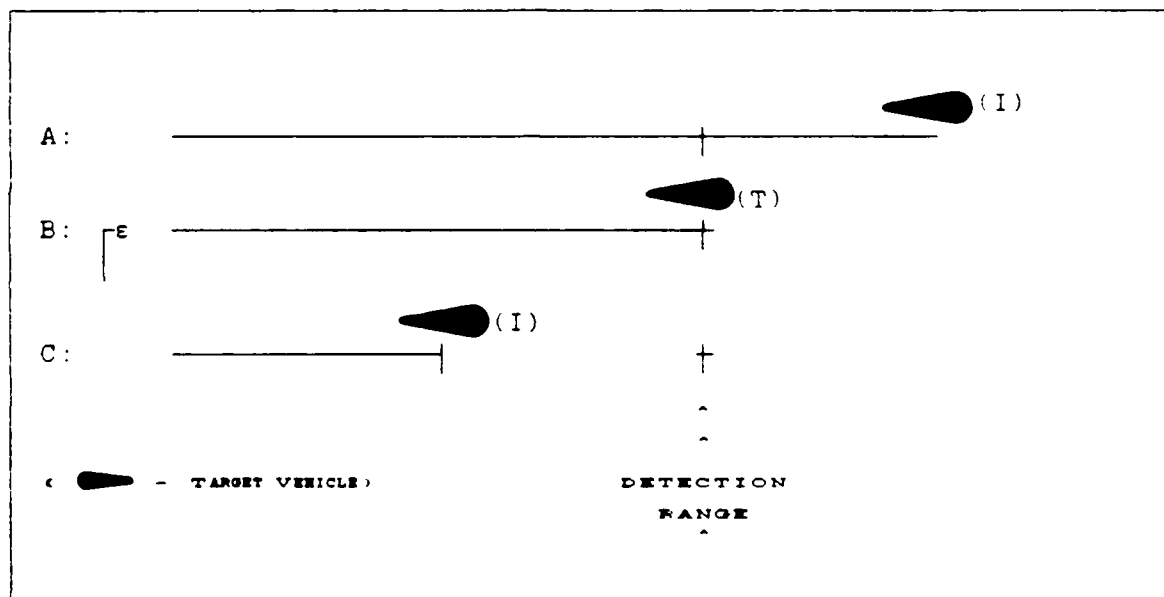
Figure 3.3.   True (T) and Indicated (I) Target Positions

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.

	a.	b.	c.	c.1	c.2	d.	d.1	d.2	e.	f.	g.
	1	1	69.	20.	12.	34.	02.	00.	10.0	**21.4**	2.0
	1	2	69.	23.	00.	34.	05.	10.	10.0	21.4	2.0
	1	3	69.	20.	25.	34.	19.	30.	10.0	21.4	2.0

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

```
1200  1200  1200  1200  1200  1200  1200  1200  1200  1200  1200
  30    60   100   170   270   340   300   225   140    90   100
  15    20     9     6    30   125    60    20     9     6     5
  40    10     3     4    56   230     5     3     4     5     5
  10     8     3     4    22   250    20     2     4     5    11
   7     4     3    _4_   30   450    20   2.5     7    25    40
   4     7     2     3    15   120    35     3     4     5    15
   4     5     2     3     7    60    20     4     4     4     4
   5     8     9     8    35   170   100    10     4     5     5
  15    30    60   100   200   300   230   130    70    35    20
 600   600   600   600   600   600   600   600   600   600   600
```

Row 1
```
   38.02      38.02      38.02      38.02      38.02      38.02      38.02
   38.02      38.02      38.02      38.02
```
Row 2
```
   15.12      17.98      20.43      23.32      26.18      27.74      26.88
   25.02      22.22      19.90      20.43
```
Row 3
```
   12.71      13.66      11.19      10.11      15.12      21.60      17.98
   13.66      11.19      10.11       9.66
```
Row 4
```
   16.24      11.49       8.50       9.14      17.67      25.16       9.66
    8.50       9.14       9.66       9.66
```
Row 5
```
   11.49      10.86       8.50       9.14      13.99      25.69      13.66
    7.68       9.14       9.66      11.76
```
Row 6
```
   10.51       9.14       8.50       9.14      15.12      29.75      13.66
    8.12      10.51      14.44      16.24
```
Row 7
```
    9.14      10.51       7.68       8.50      12.71      21.38      15.71
    8.50       9.14       9.66      12.71
```
Row 8
```
    9.14       9.66       7.68       8.50      10.51      17.98      13.66
    9.14       9.14       9.14       9.14
```
Row 9
```
    9.66      10.86      11.19      10.86      15.71      23.32      20.43
   11.49       9.14       9.66       9.66
```
Row 10
```
   12.71      15.12      17.98      20.43      24.29      26.88      25.16
   21.81      18.68      15.71      13.66
```
Row 11
```
   31.97      31.97      31.97      31.97      31.97      31.97      31.97
   31.97      31.97      31.97      31.97
```

Figure 4.2.   Radar Cross Sections with Corresponding
              Radar Ranges -- Control Group

```
120.0    120.0    120.0    120.0    120.0    120.0    120.0    120.0
120.0    120.0    120.0

  3.0      6.0     10.0     17.50    27.0     34.0     30.0     22.50
 14.0      9.0     10.0

  1.50     2.0      0.90     0.60     3.0     12.50     6.0      2.0
  0.90     0.60     0.50

  4.0      1.0      0.30     0.40     5.60    23.0      0.50     0.30
  0.40     0.50     0.50

  1.0      0.80     0.30     0.40     2.20    25.0      2.0      0.20
  0.40     0.50     1.10

  0.70     0.40     0.30     0.40     3.0     45.0      2.0      0.25
  0.70     2.50     4.0

  0.40     0.70     0.20     0.30     1.50    12.0      3.50     0.30
  0.40     0.50     1.50

  0.40     0.50     0.20     0.30     0.70     6.0      2.0      0.40
  0.40     0.40     0.40

  0.50     0.80     0.90     0.80     3.50    17.0     10.0      1.0
  0.40     0.50     0.50

  1.50     3.0      6.0     10.0     20.0     30.0     23.0     13.0
  7.0      3.50     2.0

 60.0     60.0     60.0     60.0     60.0     60.0     60.0     60.0
 60.0     60.0     60.0


Row   1
21.38    21.38    21.38    21.38    21.38    21.38    21.38    21.38
21.38    21.38    21.38
Row   2
 8.50    10.11    11.49    13.21    14.72    15.60    15.12    14.07
12.49    11.19    11.49
Row   3
 7.15     7.68     6.29     5.69     8.50    12.15    10.11     7.68
 6.29     5.69     5.43
Row   4
 9.14     6.46     4.78     5.14     9.94    14.15     5.43     4.78
 5.14     5.43     5.43
Row   5
 6.46     6.11     4.78     5.14     7.87    14.44     7.68     4.32
 5.14     5.43     6.62
Row   6
 5.91     5.14     4.78     5.14     8.50    16.73     7.68     4.57
 5.91     8.12     9.14
Row   7
 5.14     5.91     4.32     4.78     7.15    12.02     8.84     4.78
 5.14     5.43     7 15
Row   8
 5.14     5.43     4.32     4.78     5.91    10.11     7.68     5.14
 5.14     5.14     5.14
Row   9
 5.43     6.11     6.29     6.11     8.84    13.12    11.49     6.46
 5.14     5.43     5.43
```

```
(Figure 4.3 cont.)


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

to the maximum range of the radar that was created for this

thesis.   The minimum range was set at two nmiles, as this is

the best estimate of the minimum range a SAM would need to

successfully react.   Further, since the objective of this

thesis is to determine if radar cross section affects

results generated by TFTAEXP we only need to use one set of

values for all radar sites.   Thus the maximum range at each

site will be set equal to one another.   A similar situation

can be imagined for a target vehicle flying past a number

of, real world, similar SAM sites.   Figure 4.2 represents

th base or standard radar cross sections that were used for

this imaginary target vehicle.

        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.

        Figure 4.4 again represents the standard RCS data file

```
12000.0  12000.0  12000.0  12000.0  12000.0  12000.0  12000.0
12000.0  12000.0  12000.0  12000.0
  300.0    600.0   1000.0   1750.0   2750.0   3400.0   3000.0
 2250.0   1400.0    900.0   1000.0
  150.0    200.0     90.0     60.0    300.0   1250.0    600.0
  200.0     90.0     60.0     50.0
  400.0    100.0     30.0     40.0     56.0   2300.0     50.0
   30.0     40.0     50.0     50.0
  100.0     80.0     30.0     40.0    220.0   2250.0    200.0
   20.0     40.0     50.0    110.0
   70.0     40.0     30.0     40.0    300.0   4500.0    200.0
   25.0     70.0    250.0    400.0
   40.0     70.0     20.0     30.0    150.0   1200.0    350.0
   30.0     40.0     50.0    150.0
   40.0     50.0     20.0     30.0     70.0    600.0    200.0
   40.0     40.0     40.0     40.0
   50.0     80.0     90.0     80.0    350.0   1700.0   1000.0
  100.0     40.0     50.0     50.0
  150.0    300.0    600.0   1000.0   2000.0   3000.0   2300.0
 1300.0    700.0    350.0    200.0
 6000.0   6000.0   6000.0   6000.0   6000.0   6000.0   6000.0
 6000.0   6000.0   6000.0   6000.0


 Row 1
67.61 67.61 67.61 67.61 67.61 67.61 67.61 67.61 67.61 67.61
67.61
 Row 2
26.88 31.97 36.32 41.78 46.78 49.33 47.81 44.49 39.51 35.38
36.32
 Row 3
22.61 24.29 19.90 17.98 26.88 38.41 31.97 24.29 19.90 17.98
17.18
 Row 4
28.89 20.43 15.12 16.24 17.67 44.73 17.18 15.12 16.24 17.18
17.18
 Row 5
20.43 19.32 15.12 16.24 24.88 44.49 24.29 13.66 16.24 17.18
20.92
 Row 6
18.68 16.24 15.12 16.24 26.88 52.91 24.29 14.44 18.68 25.69
28.89
 Row 7
16.24 18.68 13.66 15.12 22.61 38.02 27.94 15.12 16.24 17.18
22.61
 Row 8
16.24 17.18 13.66 15.12 18.68 31.97 24.29 16.24 16.24 16.24
16.24
 Row 9
17.18 19.32 19.90 19.32 27.94 41.48 36.32 20.43 16.24 17.18
17.18
```

```
(Figure 4.4 cont.)


 Row1022.61 26.88 31.97 36.32 43.20 47.81 44.73 38.79 33.23
27.94 24.29
 Row11
56.85 56.85 56.85 56.85 56.85 56.85 56.85 56.85 56.85 56.85
56.85
```

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 nmiles 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 nmiles or

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 $\sigma^{1/4}$ 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 :

$$
\begin{array}{lll}
Pt & = & 1 \times 10^{5} \ (watts), \\
G & = & 1 \times 10^{3} \ (dB), \\
Lambda & = & 9.993 \times 10^{-3} \ (m), \\
F & = & 10 \ (dB), \\
B & = & 6 \times 10^{5} \ (Hz), \\
S/N & = & 31.6 \ (dB), \\
1.1507 & = & \text{a conversion from statute miles to} \\
& & \text{nautical miles,}
\end{array}
$$

and,
$$R_{max} = (5.61)(1.1507)(\sigma)^{1/4}, \qquad (4.1)$$

$$R_{max} = 6.4595(\sigma)^{1/4} = R_o(\sigma)^{1/4}. \qquad (4.2)$$

Then, when σ equals $4m^2$, R_{max} is equal to 9.135 nmiles; when
σ 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 U N C L A S S I F I E D
        PROGRAM TFTAEXP

        Dimension El(12), Az(12)
   C    These two dimensions are set up to equal the same
   C    dimensions of the  radar range array, by Elevation and
   C    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)
3       Continue
        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

```fortran
        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
c  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
        Write(31,*) DMAX
c       Write(32,20) DMIN
        Write(32,*)DMIN
        Write(6,*) 'MAXimum radar detection range is = ',
        DMA
c       Write(6,*)
c       Write(6,*) 'Minimum radar detec range is = ',DMIN
c20     Format(10(1x,F10.2))
        return
        End
```

Figure 4.6. Subroutine MAXMIN

```fortran
      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
      c 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

        IF (DRD(NP) .LT. RNGMIN(NZ)) THEN
           LIOS1(NZ,NP) = 0
             GO TO 270
        ENDIF
      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)
```

```
(Figure 4.7 cont.)

      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
           EndIf
1420   Continue
1421      CONTINUE
       Write(6,*)'AzCol is  ', AzCol
       WRITE(6,*)'AZMUTH IS   '. AZMUTH
       If (TLOOK(ELROW, AZCOL) .LT. DRD(NP)) THEN
         LIOS1(NZ, NP) = 0
         Go to 270
         EndIf
c  If radar range is less than actual target range -
c  detection = 0
c       IF(DRD(NP) .LT. RNGMIN(NZ)) THEN
c           LIOS1(NZ,NP) = 0
c           GO TO 270
c       ENDIF
    c
```

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)
     1*COS(AFPLAR)*COS(AFPLOR-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), NP 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.

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

Figure 4.9.   Function ELANG or Elevation Angle Calculations

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

$$\theta° = \# \text{ radians} * \frac{180}{\pi}$$

where $\theta°$ 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 ELVANG = 39° then the default is to 30°,

If ELVANG = 59° the default is still to 30°,

If ELVANG is between 60° through 70° the default is to 60°

	A	1	2	3	4	5	6	7	8	9	10	11	(Col #)
E	Z												
L		0	10	30	60	80	90	100	120	150	170	180	-θ°-

1	-90
2	-80
3	-60
4	-30
5	-10
6	0
7	10
8	30
9	60
10	80
11	90
	-θ°-
(Row #)	

RADAR

RANGE

VALUES

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.
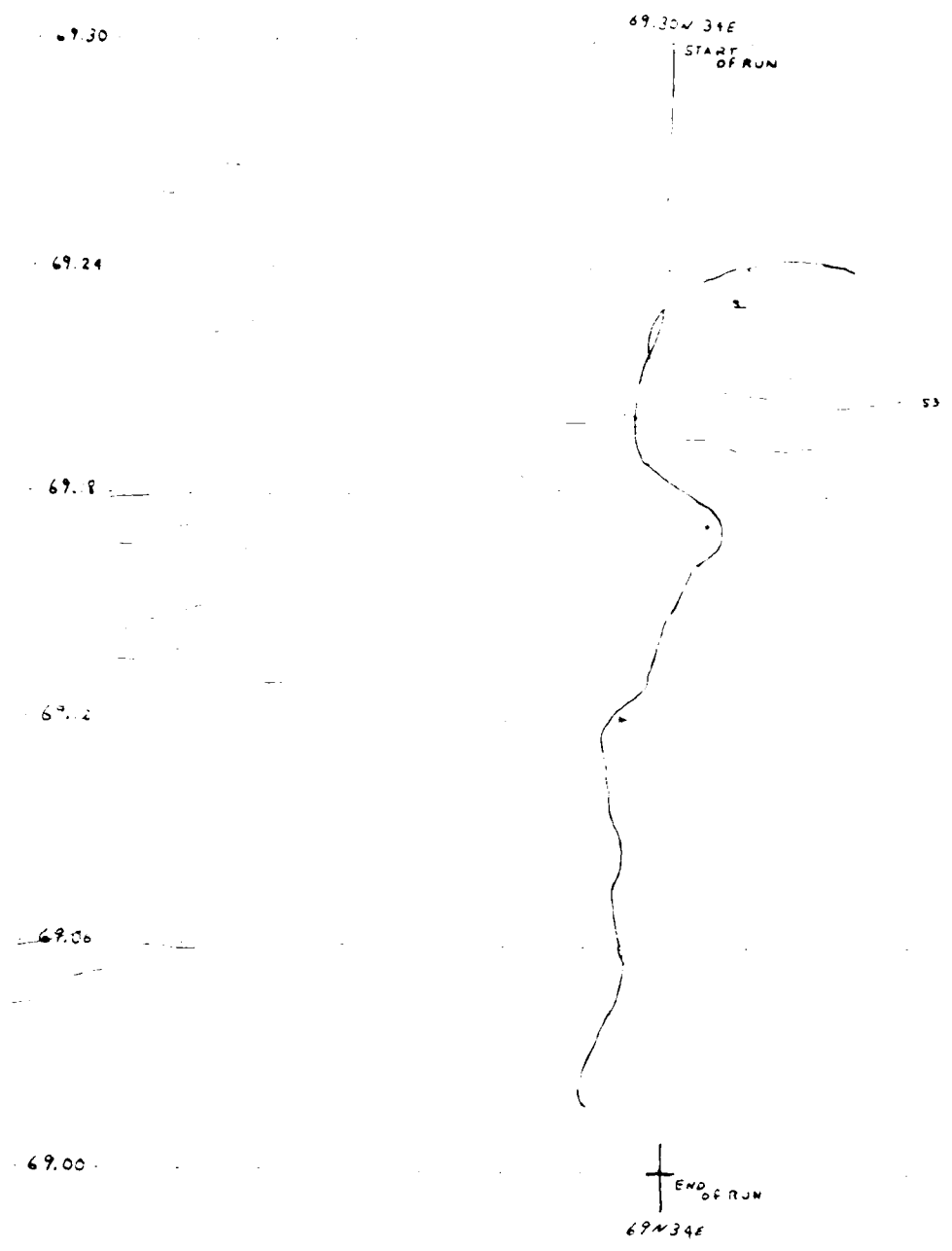
Figure 4.12.a Flight Path Generated by BLUEMAX II

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.

```
                               l
    a.   b--c--d--e.  f--g--h--i.   j.   k⌐ | ⌐m
   ────────────────────────────────────────────
    0.00 69.29.60.00 34. 0. 0.00  -3.142  011   <───┐
    0.50 69.29.57.50 33.59.59.90   3.142  011        │  Detection
    1.00 69.29.55.00 33.59.59.80   3.142  011        │  by sites
    1.50 69.29.52.50 33.59.59.70   3.142  011        │  2 & 3
    2.00 69.29.49.90 33.59.59.50   3.142  011        │
    2.50 69.29.47.40 33.59.59.40   3.142  011        │
    3.00 69.29.44.80 33.59.59.30   3.142  011        │
    3.50 69.29.42.30 33.59.59.20   3.142  011        │
    4.00 69.29.39.70 33.59.59.10   3.142  011   <───┘
         •               •               •
         •               •               •
         •               •               •
  403.00 69. 0. 7.50 33.59.41.30   2.393  000   <───┐No
  403.50 69. 0. 5.60 33.59.45.90   2.393  000        │detection
  404.00 69. 0. 3.80 33.59.50.60   2.393  000        │by any
  404.50 69. 0. 1.90 33.59.55.20   2.393  000        │sit
  405.00 69. 0. 0.10 33.59.59.90   2.393  000   <───┘
   ──────────────────
    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.
               ·l· is a detection by radar,
               ·0· is no detection by radar.
```

Figure 4.13. Output Line of Sight Data File

	SERIES A				SERIES B		
Col 1		**Col 2**		**Col 1**		**Col 2**	
0.00	011	0.00	010	202.00	101	202.00	101
0.50	011	0.50	010	202.50	101	202.50	101
1.00	011	1.00	010	203.00	101	203.00	101
1.50	011	1.50	010	203.50	101	203.50	101
2.00	011	2.00	010	204.00	101	204.00	101
2.50	011	2.50	010	204.50	101	204.50	101
3.00	011	3.00	010	205.00	001	205.00	001
3.50	011	3.50	010	205.50	001	205.50	001
4.00	011	4.00	010	206.00	001	206.00	001
4.50	011	4.50	010	206.50	000	206.50	000
5.00	011	5.00	010	207.00	000	207.00	000
•	•	•	•	207.50	000	207.50	000
•	•	•	•	208.00	000	208.00	000
•	•	•	•	208.50	000	208.50	000
156.00	100	156.00	100	**209.00**	001	209.00	000
156.50	100	156.50	100	209.50	001	209.50	000
157.00	100	157.00	100	210.00	001	210.00	000
157.50	100	157.50	100	210.50	001	210.50	000
158.00	100	158.00	100	211.00	001	211.00	000
158.50	101	158.50	101	211.50	001	211.50	000
159.00	101	159.00	101	212.00	001	212.00	000
159.50	101	159.50	101	**212.50**	001	212.50	000
160.00	101	160.00	101	213.00	000	213.00	000
160.50	101	160.50	101	213.50	000	213.50	000
161.00	101	161.00	101	214.00	000	214.00	000
161.50	101	161.50	101	214.50	000	214.50	000
162.00	101	162.00	101	215.00	000	215.00	000
162.50	101	162.50	101	215.50	000	215.50	000
				216.00	000	216.00	000
	k			216.50	000	216.50	000
	l			217.00	000	217.00	000
	m			217.50	000	217.50	000
				218.00	000	218.00	000
				218.50	001	218.50	000
				219.00	001	219.00	000
				219.50	001	219.50	000
					k		
					l		
					m		

Figure 4.14.   Comparison of Output Detection Results
Between the Enhanced & Unenhanced
Versions of TFTAEXP

Of prime interest are lines k, l, 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, l, 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.

	RADAR ADDED			NO RADAR ADDED		
- Site #'s with Number of Detections -						
1	2	3		1	2	3
Base Model				Base Model		
112	155	0		112	155	49 <--
0	4	96	<--	0	4	96 <--
0	0	0		0	0	8 <--
0	0	0		0	0	29 <--
112	159	96		112	159	182
Base Model RCS * 10				Base Model RCS * 10		
112	155	0		112	155	49
0	4	96		0	4	96
0	0	0		0	0	8
0	0	0		0	0	29
112	159	96		112	159	182
Base Model RCS ÷ 10				Base Model RCS ÷ 10		
112	155	0		112	155	49
0	4	96		0	4	96
0	0	0		0	0	8
0	0	0		0	0	29
112	159	96		112	159	182

Table 4.1

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,
therefor 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:

$$R_c = \left[\frac{\sigma_t \ (SCV)}{\Theta_B \ (R_R) \ \sigma_o (S/C)_{min}} \right] \qquad (5.1)$$

where

σ_t =   Targets radar cross section (m^2)
SCV   =   Sub-clutter visibility ($\approx$ 20 to 30 dB)
Θ_B =   Radar bandwidth (in azimuth angle, $\approx$ 1.0° to 1.4°)
R_R =   Radar range resolution, $\approx \tau$ C/2
        with:
        τ as the pulse width and $\approx$ .3 to .7 μ sec.
        C as the speed of light,
σ_o =   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.

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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 difference between this and the VAX version. Line 3, $LARGE, 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 ever line numbers are missing, some deletions for printing this appendix were required.

****

```
1       Program DETECT
2 c                      (saved under RCS9.for)
3 $LARGE
4 c   $LARGE 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, Pi, PRF, SN, Tau, Wavln, TgtRng, NoisdB
10      +       Runamb
11      INTEGER Answr, ROW, COL
12      COMMON /B1/ Ae, Bndwth, Clite, F, Freq, Gain, Htrdr,
13      +            Pi, PRF, SN, Tau, Wavln, 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 nmiles/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 Repeted 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 nmiles.     *
*     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                                        *
****************************************************************************
****************************************************************************
44
45          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          F = 10.
52 c         Write(*,*)'Enter in the receiver frequency '
53 c         Read(*,*) Freq
54          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 '
```

```fortran
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        SN = 1.5D+1
73 c      Write(*,*) 'Enter in the pulse width, ''Tau'', in
          scientific notaion
74 c      Write(*,*) 'i.e., 2 micro seconds is 2.0D-6, D for double
          precisi
75 c      Read(*,*) Tau
76        Tau = 2.0D-6
77        Wavln = Clite/Freq
78        Runam = (Clite/(2.* PRF)) * .00053995680
79        Runamb = Runam * 1.1507
80 c Converts from meters/sec to nmiles/sec:m/s*km/m*smi/km*nmi/smi
81
82        Write(*,*) 'Do you want to build an array of Radar Cross'
83        Write(*,*) 'Section datas?  Type 1 then return'
84        Write(*,*)
85        Write(*,*) 'Do you want to use an existing RCS array?'
86        Write(*,*) '                    Then type 2'
87        Write(*,*)
88        Write(*,*) 'Do you want to use the constants in this
          program?'
89        Write(*,*) '                    Type 3'
90        Read(*,*) ANSWR
91
92        If (ANSWR .EQ. 1) Then
93          Write(*,*) 'Enter in the size of the array for your Radar'
94          Write(*,*) 'Cross Sections.  Type in the * of Rows first '
95          Write(*,*) 'then the * of columns. '
96          Read(*,*) ROW,COL
97          Write(*,*)
98          Write(*,*) 'The * of rows columns are =    ', ROW, COL
99          Write(*,*)
100                Call BUILD (ROW,COL)
101
102       Else If (ANSWR .EQ. 2) Then
103               Write(*,*) 'Enter in the dimensions of the external
          array '
104               Write(*,*) 'that will be used. Type in the * of Rows'
105               Write(*,*) 'first then the * of columns. '
106               Read(*,*) Row, Col
107               Write(*,*) 'The * of rows columns are =    ', ROW, COL
108                 Go to 10
109
110       Else If (ANSWR .EQ. 3) Then
111                 Go to 10
112       End If
113
114       Write(*,*) ' To continue type 1, to quit type 2 '
```

```
115        Read (*,*) Think
116          If (Think .EQ. 1) Then
117            Go to 10
118              Else If (Think .EQ. 2) Then
119                Go to 430
120          End If
121 10     CALL RMAX (Answr, ROW, COL, Runamb)
122        STOP
123 c  end of program detect
124 430    END
125
**********************************************************************
127
128 500    SUBROUTINE RMAX (Answr, ROW, COL, Runamb)
129        INTEGER ROW, COL, Answr, Compar(100,100)
130        REAL tSigma(100,100), Sigma, TgtRng, RdrRng(100,100)
131 c  tSigma is for a temporary Sigma
132 c      Write(*,*) 'Row and Col = ', Row, Col
133        If (ANSWR .EQ. 3) Then
134          Go to 510
135            Else If (ANSWR .EQ. 1 .OR. ANSWR .EQ. 2) Then
136              Go to 520
137        End If
138
139 510    Write(*,*) 'Please enter the Average Radar Cross Section'
140        Write(*,*) 'for your target'
141        Read(*,*) Sigma
142 c                    No format, else you would have to type
143 c                    in the number exactly as a format statement
144 c                    specified (what a pain in the ass).
145
146          N=1
147          I=1
148          Write(*,650) Sigma
149
150        Call RANGE(RdrRng(N,I), Sigma, TgtRng, N, I)
151          Write(*,652) RdrRng(N,I), Runamb, Sigma
152        If (RdrRng(N,I) .LT. TgtRng) Then
153          Write(*,*) 'Target can not be seen for this single RCS
            value'
154          Else If (RdrRng(N,I) .GE. TgtRng) Then
155            Write(*,*) 'Target is probably within range of the '
156            Write(*,*) 'radar and may be detectable.'
157        End If
158        Write(*,*) 'The unambigious range of the radar is ',Runamb
159        RETURN
160 c  Return: Goes back to CALL RMAX
161
162 520    OPEN(60, FILE='TEST', STATUS='Old')
163 c      Write(*,*) 'I am now at 520 '
164 c      Write(*,*) 'SR RMAX ..... ROW  &  COL are = ', ROW, COL
165
```

```
166            Do 530 N=1,ROW
167                READ(60,655) (tSigma(N,I), I=1,COL)
168 530     Continue
169 c   This Do-loop saves the RCS var's 'N & I', from BUILD, in
170 c   the array  DIMENSION tSigma, in essence it is loading
171 c   up a temp. array.
172
173            Do 640 N=1,ROW
174                Do 630 I=1,COL
175                Sigma = tSigma(N,I)
176 540     Write(*,*) 'I am now at line 540~~~~~~~~~~~~~ START ~~~ '
177 c          Now tSigma is being read, set equal to Sigma, and
178 c          passed into the Range subroutine for the RdrRng
179 c          equation to work on.  Then they're sent to the Check
180 c          subroutine and the result is put into another array
181 c          for storage.
182
183                Call RANGE(RdrRng(N,I), Sigma, TgtRng, N, I)
184                Write(*,*) 'I am going into Check now'
185                Call CHECK(RdrRng(N,I), N, I, Compar, TgtRng)
186
187 630         Continue
188 635     Write(*,*) 'I am now at line 635'
189 640         Continue
190
191                Do 645 N=1,ROW
192                    Write(60,680) (Compar(N,I), I=1,COL)
193                    Write(*,*) 'I am now above line # 645 '
194 645         Continue
195 c   COMPAR data is being written to Unit 60.  In this case
196 c   data from the array COMPAR, created in the Check subroutine,
197 c   is being written to file 60 in format 680.  This puts the
198 c   1's and 0's at the end of the array of radar cross sections.
199         OPEN(70, File='Look', Status= 'NEW')
200                Do 649 N = 1,Row
201                    Write(60,656) N, (RdrRng(N,I),I=1,Col)
202                    Write(70,655) (RdrRng(N,I),I=1,Col)
203                    Write(*,*) 'I am now above line # 649 '
204 649         Continue
205 650     Format (1x,'The value you have entered is   ',1x,F15.4)
206 652     Format (1x,'The radar range ',F7.2,/,'  Runam is  ',F7.2,
207        +1x,'  and Sigma is  ',F7.2/)
208
209 655     Format (10(1x,F6.2))
210 c   format 655 has to be the same as format 870
211 656     Format (1x,'Row',I3,/,10(1x,F6.2))
212 680     Format (10(1x,I6))
213         CLOSE(70)
214 c   end of subroutine RMAX
215         RETURN
216         END
217
```

```
218
**********************************************************************
220
221        Subroutine RANGE(RdrRng, Sigma, TgtRng, N, I)
222
223        REAL     Sigma, Ae, Bndwth, Clite, F, Freq, Gain,
224       +         Htrdr,Pekpwr, Pi, PRF, SN, Tau, Wavln, TgtRng,
225       +         RngRdr
226        COMMON /B1/ Ae, Bndwth, Clite, F, Freq, Gain, Htrdr,
227       +         Pekpwr, Pi, PRF, SN, Tau, Wavln
228
229 c        Write(*,*) 'Wavelength = ...........', Wavln
230 c        Write(*,*) 'Gain is ................',Gain
231 c        Write(*,*) 'Noise figure F = .......', F
232 c        Write(*,*) 'This is Tau.............', Tau
233
234        Bndwth = 1.2/Tau
235 c        Write(*,*) 'Bandwidth = ...........', Bndwth
236 c        Write(*,*) 'Signal to Noise ratio =', SN
237 c        Write(*,*) 'Sigma is equal to    =', Sigma
238
239 700    Write(*,*) 'I am now at line 700'
240        RdrRng = (Pekpwr)*(Gain**2)*(Wavln**2)*(Sigma)/
241       +         (F*Bndwth*SN)
242          RdrRng = 11.72 * (RdrRng**(.25))
243            RdrRng = RdrRng * 1.1507
244 c  Converts from stmiles to nmiles.
245
246
247 720    Write(*,*) 'I am now at line 720 RdrRng =', RdrRng
248 c  Converts from stmiles to nmiles.
249 c        Write(*,*) 'PRF =   ', PRF
250 750      TgtRng = 50.
251
252 c  End of subroutine RANGE
253        RETURN
254        END
255
**********************************************************************
257
258        Subroutine CHECK(RdrRng, N, I, Compar, TgtRng)
259
c Subroutine 'Check' looks at the radar sites range to the targets
c vs. the unambiguous range of the radar. The DIMENSION Check
c is created and filled with 1's for detection, and 0's for no
c detection.  The array will later be added to the bottom of the RCS
c array created in the BUILD subroutine or outside this program.
265
266        Integer COMPAR(100,100)
267        Write(*,*) 'What are the Ns and Is down here? ', N, I
268          IF (RdrRng .LT. TgtRng) THEN
269            COMPAR(N,I) = 0
```

```
270              Else If (RdrRng .GE. TgtRng) Then
271                  COMPAR(N,I)=1
272              End If
273                  Write(*,*) 'I am leaving check now'
274 c          RETURN
275          END


     Type         Offset P Class

AR INTEGER*4        12 *
   INTEGER*4         8 *
   INTEGER*4         4 *
NG REAL              0 *
NG REAL             16 *



276
**********************************************************************
278
279      Subroutine BUILD (ROW,COL)
280
281 c This program will allow you to build an array of
282 c Radar Cross Section Values that will be called in
283 c for later use.  Subroutine AVRCS is average RCS for
284 c aspect angles near nose-on for the T-38.  In the
285 c Dimension stmt the rows and columns, respectively,
286 c can be changed to reflect larger or smaller arrays.
287 c Make sure to change the read and write stmts.
288          REAL  AVRCS(100,100)
289          INTEGER Row, Col
290          OPEN(50,File ='TEST',Status='NEW')
291          Write(*,*) 'SR Build where ROW and COL are = ', ROW, COL
292 c                   Use unit 50 to read RCS data into an array:
293 c                   for use at a later time
294
295          Write(*,*)
296          Write(*,*) 'Prepare to enter in the data for your array. '
297      Write(*,*) 'Enter in your first Row of numbers, hit return,'
298          Write(*,*) 'then continue until you''re finished.  The '
299          Write(*,*) 'program will give you the system prompt when '
300          Write(*,*) 'all the figures have been entered.'
301
302          Do 800 N = 1,ROW
303              Read(*,*) (AVRCS (N,I), I = 1,COL)
304              Write(50,870) (AVRCS(N,I), I = 1,COL)
305              Write(*,*)
306 800      Continue
307
308 c
309 c
310 c
311 c
```

```
312 c
313
314
315 c    N = 1,ROW is the # of rows
316 c    I = 1,COL  is the # of columns
317
318       Do 830 N = 1,ROW
319           Write(*,875) N, (AVRCS(N,I), I = 1,COL)
320 c         Write(*,870) (AVRCS(N,I), I = 1,COL)
321 830   Continue
322 c   This loop is writing the data to the screen for a final check.
323
324       Write(*,*)
325       Write(*,*) 'Is this data ok?  If not restart and retype '
326       Write(*,*) 'it in, or better still call up the newly '
327       Write(*,*) 'created file and edit with any text editor.'
328       Write(*,*)
329
330 870   Format(10(1x,F6.2))
331 c   format 870 has to be the same as format 655
332 875   Format(1x,'Row ',I3,/,10(1x,F6.2)
* Warning -- Invalid format, Error 1200
333       CLOSE (50)
334 c  Closes the array and end of subroutine BUILD
335       END
336
**********************************************************************
```

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         Program MAXMIN
2 #Large
3         Real LOOK(100,100), tLOOK(100,100), max, min
4         Integer Row, Col
5         Open(20, file='LOOK', Status='old')
6         Open(21, file='max', Status='new')
7         Open(22, file='min', Status='new')
8         Write(*,*) 'Enter in the # of rows and columns '
9         Read(*,*) row,col
10        Do 11 I = 1,row
11           Read(20,20) (tLOOK(I,J), J=1,col)
12 11      continue
13 c   this builds a temp array of radar detection range values
14        max = 0
15        min = 9999
16        Do 22 I = 1,row
17          Do 21 J=1,col
18            If ( tLOOK(I,J) .GT. MAX) THEN
19              MAX = tLOOK(I,J)
20            End If
21 21        continue
22 22      continue
23
24        Do 24 I = 1,Row
25          Do 23 J = 1,Col
26              If ( tLOOK(I,J) .LT. Min) Then
27                Min = tLook(I,J)
28              End If
29 23        continue
30 24      continue
31        Write(21,20) max
32        Write(22,20) min
33
34 c      Write(*,*) 'Maximum radar detection range is  ', Max
```

```
35 c        Write(*,*) 'Minimum radar detection range is   ', Min
36          Write(*,*)
37 c        Write(*,*) 'What value would you like to see, enter '
38 c        Write(*,*) 'in the row and column '
39 c        read(*,*) Row,Col
40 c        Write(*,*) 'The number is   ',tLOOK(row,col)
41 20       Format(10(1x,f6.2))
42          stop
43          end
```

<u>Vita</u>

<u>Jeffrey D. Hearrell</u>

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.

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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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