ESD-TR-78-377

See back page for 1473

LEVEL II

(12)

Project Report

TT-14

E. T. Bayliss
J. H. Cosgrove

HOWLS LOCATER Computer Program: Description and User's Guide

26 December 1978

Prepared for the Defense Advanced Research Projects Agency
under Electronic Systems Division Contract F19628-78-C-0002 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

Approved for public release; distribution unlimited.

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology. This work was sponsored by the Defense Advanced Research Projects Agency under Air Force Contract F19628-78-C-0002 (ARPA Order 2752).

This report may be reproduced to satisfy needs of U.S. Government agencies.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Raymond L. Loiselle

Raymond L. Loiselle, Lt. Col., USAF
Chief, ESD Lincoln Laboratory Project Office

12

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LINCOLN LABORATORY

HOWLS LOCATER COMPUTER PROGRAM: DESCRIPTION AND USER'S GUIDE

E. T. BAYLISS
J. H. COSGROVE
Group 45

PROJECT REPORT TT-14

26 DECEMBER 1978

Approved for public release; distribution unlimited.

LEXINGTON MASSACHUSETTS

ABSTRACT

LOCATER is a computer program used to simulate projectile tracking radar estimation of weapon locations from real or simulated projectile tracking data. A complete mathematical description of the modified point mass trajectory modeling, radar random errors, wind, refraction, multipath and the maximum likelihood estimator is included. Detailed user instructions and samples are covered. A programmer's guide to modification of the 7000 line FORTRAN program is included.

CONTENTS

1.0 SUMMARY

LOCATER* is a computer program designed to simulate a projectile tracking radar (PTR) and to estimate weapon locations from real or simulated projectile tracking data. This 7000 line FORTRAN program was developed as a tool in support of the Army/DARPA HOWLS program to investigate the application of new technology to the problem of locating artillery. Over a 3 year period this program was used to investigate a broad class of problems concerning projectile tracking radar performance. It is organized in a modular way so that it can be easily understood, used and modified by any analyst or programmer. It is reasonably efficient - but like any detailed simulation it can only be used to perform specific analysis and gain insight - not to simulate an entire battle scenario.

LOCATER simulates a projectile trajectory using a modified point mass dynamic model which includes effects of drag and projectile spin. A projectile tracking radar measures this trajectory with associated random errors in range, azimuth, elevation and doppler which are statistically modeled as independent bias, jitter and thermal noise errors. The environment is modeled with wind and air density affecting the trajectory and refraction and multipath affecting the radar measurements. The location estimator takes these simulated errored measurements (or real radar measurements) and makes an estimate of the most likely launch location for the weapon. The estimator also uses a statistical model of radar errors and can use meteorological, multipath as well as *a priori* data about projectile parameters. The estimator is very flexible allowing any subset of measurement dimensions (e.g., azimuth, elevation) to be used in estimating any subset of states (e.g., excluding drag and spin). When real data is processed this feature plus the ability to automatically edit out bad points (e.g., $> 2\sigma$) gives good performance even with poor data. When simulating a radar, a number of independent simulations are run for a given trajectory (i.e., different errors) and the statistical performance is summarized (i.e., weapon location CEP).

Over the three years of using LOCATER in the HOWLS project it has been applied to a wide variety of problems: Performance evaluation of various proposed PTR concepts, development of an improved Upleg/Downleg weapon location algorithm, validation of algorithm performance by processing real data, simulation of multiple radar tracking nets, evaluation of performance degradation due to projectile RCS variation with aspect and multipath errors, and the

---

*The name LOCATER suggests the program's function as is the achronym "Location Of Counterfire Artillery Through Trajectory Estimation by Radar".

performance of a radar without elevation measurements. Examples of LOCATER operation in four cases are included with all input and output.

Both the input and output is organized in a modular way that makes their operation easy to learn and use. Input parameters are specified in up to 16 free-form data packets. Typically only a few of these are required. For example, only four are needed to process real data. Input of real data is flexible with run time formats allowing input from cards or tape units. In operation, multiple runs are usually made so that the only packets with parameters that change need to be re-specified - other values remain in effect - making parameter changing easy with only a few cards.

The output is organized into 9 independent (optional) sections:

1. Listing of input cards
2. Nominal projectile trajectory generated
3. Estimator states after each iteration till convergence
4. Track file measurements with editing notes
5. State covariance matrix and correlation coefficients
6. Estimated launch conditions (e.g., velocity, QE, etc.)
7. Track residual errors
8. State estimation parameters (e.g., drag and spin)
9. Launch point location errors

Plots of residual errors (7) and launch point errors (9) are done by separate programs using files prepared by LOCATER.

A complete mathematical description of all modeling and the maximum likelihood estimator is included to bridge the gap between theory[1] and the implementation in LOCATER. The maximum likelihood equations are solved iteratively with a technique that requires only an approximate initial estimate. The number of states to be estimated is selectable (usually 6 to 8) but the state vector is expandable up to 17 states. A numeric transition matrix is used thus permitting easier change to the equations of motion.

Program modification is facilitated by a mathematical description which includes the identification of certain key program variables. Typical program modifications are illustrated as a guide to programmers changing dimensions of arrays for radar measurements and meteorological conditions, adding data packets for input parameters, and modifying the equations of motion.

2.0 INTRODUCTION

2.1 History of LOCATER Program Development

A broad study of projectile tracking radars was undertaken in 1975 as part of the DARPA/Army HOWLS program. The general charter of the HOWLS program was to find ways of applying new technology to the location of hostile indirect-fire weapons, i.e., artillery and mortars. The phase of the project directed toward projectile tracking radars was to exploit new technology in the area of advanced computers, precision guided munitions, multistatic sensors, and light-weight highly mobile sensor platforms. These advanced technologies were postulated as being available for development in the mid-1980's.

Over the past 3 years of the projectile tracking radar investigation, a variety of analytic tools have been used to support this study. First, there was need of a simulator to investigate the accuracy of projectile tracking radars in the various systems concepts proposed for the 1980's. Later as advanced tracking algorithms were explored it became essential to have a tool for processing real radar data through experimental algorithms. In order to fill the gap in real radar data, it was necessary to use special precision ballistic trajectory generators such as the BRL modified point mass program or trajectories produced by outside agencies, for example RAP (Rocket assisted projectiles) trajectories, or rocket trajectories that were simulated for other purposes and thus it was necessary to use these externally generated trajectories as models for a system simulator. Near the end of the project is was possible to arrange for field measurements of a variety of projectile types in order to complete the spectrum of trajectories with which to test proposed advanced tracking algorithms. With this high precision tracking data, it was necessary to add features that would allow for algorithm validation and modification, ability to change the dynamic tracking model easily, and to analyze the characteristics of the residual errors. The majority of these requirements for analytic tools were met through the development of an omnibus projectile tracking program called LOCATER.

The LOCATER program evolved to meet the need for system analysis tools described above. Early system analysis and parametric studies were performed with a modified exo-atmospheric program called HWLPTR (Hostile Weapons Locating Projectile Tracking Radar). HWLPTR included modifications to allow for simulation of endo-atmospheric ballistic trajectories but the program structure was somewhat inefficient for projectile tracking work and somewhat difficult to modify. As it became clear that the projectile tracking investigation would expand into other other applications, it was decided to redesign and write a new program specifically for endo-atmospheric projectile tracking investigations. This work was started in the Fall of 1976 and resulted in the writing of 7,000 lines of FORTRAN code which became operational in January 1977. This program, called LOCATER, was written for the CDC 6600 computer and uses 66 K decimal words of storage. The program was designed to be flexible and uses an easily modified modular construction. Input to the program is in the form of data packets submitted in batch. Output is prepared in the form of a number of output SECTIONS each independent of one another. Internally, a generalized state vector structure is used which is easily modified and numerical integration is used to keep the state vector extrapolation transparent to the particular system model being used. Continued evolution of this program is expected as it is now in a form which is easily maintainable. As new modifications are added to the program, future versions of the program will be documented in addenda to be attached to this Tactical Technology report. All programs and documentation are to be made available on tape. The program was written to be operated on the Lincoln CDC-6600 computer, however, the FORTRAN conventions used in writing this program were chosen to make conversion for use on IBM-370 equipment very straightforward.

2.2 Purpose

The purpose of this report is to familiarize potential users of the LOCATER program with its features and capabilities. For those who are already users of the program it serves as a reference guide for both the preparation of input and the interpretation of output. For those who wish to make software modifications, it serves as a system description and programming guide. The basic function of the program is to locate hostile weapons from radar tracking data on the fired projectile. The purpose of the program is to serve as a general purpose analytic tool for investigating the effects on weapon location accuracy of radar system parameters, trajectory modeling and estimation algorithms, and environmental effects such as wind, tropospheric refraction, and multipath. The program is designed to provide analysis of these effects by analytic modeling, statistical modeling, and through analysis of real data. The program is designed to be useful in a wide variety of analyses of sensors designed to measure tactical ballistic projectiles. The program is designed to be functionally useful in a research and development environment. It is user oriented, modular, and easily modified. It's designed to operate efficiently in a batch environment with graphics being provided by separate special-purpose plotting programs. A complete description of the program capabilities and features can be found in Section 3.

2.3 Scope

This report contains a complete description of the operation and use of version 2.0 of the LOCATER program. Version 2.0 of LOCATER was achieved in March 1978. As with any R&D analysis tool, continued change is to be expected. It is planned to describe any subsequent revisions to the program in addenda to this report.

A complete description of program capabilities and features is included in Section 3. This includes information a potential user would need to know to determine if the program would solve his particular problem, and furthermore, the kind of information needed to determine if the program would be usable with a given set of computer equipment. Application of the program to particular projectile tracking problems is covered in Section 4. These applications are illustrated concretely by the examples of program operation included in Section 7. Additional potential applications of the program are also included. A complete description of the mathematical background for the program is included in Section 5. The mathematical basis in theory of operation used in the LOCATER program can be found in Reference 1. However, the actual implementation in the LOCATER program differs in several important details; namely, the inclusion of a more general dynamic model for the projectile which includes induced drag and magnus acceleration and the use of numerical transition matrices. These are covered in Section 5. A general users' guide and reference is contained in Section 6 which includes a description of the preparation of the input data packets as well as a complete description and interpretation of each output section. Four complete demonstration examples of program operation are included in Section 7. These are designed to illustrate the wide variety of applications of this program. Finally, Section 8 provides a guide to programmers for understanding the internal program operation and for making potential modifications to the program.

This report does not cover the results of any of the projectile tracking analyses performed as part of the HOWLS program. The use and effectiveness of various projectile tracking radar concepts and projectile tracking algorithms is covered in other Tactical Technology reports (TM1977-15 and TT-23).

3.0 PROGRAM CAPABILITIES

This section is directed at the potential user or person who wishes to get an overview of what this program will do. We will start by giving a very brief description of the way in which the program operates. Next, we will describe the program capabilities for modeling the projectile trajectory of the radar in the environment. The parameters considered in the trajectory estimation process will then be described and finally some program features will be described.

3.1 Program Operation

The LOCATER program was designed to both simulate projectile tracking radar operation and reduce experimental recorded radar data producing a launch point estimate. The major operating modes for the LOCATER program are depicted schematically in Figure 3-1. When in the radar simulation mode, an internal trajectory generator produces the position and velocity measurements for the modeled trajectory. A radar noise generator then adds random radar measurement errors which model the error statistics of the particular radar being simulated. These simulated trajectory measurements are then processed through the maximum likelihood weapon location algorithm and the predicted launch point is collected for output. This process is repeated many times in Monte Carlo simulations of radar operation. The collected launch points are then statistically processed to determine the expected CEP.

When experimental recorded radar data is to be processed, the internal trajectory generator is not needed. The data is entered directly through a simple coordinate transformation, and of course no radar noise needs be added to the real measurements, and it is processed directly by the maximum likelihood weapon location algorithm, the output being the launch point prediction as well as other statistical quantities such as azimuth of fire, QE, etc. If many similar trajectories are to be processed, and the true launch point is known, an experimental CEP can also be generated.

With the program structure shown, it is possible to use an externally generated trajectory in place of the internal trajectory generator for use in the simulation mode. Such detailed trajectory modeling programs as the Ballistic Research Labs' 6-degree-of-freedom model or the modified point mass model can easily be employed. Here again the radar noise generator is used to add simulated radar measurement noise to the unerrored trajectory measurements. The coordinate transformation is generally required to convert from the modeling coordinate system centered at the launch point to the measurement coordinate system centered at the radar.

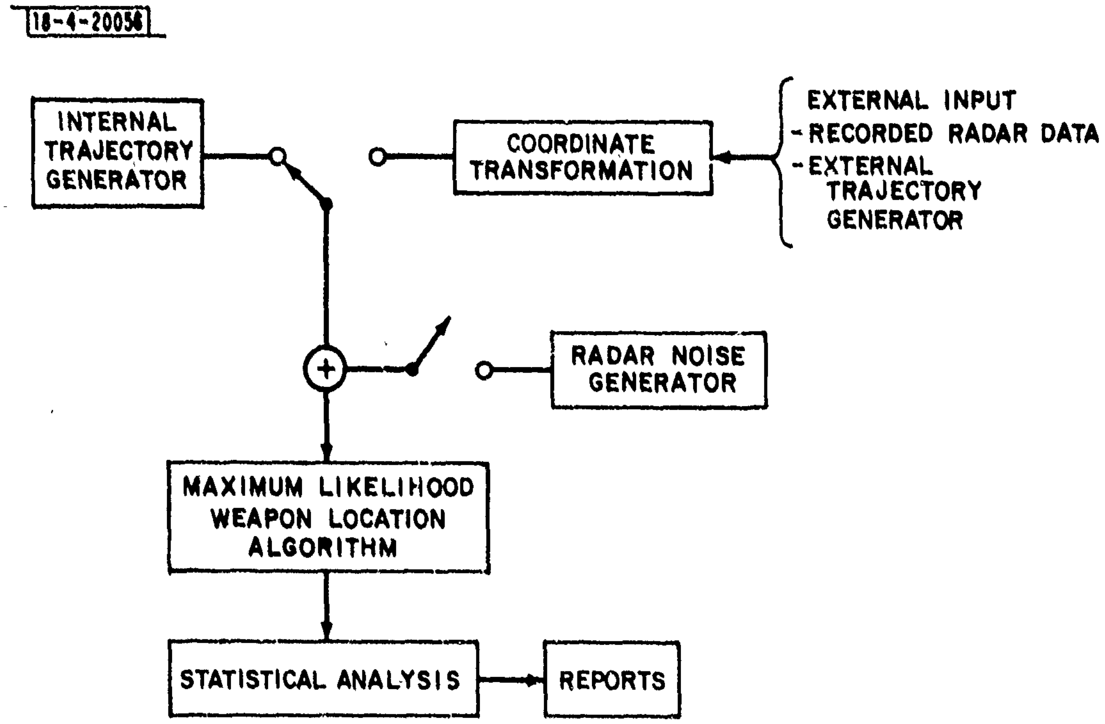


Fig. 3-1. LOCATER program.

The LOCATER program is extremely modular giving it a flexibility to operate in any combination of modes that are implemented. For example, it is possible to take experimentally recorded radar data and add additional radar noise to it. This might be done, for example, to model a projectile tracking radar of low precision with experimentally recorded metric measurements from a high precision tracking radar.

3.2 Weapon Modeling

Of course the modeling of weapon projectile characteristics applies only to trajectories generated by the internal trajectory generator. It is possible to specify up to 5 weapons and/or trajectories to be modeled at once. Each weapon is located in a local UTM coordinate system including its elevation above sea level. The initial conditions for the trajectory are specified in terms of the azimuth of fire, the QE and the initial velocity of the projectile at the time of launch. The projectile characteristics which are modeled include the diameter, mass, and drag curve to be used with the projectile. A spin constant is also specified which determines the lift acceleration and other minor accelerations dependent upon the projectile spin. In addition to these factors, the effects of gravity, Coriolis force, wind and density variations are also included in the ballistic trajectory calculations. The radar cross section of the projectile can be either specified as a constant or it can be modeled as a table of radar cross section values as a function of aspect angle where aspect angle is defined as the angle between the projectile velocity vector and a line from the projectile to the observing radar. In simulation runs, it is possible to specify a drag and spin uncertainty so that the drag and spin factors can be varied over a range to simulate the uncertainty in these characteristics on a round-to-round basis. When external trajectories are used in place of the internally generated ones, it is often necessary to convert the coordinates produced by the external trajectory generator into those that correspond to the actual location of the observing radar. To do this a special feature has been added that allows the origin of the trajectory to be specified in terms of its UTM coordinate location and elevation above sea level. This coordinate transformation is usually not required for experimental recorded radar data because that data is usually made available in radar measurement coordinates of range, azimuth, elevation, and doppler.

3.3 Radar Modeling

Up to 5 radars may be modeled at one time in the program. Each of these radars may track any or all of the weapons specified above. The tracking interval for each radar weapon pair can be specified in terms of altitude, time, or in terms of elevation angle to determine the track segment for a particular radar. Most often one specifies the elevation coverage of the radar and lets tracking take place automatically. For multi-sensor tracking, the measurements will be converted to the coordinates of the base radar and the radar covariance matrix will likewise be converted to the base radar coordinates so that the maximum likelihood algorithm can combine all the measurements to produce the most likely launch point. This capability can be used to investigate the geometric sensitivity to various multi-sensor tracking configurations. The location of each radar is specified in the UTM coordinate system along with the altitude. The type of radar modeled is a tracking radar which measures range, azimuth, elevation, doppler, and signal-to-noise ratio. Phased array radar angle measurements are not presently modeled in the program. For each of the measurement dimensions except the signal-to-noise ratio, the user can specify an error model composed of a bias, a statistically independent jitter error which does not vary with signal-to-noise ratio or range, and a statistically independent thermal error which does depend upon signal-to-noise ratio and hence range of the radar to the target. The sensitivity of the radar is also specified so that signal-to-noise ratio may be simulated as a function of range and radar cross section. When Monte Carlo simulations are run, a random number generator is used to supply numbers selected from a normal probability distribution. These numbers are then scaled by the sigmas specified for bias, jitter, and thermal sigmas. In computing the thermal error the range is used to compute the signal-to-noise ratio and its square root then is used to divide the specified thermal sigmas. The signal-to-noise ratio is computed from the sensitivity, the range, and the radar cross section. If a radar cross section aspect angle table is provided, then radar cross section is recomputed at each point based on the computed aspect angle for the target.

An important feature of the program is the ability to model any subset of measurement dimensions; for example, a radar was modeled which measured only range, azimuth, and doppler or a sensor could be modeled which made only angle measurements. When any of the three position measuring dimensions is missing, it is often possible to use the geometric diversity of the trajectory to infer the missing positional information.

During the trajectory estimation calculation, the maximum likelihood algorithm uses the radar error sigmas specified in the radar model. It is, however, possible to specify a different radar model to be used in the estimation process than in the measurement generation. This model is also used during the processing of recorded radar data. The radar model includes provisions for removing known biases in range, azimuth, elevation, and doppler. In addition, a specular multipath model is included for removing known multipath from the elevation measurement. Both biases and the multipath can be included in the estimation process discussed in Section 3.5.

3.4 Environmental Modeling

The atmospheric model is used both in the generation of trajectories for simulation and in the maximum likelihood weapon location algorithm. The atmospheric model includes wind speed, direction, air density, and air temperature. Three options are provided for specifying these conditions: First is a standard option which uses standard density and temperature profiles and no wind. Second is a ground conditions specification where the density and temperature profiles are scaled to match the specified ground conditions and the wind speed and direction are assumed to be constant with altitude. The third option is a layered meteorological model where the wind speed direction, air density and temperature are specified as a function of altitude. This specification is designed to mesh with the standard meterological reporting format.

The propagation of the radar signal can be simulated to include effects of tropospheric refraction on the range and elevation measurements. The effects of multipath errors in the elevation measurement can also be simulated either by specifying a functional form for the error or by specifying a table of elevation errors (see Section 5.4.4 for more detailed description of the multipath simulation).

3.5 Trajectory Estimation Process

Although the LOCATER program is configured to handle several tracking algorithms, only the maximum likelihood estimator is presently implemented. The operation of the maximum likelihood estimator will be briefly described using Figure 3-2. For a more rigorous exposition of the theory, see Ref. 1. Radar measurements are taken of a projectile trajectory as illustrated by the dots on Figure 3-2. The state of the projectile at each point along the trajectory is then described by a state vector which includes the 3 position and 3 velocity states in addition to several parametric states to be described below. The radar measurements are assembled into a track file which includes all of the track points measured on a particular trajectory. An initial estimate of the state vector is made by a simple polynomial regression on a few of these measurements. This initial state referred to as X_0^1 is used to start the estimation process. This state vector is extrapolated by integrating the states to each of the measurement times in the track file. The state vector is then transformed into the measurement dimensions and the difference is computed to determine the residual errors from each measurement. These errors are then used to solve the maximum likelihood equation for the linear perturbation $\delta\hat{X}_0$ which is the most likely

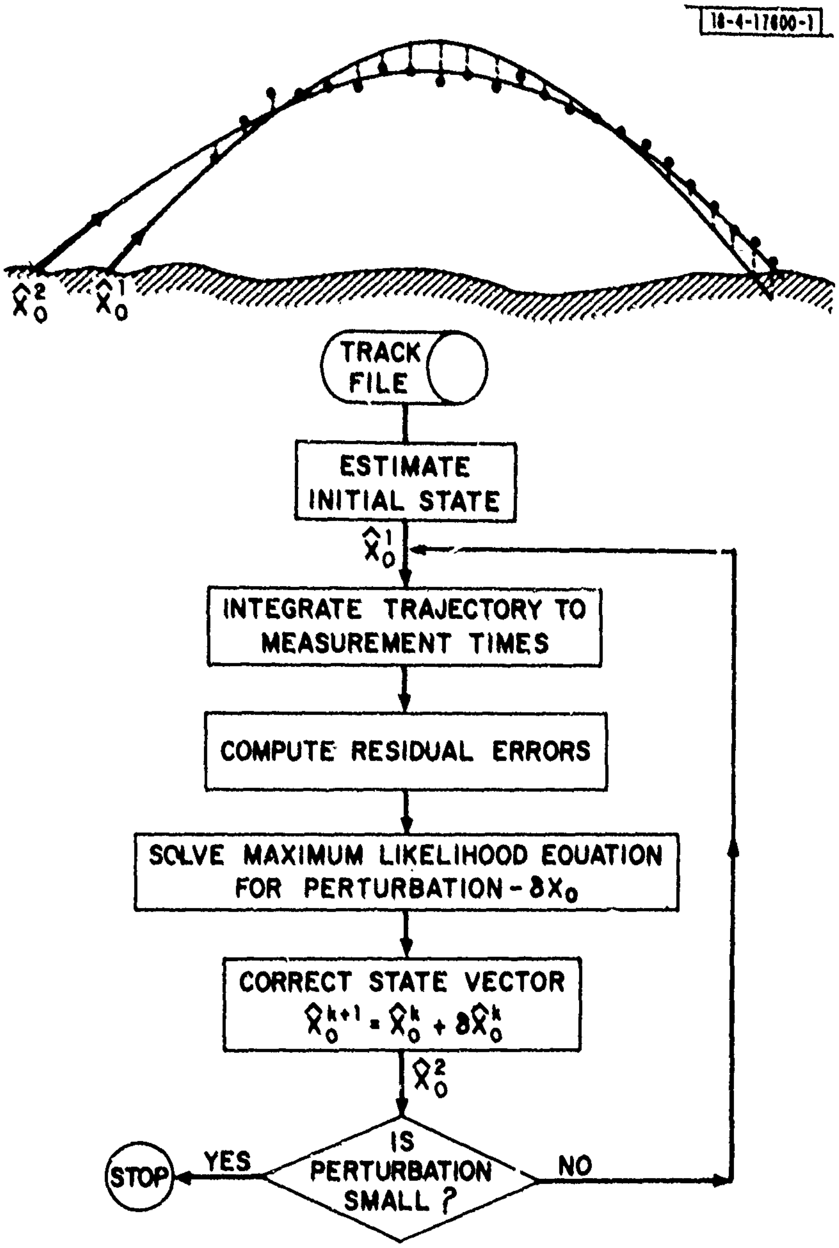


Fig. 3-2. Maximum likelihood estimation.

linear perturbation to the initial state vector which would remove the residual errors. Next, this perturbation is added to the initial state vector to create a new state vector. The perturbation is tested to see if it is small enough to terminate the iteration process. If it is not, the corrected state vector is then used to start another iteration of the process as illustrated in Figure 3-2. Any or all of the states may be tested for convergence. We have generally tested only the position state and asked that the perturbation be less than 1/2 meter. In LOCATER, a total of 10 states are modeled: 3 position, 3 velocity, and 4 parameters, one of which is a drag scale factor which is used to scale the drag obtained from an internally stored drag table which is a function of Mach number. Secondly, a spin constant is included which relates the spin derived accelerations principally lift for the projectile and two states which can be used to estimate wind in the east and north directions. The program has options to suppress the estimation of any subgroup of these states. For example, the wind states are generally not estimated but are measured *a priori* values. The spin constant and the drag may not be estimated; for example, if the radar measurements are too poor to support estimation of these additional parameters. During processing the maximum likelihood estimator uses the measurement error statistics specified in the radar model in order to determine the correct weightings of radar measurements. The signal-to-noise ratio used for scaling the thermal error variance can use a natural signal-to-noise measurement in the case of real recorded data or it can be generated based on the range and sensitivity of the radar for simulated trajectories. For simulated trajectories, the radar model used for trajectory estimation may be different than that used to generate the radar measurements. The initialization of the state vector can be either from a) the true target location, which speeds convergence in simulation cases, b) the average value of the state vector, again in cases of Monte Carlo simulations where parameters are varied parametrically such as drag, or c) through polynominal regression of the radar measurements. This would be used if the true position was not known for recorded radar measurements.

It is possible to incorporate *a priori* information known about the state of the trajectory. For example, it may be possible to give a good estimate of the probable projectile drag or spin constants, or perhaps, test data is being reduced and you know the actual launch position very accurately. These measurements may be specified along with the uncertainty associated with the measurements. These data are weighted with the appropriate covariance and incorporated in the maximum likelihood estimation. One important characteristic of the LOCATER program is the ability to vary the number of states to be estimated. For example, any of the ten states described above may be deleted from a given estimation. For example, it may not be desirable to estimate projectile spin constant because of poor quality of radar data. When a state is dropped the initial value of the parameter is used throughout the computation.

Several special features have been added to the maximum likelihood estimator. First of these is the ability to estimate radar biases in range, azimuth, elevation and doppler. This is especially useful when reducing data with considerable geometric diversity such as a long trajectory or data taken from multiple radars. One must be aware, however, that this technique sometimes leads to indeterminate results. A similar capability has been added with regard to the estimation of multipath errors. A simple functional form for elevation multipath errors, described fully in Section 5.4.4, is used and the three coefficients for this functional form are included in the maximum likelihood estimation so that multipath from a single specular reflection may be removed from low angle tracking data.

Of particular value in processing experimental recorded radar data, is the ability to automatically edit track points. Three optional methods are included for automatic editing of radar track points. First is the use of a polynomial fit to the measured data in order to pre-edit and delete measurements of more than a certain distance from the fitted polynomial. This is particularly helpful in removing erroneous target associations, such as from aircraft, from the track file. The second method is to set a signal-to-noise threshold below which a track point will not be accepted. This, in effect, simulates a detection threshold. The third automatic editing technique is to allow the maximum likelihood algorithm to converge, then compute the average weighted square residual error and standard deviation for each measurement component, and reject points with a residual error greater than Nσ where N is a factor specifiable. This last technique has been found useful in removing points which are erroneous because of improper target centroids.

3.6 Program Features

The LOCATER program is highly flexible in terms of the output that is produced. It can report as little or as much of the information that the user requires. The output is organized into a series of report SECTIONS from 1 - 10, any of which may be printed or not, at user option. For example, input cards may be printed, or not. The generated trajectory for a simulation may be printed. The states of the maximum likelihood estimate can be printed at each iteration desired to show convergence. The state covariance matrix and correlation coefficient matrix can be printed and the track residuals can be printed as well as plotted, showing the deviation of the measured points from the fitted trajectory. The generated measurements, together with the radar weights, may be printed as part of each trajectory estimate. An estimate of launch conditions and residual statistics is presented which describes the estimated velocity, firing azimuth and quadrant elevation (QE) for each trajectory processed. The maximum likelihood estimate of each of the parametric states is presented, such as the drag constant and spin constant. The key output is the launch point estimation. This can be selected as being the launch point, the impact point or some intermediate intercept point. This would be useful, for example, with guided projectiles. For a group of trajectories, either real or simulated, the projected xy launch points are plotted, the mean launch point is calculated and the CEP is calculated. The major and minor axes of the error elipse are also calculated and plotted with the launch points.

Some of the key features which make the program particularly user-oriented are the simple, defaulted input through the use of data packets which gives the user the ability to stack multiple runs while only changing the parameters that change from run to run. The ease and flexibility of specifying either cards or tape for external input data is also of interest. In general, great care has been taken to provide a great flexibility of options through using a modular program structure, it is possible to specify the various model parameters, completely independently. The program operation has been planned in a logical way to allow almost complete flexibility in the selection of the various options, for example, the ability to select various states to be estimated, to select the measurement dimensions of the radar, to use multiple radars, to select various intercept conditions, and the ability to specify track segments with great flexibility.

The program was designed so that the plotting software was separate from the main LOCATER Program. LOCATER prepares summary files for example, of the launch point estimations which can then be processed by external plotting programs. All report sections for LOCATER are configured for 8 1/2 x 11 paper so no photo reductions are required. Internally, the LOCATER program is designed to be easily modified using a structured modular construction. Examples of design decisions made to facilitate future modification are the variable dimensions assigned to the state vector, allowing for the incorporation of additional states, should they be required in the future. Another example is the use of a numerical transition matrix to perform the integration of the state vector along the trajectory. This feature allows the dynamic model for the projectile to be changed with little impact on the rest of the program. These design features have resulted from several iterations of program redesign and many hundreds of computer hours of program execution.

4.0 LOCATER APPLICATIONS

Because of the LOCATER program's great flexibility there is an almost unlimited range of potential application. Perhaps the best way to illustrate this range of application is to recount all of the applications of the program to the HOWLS projectile tracking radar investigation. This section presents a number of selected applications of the LOCATER program to various HOWLS applications. These applications are selected to represent the range of potential LOCATER applications, but should not be interpreted as representing the results or conclusions of the HOWLS projectile tracking radar study.

4.1 PTR Concept Study

One of the early applications of the LOCATER program was a parametric investigation of various projectile tracking radar concepts. In this investigation were short range, long range radars, narrow beamed or broad beamed, slow tracked rate or rapid, phased array, or rotating antenna systems, single radar or multiple radar sites. In short, as many different approaches to solving the projectile tracking radar program as could be conjured up. Each of the several candidate systems went through a preliminary design study in which the system parameters were varied and a first level optimization was performed within the constraints placed on each concept. The result was a series of radar models which were used in LOCATER simulations. In order to fairly evaluate the various competing system concepts, a standard set of representative target trajectories was prepared. Each of the candidate systems was simulated in Monte Carlo mode against this representative set of trajectories. What resulted was a matrix of weapon location accuracies for each candidate radar against each weapon trajectory. Typically 20 Monte Carlo runs were made for each radar target pair. Such wide scale simulation efforts can take many hours of computer time. LOCATER'S efficiency has been improved in several areas so that its efficiency in carrying out large scale Monte Carlo simulation is very respectable. It is possible to estimate the amount of time required for such simulations fairly accurately (see Section 6.6 for methods of run-time estimation).

4.2 RCS Performance Degradation

In conjunction with the study of various PTR concepts, it was realized that the variation in radar cross-section (RCS) might have a significant effect on radar performance. The projectile's radar cross section varies as a function of the aspect angle to the viewing radar. This aspect angle is a function of the radar to projectile target geometry, and in general, varies considerably over the course of a trajectory. The projectile's radar cross section may vary many dB over the course of a typical trajectory. What then should be the radar cross section value used to model a given projectile type? In answering this question we added the capability for simulating the actual radar cross section fluctuation as a function of aspect angle. It was assumed that the projectile body axis was stabilized and aligned with the velocity vector. The aspect angle between the velocity vector and the line of sight to the radar was then calculated and the result was used to look up the radar cross section from a table of stored radar cross section values. The number of different trajectory geometries were simulated for different radar coverage angles. The results of these simulations were as accurate as could be obtained using the full knowledge of radar cross section distribution for a particular projectile.

In order to expedite the evaluation of the radar system concepts it was desired to use a representative constant cross section in the simulation for each projectile type. It had been proposed to use a radar cross section equal to the median radar cross section over the range of aspect angle from 0 to 60 degrees. It was reasoned that this represented a realistic range of probable viewing angles for typical radar engagement geometry. Additional simulations were then run using these constant cross sections which were then compared with the more detailed simulations described above. In all cases the detailed simulations gave slightly better weapon location statistics than the constant cross section assumptions. Thus it was conservative to assume a constant cross section in the system concept simulation. Using this method it is possible to calculate an effective radar cross section for each projectile type and target geometry. Because of this simplification, it was possible to carry out the system simulation more rapidly because the various target radar cross sections did not have to be digitized for input into the radar model and of course, the simulation itself ran somewhat more quickly.

4.3 Algorithm Development

As a result of the system concept study, certain system concepts were identified as being very promising. In order to take advantage of these new system concepts, a new projectile tracking algorithm was developed to make better use of downleg tracking information. The LOCATER program was used extensively in developing this downleg tracking algorithm. One aspect of the improved weapon location algorithm was the development of the maximum likelihood state estimation technique for projectile tracking. This technique is a very general one and in fact, its the basis for the current tracker used in LOCATER. The other aspect of downleg tracking, which needed considerable attention was the development of a realistic trajectory dynamic model. Because of the rather long extrapolation times involved for downleg data most of the errors associated with them come about through errors in the dynamic model for the trajectory. One way to investigate the effects of such a model were to employ an external trajectory generator which contained as much as was known about the ballistic behavior of projectiles. The US Army Ballistics Research Laboratory (BRL) has several models which contain a very accurate aerodynamic models for projectile dynamics. One of these was used for our studies. This model was used as input to the LOCATER program and were used as a basis for simulated trajectory. The program was run using the maximum likelihood estimation and the internal observational dynamic model to determine estimated launch points, biases and systematic errors in the resulting launch points were then correlated with various model inaccuracies. Gradually, the observational model was improved thus reducing these systematic errors. One should note that it is not possible to include in the observational radar model for projectiles all of the *a priori* aerodynamic information presented in the BRL model. To do this one would need to know *a priori* the shell type, the moment of inertia, etc.

Because the LOCATER program is designed using a numerical transition matrix with which to integrate the trajectory forward or backward, this decouples the program from the actual dynamic model being used. Thus the acceleration generation subroutine can be changed quite easily to reflect changes in the dynamic model employed for weapon location. This has been a great help in exploring the effects of secondary acceleration such as the yaw induced drag, the magnus acceleration and the lift acceleration. Additional features which have been very helpful are the ability to resolve the residual errors relative to the instantaneous velocity vector. This example illustrates the use of the LOCATER program in improving the projectile tracking algorithm.

4.4 Real Data Performance Validation

Soon after the completion of the systems simulation studies, some real recorded track data became available from one of the early projectile tracking radar (T123).[13] It seemed appropriate at the time to try the new improved weapon location algorithms on this recorded radar data. Since those early tests the LOCATER program has been used to process recorded radar tracking data from five different radars. The processing of this data with LOCATER has proven to be most informative particularly in showing the performance of the weapon location algorithm. Recently, a series of projectile tracking tests have been performed using the AN/FPS-16 radar at Wallops Island, VA. The data from these tests has been processed by LOCATER, in order to validate the performance of the upleg-downleg weapon location algoritlm. By processing a series of different trajectories using different projectiles it is possible to get a very good understanding of the strengths and weaknesses of a particular algorithm. Several of the tools that LOCATER gives us are particularly helpful in this regard. First, there is a miss distance distribution this shows us the bias and the spread in predicted launch points (see Section 7.1). The spread in the launch points is due to random errors from radar noise and round to round variation in the projectiles themselves. The bias errors, the offset of the cluster, are due to systematic errors most likely from errors in the model of the ballistic trajectory, but other sources of systematic errors would be radar biases and errors in meterological conditions. A second useful report is in SECTION 7 where the residual errors are presented. A plot of the residual errors in each radar measurement dimension is also provided. This provides a way to quickly evaluate the goodness of fit in the estimated trajectory. In the example shown in Section 7.1, one can see that the errors in the radar range systematically deviate from the estimate. This shows us there is more systematic error in the range dimension than either of the angle dimensions. Another useful report is the covariance matrix and the correlation coefficient presented in SECTION 5. This permits one to quickly observe the degree of correlation between various states in the estimation process. This will vary depending upon the trajectory and the viewing geometry. We have had cases of real data (TT-25)[15] where several states were almost linearly correlated, for example, the vertical position and vertical velocity were all linearly correlated with the drag constant. When this occurs the estimation process may not converge and if it does converge the answer is not unique. With LOCATER it is, however, possible to easily remove one of the dependent states. Another example is that one would not normally want to estimate both the projectile drag and the wind velocity at the same time since these tend to be highly coupled states. Another useful report is the estimation statistics which present the results of the state estimation for the parameter states such as drag and spin. From a series of tests such as those illustrated in Section 7.1, one can get an estimate of the uncertainty in estimating a particular state. Take the spin parameter, for example, which can be estimated in the example with about a 3% standard deviation. This variation in the estimate is composed of errors resulting from the radar measurement errors and round to round variations in the actual spin constant. In the simulation mode one could get an idea as to exactly how much of the error was due to radar measurement errors. For some radars, however, the radar measurements are much less accurate than they were for the AN/FPS-16 radar, and in fact these radars have great difficulty in estimating the spin parameter. In such cases estimation errors of 100% of the expected spin parameter value are sometimes obtained. When this is found it is often more beneficial to eliminate the estimation of the spin constant and

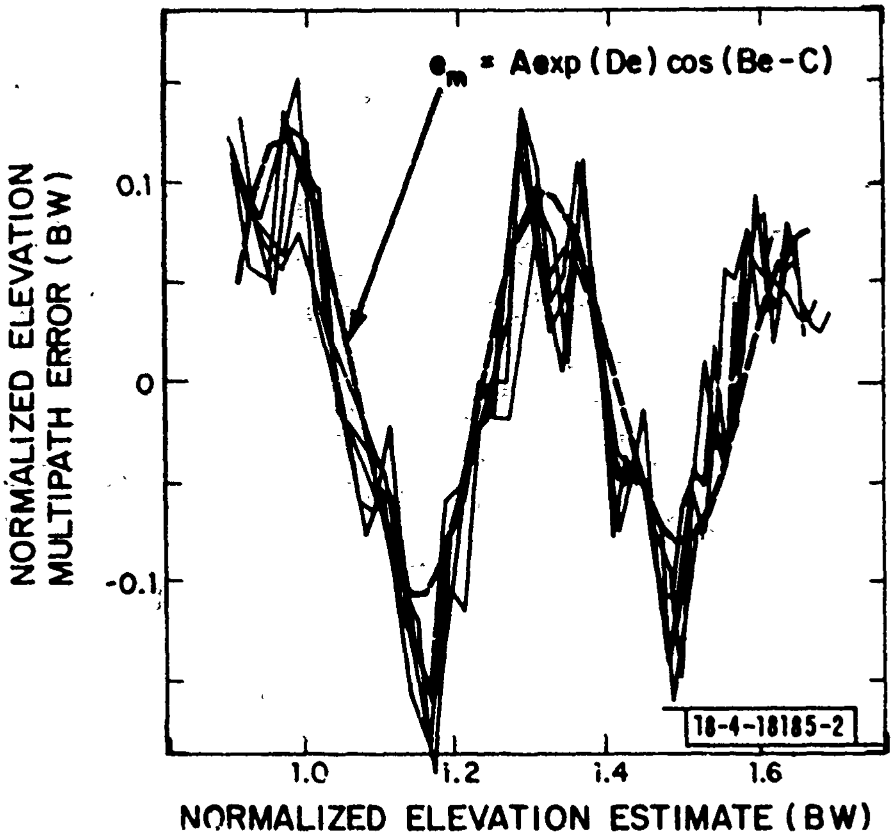


Fig. 4-1. Typical multipath errors.

use a nominal *a priori* value.

From these type of reports, one can obtain a very complete picture as to the performance both of the particular radar involved and of the weapon location algorithm being evaluated.

4.5 Data Editing

Whenever real data is being analyzed, the likelihood of including bad data is present. In order to conveniently treat this possibility, a very flexible data editing facility has been included in LOCATER. There are at least 2 causes for the bad data points being included in the data, the first is erroneousdata association, that is, track points or detections from other objects have been mixed into the track file for a particular projectile, the second reason is that for some reason or other the measurement process has given a value outside of the range expected, usually because the modeling of that process has ignored some physical phenomenon. In the real data example shown in Section 7.1, the estimator converges using all the track points and then it finds that one measurement, that is the last track point elevation measurement, is more than 4 sigma from the mean. The value for this point is then thrown out and the trajectory is refit using the remaining points. Looking at the residual error for the points, one might conclude that the range and azimuth for that point are entirely reasonable but the elevation is significantly different from the expected trajectory. The most likely explanation for this is multipath as the projectile approached the flat surface of the water. This multipath caused the elevation of monopulse measurement to be in error but did not affect the range or azimuth measurement. This is an example where the physical process, that of multipath, was not assumed in the measurement model. In other cases where data has been processed from a track while scan radar, we found data points which agree in one or two dimensions but obviously do not agree in others. Subsequent investigations show that these data points came from aircraft rather than projectiles. If these bad data points were not edited out of the data, they would have a severe effect on the overall quality of the trajectory fit. Because the estimation process is using the square of the residual error, a few large residual errors can completely dominate the fitting process. Sometimes bad data points cause such deviations in the trajectory that the estimator fails to converge initially on an estimate. For these cases a pre-edit feature has been included in the LOCATER and this feature allows the user to do a polynominal regression on each of the measurement dimensions and exclude points that are more than a prescribed distance from the polynominal.

4.6 Meteorological Effects

The meteorological conditions play a very significant role in determining the trajectory that a projectile will take. The integrated effect of the wind on the projectile can move the trajectory many 10's of meters. Because of these factors it is standard practice for artillery units to have direct access to the meteorological reporting facilities of a tactical unit. Having access to this information is equally important to the radar weapon location operation. In order to adequately model these environmental conditions, LOCATER includes a wind and atmospheric density model which will incorporate standard meteorological reporting data. LOCATER is able to handle data in several forms. The most usual form is to have a layered wind report taken with meteorological ballons and radiosondes. However, if these are not available one may supply the surface wind conditions, and use these as averages. One should be aware, however, that the surface wind is usually not the average wind aloft. These are usually somewhat greater and often in different directions. We have, on occasion, tried to reduce data for which no meteorological data existed. Under certain conditions rather significant sensitivity to the assumed wind is found (TT-23).[13] There is a very direct coupling between the wind velocity along the gun target line and the drag assumed for the projectile. So, to some degree, an error in the assumed wind along the gun target line will be offset by a compensating error in the estimated drag for the projectile. Thus, the net effect on the estimated weapon location may be small.

Because of the direct coupling between the drag assumed and the wind velocity it is possible to turn the problem around and make an estimate of the wind velocity, given the drag and spin characteristics of the projectile. For example, under control tests, a projectile is fired with initial conditions and with a known drag characteristic and spin deflection characteristic. LOCATER can then be used to estimate the east and north wind average velocity component. However, unless the data quality is exceptionally high, this procedure does not yield a very great confidence in the wind measurement.

4.7 Multipath Degradation

Multipath reflections of the radar signal can be a significant source of error in the elevation measurement. This is particularly troublesome where measurements of low elevation angle trajectories are being made. The most typical type of multipath is where a specular reflection occurs on the ground in front of the radar, causing a strong interfering signal to be combined with the direct signal. This tends to proudce a periodically varying systematic error in the elevation measurement in radars using a monopulse angle measurement.

In examining a real recorded radar data, we have found that multipath errors often are present. Because of that we have included in LOCATER the facility for both simulating the multipath errors and a rudimentary capability for estimating what they are.

In one particular application, we processed five low angle trajectories and found very systematic elevation error (Figure 4-1). It was found that a decayed sine wave as shown by these dashed curve was a very good fit to the systematic error. Facilities were added to the estimator in LOCATER to allow the fitting of such a sine wave and the estimation of its period, its phase and its amplitude. Using this approach on each individual trajectory, it was possible to remove most of the systematic error present in the elevation measurement. In this way, the measurement model was extended to more closely resemble the actual physical process at work in the real data measurement. The estimation of the additional parameters is, of course, dependent upon having high quality radar measurement in the first place, and upon the high degree of predictability inherent in a well modelled ballistic trajectory.

Because of the demonstrated importance of the multipath errors it was decided to also include them in the simulation of a radar. Two methods were provided for including multipath errors 1) to use the simple functional model illustrated in Fig. 4-1 and 2) supply a table of measured vs. true elevation angles to be used in generating elevation measurements for the simulated radar. An application of the table simulation of multipath errors was provided by the collection of typical multipath measurement errors as part of the HOWLS program. This measurement effort has provided us with multipath errors expected in various typical tactical sightings. With this information it is possible to simulate the effects on a proposed radar design of typical multipath errors. One can then evaluate the degree to which these multipath errors degrade the weapon location estimate for various trajectory geometries. If the degradation in weapon location accuracy is significant one may wish to include some form of a multipath estimation in the weapon location algorithm.

4.8 Simulated Radar Performance

A somewhat different application of the radar simulation capability is that described in 4.1 which is used to perfect a particular radar design. One such example of the use of LOCATER for this purpose was in the development of the hemispheric coverage radar designed for the HOWLS program. As various aspects of the design became more concrete the radar model could be made more exact in those areas. An example of this was discussed in Section 4.7 concerning the multipath simulation. By taking great care in the way in which the radar is simulated it is possible to almost exactly duplicate the results to be expected by the real radar once it is built. One area that is somewhat more difficult to evaluate is the degree to which the radar model will match the real projectile model. In order to shed some light on that aspect of simulation the LOCATER program has been used in a somewhat hybrid mode in which highly accurate radar data taken with the AN/FPS-16 radar was used as a base for performing simulations. The AN/FPS-16 radar trajectory was fed in as an external trajectory and the noise generator for the less accurate radar to be simulated was added to the input data. This gave both a realistic appraisal of the modeling errors which were present in the original radar data plus a realistic representation of the random radar measurement errors which were added using the radar noise generator. By using the coordinate transformation (Fig. 3-1) to place the trajectory in various geometries it is possible to evaluate a number of different situations in a very realistic manner.

4.9 Tracking Without Elevation

The LOCATER program provides the capability for working on a subset of the normal radar measurement dimensions of range, azimuth, elevation, doppler and signal to noise ratio. In one particular application we were given radar data taken with a radar that did not measure elevation. It did however measure range, azimuth and doppler. With this information it is possible to predict weapon location and the tools that LOCATER provides gave us the further capability of analyzing what geometries such a radar was particularly sensitive to. With the covariance matrix output (SECTION 5) we were able to determine that the radar was particularly sensitive to assumptions concerning the wind and the drag parameters when it was tracking low elevation trajectories. It was learned that it was not capable of making good estimate of drag or spin.

An application of the hybrid mode discussed in 4.8 is the selective degradation of a particular radar measurement. For example, it is possible to add radar noise to a particular radar dimension, say the range dimension. In this way it will be possible to simulate the radar measurement with a degraded range resolution capability for example. This application has merit in determining tradeoffs in measurement accuracy.

4.10 Deleting State Estimation Variables

One often encounters situations where the full set of state estimation variables cannot simultaneously be estimated. We've already mentioned that it is not possible to simultaneously estimate the wind parameters and the drag parameter. Often it is not possible to estimate the spin or drag parameters simply because the radar data quality is not sufficient. In one particular simulation study, it was found that quite often the spin parameter was not very accurately estimated, in fact, the standard deviation of the spin estimates often exceeded 100% of the value expected. When this was encountered, the LOCATER facility for eliminating the spin state from the estimate was used and it was replaced with an *a priori* estimate of the nominal value for spin constant. Because this nominal value was often closer to the true value than the previous estimate would have been, the overall quality of the weapon location estimate improved. It therefore may be very desirable to eliminate one of the state variables from the estimate, particularly when using poor quality radar data.

4.11 Multiple Radar Nets

In the modern battlefield situation there very likely will be many sensors present, some which have overlapping coverages. It may be of interest to investigate the possibility of combining the tracking information from several sensors. LOCATER provides a very convenient way of combining track information from numerous sensors with overlapping coverage. One application of this capability was the investigation of a multiple sensor concept as part of the projectile tracking radar concept investigation. One such concept employed a net of 2 or 3 sensors and combined the tracking information from each sensor. The provisions for doing this in LOCATER are very simple but effective. One of the radar locations is designated as the base location or the origin and the measurements from the other sensors are transformed into that coordinate system and the estimation process is placed in the coordinate system. Now the specification of the track interval will allow overlapping of track; tracks may be either concurrent, that is identical track times, or they may be independent and asynchronous in their tracking. The only thing that is not simulated is the computation of bistatic doppler. The corresponding radar covariance matrices are transformed into the base coordinate system and the maximum likelihood estimate is performed combining all of the available information.

An example of overlapping track coverage with two radars is shown in Section 7.4. In this example the two radars have identical elevation coverages but are unsynchronized so in this case the track points are offset by one another by 2/10 of a second (see SECTION 4 of the output). In such examples, we find that the relative position of the 2 radars relative to the trajectory geometry may make a significant difference in the composite accuracy of the weapon location. In the case illustrated, the miss distance plot (see SECTION 9 of the output), shows that the distribution of estimated launch points lies on the gun target line and is relatively narrow in the orthogonal direction because this is the direction that the radars tend to measure range in. This type of crossing trajectory is just the type which is a candidate for cooperative tracking between 2 or more radars situated along the FEBA.

4.12 Angle Only Sensors

Because of LOCATER's inherent capability to handle multiple sensors which was described in the previous section, it is possible to consider special situations for example where the sensors do tracking in angle only. This might correspond to some type of optical tracking system. By specifying sensors which measure only angles, and then using multiple sensors with overlapping coverage it is possible for LOCATER to process trajectories using one sensor as the base for making the state estimate. Using LOCATER in the simulation mode, it would be possible to investigate the sensitivity to trajectory geometries, the intersensor baseline length, total tracking time and tracking rate. Such a study could be performed iteratively changing the sensor parameters such as angular accuracy, track time and so forth until the desired weapon location accuracy was provided, and the sensor parameters have been optimized. The flexibility of LOCATER program is largely directed towards investigation of individual sensor performance as we have described above.

4.13 Battle Scenarios

The LOCATER program is not a battle simulator; its capabilities are somewhat limited for dealing with ensembles of targets and sensors. Nevertheless when it comes to performing large scale battle scenarios it is important to have an accurate representation of the probable weapon location accuracy for the various individual weapon location estimates. The most efficient method of providing this realism in a large battle simulation is to use a program such as LOCATER to parameterize the important variables for use in the more general battle simulation. By abstracting these key variables, it is possible to more efficiently simulate the large scale battld scenario while retaining the realism of the detail tracking simulation.

One application of this technique was to simulate a battle scenario with more than 100 trajectories and about a dozen sensors employed at an actual battle location including the topographic terrain information. The weapon location accuracy was handled parametrically by abstracting the key relationships from a series of trajectory simulations using an early version of LOCATER. Key variables were the track extrapolation time and the length of time that the projectile was tracked. Similarly the effects of actual terrain masking were simulated through the use of a topographic map and a line of sight function used to determine the time of the track initiation and track termination. This type of battlefield scenario with its topographic realism enables the designer to realistically evaluate the relative merits of radar tracking geometry, tracking time and range. The rather complex interaction of these factors can be evaluated in a realistic way using parameterized large scale battle scenario simulators.

5.0 MATHEMATICAL GUIDE TO LOCATER

The purpose of this section is to describe the mathematics implemented in LOCATER. Mathematical symbols and their equivalent FORTRAN variables are described to relate the program coding to the mathematics. Vectors are denoted by the underscore character, e.g., $\underline{A}$, while matrices are depicted by a tilda, e.g., $\tilde{\phi}$.

The estimator theory presented in section 5.5 has been developed elsewhere.[1]

5.1 Earth Model

The earth model used in the LOCATER program is taken from the Department of Army technical manual on transformation of coordinates from geographic to grid.[3] The earth's shape is considered as an ellipsoid (oblate spheroid) with the semi-minor axis being the earth's rotation axis.

A radar location (Fig. 5-1) with respect to the ellipsoidal surface is specified by three items:

1. Latitude, ϕ, measured from $-\pi/2$ at south pole to $\pi/2$ at north pole (radians).
2. Longitude, λ, measured from the Greenwich meridian (radians) $(0 \le \lambda \le 2\pi)$.
3. Altitude, H, of radar above the ellipsoidal surface (meters). The ellipsoidal surface is considered to be at mean sea level $(H = 0)$.

The physical constants of the earth model are:

Symbol	Description	Value	Variable Name	Defining Subroutine
R_N	north pole radius	6356583 m	NORPOL	INITIAL
ε	eccentricity	.0822719	ECCEN	INITIAL
ω	rotation rate	7.2921×10^{-5} sec^{-1}	OMEGA	INITIAL

The radius of the earth ellipsoid, R_e, at the radar location is:

$$R_e = R_N/(1-\varepsilon^2\cos^2\phi_c)^{\frac{1}{2}} \tag{5-1}$$

where

$$\begin{aligned}\phi_c &= \tan^{-1}[(1-\varepsilon^2)\tan\phi] && \text{if } \phi \ne \pm\tfrac{\pi}{2}\\ &= \phi && \text{if } \phi = \pm\tfrac{\pi}{2}\end{aligned}$$

5.2 Coordinate Systems and Transformations

There are three coordinate systems used in the LOCATER program. They are:

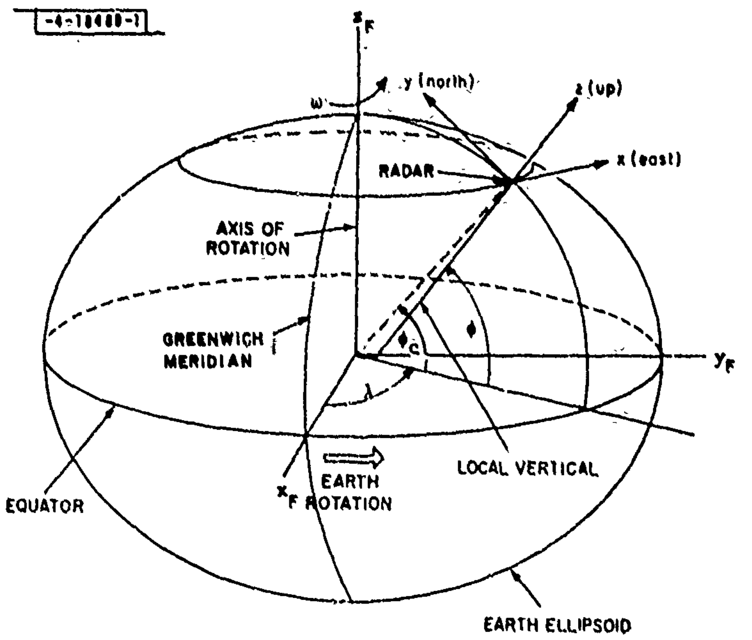


Fig. 5-1. Earth surface fixed XYZ and earth centered fixed $X_F Y_F Z_F$.

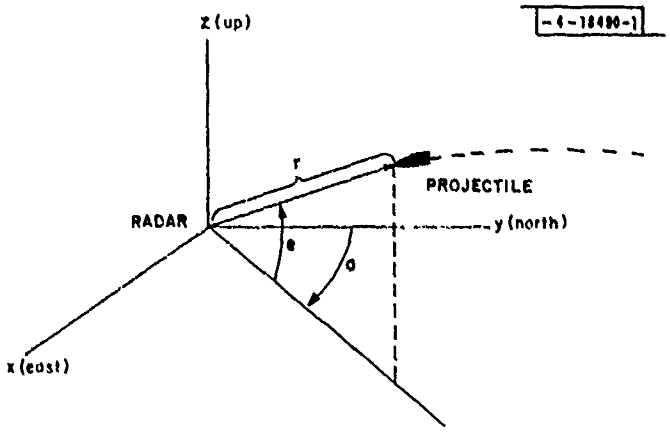


Fig. 5-2. Radar measurement coordinates (polar RAE).

1. Earth Surface Fixed (ESF)
   This is a cartesian system with origin at the radar.
2. Radar Measurement Space (RAE)
   This is a polar coordinate system with origin at the radar describing the measurement space (range, azimuth, elevation, and doppler).
3. Earth Centered Fixed (ECF)
   This is a cartesian system with the origin at the center of the earth.

5.2.1 Earth Surface Fixed (ESF)

The ESF coordinate system is a right-handed cartesian system fixed on the surface of the earth with the origin at the radar location (Fig. 5-2). This system is the frame of reference for the equations of motion described in section 5.3.

The three coordinate axes have the following orientations:

x	locally east, tangent to earth's surface at the radar.
y	locally north, tangent to earth's surface at the radar.
z	normal to earth's surface (x-y plane) at the radar (upwards).

The states of the projectile can be represented by a 6 element state vector, $\underline{S}$, composed of 3 position components x,y,z (in meters) and 3 velocity components $\dot{x},\dot{y},\dot{z}$ (in meters/sec).

5.2.2 Radar Measurement Space (RAE)

The RAE system is a polar coordinate system with the origin at the radar location and is coincident with the ESF origin. This RAE system is the reference frame for the radar measurements (Fig. 5-2) which are:

r	Slant range from radar to projectile (m)
a	Azimuth angle (radians) of the projectile measured clockwise from north $(0 \le a \le 2\pi)$.
e	Elevation angle (radians) of the projectile above the earth tangent plane $(-\frac{\pi}{2} \le e \le \frac{\pi}{2})$.
$\dot{r}$	Doppler (m/s). This is the radial component of the projectile's velocity. A positive doppler means the projectile is moving away from the radar.
$\dot{a}$	Time rate of change of azimuth angle, a (radians/sec).
$\dot{e}$	Time rate of change of elevation angle, e (radians/sec).

The elements, $\dot{a}$ and $\dot{e}$, are included in the definition of the RAE system only for completeness. They are, however, not directly measured by the radar.

The projectile states in RAE are represented by a six element vector, $\underline{R}$, with the components $r,a,e,\dot{r},\dot{a}$ and $\dot{e}$.

5.2.3 Transformations Between ESF and RAE

ESF to RAE

The nonlinear transformation for a state vector, $\underline{S}$, in the ESF coordinate system to a state vector, $\underline{R}$, in the RAE system is represented by the function, $\underline{f}$.

$$\underline{R} = \underline{f}(\underline{S}) \tag{5-2}$$

The function, $\underline{f}$, expanded, has the following components:

$$\begin{aligned}
r &= \left[x^2 + y^2 + z^2\right]^{\frac{1}{2}} \\
a &= \tan^{-1}[x/y] \\
e &= \tan^{-1}\left[z/(x^2 + y^2)^{\frac{1}{2}}\right] \\
\dot{r} &= (x\dot{x} + y\dot{y} + z\dot{z})/r \\
\dot{a} &= (y\dot{x} - x\dot{y})/(x^2 + y^2) \\
\dot{e} &= (\dot{z}r - z\dot{r})/\left(r(x^2 + y^2)^{\frac{1}{2}}\right)
\end{aligned} \tag{5-3}$$

The transformation from ESF to RAE is implemented in subroutine XYZRAE(SBAR,RBAR) where SBAR is a 6-element array (input) representing the states of $\underline{S}$ in ESF and RBAR is a 6-element array (output) representing the states of $\underline{R}$ in RAE.

RAE to ESF

The nonlinear transformation from a state vector, $\underline{R}$, in the RAE system to a state vector, $\underline{S}$, in the ESF system is represented by the function, $\underline{f}^{-1}$.

$$\underline{S} = \underline{f}^{-1}(\underline{R}) \tag{5-4}$$

The transformation, $\underline{f}^{-1}$, expanded is:

$$\begin{aligned}
x &= r \cos(e) \sin(a) \\
y &= r \cos(e) \cos(a) \\
z &= r \sin(e) \\
\dot{x} &= [\dot{r} \cos(e) - r\dot{e} \sin(e)]\sin(a) + r \cos(e) \cos(a)\, \dot{a} \\
\dot{y} &= [\dot{r} \cos(e) - r\dot{e} \sin(e)]\cos(a) - r \cos(e) \sin(a)\, \dot{a} \\
\dot{z} &= \dot{r} \sin(e) + r\dot{e} \cos(e)
\end{aligned} \tag{5-5}$$

The transformation, $\underline{f}^{-1}$, from RAE to ESF is implemented in subroutine RAEXYZ(RBAR,SBAR) where RBAR is a 6-element array representing the states of $\underline{R}$ in RAE and SBAR is a 6-element array representing the states of $\underline{S}$ in ESF.

5.2.4 Earth Centered Fixed (ECF)

The Earth Centered Fixed (ECF) coordinate system is a right-handed cartesian system fixed in the rotating earth with the origin located at the center of the earth. The orientation of the coordinate axes, as shown in Fig. 5-1, is x_F intersecting the Greenwich meridian, z_F directed along the earth's rotation axis pointed toward the north pole, and y_F constructed such that $x_F \times y_F = z_F$.

The ECF system is used as an intermediate coordinate system between two ESF systems in multistatic systems analysis or in simulation with an externally generated trajectory.

The states of the projectile in ECF can be represented by a state vector, $\underline{X}_F$, which is composed of three position components x_F, y_F, and z_F (in meters) and three velocities $\dot{x}_F$, $\dot{y}_F$, and $\dot{z}_F$ (in meters/sec).

5.2.5 Transformation Between ESF and ECF

Given a state vector, $\underline{S}$, in ESF (introduced in section 5.2.1) and a state vector, $\underline{X}_F$, in ECF (introduced in section 5.2.4) the transformations between the two systems will be established below.

A radar location on the earth ellipsoid model (section 5.1) is specified by:

1. Longitude, ϕ
2. Latitude, λ
3. Height above ellipsoid, H

This location is the origin of the ESF coordinate system as shown in Fig. 5-1.

The transformations between ESF and ECF amounts to 2 rotations and 1 translation.[2] They are:

$$\underline{S} = \underset{\sim}{A}\,\underline{X}_F + \underline{b} \tag{5-6}$$

where $\underset{\sim}{A}$ is a 6 x 6 partitioned matrix.

$$\underset{\sim}{A} = \left[\begin{array}{c|c} \underset{\sim}{a}(\phi,\lambda) & \underset{\sim}{0} \\ \hline \underset{\sim}{0} & \underset{\sim}{a}(\phi,\lambda) \end{array}\right] \tag{5-7}$$

Each submatrix $\underset{\sim}{a}(\phi,\lambda)$ is a 3 x 3 matrix and is a function of longitude, ϕ, and latitude, λ. The other partitions of $\underset{\sim}{A}$ are 3 x 3 $\underset{\sim}{0}$ matrices.

$$\underline{a} = \begin{bmatrix} -\sin\lambda & \cos\lambda & 0 \\ -\sin\phi\,\cos\lambda & -\sin\phi\,\sin\lambda & \cos\phi \\ \cos\phi\,\cos\lambda & \cos\phi\,\sin\lambda & \sin\phi \end{bmatrix} \tag{5-8}$$

The matrix $\underline{b}$ is a 6-element translation vector.

$$\underline{b} = \begin{vmatrix} 0 \\ R_2 \\ R_1 \\ 0 \\ 0 \\ 0 \end{vmatrix} \tag{5-9}$$

$R_1 = -R_e \cos(\phi - \phi_c) - H$

$R_2 = R_e \sin(\phi - \phi_c)$

R_e = radius of earth at radar's location defined in section 5.1

$\phi_c = \tan^{-1}[(1 - \varepsilon^2)\tan\phi]$

ε = ellipsoid eccentricity defined in section 5.1

The transformation from ESF to ECF is the inverse of eqn. (5-6).

$$\underline{X}_F = \underline{A}^t(\underline{S} - \underline{b}) \tag{5-10}$$

The transformation of a state vector $\underline{S}_1$ from one ESF system to another is:

$$\underline{S}_2 = \underline{A}_2\underline{A}_1^t(\underline{S}_1 - \underline{b}_1) + \underline{b}_2 \tag{5-11}$$

where $\underline{A}_1$ and $\underline{b}_1$ are transformation matrices defined by eqn. (5-7) and (5-9) for radar 1, while $\underline{A}_2$ and $\underline{b}_2$ are transformation matrices for radar 2, and $\underline{S}_2$ is the projectile state vector relative to radar 2.

Implementation

Each RADAR data packet (section 6.2.10) defines the height, longitude and latitude of the radar by ITEMS 3 to 5. Subroutine SETUP computes the submatrix $\underline{a}$ and the first 3 elements of $\underline{b}$ based on eqns. (5-8) and (5-9). The 9 elements of $\underline{a}$, taken row-wise, and the first 3 elements of $\underline{b}$ are stored as a column vector in array RADAR from locations RADAR(50,NRADAR) to RADAR(61, NRADAR), where NRADAR is the packet number.

The ECF to ESF transformation, eqn. (5-6), is implemented in subroutine ECFXYZ. The calling sequence is:

```
CALL ECFXYZ(XFRAR,SRAR,RADAR(50,NRADAR))
```

where XFBAR is a 6-element array representing $\underline{X}_F$ (input) in ECF and SBAR is a 6-element array (output) representing $\underline{S}$ in ESF.

The inverse transformation from ESF to ECF, eqn. (5-10) is given by:

```
CALL XYZECF(SBAR,XFBAR,RADAR(50,NRADAR))
```

The transformation from one ESF system to another, eqn. (5-11), is implemented in subroutine XYZXYZ.

```
CALL XYZXYZ(S1BAR,NRAD1,S2BAR,NRAD2)
```

where S1BAR is a 6-element array (input) representing the state vector $\underline{S}_1$ relative to radar #NRAD1 while S2BAR is a 6-element array (output) representing the state vector $\underline{S}_2$ relative to radar #NRAD2.

5.3 Equations of Motion

The dynamics used in LOCATER represent the ballistic trajectory of a dynamically stabilized spinning projectile in the air.

The generic vector acceleration equation[1] is composed of gravitational acceleration $\underline{g}$, Coriolis acceleration $\underline{C}_A$, atmospheric drag $\underline{D}_g$, and lift $\underline{L}$ from a yawed spinning projectile interacting with the atmosphere. The reference frame for the accelerations is the ESF coordinate system (section 5.2.1)

The net projectile acceleration vector $\ddot{\underline{X}}$ is:

$$\ddot{\underline{X}} = \underset{\text{(gravity)}}{\underline{g}} + \underset{\text{(Coriolis)}}{\underline{C}_A} + \underset{\text{(drag)}}{\underline{D}_g} + \underset{\text{(lift)}}{\underline{L}} \qquad (5\text{-}12)$$

The 6-element state vector $\underline{S}$ of the projectile in ESF (introduced in 5.2.1) has position components x,y,z and velocity components $\dot{x},\dot{y},\dot{z}$. The 3-element vector $\dot{\underline{X}}$ represents the projectile vector velocity while $\ddot{\underline{X}}$ represents the acceleration vector.

Each term in the acceleration equation (5-12) is defined below:

Gravitational Acceleration, $\underline{g}$

$$\underline{g} = \frac{-g_n R_e^2}{|\underline{R}_d|^3} \underline{R}_d \qquad (5\text{-}13)$$

g_n acceleration from gravity at ellipsoidal surface. $g_n = 9.80665$ m/s^2

R_e radius of earth at the radar origin (meters). See section 5.1

$\underline{R}_d$ vector from center of earth to the projectile

$$\underline{R}_d = \begin{bmatrix} x \\ y \\ z + R_e + H \end{bmatrix}$$

H radar height above the ellipsoid (m)

$|\underline{R}_d|$ magnitude of $\underline{R}_d$

Coriolis Acceleration, $\underline{C}_A$

$$\underline{C}_A = -2(\underline{\omega} \times \dot{\underline{X}}) \qquad (5\text{-}14)$$

$\underline{\omega}$ earth spin vector resolved onto the ESF system

$$\underline{\omega} = \begin{bmatrix} 0 \\ \Omega \cos\phi \\ \Omega \sin\phi \end{bmatrix}$$

Ω spin rate of earth
Ω is defined in section 5.1

ϕ latitude of radar. See section 5.1

Drag Acceleration, $\underline{D}_g$

$$\underline{D}_g = -k_d \, \rho \, K_{D_0}(M) \, |\underline{V}| \underline{V} \qquad (5\text{-}15)$$

ρ atmospheric density (kg/m^3)

K_{D_0} The zero yaw drag coefficient as a function of mach number, M. See section 5.3.1.

k_d drag state (m^2/kg)

$\underline{V}$ velocity vector of projectile WRT air.

$$\underline{V} = \dot{\underline{X}} - \underline{W}_N$$

$|\underline{V}|$ projectile airspeed (m/s)

$\underline{W}_N$ wind components in ESF (m/s)

M Mach number

$$M = \frac{|\underline{V}|}{V_s}$$

V_s velocity of sound (m/s). Section 5.3.2.

Lift Acceleration, $\underline{L}$

$$\underline{L} = k_s \frac{(\underline{g} \times \underline{V})}{|\underline{g}|\ |\underline{V}|} \qquad (5\text{-}16)$$

k_s	spin state (m/s^2)
$\lvert\underline{g}\rvert$	magnitude of gravitational acceleration

Metric State Vector and Array Description

The position and velocity states of the projectile in BSF, as introduced in section 5.2.1, is represented by a 6 element state vector $\underline{S}$. It is now necessary to include the drag, spin, and wind states in the state vector description. The augmented state vector $\underline{X}$ can now be defined where the first 6 elements of $\underline{X}$ is $\underline{S}$. The components of $\underline{X}$ are:

x_1, x_2, x_3	x,y,z position states (in meters) in BSF
x_4, x_5, x_6	$\dot{x}, \dot{y}, \dot{z}$ velocity states (in meters/sec)
x_7	drag state k_d (in m^2/kg)
x_8	spin state k_s (m/s^2)
x_9	East wind component (m/s)
x_{10}	North wind component (m/s)

The internal representation of state vector $\underline{X}$ is array variable XHAT. There is not, however, a one-to-one correspondence between the components of $\underline{X}$ and elements of XHAT. The elements of XHAT are:

XHAT(1)	Time (sec)
XHAT(2),XHAT(3),XHAT(4)	x,y,z position states (meters) in BSF. This corresponds to x_1, x_2, and x_3.
XHAT(5),XHAT(6),XHAT(7)	$\dot{x}, \dot{y}, \dot{z}$ velocity states (m/s)
XHAT(8),XHAT(9),XHAT(10)	$\ddot{x}, \ddot{y}, \ddot{z}$ accelerations, synonomous with the 3-element vector $\ddot{\underline{X}}$, computed by subroutine ACCEL.
XHAT(11)	drag state k_d (m^2/kg)
XHAT(12)	spin state (m/s^2)
XHAT(13)	East wind component (m/s)
XHAT(14)	North wind component (m/s)
XHAT(15)-XHAT(20)	Unused - reserved for future states

If a state vector array XHAT is thus appropriately defined, the accelerations can be computed by a call to subroutine ACCEL.

CALL ACCEL(XHAT)

The accelerations $\ddot{x}$, $\ddot{y}$, and $\ddot{z}$, would then be stored in array elements XHAT(8),XHAT(9), and XHAT(10), respectively. See the flow chart of subroutine ACCEL in section 8.1.4.

The equations of motion, eq. (5-12), are integrated (extrapolated) by a predictor-corrector type algorithm with a maximum step size of .5 second.[1] A state vector array XHAT valid at time, XHAT(1), can be moved to another time, T, by calling subroutine EXTRAP.

CALL EXTRAP(XHAT,T)

5.3.1 Drag Force Coefficient Model

The drag force coefficient model, K_{D_0}, used in LOCATER represents the amount of zero yaw drag as a function of Mach number.

A series of drag curves have been generated for various projectile types in wind tunnel experiments and have been validated by the processing of real trajectory measurements.[4] Each drag curve is approximated by a series of fourth degree or less regression polynomials defined over different Mach number regions.

The four drag curves for the shell types of 105 mm, 155 mm, 175 mm and 203 mm are remarkably similar (Figure 5-3). Each curve has a constant value for subsonic velocities, a sharp increase in the transonic region and a decrease above Mach 1.1.

The drag curve of the 155 mm shell (Figure 5-4) was judged to be the most representative. A scale factor has been included to adjust the drag coefficient curve for other shell types.

The drag curve has been implemented as real function subprogram KDO(MACH) where MACH is the real Mach number.

5.3.2 Atmospheric Models

There are two types of atmospheric models used in the LOCATER program. They are:

1. Standard atmosphere
2. Layered meteorological profile

Each type defines atmospheric density, velocity of sound, and wind components for a given altitude either by formula evaluation or tabular interpolation. Atmospheric types are specified by the METRO data packet (Section 6.2.5).

Type 1 Standard Atmosphere

Given the altitude H_p(meters) of the projectile above mean sea level, the atmospheric density function ρ in kg/m^3 is:

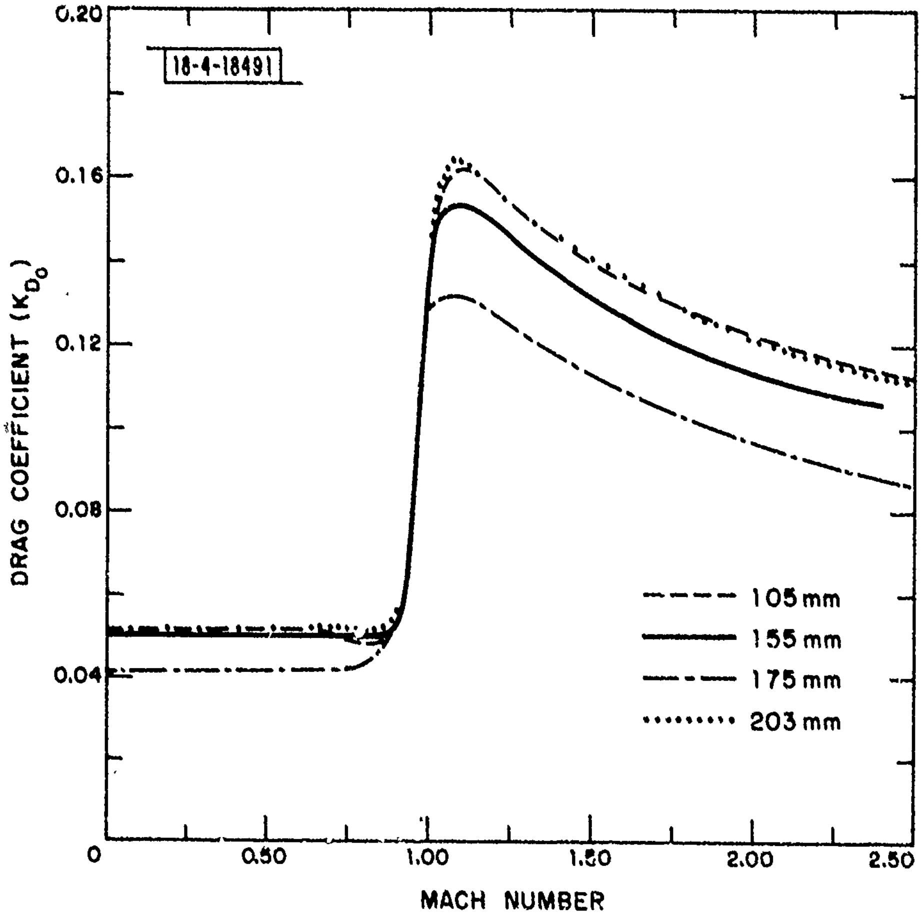


Fig. 5-3. Drag coefficients for typical U.S. projectiles.

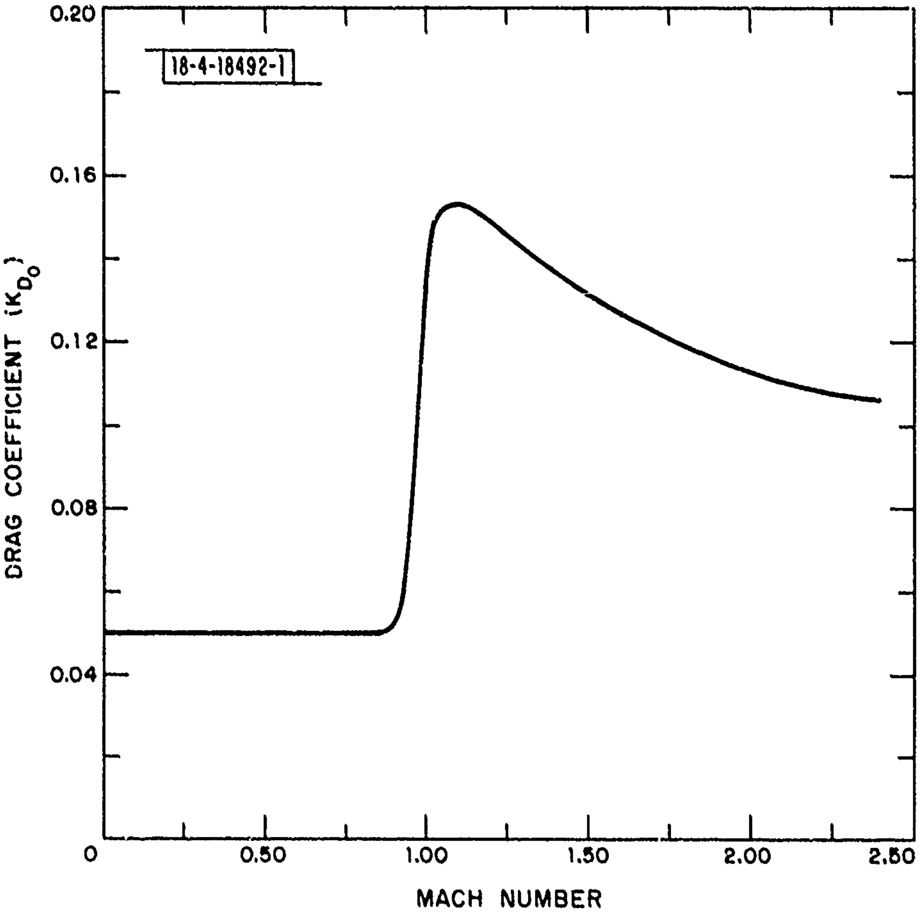


Fig. 5-4. Canonical aerodynamic drag coefficient for projectile ballistic model.

$\rho = \rho_g$	$H_\rho \leq 0$ where ρ_g is the air density on the ground (in kg/m^3)	(5-17)
$\rho = \rho_g e^{-(H_\rho/9335.4)}$	$0 < H_\rho < 40000$ m	
$\rho = 0$	$H_\rho > 40000$ m	

The velocity of sound function V_s (in m/s) is:[5,6]

$$V_s = -.0039375\ H_\rho + 20.0468(T_K)^{1/2} \tag{5-18}$$

where T_K is the ground temperature in degrees Kelvin.

The wind components for the TYPE 1 atmosphere are a constant function of altitude H_ρ. The default values for the METRO data packet are:

ρ_g	1.223 kg/m^3	ground air density
T_K	284.8°K	ground temperature
W_E	0.0 m/s	East component of wind
W_N	0.0 m/s	North component of wind

Type 2 Layered Meteorological Profile

Standard sondes taken by weather observation stations measure atmospheric pressure, temperature, wind direction and magnitude every 100 to 250 m in altitude or at 1 minute intervals.

The data to be used by LOCATER must be converted to atmospheric density (kg/m^3), temperature (deg Kelvin) and East and North wind components (m/s).

A sample "MET" table is:

Height of Density and Temp (m)	Temp °K	Density (kg/m^3)	Height of Winds (m/s)	East Wind (m/s)	North Wind (m/s)
0.0	300.73	1.16797	0.0	-3.7495	1.1118
304.8	299.83	1.13433	304.8	-2.5638	-1.3424
609.6	297.39	1.10590	609.6	-1.3125	-2.5714
914.4	293.96	1.08120	914.4	-0.1536	-3.0598
1219.2	292.43	1.04967	1219.2	0.1701	-2.9015
1524.0	290.49	1.02037	1524.0	-0.0444	-2.5546
1828.8	288.63	0.99163	1828.8	-0.3735	-2.4936
2133.6	286.99	0.96250	2133.6	-0.8256	-2.9002
2438.4	285.23	0.93493	2438.4	-1.0068	-3.4127
2743.2	283.73	0.90670	2743.2	-1.0664	-3.5984
3048.0	282.16	0.87890	3048.0	-1.2161	-3.5510
3352.8	280.59	0.85177	3352.8	-1.5483	-3.2232
3657.6	279.19	0.82493	3657.6	-2.0625	-3.1227
3962.4	277.43	0.79957	3962.4	-2.2255	-3.0280
4267.2	276.06	0.78370	4267.2	-2.2891	-3.4152

This type of meteorological profile is input to LOCATER with a METRO type data packet. See section 6.2.5.

5.4 Measurement Generation

The equations of motion described in Section 5.3 are used by the trajectory generator to produce an unerrored projectile trajectory. This unerrored projectile trajectory is converted into radar measurement coordinates and certain radar errors are added to the unerrored value. This section describes the generation of those radar measurement errors and the statistical models used.

5.4.1 Random Radar Measurement Errors

The generation of random errors is accomplished using a random number generator which produces normally distributed random numbers. The user can specify the random number sequence to be used. This is helpful when it is desired to repeat a particular random number sequence. This random generator is used for producing random errors which model the 3 sources of error described below.

Bias errors are modeled as random variables with a zero mean and a standard deviation specified by the user in the radar model description for each measurement dimension of the radar. At the beginning of each Monte-Carlo run, a random number is selected from the specified statistical distribution, this random number is used throughout the trajectory estimation for that particular Monte-Carlo experiment. Thus, if 20 Monte-Carlo runs were made 20 different bias values would be used selected from the appropriate distribution. Although not a part of the statistical specification it is possible to simulate biases with zero means by using provisions in the estimation process that was originally intended for removal of known biases.

Thermal noise is usually the dominant source of random error in radar measurements. The effect that thermal noise has in degrading radar measurement is directly proportional to the ratio of signal-to-noise power level. Accordingly the thermal error is modeled as a zero mean normally distributed random error with a variance that is inversely proportional to the signal-to-noise ratio. Formulas of this type can be found in Barton Radar Systems. For each of the track measurement dimensions, the general form of the thermal error is given in equation 5-19. σ_T is the standard deviation specified for a zero dB signal-to-noise ratio. The signal-to-noise ratio itself is modeled as a function of the radar sensitivity and the radar cross section, σ_{RCS} (equation 5-20).

$$e_B(J) = \sigma_B N(J) \qquad (5\text{-}19)$$

$$e_T = \frac{\sigma_T N(J)}{S/N} \qquad (5\text{-}20)$$

Note: r_0 is the reference range of the radar system which is the range for which the radar system would obtain a unity signal-to-noise ratio on a one square meter target. Because the random thermal errors are independent for each track point we must generate a new random number from the distribution for each track measurement.

Instrumentation errors also called jitter or range independent errors are also present in each radar measurement dimension. These errors are usually a function of the basic precision with which the measurement is made and are thus assumed to be constant regardless of the signal-to-noise ratio. These errors are modeled as a zero mean normal process with a standard deviation which is constant regardless of the target range. Because these errors are independent between track point measurement we must generate them for each track point. Thus the total random error equation 5-21 is given as the sum of the three independent components.

$$e_{RAW} = e_B(J) + e_T + e_J \qquad (5\text{-}21)$$

5.4.2 Multipath Errors

Multipath errors vary from sight to sight and from one azimuth direction to another. We have assumed in LOCATER, however, that the multipath errors are fixed and can be modeled deterministically. Two methods of modeling multipath errors have been included in LOCATER. Each model effects only the elevation measurement of the radar. The first method is to provide a functional form for the error which is added to the true elevation e to get the multipath elevation measurement e_m. This expression for the multipath error is designed to be representative of typical specular multipath. One can see that the expression in eqn. 5-22 is a good approximation to a measured multipath error by observing the approximation shown in Fig. 4-1.

$$e_m = e + \ldots . f_m(e) \qquad (5\text{-}22)$$

Multipath error equation

The second method of modeling multipath error is to provide a table look up to translate the true elevation generated into an equivalent multipath measurement for elevation (5-23).

$$e_m = f_m(e) \qquad (5\text{-}23)$$

This slightly more general approach allows one to model multipath errors generated from multiple specular reflections or to model multipath measured at an actual tactical sight. Both of these methods for generating multipath errors use only the true elevation e. Whereas, in practice, one may find variations in the multipath error as a function of the azimuth as well. The present facilities for modeling multipath are probably adequate for determining the worst case effects of multipath on weapon location accuracy. In the future one might be tempted to extend the modeling of multipath using eqn. 5-22 along the lines of the bias errors making the coefficients in eqn. 5-22 random variables selected from a distribution for each trajectory to be modeled.

5.4.3 Tropospheric Refraction Errors

When tracking projectiles at low elevation angles (under 400 mr), the radar measurements include a bias resulting from the refraction of the radar signal in the atmosphere. The result is that the target appears at a higher elevation and at a greater range than its true position. See Figure 5-5a.

The low angle refraction of a target at 30 km slant range results in a 10 m greater range and a 0.65 mr greater elevation which translates to a 22 m position error. Barton and Ward* have published corrections as a function of measured slant range, r, and elevation angle, e (see figures 5-5b and c).

In order to model refraction errors in the LOCATER program, these curves have been reduced to the approximate formulas shown below:

$$\Delta r = k_1 \left[k_2 e + r^{-1} \right]^{-1} \text{ meters} \qquad (5\text{-}24)$$

where $k_1 = 3 \times 10^{-4}$

$k_2 = 1.25 \times 10^{-4}$

$$\Delta e_0 = k_1 \left[k_2 e + r^{-1} \right]^{-1} \text{ radians} \qquad (5\text{-}25)$$

where $k_1 = 2.25 \times 10^{-8}$

$k_2 = 8 \times 10^{-5}$

In the above formulas, slant range is in meters and elevation is in radians. Both r and e are taken to be the measured values; however, no significant error results from using the true value to calculate the error to be added for simulation purposes. The refraction errors calculated using models (1) and (2) above are shown as triangles (10 mr elevation) and circles (400 mr elevation) in Fig. 5-5B. Agreement is quite good in the region of interest for projectile tracking.

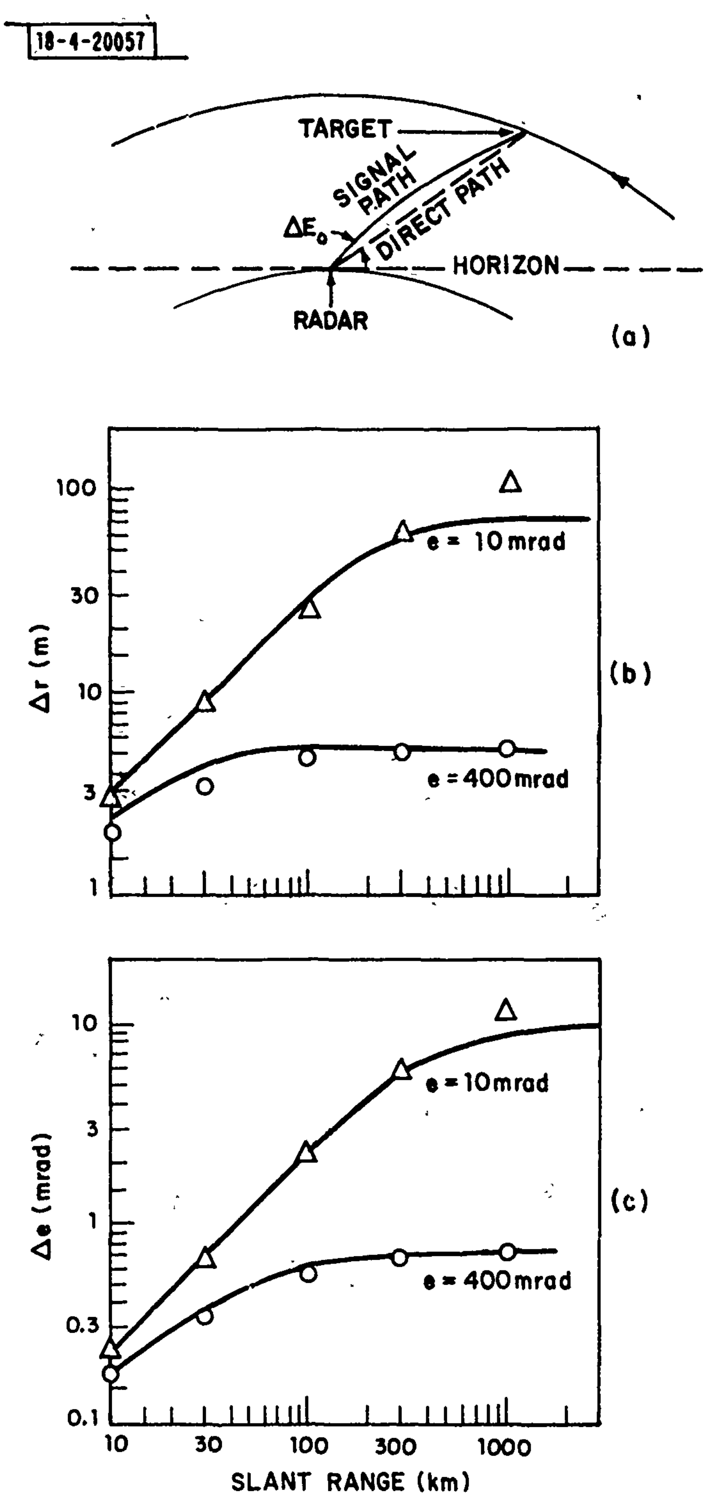


Fig. 5-5. (a) Tropospheric refraction geometry, (b) fitted range bias vs. range, (c) fitted elevation angle bias vs. range.

The errors generated by the above expressions have been added to the range and elevation measurements, respectively. They are useful for modeling the effects of nominal uncorrected tropospheric refraction errors. Although a tropospheric refraction is the result of highly variable atmospheric conditions we have not attempted to model them statistically. Neither have we used the above model to remove assumed "nominal" refraction errors from the estimate.

5.5 Maximum Likely Estimation

This section describes the solution and implementation of the maximum likely state vector estimation problem. The theory has been developed elsewhere.[1]

For a set of real or simulated radar measurements it is desired to determine the trajectory which best fits the radar measurements in a weighted-least-squares sense. Thus we can predict backwards in time (backtracking) to its intersection with the terrain.

The state vector estimation process has been generalized, so that we can, at our option, determine any states (parameters) of the system, e.g., launch positions, velocities, drag, spin, ground wind components, radar biases or a functional multipath model. Not all these states can be estimated simultaneously, but depends on the radar-weapon geometry and measurement capabilities of the radar.

5.5.1 Maximum Likelihood Estimation-- Solution and Implementation

Given a set of radar measurements, $\underline{R}_{\ell i}$, we would like to determine the "best fit" ballistic trajectory through the data such that the weighted differences between the measurements and estimates of the trajectory are minimized, where the weights, $\underline{W}_{\ell i}$, reflect our "confidence" in the measurements. Then we have obtained our maximum likely solution.

The measurement vector, $\underline{R}_{\ell i}$, refers to a vector of range, azimuth, elevation, and doppler observations taken by radar ℓ at the time t_i. This formulation will allow single or multistatic sensor analysis with either simultaneous or nonsimultaneous measurements.

The measurement weights, $\underline{W}_{\ell i}$, are themselves functions of time and radar measurement noise errors and are described in section 5.5.4.

The estimates of the trajectory, denoted by $\hat{\underline{R}}_{\ell i}$, are determined by (1) extrapolating the current "best fit" state vector, $\underline{X}$, in the ESF coordinate system, to the time, t_i, of the measurement and (2) transforming the position and velocity components of $\underline{X}$ to the measurement space, RAE, of radar ℓ.

The maximum likely equation (MLE) is: we would like to to minimize the quantity Q, where

$$Q = \sum_{i}^{N_1} \left[\underline{R}_{1i} - \hat{\underline{R}}_{1i}\right] \underline{W}_{1i} \left[\underline{R}_{1i} - \hat{\underline{R}}_{1i}\right] + \tag{5-26}$$

$$\sum_{i}^{N_2} \left[\underline{R}_{2i} - \hat{\underline{R}}_{2i}\right] \underline{W}_{2i} \left[\underline{R}_{2i} - \hat{\underline{R}}_{2i}\right] + \ldots +$$

$$\sum_{i}^{N_\ell} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i}\right] \underline{W}_{\ell i} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i}\right]$$

where

Q is the total weighted squared residual

N_1 is the number of measurements taken by the first radar ($\ell = 1$)

N_2 is the number of measurements taken by the second radar ($\ell = 2$)

N_ℓ is the number of measurements taken by radar ℓ

N is the total number of measurements $N = N_1 + N_2 + \ldots N_\ell$

i is the measurement number denoting the measurement time, t_i.

The state vector, $\underline{X}$, (introduced in section 5.3) contains the position, velocity, drag, spin, and ground wind states of the projectile in the ESF coordinate system of the base radar ($\ell = 1$). It is these states of $\underline{X}$ that we wish to determine; then we have obtained our maximum likely state vector, $\underline{X}$. The 3 position states and 3 velocity states of $\underline{X}$ are represented by a 6 element state vector, $\underline{S}$ (introduced in section 5.2.1).

To solve eqn. (5-26) by an iterative technique, we assume that $\hat{\underline{R}}_{\ell i}$ is a set of measurement estimates for the $k^{th}+1$ iteration and is composed of two terms: (1) the estimates for the k^{th} iteration and (2) the linear perturbation, $\underline{\delta R}_{\ell i}$, to the set of current estimates.

$$\hat{\underline{R}}_{\ell i} = \tilde{\underline{R}}_{\ell i} + \underline{\delta R}_{\ell i} \tag{5-27}$$

We must now define the vector of measurement perturbations, $\underline{\delta R}_{\ell i}$, in terms of a set of perturbations, $\underline{\delta S}_i$, to the state vector, $\underline{S}$, extrapolated to the time, t_i, for the base radar.

The nonlinear transformation, $\underline{f}$, for a 6-element state vector, $\underline{S}_\ell$, from ESF to RAE has been developed in section 5.2.3 by eqn. (5-2). The state vector $\underline{S}$ is relative to the base radar while $\underline{S}_\ell$ is relative to radar ℓ.

$$\hat{\underline{R}}_{\ell i} = \underline{f}(\underline{S}_{\ell i}) \tag{5-28}$$

The i subscript on $\underline{S}_{\ell i}$ indicates that the state vector $\underline{S}$ has been extrapolated to the time, t_i.

Upon differentiation of eqn. (5-28) we obtain

$$\underline{\delta R}_{\ell i} = \frac{\partial \underline{f}(\underline{S}_{\ell i})}{\partial \underline{S}_{\ell i}} \underline{\delta S}_{\ell i} \tag{5-29}$$

where

$\underline{\delta R}_{\ell i}$	set of perturbations to the radar measurement estimates at the time t_i relative to radar ℓ
$\frac{\partial \underline{f}(\underline{S}_{\ell i})}{\partial \underline{S}_{\ell i}}$	is the Jacobian of the transformation, $\underline{f}$
$\underline{\delta S}_{\ell i}$	set of perturbations to the state vector $\underline{S}_\ell$ at the time t_i relative to radar, ℓ

The Jacobian, $\frac{\partial \underline{f}(\underline{S}_{\ell i})}{\partial \underline{S}_{\ell i}}$, which hereafter is called $\underline{C}_{\ell i}$ is a matrix with maximum dimensions of 4 rows by 6 columns and must be computed for every time t_i. The terms of $\underline{C}_{\ell i}$ are evaluated in section 5.5.2 and is computed by subroutine MLEC.

Eqn. (5-29) expanded is:

$$\begin{bmatrix} \delta r \\ \delta a \\ \delta e \\ \delta \dot{r} \end{bmatrix}_{\ell i} = \underline{C}_{\ell i} \begin{bmatrix} \delta x \\ \delta y \\ \delta z \\ \delta \dot{x} \\ \delta \dot{y} \\ \delta \dot{z} \end{bmatrix}_{\ell i} \tag{5-30}$$

Equation (5-29) will now be modified to relate the state vector perturbations, $\underline{\delta S}_i$, for the base radar.

Equation (5-11) relates the transformation of a state vector, $\underline{S}_{\ell i}$, relative to radar ℓ, to another state vector, $\underline{S}_i$, relative to the base radar at the time t_i.

$$\underline{S}_{\ell i} = \underline{A}_\ell \underline{A}^t (\underline{S}_i - \underline{b}) + \underline{b}_\ell \tag{5-31}$$

where

$\underline{A}_\ell$ and $\underline{b}_\ell$ are transformation matrices defined by (5-7) and (5-9) for radar ℓ. $\underline{A}$ and $\underline{b}$ are also defined by (5-7) and (5-9) for the base radar.

Upon differentiation of eqn. (5-31)

$$\underline{\delta S}_{\ell i} = \underline{A}_\ell \underline{A}^t \underline{\delta S}_i \tag{5-32}$$

If ℓ is the base radar ($\ell = 1$), $\underline{A}_\ell \underline{A}^t = \underline{I}$. The MLE rewritten by substitution of eqn. (5-32), (5-29), and (5-27) in (5-26) is:

The transformation of the B/M vector, $\underline{a}$, to the measurement space RAE is described by the transformation, $\underline{F}(\underline{a})$, where the components of $\underline{F}$ are:

$$
\begin{aligned}
F_1 &= a_1 \\
F_2 &= a_2 \\
F_3 &= a_3 + a_5 \cos(a_6 \hat{e}_i - a_7) \\
F_4 &= a_4
\end{aligned}
\tag{5-37}
$$

$\hat{e}_i$ is the estimate of elevation at the time t_i relative to the base radar. (The 3rd component of $\hat{\underline{R}}_{1i}$ with $\ell = 1$)

The B/M component, a_5, corresponds to the amplitude of the multipath, while $2\pi/a_6$ is the period (radians) and a_7/a_6 is the phase (radians).

Equation (5-27) modified to include the bias/multipath estimates and linear perturbation is:

$$\hat{\underline{R}}_{\ell i} = \hat{\underline{R}}_{\ell i} + \delta\underline{R}_{\ell i} + \underline{F}(\underline{a})_i + \delta\underline{F}(\underline{a})_i \tag{5-38}$$

where $\delta\underline{F}(\underline{a})_i$ is the perturbation to the current set of B/M estimates $\underline{F}(\underline{a})_i$. The absence of the ℓ as a subscript indicates that $\underline{a}$ is relative to the base radar ($\ell = 1$).

The perturbation $\delta\underline{F}(\underline{a})_i$ expressed in terms of a perturbation of the B/M vector, $\underline{a}$ is

$$\delta\underline{F}(\underline{a})_i = \frac{\partial\underline{F}(\underline{a})_i}{\partial\underline{a}}\,\delta\underline{a} \tag{5-39}$$

$\dfrac{\partial\underline{F}(\underline{a})_i}{\partial\underline{a}}$ is the Jacobian of the transformation, $\underline{F}$, eqn. (5-37), and is time dependent.

$\delta\underline{a}$ is the perturbation to the current estimate of the B/M vector, $\underline{a}$.

The Jacobian, $\dfrac{\partial\underline{F}(\underline{a})_i}{\partial\underline{a}}$, is sparse; the only nonzero terms are:

$$
\begin{aligned}
\frac{\partial F_1}{\partial a_1} &= 1 \\
\frac{\partial F_2}{\partial a_2} &= 1 \\
\frac{\partial F_3}{\partial a_3} &= 1 \\
\frac{\partial F_4}{\partial a_4} &= 1 \\
\frac{\partial F_3}{\partial a_5} &= \cos(a_6 \hat{e}_i - a_7) \\
\frac{\partial F_3}{\partial a_6} &= -a_5 \hat{e}_i \sin(a_6 \hat{e}_i - a_7) \\
\frac{\partial F_3}{\partial a_7} &= a_5 \sin(a_6 \hat{e}_i - a_7)
\end{aligned}
\tag{5-40}
$$

$$Q = \sum_{\ell} \sum_{i}^{N_\ell} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}_{\ell i} A_\ell A^t \, \underline{\delta S_i}\right]^t W_{\ell i} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}_{\ell i} A_\ell A^t \, \underline{\delta S_i}\right] \qquad (5\text{-}33)$$

The matrix $\underline{C}_{\ell i} A_\ell A^t$ will henceforth be denoted by $\underline{C}'_{\ell i}$

$$Q = \sum_{\ell} \sum_{i}^{N_\ell} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}'_{\ell i} \, \underline{\delta S_i}\right]^t W_{\ell i} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}'_{\ell i} \, \underline{\delta S_i}\right] \qquad (5\text{-}34)$$

The inner summation is over the number of measurements and the outer summation is over the number of radars.

The next step in the solution of eqn. (5-34) is to relate the perturbation, $\underline{\delta S_i}$, at the time t_i, to one perturbation, $\underline{\delta X_o}$, of the state vector $\underline{X}$ at an arbitrarily specified time, t_o, called the reference time. It must be remembered that $\underline{S}$ represents the 6-element position and velocity vector of $\underline{X}$

This relationship is achieved by means of the state transition matrix, Φ_{io}, where

$$\underline{\delta S_i} = \Phi_{io} \, \underline{\delta X_o} \qquad (5\text{-}35)$$

The matrix, Φ_{io}, has maximum dimensions of 6 rows by 10 columns and is described in section 5.5.3 and computed by subroutine MLEPHI.

Equation (5-34) with substitution of (5-35) becomes

$$Q = \sum_{\ell} \sum_{i}^{N_\ell} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}'_{\ell i} \, \Phi_{io} \, \underline{\delta X_o}\right]^t W_{\ell i} \left[\underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i} - \underline{C}'_{\ell i} \, \Phi_{io} \, \underline{\delta X_o}\right] \qquad (5\text{-}36)$$

Radar Bias Estimation

For certain situations, we would also like to estimate other parameters of the radar-weapon system. These other states would include radar measurement biases and a functional multipath model for elevation only for the base radar. See Section 5.4 for simulation of these biases.

To account for these effects we have introduced a bias/multipath (B/M) state vector, $\underline{a}$, to be estimated. This is not to be confused with the ECF to ESF transformation matrix, $\underline{a}$. The components of $\underline{a}$ are:

a_1	range bias (meters)
a_2	azimuth bias (radians)
a_3	elevation bias (radians)
a_4	doppler bias (meters/sec)
a_5	multipath A_m parameter (radians)
a_6	multipath B_m parameter
a_7	multipath C_m parameter

The MLE, eqn. (5-36), with bias/multipath terms included by substitution of eqn. (5-39) and (5-38) into (5-36) is:

$$Q = \sum_{\ell} \sum_{i}^{N_\ell} \left[\underline{\Delta R}_{\ell i} - \underline{C}'_{\ell i}\, \Phi_{io}\, \underline{\delta X}_o - \underline{F}(\underline{a})_i - \frac{\partial \underline{F}(\underline{a})_i}{\partial \underline{a}}\, \underline{\delta a}\right]^t \cdot \tag{5-41}$$

$$\underline{W}_{\ell i} \left[\underline{\Delta R}_{\ell i} - \underline{C}'_{\ell i}\, \Phi_{io}\, \underline{\delta X}_o - \underline{F}(\underline{a})_i - \frac{\partial \underline{F}(\underline{a})_i}{\partial \underline{a}}\, \underline{\delta a}\right]$$

where $\underline{R}_i$ is the difference between the measurements and estimates after k iterations.

$\underline{\Delta R}_{\ell i} = \underline{R}_{\ell i} - \hat{\underline{R}}_{\ell i}$.

A *Priori* States

We would also like to include in the MLE, eqn. (5-41), prior knowledge of certain states in $\underline{X}$. This *a priori* knowledge may be available from reconnaisance or previous history and may, for example, include projectile type and hence its drag and spin characteristics.

Equation (5-41) with the terms for *a priori* states is

$$Q = \left[\underline{\delta X}_o - \underline{\delta X}_a\right]^t \underline{M}_o^{-1} \left[\underline{\delta X}_o - \underline{\delta X}_a\right] + \tag{5-42}$$

$$\sum_{\ell} \sum_{i}^{N_\ell} \left[\underline{\Delta R}_{\ell i} - \underline{C}'_{\ell i}\, \Phi_{io}\, \underline{\delta X}_o - \underline{F}(\underline{a})_i - \frac{\partial \underline{F}(\underline{a})_i}{\partial \underline{a}}\, \underline{\delta a}\right]^t \underline{W}_{\ell i} \cdot$$

$$\left[\underline{\Delta R}_{\ell i} - \underline{C}'_{\ell i}\, \Phi_{io}\, \underline{\delta X}_o - \underline{F}(\underline{a})_i - \frac{\partial \underline{F}(\underline{a})_i}{\partial \underline{a}}\, \underline{\delta a}\right]$$

The *a priori* terms in eqn. (5-42), the residual error function Q, has been developed elsewhere.[1]

We introduce the state vector $\underline{X}_a$ which contains the *a priori* states with an associated covariance matrix $\underline{M}_o$. The components of $\underline{X}_a$ are similar to $\underline{X}$ (described in section 5.3). The inverse covariance matrix, $\underline{M}_o^{-1}$, is a diagonal matrix of inverse variances of the respective states in $\underline{X}_a$. The perturbation vector, $\underline{\delta X}_a$, is defined as the difference between the *a priori* state vector, $\underline{X}_a$, and the current estimate, $\underline{X}$, after k iterations.

$$\underline{\delta X}_a = \underline{X}_a - \underline{X} \tag{5-43}$$

MLE Solution

Given the MLE, eqn. (5-42), a metric state vector, $\underline{X}$, valid after k iterations, we can solve eqn. (5-42) for the linear perturbations, $\underline{\delta X}_o$ and $\underline{\delta a}$, by minimization of eqn. (5-42) with respect to the perturbations. We will then update our current best estimates, $\underline{X}$ and $\underline{a}$, by their appropriate perturbations and test for convergence.

The time dependency, i, and radar dependency notation, ℓ, will now be dropped from eqn. (5-42)

$$Q = \left[\underline{\delta X}_o - \underline{\delta X}_a\right]^t \underset{\sim}{M}_o^{-1}\left[\underline{\delta X}_o - \underline{\delta X}_a\right] + \tag{5-44}$$

$$\sum^{N}\left[\underline{\Delta R} - \underset{\sim}{C}' \ \underset{\sim}{\Phi} \ \underline{\delta X}_o - \underline{F}(\underline{a}) - \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \ \underline{\delta a}\right]^t W \cdot$$

$$\left[\underline{\Delta F} - \underset{\sim}{C}' \ \underset{\sim}{\Phi} \ \underline{\delta X}_o - \underline{F}(\underline{a}) - \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \ \underline{\delta a}\right]$$

where the summation is over the number of measurements for all radars, N.

The partial derivatives of Q, eqn. (5-44), with respect to $\underline{\delta X}_o$ and $\underline{\delta a}$ are given by eqns. (5-45) and (5-46).

$$\frac{\partial Q}{\partial \underline{\delta X}_o} = \left[\underline{\delta X}_o - \underline{\delta X}_a\right]^t \underset{\sim}{M}_o^{-1} + \tag{5-45}$$

$$\sum^{N}\left[\underline{\Delta R} - \underset{\sim}{C}' \ \underset{\sim}{\Phi} \ \underline{\delta X}_o - \underline{F}(\underline{a}) - \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \ \underline{\delta a}\right]^t \underset{\sim}{W}[-\underset{\sim}{C}' \ \underset{\sim}{\Phi}]$$

$$\frac{\partial Q}{\partial \underline{\delta a}} = \sum^{N}\left[\underline{\Delta R} - \underset{\sim}{C}' \ \underset{\sim}{\Phi} \ \underline{\delta X}_o - \underline{F}(\underline{a}) - \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \ \underline{\delta a}\right]^t \underset{\sim}{W}\left[-\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right] \tag{5-46}$$

By setting the partial derivatives $\frac{\partial Q}{\partial \underline{\delta X}_o}$ and $\frac{\partial Q}{\partial \underline{\delta a}}$ to zero and collecting terms in $\underline{\delta X}_o$ and $\underline{\delta a}$ we then obtain

$$\left[\underset{\sim}{M}_o^{-1} + \sum^{N}(\underset{\sim}{C}' \ \underset{\sim}{\Phi})^t \ \underset{\sim}{W}^t \ \underset{\sim}{C}' \ \underset{\sim}{\Phi}\right]\underline{\delta X}_o + \left[\sum^{N}(\underset{\sim}{C}' \ \underset{\sim}{\Phi})^t \ \underset{\sim}{W}^t \ \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right]\underline{\delta a} =$$

$$\underset{\sim}{M}_o^{-1} \ \underline{\delta X}_a + \sum^{N}(\underset{\sim}{C}' \ \underset{\sim}{\Phi})^t \ \underset{\sim}{W}^t \ \underline{\Delta R} \tag{5-47}$$

$$\left[\sum^{N}\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t \ \underset{\sim}{C}' \ \underset{\sim}{\Phi}\right]\underline{\delta X}_o + \left[\sum^{N}\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t \ \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right]\underline{\delta a} =$$

$$\sum^{N}\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t(\underline{\Delta R} - \underline{F}(\underline{a})) \tag{5-48}$$

The terms $\underline{\delta X}_o$ and $\underline{\delta a}$ have been removed from the summations in eqns. (5-47) and (5-48) as they are constants. Equations (5-47) and (5-48) are recognized as simultaneous matrix equations with unknown vectors, $\underline{\delta X}_o$ and $\underline{\delta a}$.

The inverse covariance matrix, $\underset{\sim}{P}^{-1}$, is then defined as a partitioned matrix using eqn. (5-47) and (5-48).

$$\underset{\sim}{P}^{-1} = \left[\begin{array}{c|c} \underset{\sim}{M}_0^{-1} + \sum^{N} (\underset{\sim}{C}'\,\underset{\sim}{\phi})^t\, \underset{\sim}{W}^t\, \underset{\sim}{C}'\,\underset{\sim}{\phi} & \sum^{N} (\underset{\sim}{C}'\,\underset{\sim}{\phi})^t\, \underset{\sim}{W}^t\, \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \\ \hline \sum^{N} \left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t\, \underset{\sim}{C}'\,\underset{\sim}{\phi} & \sum^{N} \left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t\, \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}} \end{array}\right] \tag{5-49}$$

The residual error matrix, $\underset{\sim}{B}$, is also defined as a partitioned matrix.

$$\underset{\sim}{B} = \left[\begin{array}{c} \underset{\sim}{M}_0^{-1}\, \underline{\delta X}_a + \sum^{N} (\underset{\sim}{C}'\,\underset{\sim}{\phi})^t\, \underset{\sim}{W}^t\, \underline{\Delta R} \\ \hline \sum^{N} \left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t \underset{\sim}{W}^t (\underline{\Delta R} - \underline{F}(\underline{a})) \end{array}\right] \tag{5-50}$$

The unknown perturbations $\underline{\delta X}_0$ and $\underline{\delta a}$ are defined as the partitioned matrix $\underline{\delta V}$.

$$\underline{\delta V} = \left[\begin{array}{c} \underline{\delta X}_0 \\ \hline \underline{\delta a} \end{array}\right] \tag{5-51}$$

This linear system of simultaneous equations

$$\underset{\sim}{P}^{-1}\, \underline{\delta V} = \underset{\sim}{B} \tag{5-52}$$

can be solved for $\underline{\delta V}$ by inverting the inverse covariance matrix, $\underset{\sim}{P}^{-1}$, and postmultiplying by the residual error matrix, $\underset{\sim}{B}$.

$$\underline{\delta V} = (\underset{\sim}{P}^{-1})^{-1}\, \underset{\sim}{B} = \underset{\sim}{P}\, \underset{\sim}{B} \tag{5-53}$$

This method of solution by inverting the inverse covariance matrix is desirable if any of the terms in the covariance matrix, $\underset{\sim}{P}$, are to be examined, however, using a standard simultaneous equation routine minimizes the accumulative roundoff error as less arithmetic operations are required.

The current metric state vector, $\underline{X}$, and the bias/multipath state vector, $\underline{a}$, are then updated by their appropriate perturbations, $\underline{\delta X}_0$ and $\underline{\delta a}$, and checked for convergence.

$$\underline{X} = \underline{X} + \underline{\delta X}_0 \tag{5-54}$$

$$\underline{a} = \underline{a} + \underline{\delta a} \tag{5-55}$$

Implementation

The maximum likely estimation problem developed in the first part of section 5.5.1 is implemented in subroutine MAXLIK.

The remainder of this section is to describe the matrix names, dimensions and give an overview of program coding for a maximum likely estimator.

The following sections should be referred to for additional information on the implementation.

Section 8.3.2 Labelled common variable definitions

Section 8.1.3 MAXLIK flow chart

Track File

The measurements track file, $\underline{R}_{\ell i}$, introduced at the beginning of 5.5.1, is stored in array RMEAS(300,14) in labelled common MEAS, and allows a maximum of 300 measurements. The measurements are sorted in increasing order of time if the radar is a multisensor system.

The program run mode determines the source of the measurements. For real data analysis the measurements are read in by subroutine REALMD, for external trajectory simulation the unerrored measurements are read in by subroutine BRLIN, and for complete simulation the unerrored measurements are generated by subroutine GENER. Subroutine ENVNSE then simulates radar noise to corrupt the unerrored measurements. Refer to MONITR flow chart in section 8.1.2.

The column description of array RMEAS are:

COLUMN #	DESCRIPTION
1	Track time, t_i (seconds)
2	Range measurement (meters)
3	Azimuth measurement (radians)
4	Elevation measurement (radians)
5	Doppler measurement (meters/sec)
10	Signal noise ratio (SNR) in dB
11	Radar number

The signal noise ratio is computed by eqn. (5-64) unless it is measured.

Measurement Weights

The measurement weights, $\underline{W}_{\ell i}$, are computed by subroutine WEIGHT according to eqns. (5-61), (5-62), and (5-63) and stored in the following columns of array RMEAS:

COLUMN #	DESCRIPTION
6	Range measurement weight
7	Azimuth measurement weight
8	Elevation measurement weight
9	Doppler measurement weight

MLE Initialization

The initialization of the MLE is controlled by the ESTIMATOR data packed which is described in section 6.2.3. The packet controls determine the initial metric state vector, $\underline{X}$, the bias/multipath vector, $\underline{a}$, and which states in $\underline{X}$ and $\underline{a}$ are to be estimated. The initialization is implemented in subroutine START which is composed of 4 parts.

1. Determine the initial state vector, $\underline{X}$, which is internally represented as array XSTRT. $\underline{X}$ can be derived from 3 sources:
    a. Externally specified by a VECTOR data packet.
    b. Determined from measurements by regression.
    c. Use the nominal states in the WEAPON data packet.
2. Determine which states in $\underline{X}$ among them positions, velocities, drag, spin, and ground wind components are to be estimated and are controlled by ITEMS 8 to 17 of the ESTIMATOR packet. The 10 switches are stored in an array ISTAT1. If ISTAT1(I) is 1 then estimate the corresponding state in $\underline{X}$. The maximum number of states that can be estimated in $\underline{X}$ is variable NSX which is currently set at 10. The number of states in $\underline{X}$ to be estimated for this run is variable NS which ranges from 0 to NSX.
3. Determine the initial bias/multipath state vector $\underline{a}$, which internally is represented by variable ASTRT. The components of $\bar{a}$ are identical to ITEMS 27 to 33 of the RADAR packet for the base radar.
4. Determine which states in $\underline{a}$ are to be estimated. This is specified by a series of state estimation switches (ITEMS 18 to 24) in the ESTIMATOR data packet. This array of 7 elements is internally stored as variable ISTAT2. If ISTAT2(I) is 1 then estimate the corresponding state in $\underline{a}$. The maximum number of states in $\underline{a}$ to estimate is NPX (currently 7) while the number of states to estimate for this run, NP, varies from 0 to NPX.

Measurement Editing

The measurements in the track file can be optionally edited (rejected) and is controlled by the EDITOR data packet (Section 6.2.2). For each measurement, a data quality indicator flag will be stored in column #12 of array RMEAS. The flag has the following significance:

FLAG	SIGNIFICANCE
0	All good observations
1	Measurement was dropped by a pre-fit test. Each measurement component is fitted to a sliding polynomial and if any observation deviates from the mean more than 4 sigma, the whole measurement is flagged.

FLAG	SIGNIFICANCE
2	The signal noise ratio (SNR) of the measurement, either measured or computed by eqn. (5-64), is less than some specified threshold set by ITEM 24 of the appropriate RADAR data packet. The data edit tests (Flag 1 and 2) are done before the trajectory fitting process.
4	After initial convergence of the estimator, the average weighted track residual and sigma for each measurement component is determined. Any track residual which deviates from the mean more than a specified sigma will result in flagging the measurement.

MLE Accumulation Variables, Eqn. (5-49) and (5-50)

A major part of subroutine MAXLIK accumulates the inverse covariance matrix, $\underset{\sim}{P}^{-1}$, and residual error matrix, $\underset{\sim}{B}$.

The following scalar variables represent certain constants in the MLE, and are located in labelled common MLE1, MLE2 and INFO.

Variable Name	Value	Description
NR	6	Number of terms in the state vector, $\underline{S}$.
NMX	4	Maximum number of observations for each measurement.
NM	1 to NMX	Number of observations in the radar measurement space.
NSX	10	Maximum number of states to estimate in the metric state vector, $\underline{X}$.
NS	0 to NSX	Number of states in $\underline{X}$ to estimate for this run.
NPX	7	Maximum number of states to estimate in the bias/multipath state vector, $\underline{a}$.
NP	0 to NPX	Number of states to estimate in the bias/multipath state vector, $\underline{a}$.
NSP	NS+NP	Length of the residual error matrix, $\underset{\sim}{B}$, and order of the inverse covariance matrix, $\underset{\sim}{P}^{-1}$.
NSPX	NSX+NPX	Maximum value of NSP=size of inverse covariance matrix, $\underset{\sim}{P}^{-1}$, and residual error matrix, $\underset{\sim}{B}$.
MC		The number of Monte Carlo runs equivalent to ITEM 1 of the MISSION data packet.
NRUN	1 to MC	The current run number.
NPTMAX	≤ 300	The number of measurements in the track file. This is symbol N in eqns. (5-49) and (5-50).
NPT	1 - NPTMAX	The current measurement number.
NITER		The current iteration number.

The matrices in eqns. (5-49) and (5-50) and their equivalent FORTRAN variable array names are specified in the following table.

Math Symbol	Array Name	Maximum Dimensions	Defined Dimensions	Defining Routine	Output SECTION #
$\underset{\sim}{B}$	ERROR	(NSPX,1)	(NSP,1)	MAXLIK	
$\underset{\sim}{C}'$	C	(NMX,NR)	(NM,NR)	MLEC	
$\underline{\delta a}$	DELAI	(NPX,1)	(NP,1)	MAXLIK	3
$\underline{\Delta R}$	DELR	(NMX,1)	(NM,1)	MAXLIK	7
$\underline{\delta X}_a$	DELXA	(LXHAT)	(14)	APRIR	
$\underline{\delta X}_o$	DELXO	(NSX,1)	(NS,1)	MAXLIK	3
$\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}$	DFDA	(NMX,NPX)	(NM,NP)	DFAMAT	
$\underline{a}$	AHAT	(NPX)	(NPX)	MAXLIK	3
$\underset{\sim}{M}_o^{-1}$	XMO	(NSX)	(NS)	APRIR	
$\underset{\sim}{P}^{-1}$	COVAR	(NSPX,NSPX)	(NSP,NSP)	MAXLIK	5
$\underset{\sim}{\Phi}$	PHI	(NR,NSX)	(NR,NS)	PHIMAT	
$\underset{\sim}{W}$	W	(NMX,NMX)	(NM,NM)	WEIGHT	4
$\underline{X}$	SVXHAT	(LXHAT)	(14)	SETRND	3,6,8,9

The following list of matrix names are partial products of the above variable list used to compute each partition of the inverse covariance matrix, $\underset{\sim}{P}^{-1}$, and error matrix, $\underset{\sim}{B}$. The matrix operations are implemented using general purpose 2-dimensional matrix manipulation subroutines. This amounts to a slight overhead in CPU time but increases coding legibility.

Math Symbol	Array Name	Maximum Dimensions	Defined Dimensions
$\underline{\delta V}$	PTRB	(NSPX,1)	(NSP,1)
$\underset{\sim}{C}'\ \underset{\sim}{\Phi}$	H	(NMX,NSX)	(NM,NS)
$(\underset{\sim}{C}'\ \underset{\sim}{\Phi})^t$	HT	(NSX,NMX)	(NS,NM)
$(\underset{\sim}{C}'\ \underset{\sim}{\Phi})^t\ \underset{\sim}{W}^t$	HTW	(NSX,NMX)	(NS,NM)
$(\underset{\sim}{C}'\ \underset{\sim}{\Phi})^t\ \underset{\sim}{W}^t\ \underset{\sim}{C}'\ \underset{\sim}{\Phi}$	XX1	(NSX,NSX)	(NS,NS)
$(\underset{\sim}{C}'\ \underset{\sim}{\Phi})^t\ \underset{\sim}{W}^t\ \underline{\Delta R}$	YY1	(NSX,1)	(NS,1)
$\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t$	DFT	(NPX,NMX)	(NP,NM)
$\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t\ \underset{\sim}{W}^t$	DFTW	(NPX,NMX)	(NP,NM)
$\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t\ \underset{\sim}{W}^t\ \frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}$	XX4	(NPX,NPX)	(NP,NP)
$\left(\frac{\partial \underline{F}(\underline{a})}{\partial \underline{a}}\right)^t\ \underset{\sim}{W}^t\ \underset{\sim}{C}'\ \underset{\sim}{\Phi}$	XX2	(NPX,NSX)	(NP,NS)

The *a priori* terms in eqn. (5-49) and (5-50), $\underline{M}_o^{-1}$ and $\underline{M}_o^{-1}\ \underline{\delta X}_a$, are defined in subroutine APRIR.

After eqns. (5-49) and (5-50) have been accumulated for each good measurement, the inverse covariance matrix, $\underline{P}^{-1}$, is inverted by subroutine MATINV, and post multiplied by the error matrix, $\underline{B}$, as related by eqn. (5-53).

The partitions, $\underline{\delta X}_o$ and $\underline{\delta a}$, of the perturbation $\underline{\delta V}$ are then defined by eqn. (5-51). The current state vectors $\underline{X}$ and $\underline{a}$ are then updated by their respective perturbations $\underline{\delta X}_o$ and $\underline{\delta a}$ as given by eqns. (5-54) and (5-55).

Convergence Testing

The convergence of the state vectors, $\underline{X}$ and $\underline{a}$, is tested at the end of each iteration according to a specified option and value as specified by ITEMS 5 and 6 of the ESTIMATOR data packet.

The position or velocity state convergence test is

$$\left|\underline{\delta X}_o\right|_m \leq \varepsilon'$$

m is the respective component (1 to 6) of $\underline{\delta X}_o$

ε' specified convergence value

For other estimated states the convergence test is a fractional change of the estimated state.

$$\left|\frac{\underline{\delta X}_o}{\underline{X}}\right|_m \leq \varepsilon'$$

$$\left|\frac{\underline{\delta a}}{\underline{a}}\right|_m \leq \varepsilon'$$

m represents the respective component of $\underline{X}$ or $\underline{a}$

ε' is a fractional epsilon change

The convergence test is implemented in subroutine CONVRG.

Output

The remainder of MAXLIK is exclusively output, that is, in generating SECTION 3 to 8 of the LOCATER REPORT. Each SECTION is described in section 6.7.

SECTION #	
3	Convergence performance of estimator. Variables output are: $\underline{X}$ metric state vector $\underline{\delta X_0}$ perturbation to $\underline{X}$ $\underline{a}$ bias/multipath vector $\underline{\delta a}$ perturbation to $\underline{a}$
4	Dump of radar measurements and weights, $\underline{R}_{\ell i}$, $\underline{W}_{\ell i}$, in the track file.
5	Covariance matrix, $\underline{P}$, and correlation coefficients.
6	Launch point velocity vector of $\underline{X}$ and weighted squared residual statistics, Q.
7	Track residuals, $\underline{\Delta R}$, and measurements, $\underline{R}_{\ell i}$, for each measurement component.
8	Estimation statistics for drag, spin and wind states of $\underline{X}$, and all states of $\underline{a}$.

5.3.2 Perturbation Transformation Matrix from ESF to RAE

This section evaluates the Jacobian matrix, $\frac{\partial \underline{f}(\underline{S}_{\ell i})}{\partial \underline{S}_{\ell i}}$, in the transformation from a state vector perturbation, $\underline{\delta S}_{\ell i}$, in the ESF coordinate system to a perturbation, $\underline{\delta R}_{\ell i}$, in the RAE coordinate system at the time t_i, relative to radar ℓ. The perturbation, $\underline{\delta S}_{\ell i}$, has components δx, δy, δz, $\delta \dot{x}$, $\delta \dot{y}$, and $\delta \dot{z}$, while the perturbation $\underline{\delta R}_{\ell i}$ has components δr, δa, δe, and $\delta \dot{r}$. The perturbation components δa and δe are not considered as azimuth and elevation time rate of change, $\dot{a}$ and $\dot{e}$, are not directly measured by the radar.

The nonlinear transformation, $\underline{f}$, between a state vector, $\underline{S}_{\ell i}$, in ESF to a state vector $\underline{R}_{\ell i}$ in RAE is described by eqn. (5-3) in section 5.2.3.

The Jacobian of $\underline{f}$, $\frac{\partial \underline{f}(\underline{S}_{\ell i})}{\partial \underline{S}_{\ell i}}$, is a matrix with maximum dimensions of 4 rows by 6 columns and is composed of the following elements:

$$\frac{\partial r}{\partial x} = \cos(e)\sin(a) \qquad (5\text{-}56)$$

$$\frac{\partial r}{\partial y} = \cos(e)\cos(a)$$

$$\frac{\partial r}{\partial z} = \sin(e)$$

$$\frac{\partial r}{\partial \dot{x}} = \frac{\partial r}{\partial \dot{y}} = \frac{\partial r}{\partial \dot{z}} = 0$$

$$\frac{\partial a}{\partial x} = \cos(a)/(r\cos(e))$$

$$\frac{\partial a}{\partial y} = -\sin(a)/(r\cos(e))$$

$$\frac{\partial a}{\partial z} = \frac{\partial a}{\partial \dot{x}} = \frac{\partial a}{\partial \dot{y}} = \frac{\partial a}{\partial \dot{z}} = 0$$

$$\frac{\partial e}{\partial x} = -\sin(a)\sin(e)/r$$

$$\frac{\partial e}{\partial y} = -\cos(a)\sin(e)/r$$

$$\frac{\partial e}{\partial z} = \cos(e)/r$$

$$\frac{\partial e}{\partial \dot{x}} = \frac{\partial e}{\partial \dot{y}} = \frac{\partial e}{\partial \dot{z}} = 0$$

$$\frac{\partial \dot{r}}{\partial x} = \cos(e)\cos(a)\dot{a} - \sin(a)\sin(e)\dot{e}$$

$$\frac{\partial \dot{r}}{\partial y} = -\cos(e)\sin(a)\dot{a} - \sin(e)\cos(a)\dot{e}$$

$$\frac{\partial \dot{r}}{\partial z} = \cos(e)\dot{e}$$

$$\frac{\partial \dot{r}}{\partial \dot{x}} = \cos(e)\sin(a)$$

$$\frac{\partial \dot{r}}{\partial \dot{y}} = \cos(e)\cos(a)$$

$$\frac{\partial \dot{r}}{\partial \dot{z}} = \sin(e)$$

Implementation

The Jacobian is internally computed as array C by subroutine MLEC and must be computed for every measurement time in the track file. Subroutine MLEC computes only those rows that are necessary in the C matrix, that is, those rows that are functions of the measurement space for radar ℓ.

For example, if the radar only measures azimuth and elevation, the C matrix would be:

$$C = \begin{bmatrix} \frac{\partial a}{\partial x} & \frac{\partial a}{\partial y} & \frac{\partial a}{\partial z} & \frac{\partial a}{\partial \dot{x}} & \frac{\partial a}{\partial \dot{y}} & \frac{\partial a}{\partial \dot{z}} \\ \frac{\partial e}{\partial x} & \frac{\partial e}{\partial y} & \frac{\partial e}{\partial z} & \frac{\partial e}{\partial \dot{x}} & \frac{\partial e}{\partial \dot{y}} & \frac{\partial e}{\partial \dot{z}} \end{bmatrix}$$

5.5.3 State Transition Matrix

For our physical system it is necessary to introduce a relationship between state vector perturbations at the times of the measurements to state vector perturbations at an arbitrarily specified reference time. This relationship is the state transition matrix, $\underline{\Phi}$, which is defined as:

$$\underline{\Phi}(t_i,t_o) = \frac{\partial \underline{X}(t_i)}{\partial \underline{X}(t_o)} \qquad (5\text{-}5)$$

where

t_i is the time of the measurement

t_0 is the reference time

$\underline{X}$ is the metric state vector containing position, velocity, drag, spin and wind states (introduced in section 5.3)

A perturbation $\delta\underline{X}(t_i)$ in the system is then related to a perturbation $\delta\underline{X}(t_0)$ by

$$\delta\underline{X}(t_i) = \underline{\Phi}(t_i,t_0)\delta\underline{X}(t_0) \tag{5-58}$$

A technique used to calculate $\underline{\Phi}(t_i,t_0)$ is:

1. Start with the current state vector $\underline{X}(t_0)$ at the reference time, t_0. For all NS states that are to be estimated, duplicate $X(t_0)$ NS times yielding an augmented state vector matrix $\underline{X}_{NS}(t_0)$ with NS columns. The L^{th} component of the M^{th} state vector in $\underline{X}_{NS}(t_0)$ is $X_{LM}(t_0)$ where M varies from 1 to NS.

2. For state vector #M in $X_{NS}(t_0)$ we want to estimate the L^{th} state component. Add a small perturbation, dX_L, to the L^{th} component of the M^{th} state vector in $X_{NS}(t_0)$ calling the result $X'_{LM}(t_0)$ where the prime indicates perturbed states.

$$X'_{LM}(t_0) = dX_L + X_{LM}(t_0) \tag{5-59}$$

3. Integrate the current state vector $\underline{X}(t_0)$ and each state vector M in $\underline{X}'_{NS}(t_0)$ to the time of the measurement, t_i, giving $\underline{X}(t_i)$ and $\underline{X}'_{NS}(t_i)$.

4. The L,M element of $\underline{\Phi}$, $\Phi_{LM}(t_i, t_0)$ is then

$$\Phi_{LM}(t_i,t_0) = \frac{X'_{LM}(t_i) - X_L(t_i)}{X'_{LM}(t_0) - X_L(t_0)} \tag{5-60}$$

Note: The matrix $\underline{\Phi}$ must be computed for each measurement in the track file, except for multistatic simultaneous measurements.

The $\underline{\Phi}$ matrix is internally called variable PHI and is computed by subroutine PHIMAT.

5.5.4 Measurement Weight Matrix

The set of radar measurements, $\underline{R}_{\ell i}$ is a vector consisting of 4 observations (range, azimuth, elevation and doppler) for the ℓ^{th} radar at the time t_i. The measurement weights, $\underline{W}_{\ell i}$, is the inverse of the measurement covariance matrix $\underline{W}_{\ell i}^{-1}$ associated with the measurements, $\underline{R}_{\ell i}$

The weight matrix, $\underline{W}_{\ell i}$, is a diagonal matrix with each term being the inverse variance of the respective observation, and is computed by subroutine WEIGHT.

$$\underset{\sim}{W}_{\ell i} = \begin{bmatrix} 1/\sigma_r^2 & 0 & 0 & 0 \\ 0 & 1/\sigma_a^2 & 0 & 0 \\ 0 & 0 & 1/\sigma_e^2 & 0 \\ 0 & 0 & 0 & 1/\sigma_{\dot{r}}^2 \end{bmatrix} \tag{5-61}$$

where

$$\begin{aligned} \sigma_r^2 &= \sigma_{rJ}^2 + \sigma_{rT}^2/SNR \\ \sigma_a^2 &= \sigma_{aJ}^2 + \sigma_{aT}^2/SNR \\ \sigma_e^2 &= \sigma_{eJ}^2 + \sigma_{eT}^2/SNR \\ \sigma_{\dot{r}}^2 &= \sigma_{\dot{r}J}^2 + \sigma_{\dot{r}T}^2/SNR \end{aligned} \tag{5-62}$$

σ_{rJ}	is the sigma of range-independent range measurement noise (m)
σ_{aJ}	is the sigma of range-independent azimuth noise (rad)
σ_{eJ}	is the sigma of range-independent elevation noise (rad)
$\sigma_{\dot{r}J}$	is the sigma of range-independent doppler noise (m/s)

The range-independent measurement noise sigmas are specified by ITEMS 19-22 of the RADAR data packet for radar ℓ.

σ_{rT}	is the sigma of range-dependent range measurement noise (m)
σ_{aT}	is the sigma of range-dependent azimuth noise (rad)
σ_{eT}	is the sigma of range-dependent elevation noise (rad)
$\sigma_{\dot{r}T}$	is the sigma of range-dependent doppler noise (m/s)

The range-dependent measurement noise sigmas are specified by ITEMS 15-18 of the RADAR data packet for radar ℓ.

The signal noise ratio (SNR) is based on range to the fourth dependence.

$$SNR = 10.0^{\left(\frac{SNR_{dB}}{10.0}\right)} \tag{5-63}$$

$$SNR_{dB} = 40.0 \log_{10}(r_o/r) + RCS \tag{5-64}$$

r_o	radar reference range (m). Range at which a 0 dBsm projectile gives a return of 0 dB.
r	range to projectile (m).
RCS	radar cross section of projectile in dBsm. This is specified by a constant value (ITEM 13 of the appropriate WEAPON data packet) or a table (RCSTABLE data packet).

6.0 PROGRAM USER'S GUIDE

6.1 General Information

LOCATER is designed as an engineering tool for radar systems analysis and design, primarily to be used in a batch type environment with input as data packets which may be in any order.

The input to the LOCATER program is read by a special free format reading routine which allows alphabetic fields mixed with the numeric data values. These numeric values are henceforth referred to as input data ITEMS. This I/O technique disposes of remembering variable names for NAMELIST type I/O and field width definitions for FORMATTED I/O, but forces the user to remember the order of the input ITEMS. Most data packets have a set of default ITEMS which reduces the amount of setup time for the average run. To change any default ITEM the whole packet must be respecified. Each data packet remains active from case to case allowing easily implemented parameter studies.

For each case being run LOCATER will scan the data packets looking for inconsistencies and dump the input storage arrays and write the appropriate error message if such an error condition is raised. The arrays can also be dumped under program control (section 6.2.9.1 OUTPUT 01 data packet).

The description of the LOCATER input deck follows in section 6.2.

6.2 Locater Input

The input deck to LOCATER has the following structure:

```
TITLE card for case 1
APRIORI packet      (section 6.2.1)
EDITOR packet       (section 6.2.2)
ESTIMATOR packet    (section 6.2.3)
MEASURE packet      (section 6.2.4)
METRO packet        (section 6.2.5)
MISSION packet      (section 6.2.6)
MULTIPATH packet    (section 6.2.7)
ORIGIN packet       (section 6.2.8)
OUTPUT packet       (section 6.2.9)
RADAR packet        (section 6.2.10)
RANDOM packet       (section 6.2.11)
RCSTABLE packet     (section 6.2.12)
TOPOGRAPH packet    (section 6.2.13)
TRACK packet        (section 6.2.14)
WEAPON packet       (section 6.2.15)
VECTOR packet       (section 6.2.16)
END card
TITLE card for case 2
      .
      .
      .
END card
```

TITLE card for case N

•

•

•

END card

The TITLE card is 80 alphanumeric characters used to describe the purpose of the present run, and appears on the top of every output page of the LOCATER REPORT. The date and time are unnecessary in the TITLE as they are printed out at the bottom of each output page.

The END card ("END " in columns 1-4) signifies the end of input for the particular case being run.

All cards between the TITLE and END cards are grouped into data packets each of which has the following structure:

CARD #1	PACKET NAME CARD	
col 1-4	Packet name	first 4 letters of packet name. ex.ESTI, RADA, etc.
col 11-12	Packet number	01 to 05 are allowed for APRIORI, METRO, ORIGIN, RADAR, RCSTABLE, WEAPON, and VECTOR data packets. 01 to 09 is allowed for OUTPUT packet. The following packets must have 01 for the number: EDITOR, ESTIMATOR, MEASURE, MISSION, MULTIPATH, RANDOM, TOPOGRAPH, TRACK.
col 13-72	Alphanumeric description of data packet.	

The remaining cards in the packet (columns 1-72) contain the input data ITEMS in a field free format. The input routine will first scan for a $ in columns 1-72 skipping cards if necessary. All numeric fields (I or F type format) will be stripped off the cards ignoring all nonnumeric characters and transferred to labelled common storage arrays. Data transfer will stop when another $ is encountered. Numeric fields can not span cards and minus signs (if present) must precede the numeric value with no intervening blanks. The next input card after the card with the last $ must be another PACKET NAME card or END card, unless the data packet specifies that a numeric table is next input. There is no limit on the number of cards in a free format data packet.

Some data packets, i.e., METRO, MULTIPATH, and RCSTABLE have tables as input. These tables must be presorted in increasing order of the independent variable and followed by a blank card. The table length limits are specified in the appropriate section.

The following sections contain a detailed description of the input data ITEMS, default values and examples for each type of data packet.

6.2.1 APRIORI Data Packet

The APRIORI data packet is optional and allows the user to add any *a priori* knowledge of the launch point state vector uncertainties to the maximum likely equation.

CARD #1	PACKET NAME CARD
col 1-4	"APRI"
col 11-12	Packet Number 01-05
col 13-72	Alphanumeric description

The packet number must be the same as ITEM 7 of the ESTIMATOR data packet (section 6.2.3).

The following are required input ITEMS for the APRIORI data packet:

ITEM #	VALUE and DESCRIPTION
1,2,3	Positional (ESF) state vector sigmas (m) NOTE. A zero for any ITEM means no apriori values will be added to the maximum likely equation.
4,5,6	Velocity (ESF) state vector sigmas (m/s)
7	Drag state sigma (m**2/kg)
8	Spin state *a priori* sigma (m/s**2)
9,10	East, North wind state sigmas (m/s)

Example of APRIORI data packet:

```
APRI      01
$NO APRIORI SIGMAS ON POSITIONS 0 0 0
METERS, OR VELOCITIES 0 0 0 METERS/SEC.
THE DRAG STATE IS KNOWN TO FIVE PERCENT .000025
METERS SQUARED/ KILOGRAM
NO SPIN STATE SIGMA 0 METERS/SECOND
NO WIND STATE SIGMAS 0 0 METERS/SECOND $
```

6.2.2 EDITOR Data Packet

The EDITOR data packet optionally controls what measurements in the track file are to be included in the maximum likely equation by:

1. Data prediting. (pre-fit)
2. Data rejection due to low SNR. (pre-fit)
3. Data rejection based on large weighted squared residuals. (post-fit)

CARD #1 PACKET NAME CARD

col 1-4	"EDIT"
col 11-12	01
col 13-72	Alphanumeric description (optional)

The required input ITEMS for the EDITOR packet are:

ITEM #	VALUE and DESCRIPTION
1	Pre-edit flag 0 No data pre-edit (default) 1 Pre-edit data using sliding polynomial and reject 4 sigma values away from mean in each measurement component. (Unimplemented)
2	Low signal noise ratio flag 0 No data rejection 1 (Default) Reject data point if measured or computed SNR is lower than threshold. NOTE. The threshold value (db) is specified by ITEM 24 in the RADAR data packet.
3	Weighted residuals reject flag 0 No data rejection 1 (Default) Compute the average weighted square residual and std. dev., sigma, for each measurement component. After initial convergence reject a measurement if a value falls outside the range, average ± sigma*sigv.
4	Value of sigv associated with weighted residuals test. (Default value is 4.0).

Example of EDITOR data packet:

```
EDIT      01  REAL DATA EDIT CONTROLS FOR TEST 73
$ DO NOT PRE-EDIT DATA 0, DROP DATA IF THE MEASURED
SIGNAL NOISE RATIO IS LESS THAN THE THRESHOLD, OPTION 1.
PERFORM THE WEIGHTED SQUARED RESIDUALS TEST 1,
WITH A SIGMA OF 2.5$.
```

The above example for brevity could simply have been:

```
EDIT      01
$ 0 0 1 2.5$
```

6.2.3 ESTIMATOR Data Packet

The ESTIMATOR data packet allows the user to:

1. Estimate various states among them positions, velocities, drag, spin, ground winds, radar biases and multipath parameters.

2. Choose method of state vector initialization of estimator.
3. Specify convergence criterion of state vector.
4. Add apriori state vector and sigmas to estimator (VECTOR and APRIORI data packets).

CARD #1 PACKET NAME CARD

col 1-4	"ESTI"
col 11-12	01
col 13-72	Alphanumeric description (optional)

The required input items for the ESTIMATOR data packet are:

ITEM #	VALUE and DESCRIPTION
1	Filter number. For maximum likely estimator (MLE) use 1. Default (1)
2	RADAR packet number used to compute measurement weights. If 0 the same radar used in computing the measurements will also be used in computing weights. Default (0)
3	State vector initialization switch. Default (-2) -1 The true state vector used in calculating the measurements will be used to initialize the MLE. This option should be chosen for a complete simulation as the run time is less. -2 The nominal state vector will be used to initialize the MLE. This option can be chosen for simulation on external trajectory or real data analysis. -3 Derive initial state vector from measurements. At least one of the tracking radars must take range, azimuth and elevation. If the weapon number is 0 on the TRACK packet, this option is chosen regardless of what is specified for ITEM 3. 1-5 The state vector specified in the VECTOR packet 1-5 will be used.
4	Maximum number of iterations allowed. Default (20)
5	Convergence option. Default (1) 1. Positions converge to epsilon meters. 2. Velocities converge to epsilon (m/s)

3. Drag converges to epsilon fraction change
4. Spin converges to epsilon fraction change
5. Winds converge to epsilon fraction change
6. Biases converge to epsilon fraction change
7. Multipath parameters converge to epsilon fraction change

6 The convergence value epsilon according to ITEM 5

7 APRIORI packet number of state vector sigmas from 1 to 5 (section 6.2.1). If no variances are to be included in the MLE, ITEM 7 is a 0.

ITEMS 8-24 of the ESTIMATOR data packet are state estimation switches. A 0 means do not estimate the state. A 1 means estimate the state. The default ITEMS are:

(8-15) = 1
(16-24) = 0

8 X (East) position state estimation switch.
9 Y (North) position state estimation switch.
10 Z (Up) position state estimation switch.
11 X velocity state estimation switch.
12 Y velocity state estimation switch.
13 Z velocity state estimation switch.
14 drag (KD) state estimation switch.
15 spin (KS) state estimation switch.
16 East wind (WE) state estimation switch.
17 North wind (WN) state estimation switch.. Multiple layered winds cannot be estimated.
18 Range bias estimation switch.
19 Azimuth bias estimation switch.
20 Elevation bias estimation switch.
21 Doppler bias estimation switch.
22 Multipath A parameter estimation switch.*
23 Multipath B parameter estimation switch.*
24 Multipath C parameter estimation switch.*

*refer to section 5.5.1 for definitions of multipath parameters.

Example of ESTIMATOR data packet:

```
ESTI      01
$ USE FILTER 1 (MLE), USE SAME RADAR TO CALCULATE
WEIGHTS 0, INITIALIZE THE ESTIMATOR WITH THE NOMINAL
STATE VECTOR -2, MAX NO. ITERATIONS 10, CONVERGENCE
OPTION 1, VALUE OF .1 METERS,
NO APRIORI DATA 0,
ESTIMATE POSITIONS 1 1 1
ESTIMATE VELOCITIES 1 1 1
DO NOT ESTIMATE DRAG 0
ESTIMATE SPIN 1
DO NOT ESTIMATE WINDS 0 0, BIASES 0 0 0 0
OR MULTIPATH PARAMETERS 0 0 0 $
```

6.2.4 MEASURE Data Packet

The MEASURE data packet controls the addition of radar noise to a trajectory to simulate radar measurements. The available types of noise are:

1. Random or constant biases in range, azimuth, elevation or doppler
2. Thermal errors (range dependent
3. Jitter errors (range independent)
4. Tropospheric refraction errors
5. Multipath errors

Refer to section 5.4 for the mathematical formulation of noise errors.

CARD #1	PACKET NAME CARD
col 1-4	"MEAS"
col 11-12	01
col 13-72	Alphanumeric description

The required input ITEMS for the MEASURE packet are:

ITEM #	VALUE and DESCRIPTION
1	Bias error flag 0 No biases 1 Constant biases for each run (default) 2 Constant biases for all runs The biases are defined as ITEMS, 11-14 of the RADAR packet.
2	Thermal noise error flag 0 No noise 1 Add thermal noise (default) Thermal errors are defined as ITEMS 15-18 of the RADAR packet.
3	Jitter noise error flag 0 No noise 1 Add jitter errors (default) Jitter errors are defined as ITEMS 19-22 of the RADAR packet.
4	Tropospheric refraction error flag 0 No noise (default) 1 Add tropospheric refraction errors
5	Multipath error flag 0 No multipath errors (default) 1 Add multipath Refer to section 5.4.4 for a description of multipath errors.

Example of MEASURE data packet:

```
MEAS      01  NOISE FLAGS
$ FOR THIS SIMULATION DO NOT USE BIASES (0).
USE THERMAL AND JITTER ERRORS 1 1, BUT NO
TROPOSPHERIC REFRACTION 0 OR MULTIPATH 0 $
```

6.2.5 METEOROLOGICAL Data Packet

The METRO data packet allows the user to define a meteorological profile. There are three types of METRO packets which are:

1. Default atmosphere
2. Specified ground conditions
3. Layered "MET" profile

Refer to section 5.3.2 for mathematical description of the different atmospheres.

CARD #1	PACKET NAME CARD
col 1-4	"METR"
col 11-12	01 to 05 - must be identical to ITEM #12 of the appropriate WEAPON packet
col 13-72	Alphanumeric description

The required input ITEMS for the three types of the METRO data packet are:

TYPE 1 - DEFAULT

ITEM #	VALUE and DESCRIPTION
1	1 Signifies that the default atmosphere is to be used

Specifying a METRO packet to have the default atmosphere is equivalent to having no METRO packet in the input deck.

TYPE 2 - GROUND CONDITIONS

ITEM #	VALUE and DESCRIPTION
1	2 Signifying specified ground conditions
2	Air density at ground level (kg/m**3)
3	Wind speed magnitude (meters/sec)
4	Wind direction (0 to 360 degrees) measured where the wind is coming from clockwise from north
5	Ground temperature (degrees Kelvin)

TYPE 3 - LAYERED "MET" PROFILE

ITEM #	VALUE and DESCRIPTION
1	Signifying layered meteorological conditions

The series of cards following the METRO free format data packet (TYPE 3 only) are:

CARD #1A   VARIABLE FORMAT CARD

This card contains the FORTRAN variable format to read 1 layer (6 items in each layer) of the meteorological table. The order of the input table is specified under the description in CARD #2A.

See example of TYPE 3 METRO data packet below.

CARD(S) #2A   LAYERED METEOROLOGICAL DATA

The layered meteorological data consists of 6 items in each layer according to the variable format specified by CARD # 1A. They are:

1. Height (meters) of density and temperature
2. Temperature (degrees Kelvin)
3. Density (kg/m**3)
4. Height (meters) of winds.
5. East component of wind (m/s)
   (wind blowing torwards east)
6. North component of wind (m/s)
   (wind blowing torwards north)

CARD(S) #3A   BLANK CARD(S)

This blank card signifies the end of the table.

A maximum of 39 layers can be specified. If this value is exceeded, program changes are necessary. See Section 8.5.3. The format card must specify the format of the 6 items. The number of blank cards should be the same as the number of cards for each layer.

Examples of METRO data packets:

TYPE 1

```
METR      02        DEFAULT
$ RESTORE DEFAULT ATMOSPHERE 1 $
```

TYPE 2

```
METR      01        GROUND CONDITIONS
$ USE METRO TYPE 2 (SPECIFIED GROUND MET CONDITIONS)
AIR DENSITY IS 1.17 KG/MMM, WIND SPEED IS 10 M/S,
WIND IS COMING FROM THE EAST 90 DEGREES, GROUND
TEMPERATURE IS 289 DEGREES KELVIN.  $
```

TYPE 3

```
METR      01  MET CONDITIONS FOR ROUNDS 5124 TO 5169
```

```
THE FOLLOWING TABLE IS A LAYERED METEOROLOGICAL MESSAGE.
THE COLUMNS ARE: 1. HEIGHT(METERS) OF TEMP AND DENSITY
2. TEMPERATURE (KELVIN), 3. DENSITY (KG/M**3), 4. HEIGHT
(METERS) OF WINDS, 5. EAST WIND COMPONENT (M/S), 6. NORTH
WIND COMPONENT.
$USE TYPE 3 METRO PACKET (LAYERED), THE FORMAT IS $
(F6.1,5F10.0)
   0.0    300.73   1.16797       0.0   -3.7495    1.1118
 304.8    299.83   1.13433     304.8   -2.5638   -1.3424
 609.6    297.39   1.10590     609.6   -1.3125   -2.5714
 914.4    293.96   1.08120     914.4   -0.1536   -3.0598
1219.2    292.43   1.04967    1219.2    0.1701   -2.9015
1524.0    290.49   1.02037    1524.0   -0.0444   -2.5546
1828.8    288.63   0.99163    1828.8   -0.3735   -2.4936
2133.6    286.99   0.96250    2133.6   -0.8256   -2.9002
2438.4    285.23   0.93493    2438.4   -1.0068   -3.4127
2743.2    283.73   0.90670    2743.2   -1.0664   -3.5984
3048.0    282.16   0.87890    3048.0   -1.2161   -3.5510
3352.8    280.59   0.85177    3352.8   -1.5483   -3.2232
3657.6    279.19   0.82483    3657.6   -2.0625   -3.1227
3962.4    277.43   0.79957    3962.4   -2.2255   -3.0280
4267.2    276.06   0.78370    4267.2   -2.2891   -3.4152
6096.0    276.06   0.78370    6096.0   -2.2891   -3.4152
THIS IS A BLANK CARD
```

6.2.6 MISSION Data Packet

The MISSION data packet (mandatory) specifies:

1. The number of rounds to analyze or number of Monte Carlo runs to simulate.

2. The program run mode
   a. Simulation on an internally generated trajectory.
   b. Simulation on an externally generated trajectory.
   c. Real data reduction.

3. That the external trajectory for simulation or real measurements is on cards or tape.

CARD # 1	PACKET NAME CARD
col 1-4	"MISS"
col 11-12	01
col 13-72	Alphanumeric description (optional)

The required input ITEMS for the MISSION packet are:

ITEM #	VALUE and DESCRIPTION
1	Number of Monte Carlo runs if simulation or number of rounds if real data (no default)
2	Program run mode (no default) 1 Complete simulation 2 External trajectory for simulation with data on tape. * -2 External trajectory for simulation with data on cards. * 3 Real data reduction with data on tape. $

-3 Real data reduction with data on cards. $

*refer to section 6.2.8 for specifying the ESF origin of the external trajectory.
Refer to section 6.4 for the LOCATER input deck structure when using an external trajectory is input.

$Refer to section 6.3 for the LOCATER input deck structure when the real data is to be analyzed.

Example of MISSION data packet:

```
MISS      01   CONTROLS FOR HWLS ANALYSIS
$ ANALYZE 14 ROUNDS OF DATA, PROGRAM RUN
MODE IS 3, DATA ON MAG TAPE 3 $
```

The MISSION data packet is mandatory to do a simulation or real data reduction.

6.2.7 MULTIPATH Data Packet

The MULTIPATH data packet allows the user to modify generated elevation measurements by two multipath models:

1. Multipath error is a damped sinusoid about the true elevation.
2. A table of multipath errored elevation vs. true elevation for a given geometry or type of terrain.

ITEM 5 of the MEASURE data packet must be a 1 for addition of multipath errors in measurement generation.

MODEL 1

MULTIPATH model assumes an unerrored elevation E and computes the multipath error ΔE

$$\Delta E = -A \exp(DE) \cos \frac{2\pi}{P}(E - \phi)$$

A is amplitude of error (radians)
D coefficient in damping term (radians)
P period (radians)
ϕ phase (radians)

CARD #1	PACKET NAME CARD
col 1-4	MULT
col 11-12	01
col 13-72	Alphanumeric description

The required input parameters for a MULTIPATH data packet using model 1 are:

ITEM #	VALUE and DESCRIPTION
1	1 Signifies multipath model #1
2	The amplitude, A (radians) of the multipath error
3	The damping term, D (radians)
4	The period, P (radians)
5.	The phase, ∅ (radians)

Example of MULTIPATH model 1 data packet:

```
MULT      01
$ USE MODEL # 1
AMPLITUDE IS .006 RADIANS
DAMPING COEFFICIENT IS  .020 RADIANS
PERIOD IS .005 RADIANS .
PHASE IS .261 RADIANS$
```

MODEL 2

Multipath model 2 expects an input table of errored elevation vs. unerrored elevation.

CARD #1 PACKET NAME CARD

col 1-4	'MULT'
col 11-12	01
col 13-72	Alphanumeric description

The required input ITEMS for model 2 of the MULTIPATH packet are:

ITEM #	VALUE and DESCRIPTION
1	2 Signifies model 2

The series of cards following the MULTIPATH free format data packet (MODEL 2 only) are:

CARD # 1A VARIABLE FORMAT CARD

This card contains the FORTRAN variable format to read a pair of unerrored and errored elevation measurements.

CARD(S) # 2A ERRORED ELEVATION MULTIPATH TABLE

Each CARD #2A will contain a pair of unerrored elevation and multipath errored measurements according to the variable format CARD # 1A.

The maximum number of table entries is 99.

CARD # 3A BLANK CARD

This card signifies end of input for the multipath table.

Example of MULTIPATH model 2 data packet:

```
MULT      01 MULTIPATH OVER SAND
$ USE MODEL #2 $
(F5.3,1X,F5.3)
0.000 0.010
0.002 0.006
0.004 0.000
0.005 -.004
0.010 0.005
0.020 0,017
0.030 0.021
0.040 0.057
0.050 0.055
0.060 0.061
(blank card)
```

6.2.8 ORIGIN Data Packet

The ORIGIN data packet specifies the origin of the external trajectory when the program run mode is simulation on an externally generated trajectory, i.e., ITEM 2 of the MISSION data packet is ± 2.

CARD # 1	PACKET NAME CARD
col 1-4	"ORIG"
col 11-12	01-05 This number must be identical to the RADAR packet number which is specified by ITEM #2 on the TRACK data packet.
col 13-72	Alphanumeric description

The required input ITEMS for the ORIGIN packet are:

ITEM #	VALUE and DESCRIPTION
1	East UTM location of origin (M)
2	North UTM location of origin (M)
3	Altitude (M) of origin above sea level.

Example of ORIGIN data packet:

```
ORIG     02    2KM SOUTH FEBA
98.5 DEG WEST LONGITUDE, 34.5 DEG. NORTH LATITUDE
$ DATA BASE ORIGIN IS LOCATED AT
54600 METERS EAST
3817000 METERS NORTH
ALTITUDE OF 335 METERS$
```

For this example the RADAR number (ITEM 2 of the TRACK packet) would be a 2.

6.2.9 OUTPUT Data Packet

The OUTPUT data packet controls:

1. All printed output from LOCATER
2. Tape output
3. Plot output

LOCATER has at present 9 output SECTIONS, SECTION 1 to SECTION 9, which are controlled by OUTPUT 01 to OUTPUT 09 data packets, respectively. Section 6.5 contains examples of each output SECTION. A list of OUTPUT data packet defaults are given at the end of section 6.2.

NOTE: The word "SECTION" refers to the LOCATER REPORT (printout) while "section" refers to this document.

CARD # 1	PACKET NAME CARD
col 1-4	"OUTP"
col 11-12	The appropriate LOCATER OUTPUT data packet number 01-09
col 13-72	Alphanumeric description

The required input ITEMS for each OUTPUT section follows.

6.2.9.1 OUTPUT 01 - Input Card Listing

ITEM #	VALUE and DESCRIPTION
1	0 Do not print LOCATER input cards 1 Print LOCATER input cards. Default (1)
2	0 Do not dump common storage arrays. Default (0) 1 Dump storage arrays (3 pages). If an error detectable by LOCATER occurs, the arrays are dumped regardless of the option chosen.

6.2.9.2 OUTPUT 02 - Trajectory Coverage

SECTION 2 of the LOCATER REPORT will generate a trajectory coverage interval for a specified radar weapon system, and is controlled by the OUTPUT 02 data packet. Refer to section 6.5.2 for an example:

ITEM #	VALUE and DESCRIPTION
1	0 No output from SECTION 2 Default (0) 1 Generate SECTION 2 LOCATER output
2	RADAR packet number from 1 to 5
3	WEAPON packet number from 1 to 5
4	Time (sec) at start of coverage interval. A -999 will result in radar coverage from launch.

5	Time increment between samples (sec)
6	Time (sec) at stop of coverage interval. A -999 will result in radar coverage to weapon impact.
7	Trajectory printout format switch 0 no printout 1 Trajectory is in a ESF cartesian system (m-m-m). 2 Trajectory is in polar RAE coordinate system.
8	Trajectory tape output switch 0 No tape write 1 Trajectory is in a ESF cartesian coordinate system. 2 Trajectory is in a RAE polar coordinate system. Refer to section 8.6 for tape unit number.

6.2.9.3 OUTPUT 03 - MLE Iterations

SECTION 3 prints out the state vector and computed perturbation following each iteration of the filter and is controlled by the OUTPUT 03 data packet. Refer to Section 6.5.3 for sample output.

ITEM #	VALUE and DESCRIPTION
1	0 No output. Default (0) 1 Generate SECTION 3 of LOCATER REPORT
2	Generate SECTION 3 for a specified number of Monte Carlo runs. If 0, SECTION 3 will be produced for all runs.

6.2.9.4 OUTPUT 04 - Measurements File

SECTION 4 of the LOCATER REPORT will dump the measurements file to the printer, and is controlled by the OUTPUT 04 data packet.

ITEM #	VALUE and DESCRIPTION
1	0 No output 1 Generate SECTION 4 of LOCATER REPORT. Default (1)
2	Generate SECTION 4 of the LOCATER REPORT for a specified # of Monte Carlo runs or rounds. Default (1). If ITEM 2 is 0 SECTION 4 will be produced for all monte carlo runs.

6.2.9.5 OUTPUT 05 - Covariance Matrix

SECTION 5 of the LOCATER REPORT will print out the state covariance matrix and correlation coefficients, and is controlled by the OUTPUT 05 data packet.

ITEM #	VALUE and DESCRIPTION
1	0 No output 1 Generate SECTION 5 of the LOCATER REPORT Default (1).
2	Generate SECTION 5 for a specified # of Monte Carlo runs or rounds (default=1) If ITEM 2 is 0, SECTION 5 is output for all runs. Default (1)

6.2.9.6 OUTPUT 06 - Trajectory Parameters

SECTION 6 of the LOCATER REPORT prints out the following:

1. Launch velocity, azimuth of fire and quadrant elevation for the estimated trajectory.
2. Average weighted squared residual error for each measurement component.
3. Number of iterations to converge for each estimated trajectory.

ITEM #	VALUE and DESCRIPTION
1	0 No output 1 Generate SECTION 6 of the LOCATER REPORT. Default (1)
2	Extrapolation condition for each estimated trajectory. Default (-2) A negative option will use a pre-apogee value, a position option will use a post-apogee value. ±1 Specified altitude intersection ±2 Topographic intersection* 3 Extrapolate to specified tag time ±4 Extrapolate to specified elevation
3	The value according to option specified by ITEM 2. If ITEM 2 is ±1 Value is altitude (meters) ±2 Value is zero (default) 3 Value is a time (seconds) ±4 Value is elevation (radians)

*Refer to TOPOGRAPHIC data packet, section 6.2.13, for various terrain types.

If the default OUTPUT 06 and TOPOGRAPH 01 data packets are used, each estimated trajectory will be back extrapolated to the input height of the weapon (specified by ITEM 4 of the WEAPON data packet).

6.2.9.7 OUTPUT 07 - Track Residuals

SECTION 7 of the LOCATER TEST REPORT prints out differences between the measurements and the estimated trajectory for each measurement component. SECTION 7 is controlled by the OUTPUT 07 data packet.

ITEM #	VALUE and DESCRIPTION
1	0 No printed output 1 Generate SECTION 7 output. Default(1)
2	0 No tape output. Default(0) 1 Write residuals to tape for subsequent plotting.
3	Generate SECTION 07 output for a specified number of runs. If ITEM 3 is zero, SECTION 07 is produced for all runs. Default (1)

6.2.9.8 OUTPUT 08 - Estimation Statistics

SECTION 8 of the LOCATER TEST REPORT prints out state estimation parameters for each fit trajectory, and is controlled by the OUTPUT 08 data packet.

ITEM #	VALUE and DESCRIPTION
1	Generate SECTION 08. Print statistics on drag, spin, wind, biases and multipath parameter estimation. Default (1)

6.2.9.9 OUTPUT 09 - Weapon Location

SECTION 9 of the LOCATER REPORT:

1. Controls the extrapolation of each fit trajectory according to a specified option.
2. Computes position differences between nominal and estimated trajectory for each run.
3. Computes CEP (median miss distance).
4. Plots miss distances.

ITEM #	VALUE and DESCRIPTION
1	Option for extrapolation of estimated state vector. A negative option means the value will be at pre-apogee, a positive option means the value is at post-apogee. Default (-2)

	±1	Extrapolate state vector to a specified altitude.
	±2	Extrapolate state vector to a topographic surface. For options 2 or -2 when no topographic map is read in the option changes to 1 or -1 with the altitude being that of the weapon.
	3	Extrapolate to a specified tag time.
	±4	Extrapolate to time relative to last track time.
2		Value according to option specified by ITEM 1. If option in ITEM 1 is
	±1	Value is altitude (meters)
	±2	Value is zero
	3	Value is time (sec)
	±4	Value is time increment (sec)
3	0	No plot
	1	Plot miss distances. Default(1)

ITEMS 1-3 may be stacked up to 33 times. The OUTPUT 09 controls can be used to simulate a predictor type interceptor model or launch point location errors.

OUTPUT DATA PACKET DEFAULT SUMMARY

OUTPUT 01 INPUT CARDS/STORAGE ARRAYS

ITEM #	Default	
1	1	Print LOCATER input cards
2	0	Do not dump storage arrays

OUTPUT 02 TRAJECTORY COVERAGE

ITEM #	Default	
1	0	No coverage
	All other ITEMS are undefined	

OUTPUT 03 MAXIMUM LIKELY ESTIMATOR ITERATION SECTION

ITEM #	Default	
1	0	No SECTION 3 output
	All other ITEMS are undefined	

OUTPUT 04 MEASUREMENTS FILE

ITEM #	Default	
1	1	Generate SECTION 4 output
2	1	Print measurement for only 1 run

OUTPUT 05 STATE COVARIANCE MATRIX

ITEM #	Default
1	1 Generate SECTION 5 output
2	1 Print covariance for 1 run

OUTPUT 06 TRAJECTORY PARAMETERS

ITEM #	Default and Description
1	1 Generate SECTION 6 output
2	-2 Define trajectory parameters at launch.
3	0 Use topographic height at weapon location.

OUTPUT 07 TRACK RESIDUALS

ITEM #	Default and Description
1	1 Generate SECTION 7 output
2	1 Residuals written to tape
3	1 Residuals plotted for 1 run

OUTPUT 08 ESTIMATION STATISTICS

ITEM #	Default and Description
1	1 Generate SECTION 8 output

OUTPUT 09 WEAPON INTERCEPT

ITEM #	Default and Description
1	-2 Compute miss distances at
2	0 launch height of weapon and
3	1 plot miss distances

Each default OUTPUT data packet is defined in subroutine INITAL.

6.2.10 RADAR Data Packet

The RADAR data packet allows the user to specify up to five radar models. The parameters include:

1. Location coordinates
2. Environmental errors (biases, thermal, and jitter noise)
3. Sensitivity and detection threshold

CARD #	PACKET NAME CARD
col 1-4	"RADA"
col 11-12	01-05
col 13-17	Alphanumeric description (optional)

There are no default RADAR data packets.

The required input ITEMS for the RADAR packet are:

ITEM #	VALUE and DESCRIPTION
1	East UTM coordinate (meters)

2	North UTM coordinate (meters)
3	Height above sea level (meters)
4	Longitude (0 to 2 pi radians) measured east from the Greenwich meridian.
5	Latitude (radians) measured from -pi/2 south pole to pi/2 at north pole.

If multiple radar run the longitude and latitude of the radars, except for the base radar, should be zero.*

Items 6-10 are flags (0 or 1) specifying the radar measurement space. A zero signifies that the measurement was not taken.

6	Range measurement flag
7	Azimuth measurement flag
8	Elevation measurement flag
9	Doppler measurement flag
10	Signal noise ratio measurement flag. SNR is used to compute measurement weights in the filter. If SNR was not measured, a value based on range **4 will be used (refer to section 5.4) If program run is complete, simulation ITEM 10 should be 0.

ITEMS 11-14 are radar biases used in measurement generation. ITEM 1 of MEASURE data packet (SECTION 6.2.4) must be nonzero to include biases. If the measurement component is not part of the radar measurement space, use a zero.

11	Range bias (meters)
12	Azimuth bias (radians)
13	Elevation bias (radians)
14	Doppler bias (m/s)

ITEMS 15-18 are sigmas of range dependent (thermal) errors used in measurement noise generation. ITEM 2 of the MEASURE packet must be 1 for thermal errors to be included. If the radar does not take a particular measurement use zero for the appropriate thermal error.

15	Sigma of range-dependent range noise (meters)
16	Sigma of range-dependent azimuth noise (radians)
17	Sigma of range-dependent elevation noise (radians)
18	Sigma of range-dependent doppler noise (m/s)

ITEMS 19-22 are sigmas of range independent (jitter) noises used in measurement generation. ITEM 3 of the MEASURE packet must be 1 for jitter errors to be included. If the radar does not take a particular measurement use zero for the sigma.

19	Sigma of range independent range noise (meters)
20	Sigma of range independent azimuth noise (radians)
21	Sigma of range independent elevation noise (radians)
22	Sigma of range independent doppler noise (meters/sec)
23	Reference range (sensitivity parameter) Range (meters) at which a 1 square meter target (0 dbsm) returns a signal noise of 0 db.
24	Detection threshold (db) Radar measurements with computed or measured signal noise ratio less than the specified threshold will not be included in the estimator.
25	Frequency (Hz)
26	Elevation beamwidth (radians)

ITEMS 27 to 33 are considered removable biases and multipath model parameter errors from the measurements. If any parameter is to be estimated, the value specified will be used as an initial value. Refer to the description of the ESTIMATOR data packet (section 6.2.3) for estimation of bias and multipath errors. A bias is defined to be a measured minus estimated quantity.

27	Removable range bias (meters)
28	Removable azimuth bias (radians)
29	Removable elevation bias (radians)
30	Removable doppler bias (meters/second)

Refer to section 5.5.1 for a description of multipath parameters.

31	Multipath A parameter
32	Multipath B parameter
33	Multipath C parameter

* For multiple radar projectile tracking a base radar is chosen which is specified by ITEM 2

RADAR of the TRACK data packet. For each additional RADAR data packet specified in the TRACK packet, ITEMS 4,5,and 27-33 of that RADAR packet should be zero as these values will be defined later. This means that biases can only be estimated for the base radar (assuming that the other radars have negligible or known biases)

Example of the RADAR data packet:

```
RADA      02    TPM-5
THE TPM-5 IS AN RAE HORIZON SCANNING FENCE RADAR
LOCATED AT 98 DEG 45 MIN W., 34 DEG 30 MIN N.
$ LOCATION AT FT. SILL, OKLAHOMA 52300 METERS E,
1700 METERS N, HEIGHT 375 METERS.
LONGITUDE 4.559673 RADIANS MEASURED EAST OF
GREENWICH.  LATITUDE .602139 RADIANS
MEASUREMENT SPACE IS RANGE (1), AZIMUTH (1) AND
ELEVATION (1)  NO DOPPLER (0) OR SNR (0)
BIASES 1.0 M RANGE, .0005 RADIAN AZ,.0005  RADIAN ELEVATION
AND 0.0 M/S DOPPLER.
THERMAL ERRORS 3.0 M, .004 RADIANS, .004 RADIANS, 0.0 M/S
JITTER ERRORS .3M, .0005 RADIANS, .0005 RADIANS, 0.0 M/S
REFERENCE RANGE (RANGE AT WHICH A ZERO DBSM TARGET
RETURNS A SNR OF ZERO DB) IS 636000 METERS.
THE DETECTABILITY THRESHOLD IS 12 DB
FREQUENCY IS X BAND (9500000000 HZ)
ELEVATION BEAMWIDTH IS .017 RADIANS
NO REMOVABLE BIASES 0.0 0.0 0.0 0.0
NO REMOVABLE MULTIPATH 0.0 0.0 0.0
$
```

6.2.11 RANDOM Data Packet

The RANDOM packet initializes the LOCATER random number routine.

CARD # 1 PACKET NAME CARD

col 1-4	"RAND"
col 11-12	01
col 13-72	Alphanumeric description (optional)

The required input ITEMS for the RANDOM packet are:

ITEM #	VALUE and DESCRIPTION
1	Random number seed ≠ 0 (default is 1010101)

Example of RANDOM data packet:

```
RAND      01    SEED INITIALIZATION
$ USE 3011 FOR RANDOM NUMBER SEED $
```

6.2.12 RCSTABLE Data Packet

The RCSTABLE data packet allows the user to use a RCS vs aspect angle table to model signature fluctuations. To use a RCS vs aspect table, ITEM 13 of the WEAPON packet must be a 1.

CARD # 1	PACKET NAME CARD
col 1-4	"RCST"
col 11-12	01-05 ITEM 14 of the WEAPON packet must be the same number.
col 13-72	Alphanumeric description

CARD #2 FORMAT CARD

The format to read in each pair of aspect angle and RCS values ,i.e., two format items.

CARD(S) #3 TABLE CARDS

The table of Aspect Angle (degrees) and RCS values (dbsm) according to the format card. There is a maximum of 99 allowable entries.

CARD(S) #4

Blank card signifying end of table

Example of RCSTABLE data packet:

```
RCST      03     STATIC C BAND TABLE
(F3.0, 1X, F3.0)
000 010
005 008
010 003
011 -20
012 -16
013 005
020  12
050 -12
090 -06
blank card
```

This would result in the table:

Aspect Theta(deg)	RCS(dbsm)
0.0	10.0
5.0	8.0
10.0	3.0
11.0	-20.0
12.0	-16.0
13.0	5.0
20.0	-12.0
50.0	-12.0
90.0	-6.0

6.2.13 TOPOGRAPH Data Packet

The TOPOGRAPH data packet allows 3 types of terrain:

1. Use WEAPON altitude for constant map height.
2. Use constant specified altitude.
3. Use digital topographic rectangular map.

CARD # 1	PACKET NAME CARD
col 1-4	"TOPO"
col 11-12	01
col 13-72	Alphanumeric Description

The required input ITEMS for the TOPOGRAPHIC data packet are as follows:

TERRAIN type 1 - constant weapon altitude (default)

ITEM #	VALUE and DESCRIPTION
1	0 signifying terrain type 1. Default (0).
2	Uncertainty (meters) in measurement of ground height above sea level. If real data run mode, ITEM 2 should be zero. Default (0.0)

TERRAIN type 2 - constant specified altitude

ITEM #	VALUE and DESCRIPTION
1	1 signifying terrain type 2
2	Uncertainty (meters) in measurement of ground altitude
3	Ground altitude (m) above sea level

TERRAIN type 3 - digital topographic map

ITEM #	VALUE and DESCRIPTION
1	2 signifying digital map mode.
2	UTM east coordinate of lower SW corner of map (meters).
3	UTM north coordinate of lower SW corner of map (meters).
4	Number of columns (S to N) in map.
5	Number of rows (W to E) in map.
6	East grid spacing (meters).
7	North grid spacing (meters).

At present, terrain type 3 is unimplemented.

6.2.14 TRACK Data Packet

The TRACK data packet specifies the RADAR - WEAPON combinations and determines track segments depending on specified radar coverage limits. There are no defaults for the TRACK packet.

CARD #1	PACKET NAME CARD
col 1-4	"TRAC"
col 11-12	01
col 13-72	Alphanumeric description

The required input ITEMS for the TRACK data packet in complete simulation mode are:

ITEM #	VALUE and DESCRIPTION
1	Packet number of WEAPON to be used, from 1 to 5.
2	Packet number of RADAR to be used, from 1 to 5.
3	Number of track intervals

ITEMS 4-8 are repeated for each track interval.

ITEM #	VALUE and DESCRIPTION
4	Coverage option at start of interval ±1 specified altitude ±2 topographic map intersection 3 specified time ±4 specified elevation If the option is negative the value will be pre-apogee, if the option is positive the value will be post-apogee. An option of -3 is illegal.
5	The value according to the option in ITEM 4. If the magnitude of ITEM 4 is 1 value is altitude (meters) 2 value is 0.0 3 value is time (sec) 4 value is elevation (radians)
6	Coverage option at end of track interval. See options under ITEM #4.
7	Value according to option specified by ITEM 6.
8	PRI (pulse repetition interval) in sec.

ITEMS 2-8 are repeated for each RADAR that is tracking the WEAPON. The total number of ITEMS must be less than 100.

The required input ITEMS of the TRACK packet for external trajectory input or real data analysis are:

ITEM #	VALUE and DESCRIPTION
1	Packet number of WEAPON to be used.

2	Packet number of first tracking RADAR.
3	Packet number of second tracking RADAR.

ITEM 2 is repeated for each tracking radar.

Refer to section 6.4 for LOCATER deck structure when external data or real measurements is to be analyzed.

Refer to section 6.2.10 for description of multiple radars.

Examples of TRACK data packets:

```
TRAC      01  COVERAGE LIMITS FOR MPS-33
$USE WEAPON 1 TRACKED BY RADAR 2
THERE ARE 2 INTERVALS:
THE FIRST INTERVAL
PRE-APOGEE ELEVATION -4 VALUE IS .05 RADIANS
PRE-APOGEE ELEVATION -4 VALUE 1.0 RADIANS
PRI (PULSE REPETITION FREQUENCY) OF .5 SECONDS.
THE SECOND INTERVAL
TIME OPTION 3 VALUE OF 76 SECONDS TO
POST-APOGEE ALTITUDE OPTION 1 VALUE 100 METERS
PRI .4 SECONDS $
```

```
TRAC      01  REAL DATA
$USE WEAPON 1 TRACKED BY MULTIPLE RADARS 1,2,4$
```

```
TRAC      01  MULTIPLE RADARS NONSIMULTANEOUS MEASUREMENTS
$USE WEAPON 2 TRACKED BY
RADAR 1 (HEMISPHERIC COVERAGE)
1 INTERVAL,  PRE-APOGEE ELEVATION OPTION (-4)
VALUE OF .0873 TO POST-APOGEE ELEVATION
OPTION (4) VALUE OF .0873 ,PRI 2.0 SECONDS
AND
RADAR 2 (FENCE)
1  INTERVAL,  PRE-APOGEE ELEVATION OPTION
(-4) VALUE OF .0175 RADIANS TO
PRE-APOGEE ELEVATION OPTION (-4)
VALUE OF .07 RADIANS PRI=.1 SECONDS $
```

```
TRAC      01  REAL DATA SINGLE RADAR
$USE WEAPON #3 TRACKED BY RADAR #1 $
```

6.2.15 WEAPON Data Packet

The WEAPON data packet defines the metric state vector of the projectile, the radar cross section (variable or constant) and chooses a set of meteorological conditions.

There are no defaults for any WEAPON packet.

CARD#1	PACKET NAME CARD
col 1-4	"WEAP"
col 11-12	01 to 05
col 13-72	Alphanumeric description

The required input ITEMS for the WEAPON data packet are:

ITEM #	VALUE and DESCRIPTION
1	Tag time associated with input state vector (sec). Usually 0.0
2	East coordinate of weapon in UTM (meters)
3	North coordinate of weapon in UTM (meters)
4	Height of weapon above sea level (meters)
5	Projectile initial velocity (m/s)
6	Azimuth of fire (mils) measured clockwise from north 0 to 6400 mils. (3200 mils = pi radians)
7	Quadrant elevation (mils) 0 is horizontal, 1600 is vertical
8	Projectile diameter (meters)
9	Projectile mass (kg)
10	Scale factor for drag table (nominally 1.0)
11	Drag curve number. At present only 1 drag curve is implemented so use 1
12	METRO packet number from 01 to 05. If no METRO packet is defined, the default atmosphere is used (SECTION 6.2.5)
13	RCS (radar cross section) option 0 constant RCS 1 table of RCS vs aspect angle
14	If ITEM 13 is 0, RCS value (dbsm). If ITEM 13 is 1 the RCS table number from 01 to 05 (Section 6.2.12)
15	Spin state (m/ss).
16	DRAG uncertainty ex. .05 0 if real data analysis

17	Spin uncertainty 0 if real data analysis

Example of WEAPON data packet:

```
WEAP      03  155 MM HOWITZER
QE=45 DEG, AZIMUTH=37 DEG, CHARGE 7W
$TAGTIME 0 SEC, POSITIONS EAST,NORTH 20000.0,27000.0 M
ALTITUDE OF 78 METERS.  INITIAL VELOCITY 564 M/S,
AZIMUTH OF FIRE 658 MILS, QUADRANT ELEVATION
800 MILS, DIAMETER .155 M, MASS 43.5 KG, DRAG
SCALE FACTOR 1.0, CURVE #1, USE
METEOROLOGICAL SET  1.
USE CONSTANT (0) RCS OF -10 DBSM, SPIN STATE
.2 MM/KG, DRAG UNCERTAINTY .05, SPIN
UNCERTAINTY 0.0$
```

6.2.16 VECTOR Data Packet

The VECTOR data packet is optional and allows the user to specify a starting state vector for the maximum likelihood estimator.

CARD #1	PACKET NAME CARD
col 1-4	"VECT"
col 11-12	Packet number 01-05 ITEM 3 of the ESTIMATOR data packet must be the same.
col 13-72	Alphanumeric description

The required input ITEMS for the VECTOR packet are:

ITEM #	VALUE and DESCRIPTION
1	Tag time of state vector (sec)
2,3,4	Positions X,Y,Z in ESF (meters)
5,6,7	Velocities X,Y,Z (m/s)
8	Drag state (mm/kg)
9	Spin state (m/ss)
10,11	East, north ground wind components. If METRO packet is layered, ITEMS 10,11 are ignored.

Example of VECTOR data packet:

```
VECT      02  APRIORI STATE VECTOR
$ TAG TIME OF 0 SECONDS
ESF POSITIONS RELATIVE TO RADAR 20000 M E., 1000 M N., 100 M UP
VELOCITIES -100 M/S, 275 M/S, 300 M/S
DRAG STATE .0005564 MM/KG
SPIN STATE .15 M/SS
NO EAST WIND COMPONENT 0 M/S
```

VECTOR

WIND BLOWING TOWARDS NORTH 10 M/S $

ITEM 3 of the ESTIMATOR data packet would be a 2.

6.3 Real Data Analysis

Real data analysis was primarily included in the LOCATER program for validation of the estimation theory and the projectile dynamic model.

Features of real data analysis include:

1. Multiple sensors with simultaneous or non-simultaneous measurements.
2. Each tracking radar's measurement space may be subset of range, azimuth, elevation or doppler.
3. Weapon information (true launch point, projectile type or cross section) is optional input. See section 6.2.15 WEAPON data packet.
4. Optional state vector initialization from the measurements. See section 6.2.3 ESTIMATOR data packet.
5. Optional usage of measured signal noise ratio for computation of measurement weights.
6. A priori radar biases may be removed.
7. Optional automatic data editing. See section 6.2.2 EDITOR data packet.
8. Layered meteorological conditions including winds, temperature and atmospheric density.
9. The measurements can be on magnetic tape, disk file or cards.

The mandatory data packets for real data analysis are:

1.	MISSION	(section 6.2.6)
2.	TRACK	(section 6.2.14)
3.	ESTIMATOR	(section 6.2.3)
4.	RADAR	(section 6.2.10)

The real data analysis run mode of LOCATER is set by ITEM #2 of the MISSION data packet. If ITEM #2 is 3 the measurements are on magnetic tape, if -3 they are on cards.

If the real data is on cards, the following sequence of cards must follow the LOCATER END card of the appropriate case.

CARD #1 VARIABLE FORMAT CARD

This card contains a FORTRAN variable format description to read the time and associated measurements. The order that the values must be read are:

1. Time
2. Range
3. Azimuth
4. Elevation
5. Doppler
6. Signal noise ratio.

If any particular measurement is not included in the radar measurement space the format for that item would not be specified. ITEMS 6-10 of the RADAR data packet specify the measurement space of the radar. For example if the radar does not take elevation then ITEM 8 of the RADAR data packet must be a 0 and the format item for elevation would not be included in the variable format card.

Example:

Assume the radar measurement space is range,
azimuth and doppler, only.
A sample data record has the values doppler, time,
azimuth and range in the following format.

(F12.2, F15.4, F11.8, F12.2)

The input orde› that LOCATER requires is time, range,
azimuth and doppler. The variable format
CARD #1 would then be

(T13, F15.4, T39, F12.2, T28, F11.8, T1, F12.2)

CARD #2 TITLE CARD

This card contains an alphanumeric description of the following data set in columns 1 - 80.

CARDS #3 DATA CARDS

The data cards contain the time and measurements according to the variable format card specified on CARD# 1. The units for the data are:

1.	Time	seconds
2.	Range	meters
3.	Azimuth	radians
4.	Elevation	radians
5.	Doppler	meters/second
6.	SNR	db

CARD # 4 BLANK CARD

This card signifies that the data set has been input. Note this card must be on same unit that CARDS # 2 and 3 are on.

CARDS # 2-4 are repeated for as many rounds as specified by ITEM # 1 of the MISSION data packet.

If the data is on magnetic tape CARDS # 2-4 will be on tape while the format card will always be a card. The CARD # 4 may be a blank card or a tape mark (EOF). The tape must be attached as TAPE2. See section 6.5.2.

REFER TO SECTION 7.1 FOR AN EXAMPLE OF REAL DATA ANALYSIS WHEN THE REAL DATA SET IS ON TAPE.

For analysis of multiple radar data the sequence of data following the LOCATER END card of the appropriate case is:

CARD #1	variable format card for first radar
CARD #2	Title card of data set 1 for first radar
CARDS #3	Data cards of set 1 for first radar
CARD #4	blank card
CARD #1	variable format card for second radar
CARD #2	title card for data set 1 for second radar
CARDS #3	data cards of set 1 for second radar
CARD #4	blank card
CARD #2	title card of data set 2 for first radar
CARDS #3	data cards of set 2 for first radar
CARD #4	blank card
CARD #2	title card of data set 2 for second radar
CARD #3	data cards of set 2 for second radar
CARD #4	blank card
CARD #2	title card of data set N for first radar
CARDS #3	data cards of set N for first radar
CARD #4	blank card
CARD #2	title card of set N for second radar
CARDS #3	data cards of set N for second radar
CARD #4	blank card

6.4 External Input Trajectory

The flow of LOCATER in complete simulation mode is:

1. Generate a trajectory segment using the internal dynamics of LOCATER.
2. Add radar noise errors to produce measurements.
3. Estimate a state vector through the measurements.

The external input trajectory mode replaces step 1 in the above flow hence permitting the usage of trajectories generated by higher level dynamics (3 DOF modified point mass trajectory simulator or a complete 6 DOF rigid body simulation).

The purpose of this is to ascertain the effects of using a simpler dynamic model, e.g.,model biases, timing, etc., for estimation.

Features of the external trajectory input simulation mode are:

1. Multiple radars making simultaneous measurements
2. Each radar may have a subset of the measurement space: Range, azimuth, elevation, doppler.
3. Optional state vector initialization from measurements.
4. Automatic data editing.
5. Layered meteorological conditions.

The following data packets are mandatory when using an externally input trajectory:

1.	MISSION	6.2.6
2.	TRACK	6.2.14
3.	ESTIMATOR	6.2.3
4.	RADAR	6.2.10
5.	ORIGIN	6.2.8

The program run mode is determined by ITEM #2 of the MISSION data packet. If the mode is -2 the external trajectory is on cards, if +2 the external trajectory is on magnetic tape.

If the external trajectory is on cards it must follow the LOCATER END card of the appropriate case in the following sequence.

CARD # 1 VARIABLE FORMAT CARD

This card contains a variable format description to read 7 items : time, 3 positions, 3 velocities.

Example: (F10.5,3F12.2,3F12.4)

CARD #2 TITLE CARD

Alphanumeric description of data set.

CARD #3 EXTERNAL TRAJECTORY

The external trajectory in an ESF coordinate system according to the variable format card. Items are: time (sec), 3 positions (meters), and 3 velocities (m/s).

CARD #4 BLANK CARD

If the run mode is specified as +2 the CARDS #2-4 must be on magnetic tape. CARD #4 on tape can be a blank record or a tape mark (EOF). The tape must be attached as TAPE2. See section 6.5.2.

REFER TO SECTION 7.3 FOR A SAMPLE RUN USING AN EXTERNALLY GENERATED TRAJECTORY.

6.5 Processing

The processing of LOCATER is designed to be done in a batch or remote job entry type of environment. This arrangement is ideal for parametric studies where the input data deck is continually being changed.

Section 6.5.1 describes the LOCATER run deck components:

1. CONTROL CARDS - cards necessary for attachment of files, recompilations, data set definitions, and program execution.

2. LOCATER source library changes. The source for LOCATER is stored in a compressed format called an UPDATE file.(7) This allows a unique identifier for each card in the source file which may easily be modified or deleted. An UPDATE library can be

completely restored to any previous level of operation.

3. LOCATER INPUT CARDS
   This is the input to the LOCATER program which is described in Sections 6.2.1 to 6.2.16.

4. PLOT DESCRIPTOR CARD
   This card of 80 alphanumeric characters will appear on all plots for unique identification.

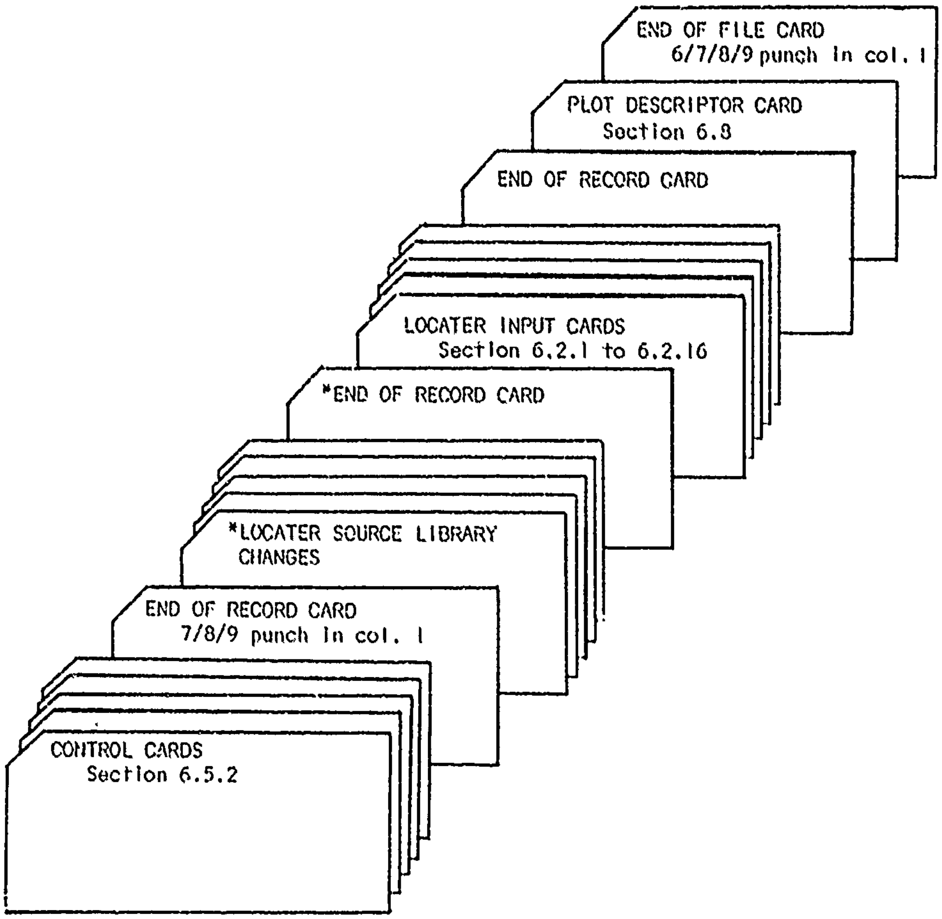
Section 6.5.2 is the list of control cards for the execution of the LOCATER program. SCOPE 3.4 reference manual.[8]

The following files are LOCATER related:

1.	LOCATERPL	source (FORTRAN) of LOCATER in UPDATE storage format
2.	LOCATERTEXT	binary of LOCATERPL
3.	MATRIX	binary of 20 matrix manipulation routines
4.	MISSCEPPL	source(FORTRAN) of the miss distance plotting program
5.	MISSEPPTEXT	binary of MISSCEPPL
6.	RESIDUALPLOTPL	source (FORTRAN) of the track residuals plotting routine
7.	RESIDUALPLOTTEXT	binary of RESIDUALPLOTPL

Files 4 and 6 are not used for every run of LOCATER.

6.5.1 LOCATER DECK SETUP (CDC 6600 - SCOPE 3.4)



*If there are no changes to the LOCATER program, the cards with the * are to be removed from the deck.

6.5.2 Control Cards - Scope 3.4

```
JOBNAME,TIME,MFL.
ACCOUNT,NAME
ATTACH,OLDPL,LOCATERPL,CY=3,MR=1,ID=COSGROVE.
UPDATE(I=INPUT,P=OLDPL,C=COMPILE)+
FTN(A,R=2,SL,B=TEXT,OPT=0,T)
REWIND,TEXT.
ATTACH,OLD,LOCATERTEXT,CY=1,MR=1.
COPYADD(OLD,TEXT,LOCATER)
REWIND,LOCATER.
ATTACH,MATRIX,MATRIX,ID=COSGROVE,CY=1,MR=1.
REQUEST,TAPE2,MT,*  EXTERNAL DATA,OR REAL DATA
MAP(PART)
LDSET(LIB=MATRIX,PRESET=INDEF)
LOCATER,PL=100000.
COPYCF(INPUT,PLOTHDR)
COPYBF(DUM,PLOTHDR)
ATTACH,MISPLT,MISSCRPTEXT,ID=COSGROVE,CY=4,MR=1.
MAP(OFF)
MISPLT(PLOTHDR)
RETURN,FILMPR.
ATTACH,PLOTTS,RESIDUALPLOTTEXT,ID=COSGROVE,MR=1,CY=1.
ATTACH,TICKG,TICKGTEXT,MR=1,CY=1,ID=COSGROVE.
LOAD(TICKG)
PLOTTS(PLOTHDR)
REWIND,TAPE1.
COPYSBF,TAPE1.
```

*For real data analysis or external trajectory input and if data is on tape this card is necessary.

+If there are no source library changes the I=INPUT should be replaced by I=NULL.

6.6 Storage, Run Time Estimates

The current core requirements for execution of LOCATER is as follows.

	Words	
	Decimal	Octal
Labelled Common	12K	27K
Program binary	20K	47K
Buffer storage	20K	47K
System routines	14K	33K
Total	66K	200K

An estimate of virtual run time for LOCATER can be determined from the following formula:

$$\text{Run Time} = .04NM \sum_{K} (T_F - T_I)/P$$

where:

Run Time	Central processing (virtual) time of run in decimal seconds including all I/O
T_F	End of track segment(sec) for the kth segment
T_I	Start of track segment(sec) for the kth segment
P	.5 if the PRI (pulsed repetition frequency) $\geq$ .5 sec PRI if PRI $<$ .5 sec
k	Number of track segments
N	Number of iterations for estimator to converge which is usually 2-3 based on a state vector convergence of .5 m in each position.
M	Number of monte carlo runs to simulate or rounds of real data to analyze.

Example:

Statistics are available for analysis of 10 rounds of real data with each data set having 1 track segment from 30 sec to 50 sec with a PRI of .2 second. The estimate of run time from the formula is 53 seconds while the actual run time was 58 seconds.

6.7 LOCATER REPORT Sections

The output from the LOCATER program is divided into 9 sections, SECTION 1 to 9. Each section may be cut into 8-1/2 x 11 in. pages to be put in a notebook. The LOCATER title card will appear at the top of each page while the section number, date, time and page number will be at the bottom.

Each output section contains the following:

SECTION 1	Input cards/packet storage arrays
2	Nominal radar weapon trajectory coverage
3	Estimator iterative output
4	Track file (measurements and weights)
5	State covariance matrix and correlation coefficients
6	Launch conditions and weighted residual statistics
7	Track residuals
8	State estimation statistics
9	Launch point locations (miss distance)

The output for each LOCATER SECTION is controlled by the OUTPUT data packet with the same number, i.e., the OUTPUT 07 data packet controls the printout for SECTION 7. Various sections like SECTIONS 2, 7 and 9 have other than printed output which is used for external graphics generation.

The rest of section 6.7 describes the printout format of each SECTION of the LOCATER REPORT.

6.7.1 Section 1 - Input Cards/Packet Storage Arrays

This output SECTION contains:

1. A copy of the input data deck
2. A list of the packet storage arrays names and defined elements (3 pages)

See section 8.3.1 for the description of the input storage array names for each packet type.

The following sample of SECTION 1 produces the sample output from each SECTION in the remainder of section 6.7.

```
                     LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
--------------------------------------------------------------------------------------------------

                                    ----INPUT DATA CARDS----

                     LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
    MISSION    01
        USING 2 HEMISPHERIC COVERAGE RADARS WITH A BASELINE
        OF 5 KM, TRACK A LOW QE 105 MM MORTAR SHOT.
        $RUN 20 MONTE CARLO RUNS. COMPLETE SIMULATION MODE 1 $
    WEAPON     01  LOW QE 105 MM MORTAR
        $TAG TIME OF 0 SECONDS, POSITIONS ARE 10000 METERS EAST,
        500 METERS NORTH AT ALTITUDE OF 30 METERS.
        INITIAL VELOCITY (CHARGE THREE) IS 393 M/S.
        AZIMUTH OF FIRE IS 5867 MILS CLOCKWISE FROM NORTH.
        QUADRANT ELEVATION 300 MILS.
        SHELL DIAMETER .105 METERS, MASS 15 KG.
        DRAG FACTOR 1.0, USE DRAG CURVE 1
        USE METRO PACKET NUMBER 4
        RCS OPTION 0 (CONSTANT VALUE) WHICH IS -12 DBSM.
        SPIN CONSTANT IS .15 M/SS
        DRAG UNCERTAINTY IS .05 (FIVE PERCENT). SPIN
        UNCERTAINTY IS 0  $
    RADAR      01      HCR SOUTH
        THE SENSOR IS A COMPOSITE OF 2 HCR RADARS, WITH
        THE SOUTHERNMOST RADAR TO BE CONSIDERED THE BASE.
        NON-SIMULTANEOUS MEASUREMENTS ARE TAKEN.
        $LOCATION 0 METERS EAST, 0 METERS NORTH, AT ALTITUDE
        OF 40 METERS. LONGITUDE IS .17453293 RADIANS,
        LATITUDE IS .87266463 RADIANS.
        RADAR MEASUREMENT SPACE IS RANGE (1), AZIMUTH (1)
            ELEVATION(1) AND DOPPLER(1).
            SNR WAS NOT TAKEN 0.
        BIAS ERRORS FOR MEASUREMENT GENERATION ARE
             1.0 METERS RANGE, .0009 RAD AZ, .00058 RAD EL,
             AND .2 M/S DOPPLER
        THERMAL ERROR SIGMAS 50 M RANGE,.0925 RAD AZ,
             .0925 RAD EL, AND  9.7 M/S DOPPLER
        JITTER ERROR SIGMAS 5 M RANGE, .001 RAD AZ,
             .001 RAD EL, AND .5 M/S DOPPLER
        REFERENCE RANGE IS 159000 METERS.
        MEASUREMENT THRESHOLD IS 13 DB.  FREQUENCY 3300000000 HZ
        ELEVATION BEAMWIDTH IS .0873 RADIANS.
        NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ, 0 RAD EL,
             0 M/S DOPPLER.
        NO REMOVABLE MULTIPATH PARAMETERS A IS 0, B IS 0
        C IS 0  $
    RADAR      02      HCR NORTH
        $LOCATION -500 METERS EAST, 5000 METERS NORTH, AT ALTITUDE
        OF 40 METERS. LONGITUDE IS COMPUTED INTERNALLY 0.0
        LATITUDE IS COMPUTED INTERNALLY 0.0
        RADAR MEASUREMENT SPACE IS RANGE (1), AZIMUTH (1)
            ELEVATION(1) AND DOPPLER(1).
            SNR WAS NOT TAKEN 0.
--------------------------------------------------------------------------------------------------
          SECTION  1      03/21/78  15.38.32          PAGE   1
```

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
--------------------------------------------------------------------------
        BIAS ERRORS FOR MEASUREMENT GENERATION ARE
             1.0 METERS RANGE, .0009 RAD AZ, .00058 RAD EL,
             AND .2 M/S DOPPLER
        THERMAL ERROR SIGMAS 50 M RANGE,.0925 RAD AZ,
             .0925 RAD EL, AND  9.7 M/S DOPPLER
        JITTER ERROR SIGMAS 5 M RANGE, .001 RAD AZ,
             .001 RAD EL, AND .5 M/S DOPPLER
        REFERENCE RANGE IS 159000 METERS.
        MEASUREMENT THRESHOLD IS 13 DB.  FREQUENCY 3300000000 HZ
        ELEVATION BEAMWIDTH IS .0873 RADIANS.
        NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ, 0 RAD EL,
             0 M/S DOPPLER.
        NO REMOVABLE MULTIPATH PARAMETERS A IS 0, B IS 0
        C IS 0  $
    TRACK      01  MULTIPLE RADAR COVERAGE LIMITS
        $USE WEAPON PACKET 1
        RADAR NUMBER 1, 1 TRACK INTERVAL,
        PRE-APOGEE ELEVATION OPTION -4 VALUE OF .008 RADIANS
             TO POST-APOGEE ELEVATION OPTION 4 VALUE OF
             .008 RADIANS. THE PRI IS 2.0 SECONDS.
        RADAR 2, 1 TRACK INTERVAL
             TIME OPTION 3 OF .2 SECONDS TO POST APOGEE
             ELEVATION OPTION 4, VALUE OF .008 RADIANS.
             THE PRI IS 2.0 SECONDS.
        $
    ESTIMATOR 01
        $USE FILTER 1, USE SIGMAS IN RADAR PACKET 1 FOR WEIGHTS,
        USE TRUE STATE VECTOR FOR INITIALIZATION -1, MAXIMUM
        NUMBER OF ITERATIONS IS 20, POSITIONAL CONVERGENCE
        OPTION 1, VALUE = .5 METERS, NO APRIORI DATA 0,
        ESTIMATE POSITIONS EAST 1 NORTH 1 HEIGHT 1
                 VELOCITIES EAST 1 NORTH 1 HEIGHT 1
                 DRAG 1 NO SPIN 0
                 NO WIND 0 0
                 NO BIASES 0 0 0 0
                 NO MULTIPATH PARAMETERS 0 0 0
        $
    MEASURE    01  ERROR GENERATION
        $IN SIMULATING RADAR MEASUREMENTS INCLUDE
        BIASES 1,THERMAL ERRORS 1, JITTER ERRORS 1,
        AND TROPHOSPHERIC REFRACTION 1, NO MULTIPATH 0 $
    METRO      04  GROUND CONDITIONS
        $METRO PACKET TYPE 2 (GROUND CONDITIONS)
        AIR DENSITY IS 1.15 KG/MMM
        WIND SPEED IS 5 M/S ( ABOUT TEN KNOTS)
        WIND IS COMING FROM THE N.E. ( 45 DEGREES)
        GROUND TEMPERATURE IS 266.5 DEG KELVIN$
    OUTPUT     02  NOMINAL TRAJECTORY
        $COVERAGE OPTION 1, RADAR 1, WEAPON 1
        TIME INITIAL OF 0 SECONDS EVERY .5 SEC TO IMPACT
        OPTION -999. PRINTOUT IN POLAR COORDINATES
        OPTION 2, NO TAPE PRINTOUT 0  $
--------------------------------------------------------------------------
            SECTION  1      03/21/78  15.38.32          PAGE   2
```

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
-------------------------------------------------------------------------------
   OUTPUT     03  CONVERGENCE
       $GENERATE SECTION THREE OF THE LOCATER TEST REPORT
       1 FOR ONLY 1 RUN $
   OUTPUT     07
       $PRINT TRACK RESIDUALS 1, WRITE THEM TO TAPE FOR PLOTTING 1,
       FOR ALL RUNS 0    $
   RANDOM     01  RANDOM NUMBER SEED INITIALIZATION
       $RANDOM NUMBER SEED IS 3674231 $
   END
```

```
-------------------------------------------------------------------------------
           SECTION  1       03/21/78  15.38.32           PAGE   3
```

6.7.2 Section 2 - Nominal Radar Weapon Trajectory Coverage

This output SECTION prints a portion of a trajectory in either metric or polar coordinates and is controlled by the OUTPUT 02 data packet. See Section 6.2.9.2 for the description of the various items and options available for SECTION 2.

At the top of each page the LOCATER title card followed by the RADAR and WEAPON packet numbers used for coverage are printed.

The intervals of coverage for polar type, RAE, output is described by 9 columns with the following header information.

TIME(SEC)	Coverage time (sec).
R(M)	Slant range (meters) from radar to projectile.
AZ(MR)	The azimuth bearing (mr). of the weapon measured 0 to 2000 pi clockwise from North.
EL(MR)	Elevation (mr) of weapon from earth tangent plane measured from -1000 pi/2 straight down to 1000 pi/2 at zenith.
RDOT	Doppler component (m/s) which is the projection of the velocity vector along the line of sight from radar to weapon. A negative doppler means the weapon is moving towards the radar.
AZDOT	Time rate of change of azimuth (mr/sec).
ELDOT	Time rate of change of elevation (mr/sec).
VEL	Velocity magnitude (m/s).
SNR(DB)	Signal noise ratio (db) assuming range **4 dependence.

The metric type printout has the following format.

TIME(SEC)	Coverage time in seconds
X(M)	X position (meters) in a ESF coordinate system with origin at radar.
Y(M)	Y position (meters).
Z(M)	Z position (meters) in the vertical direction. (positive is upwards)
XDOT	X axis velocity (m/s).
YDOT	Y axis velocity (m/s).
ZDOT	Z axis velocity (m/s)

VEL	Velocity magnitude (m/s).
SNR(DB)	Signal noise ratio (db) assuming range**4 dependence.

A sample of SECTION 2 follows with polar type output.

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
--------------------------------------------------------------------------------
                         RADAR  1 TRACKING WEAPON  1

TIME(SEC)  R(M)    AZ(MR)  EL(MR)    RDOT  AZDOT    ELDOT   VEL   SNR(DB)

   0.000 10012.5 1520.84    -1.79 -171.6  -33.43    11.36  393.0  36.03
    .500  9929.3 1504.19     3.75 -161.4  -33.17    10.78  382.1  36.18
   1.000  9851.0 1487.67     9.00 -151.8  -32.90    10.20  371.7  36.32
   1.500  9777.4 1471.29    13.95 -142.7  -32.63     9.61  361.8  36.45
   2.000  9708.2 1455.04    18.61 -134.1  -32.35     9.02  352.5  36.57
   2.500  9643.2 1438.90    22.97 -126.0  -32.08     8.43  343.7  36.69
   3.000  9582.1 1422.96    27.03 -118.3  -31.82     7.84  335.5  36.80
   3.500  9524.8 1407.11    30.80 -111.2  -31.59     7.25  328.0  36.90
   4.000  9470.9 1391.35    34.29 -104.5  -31.41     6.68  321.5  37.00
   4.500  9420.2 1375.68    37.48  -98.4  -31.31     6.12  316.0  37.09
   5.000  9372.4 1360.04    40.41  -92.7  -31.26     5.57  311.5  37.18
   5.500  9327.4 1344.41    43.05  -87.3  -31.26     5.02  307.7  37.27
   6.000  9285.1 1328.78    45.42  -82.1  -31.29     4.47  304.4  37.34
   6.500  9245.3 1313.13    47.52  -77.1  -31.32     3.93  301.6  37.42
   7.000  9208.0 1297.45    49.35  -72.1  -31.37     3.37  299.0  37.49
   7.500  9173.2 1281.76    50.90  -67.3  -31.41     2.82  296.6  37.56
   8.000  9140.7 1266.05    52.17  -62.6  -31.44     2.26  294.4  37.62
   8.500  9110.6 1250.32    53.16  -57.9  -31.46     1.70  292.4  37.67
   9.000  9082.8 1234.59    53.86  -53.3  -31.46     1.13  290.5  37.73
   9.500  9057.3 1218.86    54.29  -48.7  -31.45      .56  288.6  37.78
  10.000  9034.1 1203.14    54.43  -44.2  -31.43     -.01  286.9  37.82
  10.500  9013.1 1187.44    54.28  -39.7  -31.39     -.58  285.4  37.86
  11.000  8994.4 1171.75    53.85  -35.3  -31.34    -1.15  283.9  37.90
  11.500  8977.8 1156.10    53.14  -30.9  -31.28    -1.71  282.5  37.93
  12.000  8963.5 1140.48    52.14  -26.5  -31.19    -2.28  281.2  37.96
  12.500  8951.3 1124.91    50.86  -22.2  -31.10    -2.85  280.0  37.98
  13.000  8941.2 1109.38    49.29  -18.0  -30.99    -3.41  279.0  38.00
  13.500  8933.3 1093.92    47.45  -13.7  -30.86    -3.97  278.0  38.02
  14.000  8927.5 1078.53    45.33   -9.5  -30.72    -4.52  277.1  38.03
  14.500  8923.7 1063.20    42.93   -5.4  -30.57    -5.07  276.3  38.03
  15.000  8922.1 1047.96    40.26   -1.2  -30.40    -5.61  275.6  38.04
  15.500  8922.5 1032.81    37.32    2.9  -30.22    -6.14  275.0  38.04
  16.000  8925.0 1017.75    34.12    7.0  -30.02    -6.67  274.4  38.03
  16.500  8929.4 1002.79    30.65   11.0  -29.82    -7.19  274.0  38.02
  17.000  8936.0  987.93    26.93   15.0  -29.60    -7.70  273.6  38.01
  17.500  8944.5  973.19    22.96   19.0  -29.37    -8.20  273.3  37.99
  18.000  8955.0  958.56    18.74   23.0  -29.13    -8.69  273.1  37.97
  18.500  8967.5  944.06    14.27   27.0  -28.88    -9.17  273.0  37.95
  19.000  8982.0  929.69     9.57   30.9  -28.61    -9.63  272.9  37.92
  19.500  8998.4  915.45     4.64   34.8  -28.34   -10.09  273.0  37.89
  20.000  9016.8  901.35     -.52   38.7  -28.06   -10.54  273.0  37.85




--------------------------------------------------------------------------------
          SECTION  2       03/21/78   15.38.34            PAGE   4
```

6.7.3 Section 3 - Estimator Convergence Report

This SECTION prints the metric state vector and perturbation along with the bias/multipath state vector and perturbation for every iteration. Output from SECTION 3 is controlled by the OUTPUT 03 data packet and is generated by subroutine SECT03.

The data is presented in 4 rows, each of which has the following header information.

ROW 1 - METRIC STATE VECTOR

X	X position (m) of state vector at the reference time in ESF coordinate system with radar at origin.
Y	Y position (m) of the state vector.
Z	Z position (m) of the state vector.
VX	X axis velocity (m/s) in the ESF coordinate system.
VY	Y axis velocity (m/s).
VZ	Z axis velocity (m/s).
KD	Drag state (mm/kg).
KS	Spin state (m/ss).
WE	East wind component (m/s) for nonlayered meteorological type data packet. If layered METRO data WE=0.0.
WN	North wind component (m/s) for nonlayered meteorological type data packet. If meteorological profile is layered, WN=0.0.

ROW 2 - METRIC STATE VECTOR PERTURBATION

DX	X axis positional perturbation (m).
DY	Y axis positional perturbation (m).
DZ	Z axis positional perturbation (m).
DVZ	X axis velocity perturbation (m/s).
DVY	Y axis velocity perturbation (m/s).
DVZ	Z axis velocity perturbation (m/s).
DKD	Drag state perturbation (m[illegible]).
DKS	Spin state perturbation (m/ss).
DWE	East wind perturbation (m/s).
DWN	North wind perturbation (m/s).

ROW 3 - BIAS/MULTIPATH STATE VECTOR

RB	Removable range bias (meters). All biases are the measured component minus the estimate.
AB	Removable azimuth bias (mr).
EB	Removable elevation bias(mr).
DB	Removable doppler bias (m/s).
A	Multipath A (amplitude) parameter in radians.
B	Multipath B parameter. 2*pi/B corresponds to the period.
C	Multipath C parameter. C/B corresponds to the phase.

ROW 4 - BIAS/MULTIPATH STATE VECTOR PERTURBATION

DRB	Range bias perturbation (m).
DAB	Azimuth bias perturbation (mr).
DEB	Elevation bias perturbation (mr).
DDB	Doppler bias perturbation (m/s).
DA	Multipath A parameter perturbation.
DB	Multipath B parameter perturbation.
DC	Multipath C parameter perturbation.
QTOTAL	The weighted squared residuals averaged over the number of points and summed over the measurement space. For each successive iteration QTOTAL should decrease.

```
                     LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
-------------------------------------------------------------------------------------
                   SECTION   3  -  ITERATIONS

                   MONTE CARLO RUN NUMBER    1
         X        Y        Z       VX     VY     VZ        KD       KS    WE    WN
       DX        DY       DZ      DVX    DVY    DVZ       DKD       DKS   DWE  DWN
       FB   AB   EB   DB   A         B             C
      DFB  DAB  DEB  DDB  DA        DB            DC         QTOTAL

     ---- ITERATION   1
        9952.5    554.8     4.6 -186.2  322.7  111.1   .698250E-03   .15 -3.5 -3.5
           -.9    -10.9    15.8     .5     .5     .3   .640367E-05  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.            0.
       0.0  0.0  0.0  0.0  0.0  0.            0.              7.3330

     ---- ITERATION   2
        9961.7    554.0    21.4 -185.7  323.2  111.3   .704654E-03   .15 -3.5 -3.5
           -.0       .0       .0    -.0     .0     .0   .371027E-07  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.            0.
       0.0  0.0  0.0  0.0  0.0  0.            0.              3.8690

     ---- ITERATION   3
        9961.7    554.0    21.4 -185.7  323.2  111.3   .704691E-03   .15 -3.5 -3.5
           -.0       .0       .0    -.0    -.0    -.0   .831187E-11  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.            0.
       0.0  0.0  0.0  0.0  0.0  0.            0.              3.8689
```

```
-------------------------------------------------------------------------------------
            SECTION  3      03/21/78  15.40.03          PAGE   5
```

6.7.4 Section 4 - Track File (Measurements)

This SECTION prints the measurements and weights of each observation in the track file after the estimator has converged. SECTION 4 is generated by routine SECT04 and is controlled by the OUTPUT 04 data packet. See section 6.2.9.4 for a description.

First, the Monte Carlo run number is printed at the top of each page.

Each observation will then take 2 lines of print each with the following header descriptions:

LINE 1

NPT	Point number
TIME	Tag time of measurement (seconds).
RANGE	Range measurement (m).
AZIMUTH	Azimuth measurement (radians).
ELEVTN	Elevation measurement (radians).
DOPPLER	Doppler measurement (m/s).
SNR	Signal noise ratio (db).
Q(NPT)	The weighted squared residual (unitless) summed over the number of observations in each measurement.

LINE 2

WEIGHT(RANGE)	The range weight used in the estimator. See Section 5.5.5 for the definitions of measurement weights.
WEIGHT(AZIMUTH)	Azimuth weight.
WEIGHT(ELEVTN)	Elevation weight.
WEIGHT(DOPPLER)	Doppler weight.
RADAR	RADAR packet number associated with the observation.
DROP	Point drop code. 0 Good point 1 Point dropped due to data pre-editing. 2 Point dropped due to low SNR 4 Point dropped due to data post edit.

The following page is a sample output of SECTION 4. For the 12th point for example:

TIME = 12.000 sec
RANGE = 8968.1 m

RANGE WEIGHT = .0394
AZIMUTH = 1.139067 radians
AZIMUTH WEIGHT = .422E+06
ELEVATION = .051358 radians
ELEVATION WEIGHT = .422E+06
DOPPLER = -26 m/s
DOPPLER WEIGHT = 3.77
SNR = 37.95 dB
Q(NPT) = 5.72229
RADAR # = 1
DROP = 0 (point was good)

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
--------------------------------------------------------------------------------

  MEASUREMENTS, WEIGHTS FOR RUN    1

  NPT  TIME     RANGE    AZIMUTH    ELEVTN   DOPPLER    SNR     Q(NPT)
                WEIGHT   WEIGHT     WEIGHT   WEIGHT    RADAR     DROP

    1    .200  11362.6 1.976615   .004739   -297.26   33.83   6.60295
               .384E-01 .220E+06 .220E+06 .346E+01     2        0
    2   2.000   9711.6 1.457461   .023212   -134.44   36.57   4.58125
               .391E-01 .347E+06 .347E+06 .369E+01     1        0
    3   2.200  10807.0 1.931942   .021161   -261.18   34.71   2.11070
               .387E-01 .257E+06 .257E+06 .355E+01     2        0
    4   4.000   9467.2 1.390594   .035487   -105.44   37.00   3.20481
               .392E-01 .370E+06 .370E+06 .372E+01     1        0
    5   4.200  10318.4 1.892059   .032926   -234.59   35.52   2.80079
               .389E-01 .294E+06 .294E+06 .362E+01     2        0
    6   6.000   9279.4 1.327315   .046837    -81.20   37.35   3.56761
               .393E-01 .388E+06 .388E+06 .374E+01     1        0
    7   6.200   9871.6 1.851656   .044238   -215.53   36.30   1.40342
               .391E-01 .333E+06 .333E+06 .368E+01     2        0
    8   8.000   9140.7 1.262204   .054708    -62.35   37.62   5.30075
               .393E-01 .403E+06 .403E+06 .376E+01     1        0
    9   8.200   9440.6 1.808741   .052662   -200.61   37.05   6.79252
               .392E-01 .372E+06 .372E+06 .372E+01     2        0
   10  10.000   9030.7 1.201679   .056364    -43.97   37.82    .99590
               .394E-01 .415E+06 .415E+06 .377E+01     1        0
   11  10.200   9067.4 1.761956   .055616   -187.75   37.78   3.27802
               .393E-01 .412E+06 .412E+06 .376E+01     2        0
   12  12.000   8968.1 1.139067   .051358    -26.00   37.96   5.72229
               .394E-01 .422E+06 .422E+06 .377E+01     1        0
   13  12.200   8692.6 1.709552   .056748   -173.26   38.49   3.44492
               .394E-01 .452E+06 .452E+06 .380E+01     2        0
   14  14.000   8931.5 1.077673   .049279     -8.73   38.03    .92549
               .394E-01 .426E+06 .426E+06 .378E+01     1        0
   15  14.200   8372.3 1.659522   .049791   -158.02   39.17   4.27881
               .395E-01 .491E+06 .491E+06 .383E+01     2        0
   16  16.000   8930.8 1.016695   .039808      8.14   38.03   4.10057
               .394E-01 .426E+06 .426E+06 .378E+01     1        0
   17  16.200   8067.7 1.601676   .039908   -144.31   39.81   7.37031
               .396E-01 .528E+06 .528E+06 .385E+01     2        0
   18  18.000   8957.4  .957888   .020162     24.22   37.97   2.74017
               .394E-01 .423E+06 .423E+06 .377E+01     1        0
   19  18.200   7804.8 1.541854   .023879   -126.16   40.40   4.28859
               .396E-01 .562E+06 .562E+06 .387E+01     2        0

--------------------------------------------------------------------------------
            SECTION  4       03/21/78  15.38.38            PAGE   6
```

6.7.5 Section 5 - State Covariance Matrix

This SECTION contains:

1. State covariance matrix
2. Alphanumeric description of each estimated state.
3. Correlation coefficients.

The output from SECTION 5 is generated by routine SECT05 and controlled by the OUTPUT 05 data packet. See section 6.2.9.5 for a description.

The Monte Carlo run number is first printed at the top of the page.

The lower half of the symmetric state covariance matrix is printed with a maximum of 7 numbers on each line with wraparound occurring if necessary.

The matrix can be interpreted as the radar measurement space variances transformed by a similarity transformation into the integration space at the reference time.

The list of state numbers with the alphanumeric description of each state follows the covariance matrix.

The array of correlation coefficients CC is then defined from the state covariance matrix P.

CC(I,J) = P(I,J)/SQRT(P(I,I) * P(J,J))

The correlation coefficients array is likewise symmetrical and only the lower triangular half is printed.

The correlation coefficients indicate the amount of correlation (dependency) between the various estimated states. The numeric values range between -1.0 to 1.0 and have the following interpretations.

+1.0	High correlation. As variable 1 increases, variable 2 increases.
0.0	Little correlation.
-1.0	High correlation. As variable 1 increases, variable 2 decreases.

In the following sample output of SECTION 5 there is a high correlation between the Z position (state 3) and the Z velocity (state 6) as CC(6,3) = -.9036298. There is little correlation between the Z velocity (state 6) and the X velocity (state 4) as C(6,4)=-.019751).

If there is too high a correlation between estimated states the estimator could diverge or the state covariance matrix could be singular.

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
------------------------------------------------------------------------------

   SECTION    5 - STATE COVARIANCE MATRIX AND CORRELATION COEFFICIANTS MC RUN    1

      1  .30677E+01
      2  .23086E+01  .17413E+02
      3 -.61997E+00 -.23034E+01  .65090E+02
      4 -.27172E+00 -.44509E+00 -.28462E+00  .97669E-01
      5  .33848E-01 -.79983E+00  .76611E+00 -.94410E-01  .24509E+00
      6  .65672E-01  .24188E+00 -.57626E+01 -.48793E-02 -.24864E-01  .62481E+00
      7  .10540E-05  .89176E-05  .13320E-04 -.14717E-05  .15737E-05 -.69522E-06
         .39116E-10

                    STATE NUMBER          STATE
                          1             X POSITION
                          2             Y POSITION
                          3             Z POSITION
                          4             X VELOCITY
                          5             Y VELOCITY
                          6             Z VELOCITY
                          7             DRAG(KD)

   CORRELATION COEFFICIANTS

      1   1.0000000
      2    .3158650   1.0000000
      3   -.0430736   -.0684199   1.0000000
      4   -.4964018   -.3412961   -.1128851   1.0000000
      5    .0390349   -.3871601    .1916100   -.6102038   1.0000000
      6    .0474390    .0733315   -.9036298   -.0197517   -.0635375   1.0000000
      7    .0962158    .3416913    .2639798   -.7529465    .5082596   -.1406291
          1.0000000

------------------------------------------------------------------------------
           SECTION  5      03/21/78   15.38.38           PAGE   7
```

6.7.6 Section 6 - Launch Conditions and Residual Statistics

This SECTION prints the estimated trajectory parameters at a specified condition along with the weighted residual statistics for each Monte Carlo run. The output from SECTION 6 is generated by subroutine SECT06 and is controlled by the OUTPUT 06 data packet. See section 6.2.9.6 for the description.

The default data packet specifies that each estimated state vector will be extrapolated to the ground terrain at launch. This option may be overwritten if other extrapolation conditions are desired.

For each run the following is printed:

Header	Description and Units
RUN	Monte Carlo run number or real data set number
V0	Velocity magnitude (m/s) of state vector
QE	Quadrant elevation (degrees) measured -90 straight down to +90 at zenith
AZF	Azimuth of fire (degrees) measured clockwise from north (0 to 360 deg)
T FIRE	Time of estimated trajectory extrapolated to the specified condition. In the sample of SECTION 6 output, the T FIRE for run #1 is -.15 second. The state vector valid at the specified condition has a time tag of -.15 second.
QR	Weighted squared range residual (unitless) averaged over the number of good measurements in the track file.
QA	Weighted squared azimuth residual averaged over the number of good measurements in the track file.
QE	Weighted squared elevation residual averaged over the number of measurements.
QRDOT	Weighted squared doppler residuals averaged over the number of measurements.
Q TOT	Numeric sum of QR+QA+QE+QRDOT which is the total weighted square residual statistic.
FIT	0 good fit 1 Indicates that the estimator is diverging, possibly due to a near singular state covariance matrix.

NITER - Iteration counter.

If a certain measurement is not included in the radar measurement space the Q component will be zero.

The average (AVE) and std. dev. (SIG) are than computed for each of the above items based on all good runs (variable FIT must be 0).

```
                      LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
--------------------------------------------------------------------------------

           SECTION  6 - LAUNCH CONDITIONS AND WEIGHTED RESIDUAL STATISTICS

     RUN  VO    QE    AZF  T FIRE   QR     QA     QE    QRDOT  Q TOT FIT NITER
          M/S   DEG   DEG   SEC

       1 396.4 17.10 330.1   -.15   .844  1.051   .963  1.011  3.869  0    3
       2 396.5 16.89 330.1   -.12  1.627   .790   .776  1.497  4.690  0    3
       3 392.6 16.93 330.0    .01   .863   .964   .885  1.022  3.735  0    3
       4 392.0 16.83 330.0    .05   .867   .631  1.001   .881  3.380  0    3
       5 393.2 16.89 330.0   -.00  1.425   .849   .858  1.176  4.308  0    3
       6 395.7 16.92 329.9   -.12   .749   .631   .784   .829  2.994  0    3
       7 394.7 16.97 330.0   -.08   .525   .794  1.069   .658  3.046  0    3
       8 392.1 16.89 330.1    .05  1.849   .862   .833  1.304  4.847  0    3
       9 391.6 16.83 329.9    .09   .828   .687  1.302   .604  3.421  0    3
      10 397.4 16.95 330.0   -.13  1.243   .994  1.025   .520  3.783  0    3
      11 394.2 16.85 330.0   -.07  1.265  1.314   .863   .869  4.310  0    3
      12 392.5 16.87 330.0   -.04  1.398  1.291   .924   .859  4.472  0    3
      13 392.3 16.85 329.9    .04  1.210   .965  1.487  1.163  4.826  0    3
      14 392.9 16.70 330.1   -.02   .539   .848   .570   .676  2.633  0    3
      15 394.9 16.96 330.0   -.09  1.528   .984  1.401  1.006  4.920  0    3
      16 391.9 16.87 330.1    .04   .641   .463   .811  1.002  2.917  0    3
      17 386.7 16.86 330.0    .26  1.197  1.048   .803   .959  4.008  0    3
      18 395.6 16.80 329.9   -.12  1.280  1.058   .846  1.461  4.644  0    3
      19 390.5 16.99 330.0    .12  1.427  1.325  1.114  1.026  4.892  0    3
      20 389.6 16.88 330.0    .16   .728  1.069  1.621  1.081  4.499  0    3


     AVE 393.2 16.89 330.0   -.01  1.102   .931   .997   .980  4.010      3.0
     SIG   2.5   .08    .1    .11   .374   .226   .261   .255   .722      0.0

      THE ABOVE STATISTICS IS BASED ON  20 OUT OF 20 RUNS




--------------------------------------------------------------------------------
              SECTION  6       03/21/78  15.40.02           PAGE    8
```

6.7.7 Section 7 - Track Residuals

This SECTION prints the radar measurements and residuals for each point in the track file for every Monte Carlo run and plots the residuals. The output from SECTION 7 is generated by subroutine SECT07 and is controlled by the OUTPUT 07 data packet. See Section 6.2.9.7 for the description.

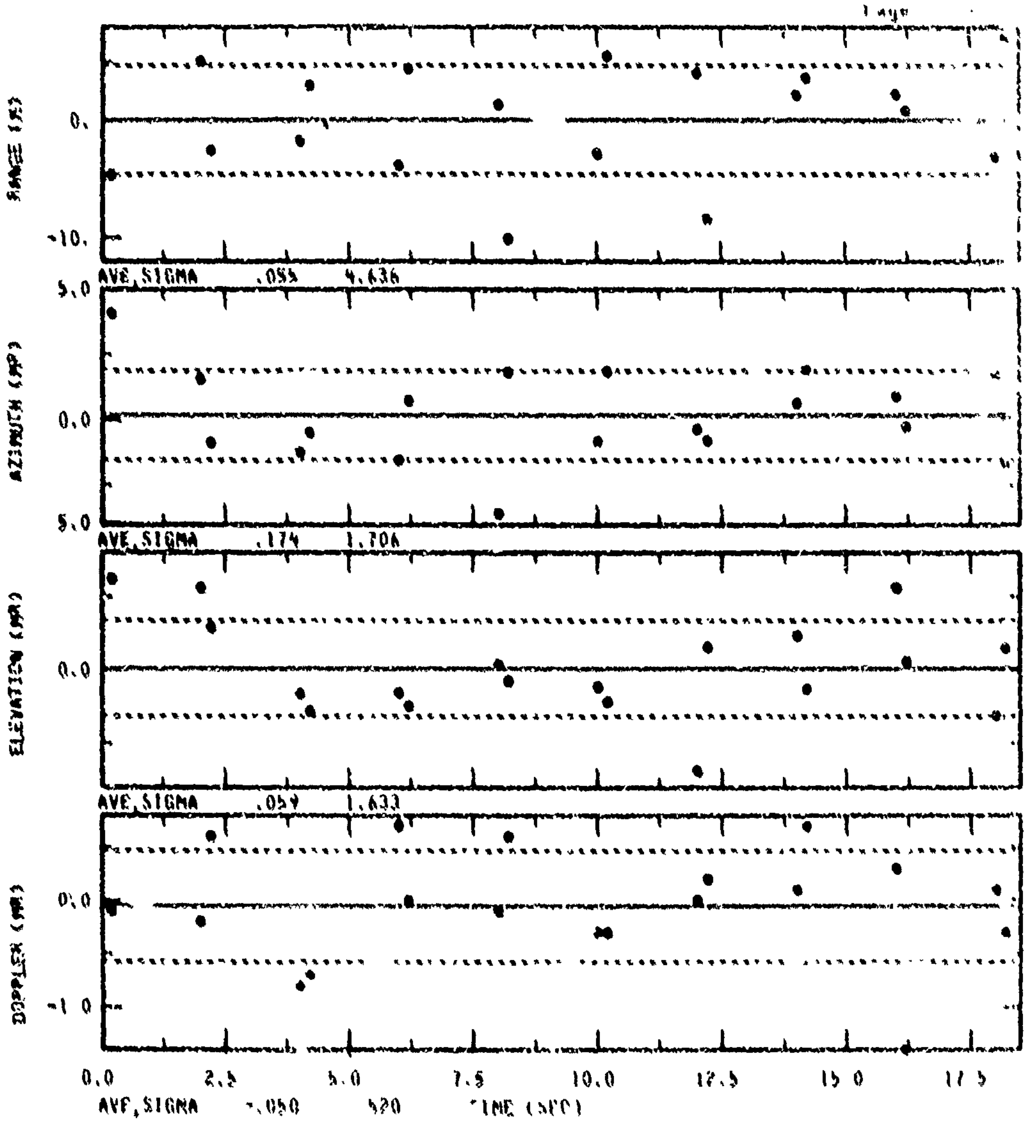
The following items are output:

HEADER	DESCRIPTION and UNITS
NPT	Point number
TIME	Time of measurement (sec)
RM	Range measurement (m)
DR	Range residual (m) which is measured range minus estimated range
AM	Azimuth measurement (radians)
DA	Measured azimuth-estimated azimuth (mr)
EM	Elevation measurement (radians)
DE	Measured elevation-estimated elevation (mr)
RRM	Doppler measurement (m/s)
DRR	Measured doppler-estimated doppler (m/s)
IDRP	Point drop code 0 good point 1 point dropped from data pre-edit test. 2 point dropped as SNR is is below specified 4 point dropped from data post-fit-edit test. If any point is dropped the residual is zero.

If the radar does not take a particular measurement component the residual is always zero. The average track residual (AVRGE) and std. dev. (SIGMA) is then computed for each measurement component based on all good points in the track file.

The graphics output of SECTION 7 plots the track residuals (measured value-estimated value) vs time (sec) for each good point in the track file. For each run every measurement component will produce 1 subplot, all of which are on 1 page. A dashed line is plotted at AVRGE + SIGMA and AVRGE - SIGMA. Points that have been dropped by the estimator will NOT be plotted.

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
------------------------------------------------------------------------------------
    SECTION   7 - TRACK RESIDUALS FOR RUN NUMBER   1

    NPT  TIME     RM     DR     AM       DA       EM       DE      RFM    DRR   IDRP

      1    .200 11363.   -4.7  1.9766   4.045    .0047    3.059 -297.3    -.1     0
      2   2.000  9712.    5.0  1.4575   1.531    .0232    2.782 -134.4    -.2     0
      3   2.200 10807.   -2.6  1.9319   -.887    .0212    1.422 -261.2     .6     0
      4   4.000  9467.   -1.8  1.3906  -1.247    .0355    -.820 -105.4    -.8     0
      5   4.200 10318.    2.9  1.8921   -.495    .0329   -1.418 -234.6    -.7     0
      6   6.000  9279.   -3.9  1.3273  -1.551    .0468    -.794  -81.2     .7     0
      7   6.200  9872.    4.3  1.8517    .706    .0442   -1.237 -215.5     .0     0
      8   8.000  9141.    1.3  1.2622  -3.583    .0547     .170  -62.3    -.1     0
      9   8.200  9441.  -10.1  1.8087   1.795    .0527    -.387 -200.6     .6     0
     10  10.000  9031.   -2.9  1.2017   -.830    .0564    -.590  -44.0    -.3     0
     11  10.200  9067.    5.4  1.7620   1.833    .0556   -1.091 -187.7    -.3     0
     12  12.000  8968.    4.0  1.1391   -.369    .0514   -3.447  -26.0    -.0     0
     13  12.200  8693.   -8.4  1.7096   -.803    .0567     .754 -173.3     .2     0
     14  14.000  8931.    2.1  1.0777    .628    .0493    1.160   -8.7     .1     0
     15  14.200  8372.    3.6  1.6595   1.905    .0498    -.660 -158.0     .7     0
     16  16.000  8931.    2.2  1.0167    .888    .0398    2.790    8.1     .3     0
     17  16.200  8068.     .8  1.6017   -.290    .0399     .272 -144.3   -1.4     0
     18  18.000  8957.   -3.2   .9579   1.727    .0202   -1.564   24.2     .1     0
     19  18.200  7805.    7.0  1.5419  -1.697    .0239     .713 -126.2    -.3     0

                      TRACK RESIDUAL STATISTICS RUN    1

                  RANGE(M)   AZIMUTH(MR)   ELEVATION(MR)  DOPPLER(M/S)

         AVRGE       .055         .174          .059          -.052
         SIGMA      4.636        1.706         1.633           .516




------------------------------------------------------------------------------------
             SECTION  7       03/21/78   15.38.38          PAGE   9
```


RANGE (M)
0.
-10.
AVE,SIGMA .055 4.636
5.0
AZIMUTH (MR)
0.0
5.0
AVE,SIGMA .174 1.706
ELEVATION (MR)
0.0
AVE,SIGMA .059 1.633
DOPPLER (MM)
0.0
-1.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
AVE,SIGMA -.050 .520
TIME (SEC)

+MC 1

6.7.8 Section 8 - State Estimation Statistics

This SECTION prints the estimator performance for each state that is constant in the trajectory. The output from SECTION 8 is generated by subroutine SECT08 and is controlled by the OUTPUT 08 data packet. See section 6.2.9.8 for the description.

There are 3 lines of output for each run:

1. Estimated state vector.
2. State vector for initialization of estimator, either true, nominal, derived from measurements, or a specified state vector (VECTOR packet) depending on option specified by ITEM #3 of the ESTIMATOR packet.
3. Difference between the estimated state vector and the state vector that initialized the estimator. (Line 1 minus Line 2)

Each column has the following headings:

MC	Monte Carlo or real data run number
KD	Drag state (mm/kg)
KS	Spin state (m/ss)
WE	East wind component (m/s)
WN	North wind component (m/s)
RB	Range bias (m)
AB	Azimuth bias (mr)
EB	Elevation bias (mr)
DB	Doppler bias (m/s)
AM	Multipath amplitude (mr)
BM	Multipath B parameter. 2 pi/BM is period.
CM	Multipath C parameter. CM/BM is the phase in radians.

Statistics on the estimation performance are at the end of SECTION 8. The first line is the average difference between the estimated state vector and the initial state vector while the second line is the std. dev. of the difference.

The following pages are examples of SECTION 8 output.

```
                          LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
-----------------------------------------------------------------------------------------------

              SECTION   8 - ESTIMATION STATISTICS (EST-TRUE)
NO          ED          ES    WE   WN   RE    AE    EE    DE    AN       DN           CN

 1    .704691E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .698250E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .644077E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 2    .705662E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .702118E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .354375E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 3    .699769E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .705987E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.621791E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 4    .704946E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .709855E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.490930E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 5    .714591E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .713724E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .867220E-06   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 6    .717946E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .717592E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .354375E-06   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 7    .721396E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .721461E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.646028E-07   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 8    .717070E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .725329E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.825911E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

 9    .731880E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .729197E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .268254E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

10    .754352E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .733066E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .212861E-04   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

11    .735866E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .736934E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.106810E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

12    .721989E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
      .740803E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                  0.
     -.188140E-04   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                  0.

-----------------------------------------------------------------------------------------------
              SECTION  8       03/21/78   15.39.23             PAGE  29
```

```
                      LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
-----------------------------------------------------------------------------------
  NC        KD        KS    WE    WN    RE    AE    FB    DB    AM      BM        CM

  13   .747244E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .744671E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .257263E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  14   .745087E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .748539E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.345199E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  15   .748880E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .752408E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.352774E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  16   .748684E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .756276E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.759224E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  17   .751107E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .760145E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.903763E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  18   .765876E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .764013E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .186241E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  19   .761268E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .767882E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.661375E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.

  20   .769969E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
       .771750E-03   .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.              0.
      -.178109E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.


       ESTIMATION STATISTICS BASED ON  20 OUT OF   20 RUNS

          KD          KS    WE    WN    FB    AE    EB    DB    AM      BM        CM
      -.158639E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.
       .765393E-05  0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.              0.




-----------------------------------------------------------------------------------
         SECTION  8      03/21/78  15.40.02           PAGE  30
```

6.7.9 Section 9 - Launch Point Estimation

This SECTION extrapolates the estimated state vectors to specified conditions allowing:

1. Launch point prediction.
2. Intercept modeling.
3. Impact point prediction.

The output from SECTION 9 is generated by routine SECT09 and is controlled by the OUTPUT 09 data packet.

The various extrapolation options are:

±1	Extrapolate to a specified altitude. A +1 means the post-apogee side of the trajectory while a -1 means pre-apogee.
+2	Extrapolate to a topographic surface. If no terrain map is input the weapon altitude is used. The + specifies post-apogee while the - specifies pre-apogee.
3	Move all state vectors to a specified time.
4	Extrapolate the state vectors to a time increment after time of last track point.

The default option is -2 i.e., compute miss distances at launch.

PRINT DESCRIPTION

The first part of SECTION 9 prints the extrapolation option and alphanumeric description along with the value. In the sample output, option -2 was specified but no topographic map was input hence the option was changed to specified altitude (option -1) which is 30 meters (height).

For each run the estimated and initialization state vector are extrapolated to the same condition and the position component differences are computed. The following is then printed.

MC	Run number
X(M)	X (East) component of miss distance (m)
Y(M)	Y (North) component of miss distance (m)
Z(M)	Z (up) component (m) The miss distance components are the estimated minus the initial positions.
R(M)	Miss distance magnitude (m). SQRT(X*X+Y*Y+Z*Z)
GOOD FIT	0 Good fit 1 Bad fit. The bad fit miss distances are not included in the statistics.

In the sample SECTION 9 output, the estimated state vector was 15.9 m. East and 30.5 m. North of the true launch location for the 11th run.

For all good fits the average and std. dev. of the miss distance components are computed and printed.

The next line contains:

1.	Average R	average miss distance (m)
2.	Sigma R	std. dev. on miss distance (m)
3.	CEP	the median miss distance (m)

GRAPHICS DESCRIPTION

SECTION 9 also produces a file of miss distance components which is subsequently plotted by external program MISSCEPPL when LOCATER has finished execution. The generation of this file is controlled by ITEM #3 of the OUTPUT 09 data packet. If the ITEM is 1 the file is written.

The description of the plot (see sample below) is as follows:

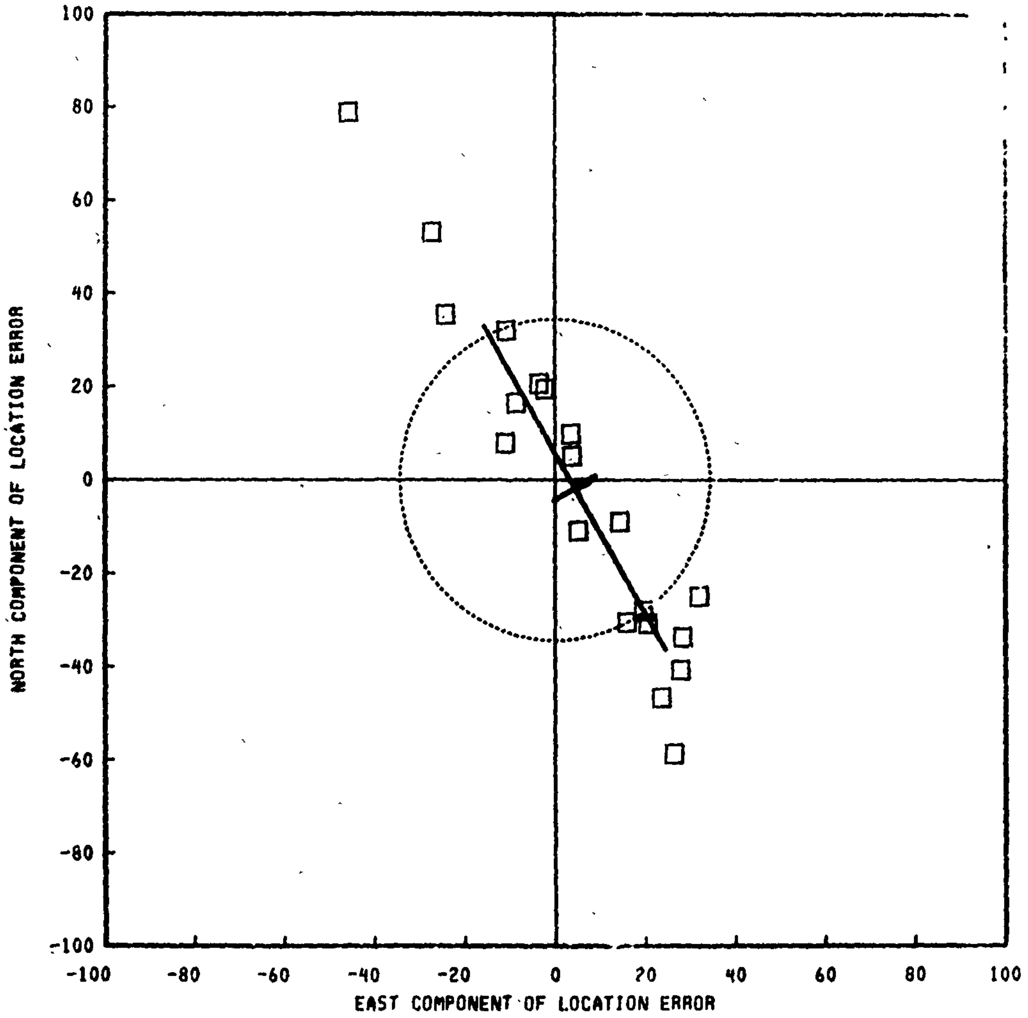
The true weapon launch location is at the coordinates (0,0) where the cross-hair lines intersect. Note that the East direction is horizontal while the North orientation is vertical.

The array of miss distances is then scanned and and appropriate grid size is chosen for either a 100 m., 200 m., 400 m., 1000 m., or 2000 m. square. Each miss distance is then plotted; the symbol used being a small square. If any miss distance is off the scale, it will not be plotted.

The covariance matrix of miss distance components is then generated and diagonalized. The ellipse semi-major, semi-minor axes along with the inclination of the semi-major axis from north is then printed.

A dotted circle with the radius of the median miss distance is then drawn with the center being the true weapon location. This is considered the CEP (circular error probable) of the system.

```
                    LOCATER PROGRAM SAMPLE OUTPUT SECTIONS
---------------------------------------------------------------------------------------
                   SECTION  9 INTERCEPT ROUTINE


     INTERCEPT   1 OPTION -2(SPECIFIED ALTITUDE  )VALUE=     30.00000
                   STATISTICS BASED ON  20 OUT OF  20 RUNS

         MC        X(M)       Y(M)       Z(M)       R(M)    GOOD FIT= 0

          1        26.3      -58.5       -.0        64.1      0
          2        23.6      -46.6       -.0        52.3      0
          3         3.6        9.7       -.0        10.4      0
          4        -3.5       20.5        .0        20.7      0
          5         3.8        5.0       -.0         6.3      0
          6        32.0      -24.9       -.0        40.5      0
          7        19.7      -28.1       -.0        34.3      0
          8        -8.6       16.4        .0        18.5      0
          9       -10.8       31.8        .0        33.6      0
         10        27.8      -40.6       -.0        49.2      0
         11        15.9      -30.5       -.0        34.4      0
         12        14.3       -9.1       -.0        16.9      0
         13        -2.2       19.4        .0        19.5      0
         14         5.2      -10.9       -.0        12.1      0
         15        20.5      -30.8       -.0        37.0      0
         16       -10.9        7.8        .0        13.4      0
         17       -45.8       78.6        .1        91.0      0
         18        28.3      -33.6       -.0        44.0      0
         19       -24.2       35.3        .0        42.8      0
         20       -27.3       53.0        .0        59.6      0

        AVE         4.4       -1.8       -.0
        SIG        40.2        5.3       0.0
        AVERAGE R=      35.0 M, SIGMA R=    20.9 M, CEP       34.3 M









---------------------------------------------------------------------------------------
            SECTION  9      03/21/78  15.40.04          PAGE  31
```



LOCATER PROGRAM SAMPLE OUTPUT SECTIONS

```
COV CEP OF PROB .5=   27.1 M  CEP=   34.4 M
XBAR EAST=    4.4 M   YBAR NORTH=   -1.8 M
ELLIPSE AXIS   MAJOR=   40.2 M   MINOR=    5.3 M   THETA= 149.9 DEG
```

6.8 Plot Descriptor Card

The plot descriptor card (columns 1-80) contains information that uniquely identifies the output plots produced by LOCATER. Suggested content may include:

1. Run number (date or time)
2. RADAR name or parameters
3. # of estimated states
4. Projectile type

The description will be printed at the bottom of each plot page for both the miss distance (section 6.6.9) and the residual plots (section 6.6.7). If the descriptor card is left out of the run deck NO plots will be produced.

7.0 EXAMPLES OF PROGRAM OPERATION

This section exemplifies the application of LOCATER in its various modes of operation. Four demonstration runs have been prepared which are examples of:

Real data analysis	Section 7.1
Complete simulation	Section 7.2
Simulation on an external trajectory	Section 7.3
Multiple radar simulation	Section 7.4

The first three examples consider an instrumentation radar tracking the downleg portion of ten 155 mm howitzer trajectories. The purpose of the examples is to address the suitability of the dynamic model, validate the estimation algorithm and compare the performance of the trajectory estimator using the three similar data bases.

The first set consists of real recorded trajectory measurements, while the second set uses LOCATER's internal dynamics to simulate a trajectory according to the same initial launch conditions as in set 1.

The third set utilizes an external program, A Modified Point Mass Trajectory Simulation (MPMTS),[9] developed by the USA Ballistics Research Laboratory, to similarly generate a trajectory like examples 1 and 2. Gaussian measurement noise errors, characteristic of the radar's real errors, are then determined and added to data sets 2 and 3.

Example 4 addresses the problem of two hemispheric coverage radars in a netted configuration tracking a 105 mm howitzer launched with a low firing quadrant elevation. Statistically modeled bias errors, thermal and jitter errors, along with tropospheric refraction errors are included to corrupt the unerrored trajectory simulated by LOCATER.

For each set of measurements or run in examples 1 to 4, the trajectory which best fits the radar measurements will be determined. The launch point state vector will then be established by extrapolating the fitted state vector to the physical terrain. This process is termed "backtracking".

Two quantities are of paramount importance in the LOCATER REPORT. The first, located in SECTION 6, is "Q TOT" which is the total weighted squared residual error for the estimated trajectory. This may be used in conjunction with the track residuals output of SECTION 7 to determine the quality of fit over different track segments. The second quantity is the miss distance components which are the difference between the estimated launch point state vector and the true weapon location. The array of miss distances for each example are sorted in increasing magnitude, calling the median miss distance the Circular Error Probable (CEP). This is denoted by the dashed circle drawn about the true weapon location in SECTION 9 - PLOT OUTPUT.

The description of each LOCATER output SECTION may be found in section 6.7.

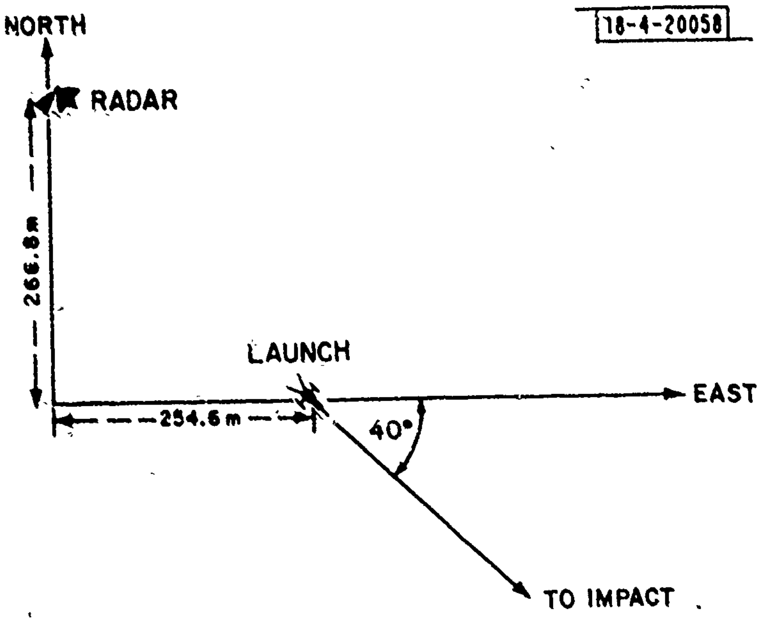
7.1 Real Data Analysis

7.1.1 Problem - Illustration

At Wallops Island, Virginia, in July 1970, a series of trajectory position measurements were taken by the AN/FPS-16[10] instrumentation radar. The data consists of presmoothed range, azimuth and elevation observations every .1 second for twenty-three 155 mm howitzer rounds which were fired with different initial velocities and quadrant elevations. Each projectile was acquired about 3 to 4 seconds after launch.

The test series included ten rounds which were fired with the same initial conditions; quadrant elevation of 700 mils (about 39.4 degrees), an azimuth of fire 130 degrees, and with a muzzle velocity of 564 m/s (charge 7W). See Figure 7-1 for the system geometry, and Table 7-2 for the meteorological conditions.

A subset of the data from 20 seconds to a nominal impact time of 54 seconds at a PRI of 2 seconds was prepared from these 10 rounds. The initial track time was chosen to construct a downleg segment which forces the integration of state vectors through the sonic transition.



WEAPON

TYPE	155-mm HOWITZER
CHARGE	7 W
INITIAL VELOCITY	564 m/sec
QUADRANT ELEVATION	700 mils (3200 mils = π radians)
AZIMUTH OF FIRE	130° CLOCKWISE FROM NORTH
FLIGHT TIME	54 sec
LAUNCH ALTITUDE	3.83 m

RADAR

NAME	AN/FPS-16 INSTRUMENTATION
MEASUREMENTS	RANGE, AZIMUTH, ELEVATION
PRI	0.1 sec
ALTITUDE	14.06 m
LONGITUDE	75.4851° WEST
LATITUDE	37.8413° NORTH

Fig. 7-1. Geometry of Wallops Island tests for demonstration examples 1 to 3. Location of AN/FPS-16 radar and 155 mm howitzer.

RUN DECK PREPARATION

The mandatory data packets for real data analysis include:

MISSION	Section 6.2.6
TRACK	Section 6.2.14
WEAPON	Section 6.2.15
RADAR	Section 6.2.10

Other packets which are necessary to override default values are:

METRO	Section 6.2.5
OUTPUT	Section 6.2.9
ESTIMATOR	Section 6.2.3

The first card in the LOCATER input deck is the TITLE card which for this example is:

AN/FPS-16 155 MM REAL DATA ANALYSIS

Each data packet then follows the TITLE card according to the rules specified in section 6.2. The body of each data packet has been indented so that the packet name card stands out. See the SECTION 1 output for the listing of the LOCATER input data cards.

TAPE PREPARATION

The real data for this example resides on 7 track magnetic tape and was prepared according to the rules specified in section 6.3. The structure is:

Title card of round 1
Time, Range, Azimuth, Elevation in format (1X,2F12.4,2F12.8)
.
.
.
Tape mark (EOF)
Title card of round 2
Measurements of round 2
.
.
.
Tape mark (EOF)
.
.
Title card of round (10)
Measurements of round (10)
.
.
.
Tape mark (EOF)

This tape would be requested as TAPE2 in the control card deck. See section 6.5.2. LOCATER does not reposition the tape so the user must insure that the tape is positioned correctly. The data set for the first round, number 5124, is shown in Table 7-1.

The output from LOCATER for this example follows in section 7.1.2.

TIME (sec)	RANGE (m)	AZIMUTH (rad)	ELEVATION (rad)
20.0000	7624.8768	2.27528652	.48736106
21.0000	7888.5288	2.27546455	.47706205
22.0000	8147.3040	2.27574354	.46645411
23.0000	8402.1168	2. 27595497	.45553377
24.0000	8650.5288	2. 27623597	.44427310
25.0000	8896.5024.	2. 27639479	.43278030
26.0000	9136.6848	2. 27674036	.42104664
27.0000	9374.4288	2. 27760254	.40867770
28.0000	9606.3816	2. 27731456	.39639603
29.0000	9834.3720	2. 27744022	.38377925
30.0000	10059.9240	2. 27794113	.37094083
31.0000	10282.7328	2. 27823259	.25774112
32.0000	10507.4936	2. 27874047	.34434071
33.0000	10718.2920	2. 27903194	.33070992
34.0000	10932.8712	2. 27943161	.31685049
35.0000	11144.7072	2. 27971610	.30276243
36.0000	11355.6288	2. 28015591	.28849809
37.0000	11564.4168	2. 28063936	.27413253
38.0000	11769.2424	2. 28088894	.25925035
39.0000	11976.8112	2. 28136540	.24450606
40.0000	12180.7224	2. 28162022	.22949473
41.0000	12384.9384	2. 28199895	.21429841
42.0000	12587.0208	2. 28247018	.19885995
43.0000	12791.5416	2. 28284018	.18337518
44.0000	12994.2336	2. 28314736	.16766574
45.0000	13197.8400	2. 28365524	.15194931
46.0000	13400.8368	2. 28395368	.13618052
47.0000	13603.8336	2. 28439001	.12003126
48.0000	13808.9640	2. 28466926	.10406700
49.0000	14012.8752	2. 28501832	.08774321
50.0000	14217.3960	2. 28545115	.07161839
51.0000	14423.4408	2. 28564663	.05542200
52.0000	14630.0952	2. 28618592	.03953628
53.0000	14837.9688	2. 28636569	.02370117

TABLE 7-1 AN/FPS-16 Radar Measurements for the first round, #5124.

HEIGHT (meters)	TEMPERATURE (°K)	DENSITY (kg/m^3)	HEIGHT WINDS (meters)	EAST WIND (m/s)	NORTH WIND (m/s)
0.0	300.73	1.16797	0.0	-3.7495	1.1118
304.8	299.83	1.13433	304.8	-2.5638	-1.3424
609.6	297.39	1.10590	609.6	-1.3125	-2.5714
914.4	293.69	1.08120	914.4	-0.1536	-3.0589
1219.2	292.43	1.04967	1219.2	-0.1701	-2.9015
1524.0	290.49	1.02307	1524.0	-0.0444	-2.5546
1828.6	288.63	0.99163	1828.6	-0.3735	-2.4936
2133.6	286.99	0.96250	2133.6	-0.8256	-2.9002
2438.4	285.23	0.93493	2438.4	-1.0068	-3.4127
2743.2	283.73	0.90670	2743.2	-1.0664	-3.5984
3048.0	282.16	0.87890	3048.0	-1.2161	-3.5510
3352.8	280.59	0.85177	3352.8	-1.5483	-3.2232
3657.6	279.19	0.82483	3657.6	-2.0625	-3.1227
3962.4	277.43	0.79957	3962.4	-2.2255	-3.0280
4267.2	276.06	0.78370	4267.2	-2.2891	-3.4152
6096.0	276.06	0.78370	6096.0	-2.2881	-3.4152

Table 7-2 - Layered meteorological conditions for demonstration examples 1 to 3.

7.1.2 Sample Output

```
                AN/FPS-16 155 MM REAL DATA ANALYSIS
---------------------------------------------------------------------------------------

                          ----INPUT DATA CARDS----

                AN/FPS-16 155 MM REAL DATA ANALYSIS
MISSION   01
    $ANALYZE 10 ROUNDS OF REAL DATA TAKEN AT WALLOPS ISLAND,
    VIRGINIA. PROGRAM RUN MODE IS 3 (DATA IS ON TAPE )$
METRO      01  METEOROLOGICAL CONDITIONS FOR ROUNDS 5124 TO 5169
    THE FOLLOWING TABLE IS A LAYERED METEOROLOGICAL MESSAGE.
    THE COLUMNS ARE: 1. HEIGHT(METERS) OF TEMP AND DENSITY
    2. TEMPERATURE (KELVIN), 3. DENSITY (KG/M**3), 4. HEIGHT
    (METERS) OF WINDS, 5. EAST WIND COMPONENT (M/S), 6. NORTH
    WIND COMPONENT.
    $USE TYPE 3 METRO PACKET (LAYERED), THE FORMAT IS $
(6F10.0)
       0.0    300.73   1.16797       0.0   -3.7495    1.1119          1
     304.8    299.83   1.13433     304.8   -2.5638   -1.3424          2
     609.6    297.39   1.10590     609.6   -1.3125   -2.5714          3
     914.4    293.96   1.08120     914.4   -0.1536   -3.0598          4
    1219.2    292.43   1.04967    1219.2    0.1701   -2.9015          5
    1524.0    290.49   1.02037    1524.0   -0.0444   -2.5546          6
    1828.8    288.63   0.99163    1828.8   -0.3735   -2.4936          7
    2133.6    286.99   0.96250    2133.6   -0.8256   -2.9002          8
    2438.4    285.23   0.93493    2438.4   -1.0068   -3.4127          9
    2743.2    283.73   0.90670    2743.2   -1.0664   -3.5984         10
    3048.0    282.16   0.87890    3048.0   -1.2161   -3.5510         11
    3352.8    280.59   0.85177    3352.8   -1.5483   -3.2232         12
    3657.6    279.19   0.82483    3657.6   -2.0625   -3.1227         13
    3962.4    277.43   0.79957    3962.4   -2.2255   -3.0280         14
    4267.2    276.06   0.78370    4267.2   -2.2891   -3.4152         15
    6096.0    276.06   0.78370    6096.0   -2.2891   -3.4152         16

TRACK      01
    $USE WEAPON 1 TRACKED BY RADAR 1 $
WEAPON     01  155 MM HOWITZER
    $TAG TIME OF 0 SECONDS
    POSITIONS ARE 254.62 METERS EAST, -266.833 METERS NORTH,
    AT ALTITUDE OF 3.83 METERS.
    INITIAL VELOCITY IS 564 M/S
    AZIMUTH OF FIRE IS 2311 MILS
    QUADRANT ELEVATION IS 700 MILS
    SHELL DIAMETER .155 METERS, MASS 43.18182 KG
    DRAG FACTOR IS 1.0, DRAG CURVE NUMBER IS 1
    USE METRO CONDITIONS SPECIFIED IN PACKET 1.
    RCS OPTION 0 (CONSTANT) VALUE OF -10 DBSM
    SPIN CONSTANT IS .25 M/SS
    DRAG UNCERTAINTY 0, SPIN UNCERTAINTY 0 $
RADAR      01  AN/FPS-16
    THE AN/FPS-16 IS AN INSTRUMENTATION TYPE RADAR LOCATED
    AT WALLOPS ISLAND, VA.
    $LOCATION IS 0 METERS EAST, 0 METERS NORTH AT ALTITUDE
    14.06 METERS. LONGITUDE 4.965721776 LATITUDE .6604552782
---------------------------------------------------------------------------------------
          SECTION  1      03/21/78  15.20.01          PAGE   1
```

```
                    AN/FPS-16 155 MM REAL DATA ANALYSIS
------------------------------------------------------------------------------
         MEASUREMENT SPACE IS RANGE 1, AZIMUTH 1, ELEVATION 1,
              BUT NO DOPPLER 0 OR SIGNAL NOISE RATIO 0.
         RADAR BIASES 0 METERS RANGE, 0 RADIANS AZIMUTH, 0 RADIANS
              ELEVATION, 0 METERS DOPPLER
         THERMAL ERROR SIGMAS ARE 50 METERS RANGE, .00078 RADIANS AZIMUTH,
              .00078 RADIANS ELEVATION AND 0.0 M/S DOPPLER
         JITTER ERROR SIGMAS ARE 1.344 METERS RANGE, .000037 RADIANS AZIMUTH,
              .000061 RADIANS ELEVATION AND 0.0 M/S DOPPLER
         REFERENCE RANGE( RANGE AT WHICH A ZERO DBSM TARGET RETURNS A SNR OF
              ZERO DB) IS 556000 METERS.
         SNR THRESHOLD IS -13 DB
         FREQUENCY IS 5600000000 HZ, ELEVATION BEAMWIDTH IS .0108 RADIANS.
         NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ,0 RAD EL,0 M/S DOPPLER
         NO REMOVABLE MULTIPATH PARAMETERS  A=0, B=0, C=0  $
     OUTPUT    02  NOMINAL TRAJECTORY
         $GENERATE SECTION TWO,OPTION(1)
         PRINT TRAJECTORY COVERAGE FOR RADAR NUMBER 1 TRACKING
         WEAPON NUMBER 1. THE TRACK INTERVAL IS TO BE
         FROM 20 SECONDS EVERY 1 SECOND TO IMPACT (-999).
         THE PRINTOUT FORMAT IS TO BE IN ECLAF RAE FORMAT 2. THERE IS
         TO BE NO TAPE OUTPUT 0  $
     OUTPUT    03
         $PRINT CONVERGENCE REPORT 1 ONLY FOR THE FIRST RUN 1 $
     OUTPUT    07
         $PRINT TRACK RESIDUALS 1, WRITE THEM TO TAPE 1, FOR
         ALL RUNS 0  $
     OUTPUT    09
         $EXTRAPOLATE THE FITTED STATE VECTORS TO THE GROUND
         OPTION -2 AT LAUNCH 0 METERS. PRODUCE MISS DISTANCE PLOTS 1$
     ESTIMATOR 01
         $USE MAXIMUM LIKELY ESTIMATOR 1, USE RADAR 0 FOR WEIGHT
         COMPUTATION. STATE VECTOR INITIALIZATION IS -3 (USE
         MEASUREMENTS. MAXIMUM NUMBER OF ITERATIONS IS 10,
         CONVERGENCE OPTION 1 (POSITIONAL) VALUE IS .5 METERS.
         NO A PRIORI VALUES 0
         ESTIMATE POSITIONS 1 EAST 1 NORTH 1 HEIGHT
                  VELOCITIES 1 EAST 1 NORTH 1 HEIGHT
                  DRAG, SPIN 1 1
                  NO WIND 0 0
                  BIASES 0 0 0 0
                  MULTIPATH 0 0 0
         $
     END
     (1X,2F12.4,2F12.8)





------------------------------------------------------------------------------
              SECTION  1      03/21/78  15.20.01          PAGE   2
```

```
              AN/FPS-16 155 MM REAL DATA ANALYSIS
-----------------------------------------------------------------------------------
                                  RADAR  1 TRACKING WEAPON  1

   TIME(SEC)   R(M)    AZ(MR)   EL(MR)    RDOT  AZDOT    ELDOT    VEL   SNR(DB)

     20.000  7721.5 2283.28  485.21   269.4      .23  -10.17  280.6  64.29
     21.000  7988.2 2283.52  474.88   264.0      .25  -10.50  277.0  63.71
     22.000  8249.6 2283.78  464.21   258.9      .27  -10.82  273.8  63.15
     23.000  8505.0 2284.06  453.24   254.0      .29  -11.13  271.0  62.61
     24.000  8757.6 2284.36  441.97   249.3      .31  -11.42  268.6  62.11
     25.000  9004.6 2284.68  430.40   244.8      .32  -11.70  266.6  61.62
     26.000  9247.3 2285.00  418.56   240.6      .33  -11.98  264.9  61.16
     27.000  9486.0 2285.[illegible]  406.45   236.6      .34  -12.24  263.6  60.72
     28.000  9720.7 2285.69  394.08   232.9      .36  -12.50  262.7  60.30
     29.000  9951.8 2286.05  381.45   229.4      .36  -12.75  262.2  59.89
     30.000 10179.6 2286.42  368.57   226.1      .37  -13.00  262.0  59.49
     31.000 10404.1 2286.80  355.46   223.1      .38  -13.23  262.2  59.11
     32.000 10625.8 2287.18  342.11   220.3      .39  -13.46  262.7  58.75
     33.000 10844.7 2287.57  328.53   217.7      .39  -13.69  263.5  58.39
     34.000 11061.2 2287.97  314.74   215.3      .40  -13.90  264.6  58.05
     35.000 11275.5 2288.37  300.73   213.2      .40  -14.11  266.1  57.72
     36.000 11487.7 2288.77  286.52   211.4      .41  -14.31  267.8  57.39
     37.000 11698.3 2289.18  272.10   209.7      .41  -14.51  269.8  57.08
     38.000 11907.3 2289.59  257.50   208.3      .41  -14.70  272.1  56.77
     39.000 12115.0 2290.00  242.72   207.1      .41  -14.87  274.6  56.47
     40.000 12321.6 2290.42  227.76   206.2      .42  -15.04  277.3  56.18
     41.000 12527.4 2290.83  212.63   205.4      .42  -15.20  280.2  55.89
     42.000 12732.6 2291.25  197.35   204.9      .42  -15.36  283.3  55.61
     43.000 12937.3 2291.67  181.92   204.6      .42  -15.50  286.6  55.33
     44.000 13141.9 2292.09  166.36   204.6      .42  -15.63  290.0  55.06
     45.000 13346.5 2292.50  150.66   204.7      .42  -15.75  293.5  54.79
     46.000 13551.4 2292.92  134.85   205.0      .42  -15.86  297.1  54.52
     47.000 13756.6 2293.34  118.94   205.5      .41  -15.96  300.8  54.26
     48.000 13962.5 2293.75  102.93   206.2      .41  -16.05  304.6  54.00
     49.000 14169.1 2294.16   86.84   207.1      .41  -16.13  308.4  53.75
     50.000 14376.7 2294.57   70.68   208.1      .41  -16.19  312.3  53.50
     51.000 14585.4 2294.98   54.47   209.3      .41  -16.24  316.1  53.25
     52.000 14795.3 2295.38   38.21   210.5      .40  -16.27  319.8  53.00
     53.000 15006.4 2295.78   21.94   211.7      .40  -16.27  323.3  52.75
     54.000 15218.7 2296.18    5.68   212.7      .40  -16.25  326.2  52.51










-----------------------------------------------------------------------------------
            SECTION  2       03/21/78  15.20.03          PAGE   3
```

```
              AN/FPS-16 155 MM REAL DATA ANALYSIS
------------------------------------------------------------------------
                   SECTION   3  -  ITERATIONS

                   MONTE CARLO RUN NUMBER   1
     X          Y          Z        VX      VY      VZ        KD          KS    WE   WN
    DX         DY         DZ       DVX     DVY     DVZ       DKD         DKS   DWE  DWN
   RB   AB   EB   DB   A         B               C
  DRB  DAB  DEB  DDB  DA        DB              DC          QTOTAL

---- ITERATION   1
    5133.4  -4363.1    3570.7  205.8 -177.0    56.4    .500000E-03  0.00  0.0  0.0
       -4.6       3.8      -2.7    1.5    -.9     1.0   .721475E-04   .22  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.              0.
   0.0  0.0  0.0  0.0  0.0  0.              0.            9274.5932

---- ITERATION   2
    5128.8  -4359.4    3568.0  207.3 -177.9    57.5    .572148E-03   .22  0.0  0.0
       -.0        .0       -.0     .0    -.0      .0    .541523E-06   .00  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.              0.
   0.0  0.0  0.0  0.0  0.0  0.              0.              28.1459

---- ITERATION   3
    5128.8  -4359.3    3568.0  207.3 -177.9    57.5    .572689E-03   .22  0.0  0.0
       1.2      -1.1        .5    -.2     .2     -.0   -.636340E-05   .00  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.              0.
   0.0  0.0  0.0  0.0  0.0  0.              0.              19.8402

---- ITERATION   4
    5130.0  -4360.4    3568.5  207.1 -177.7    57.4    .566326E-03   .23  0.0  0.0
       -.0        .0       -.0     .0    -.0      .0    .934541E-08  -.00  0.0  0.0
   0.0  0.0  0.0  0.0  0.0  0.              0.
   0.0  0.0  0.0  0.0  0.0  0.              0.              18.2106

------------------------------------------------------------------------
          SECTION  3       03/21/78   15.25.50          PAGE   4
```

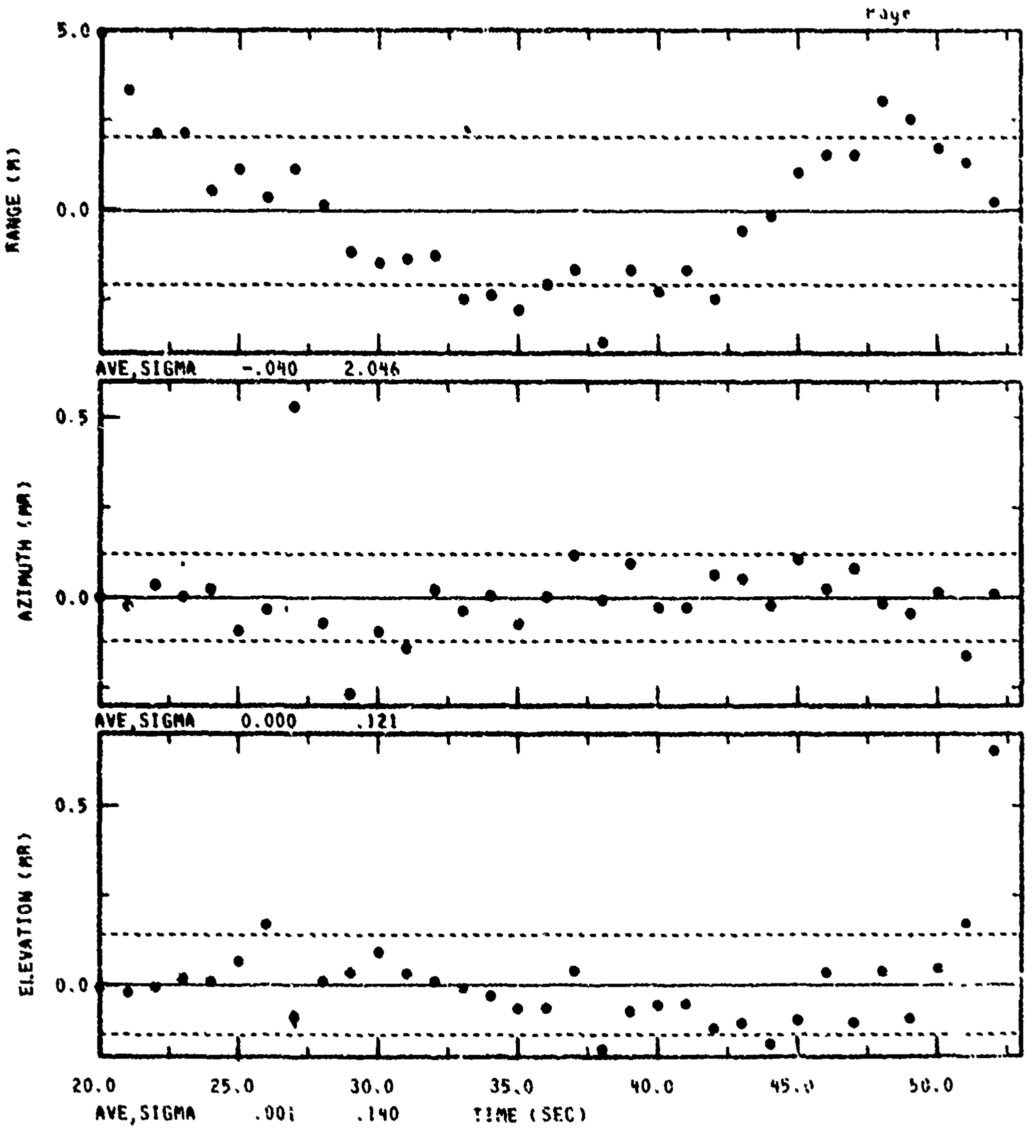
```
              AN/TPS-16 155 MM REAL DATA ANALYSIS
--------------------------------------------------------------------------------

     MEASUREMENTS, WEIGHTS FOR RUN   1

     NPT  TIME     RANGE   AZIMUTH   ELEVTN  DOPPLER   SNR    Q(NPT)
                   WEIGHT  WEIGHT    WEIGHT  WEIGHT   RADAR    DROP

       1  20.000   7624.9 2.275287  .487361      0.00  64.51 13.35068
                 .553E+00 .730E+09 .269E+090.            1        0
       2  21.000   7888.5 2.275465  .477062      0.00  63.92  6.63071
                 .553E+00 .730E+09 .269E+090.            1        0
       3  22.000   8147.3 2.275746  .466454      0.00  63.36  3.34112
                 .553E+00 .730E+09 .269E+090.            1        0
       4  23.000   8402.1 2.275955  .455534      0.00  62.83  2.54443
                 .553E+00 .730E+09 .269E+090.            1        0
       5  24.000   8650.5 2.276236  .444273      0.00  62.32   .52809
                 .553E+00 .730E+09 .269E+090.            1        0
       6  25.000   8896.5 2.276395  .432780      0.00  61.83  8.16152
                 .553E+00 .730E+09 .269E+090.            1        0
       7  26.000   9136.7 2.276740  .421047      0.00  61.37  8.42514
                 .553E+00 .730E+09 .269E+090.            1        0
       8  27.000   9374.4 2.277603  .408678      0.00  60.93205.61660
                 .553E+00 .730E+09 .269E+090.            1        0
       9  28.000   9606.4 2.277315  .396396      0.00  60.50  3.81591
                 .553E+00 .730E+09 .269E+090.            1        0
      10  29.000   9834.4 2.277440  .383779      0.00  60.09 53.21860
                 .553E+00 .730E+09 .269E+090.            1        0
      11  30.000  10059.9 2.277941  .370941      0.00  59.70 10.14647
                 .553E+00 .730E+09 .269E+090.            1        0
      12  31.000  10282.7 2.278233  .357741      0.00  59.32 16.06579
                 .553E+00 .730E+09 .269E+090.            1        0
      13  32.000  10502.5 2.278740  .344341      0.00  58.95  1.28782
                 .553E+00 .730E+09 .269E+090.            1        0
      14  33.000  10718.3 2.279032  .330710      0.00  58.60  4.55044
                 .553E+00 .730E+09 .269E+090.            1        0
      15  34.000  10932.9 2.279432  .316850      0.00  58.25  3.45106
                 .552E+00 .730E+09 .269E+090.            1        0
      16  35.000  11144.7 2.279716  .302762      0.00  57.92  9.33717
                 .552E+00 .730E+09 .269E+090.            1        0
      17  36.000  11355.6 2.280156  .288498      0.00  57.59  3.49422
                 .552E+00 .730E+09 .269E+090.            1        0
      18  37.000  11564.4 2.280639  .274133      0.00  57.28 11.63634
                 .552E+00 .730E+09 .269E+090.            1        0
      19  38.000  11769.2 2.280889  .259250      0.00  56.97 16.59434
                 .552E+00 .730E+09 .269E+090.            1        0
      20  39.000  11976.8 2.281365  .244506      0.00  56.67  9.51268
                 .552E+00 .730E+09 .269E+090.            1        0
      21  40.000  12180.7 2.281620  .229495      0.00  56.38  4.35412
                 .552E+00 .730E+09 .269E+090.            1        0
      22  41.000  12384.9 2.281999  .214298      0.00  56.09  2.93849
                 .552E+00 .730E+09 .269E+090.            1        0
      23  42.000  12587.0 2.282470  .198870      0.00  55.81 10.45647
                 .552E+00 .730E+09 .269E+090.            1        0
--------------------------------------------------------------------------------
           SECTION  4      03/21/78  15.20.26          PAGE   5
```

```
              AN/FPS-16 155 MM REAL DATA ANALYSIS
------------------------------------------------------------------------------

    MEASUREMENTS, WEIGHTS FOR RUN    1

    NPT  TIME      RANGE    AZIMUTH    ELEVTN   DOPPLER    SNR     C(NPT)
                   WEIGHT   WEIGHT    WEIGHT    WEIGHT    RADAR     DROP

     24  43.000   12791.5 2.282840   .183375       0.00   55.53   5.19856
                 .551E+00 .730E+09 .269E+090.              1         0
     25  44.000   12994.2 2.283147   .167666       0.00   55.25   7.75958
                 .551E+00 .729E+09 .269E+090.              1         0
     26  45.000   13197.8 2.283655   .151949       0.00   54.98  11.20866
                 .551E+00 .729E+09 .269E+090.              1         0
     27  46.000   13400.8 2.283954   .136181       0.00   54.72   1.03245
                 .551E+00 .729E+09 .269E+090.              1         0
     28  47.000   13603.8 2.284390   .120031       0.00   54.46   8.85331
                 .551E+00 .729E+09 .269E+090.              1         0
     29  48.000   13809.0 2.284669   .104067       0.00   54.20   5.56927
                 .551E+00 .729E+09 .269E+090.              1         0
     30  49.000   14012.9 2.285018   .087743       0.00   53.94   7.39039
                 .551E+00 .729E+09 .269E+090.              1         0
     31  50.000   14217.4 2.285451   .071618       0.00   53.69   2.25583
                 .550E+00 .729E+09 .269E+090.              1         0
     32  51.000   14423.4 2.285647   .055422       0.00   53.44  27.77243
                 .550E+00 .729E+09 .269E+090.              1         0
     33  52.000   14630.1 2.286186   .039536       0.00   53.19113.65079
                 .550E+00 .729E+09 .269E+090.              1         0
     34  53.000   14838.0 2.286366   .023701       0.00   52.95306.68199
                 .550E+00 .729E+09 .269E+090.              1         4

------------------------------------------------------------------------------
           SECTION  4      03/21/78  15.20.27           PAGE   6
```

```
                 AN/FPS-16 155 MM REAL DATA ANALYSIS
----------------------------------------------------------------------------------------------

      SECTION   5 - STATE COVARIANCE MATRIX AND CORRELATION COEFFICIANTS MC RUN   1

         1  .14663E+00
         2 -.10735E+00  .11155E+00
         3  .45225E-01 -.38459E-01  .70089E-01
         4 -.14614E-01  .98370E-02 -.88235E-03  .26535E-02
         5  .97483E-02 -.11349E-01  .74140E-03 -.16533E-02  .20992E-02
         6 -.14470E-02  .12338E-02 -.37570E-02 -.11331E-03  .95379E-04  .28303E-03
         7 -.21660E-06  .18387E-06  .51031E-07  .56792E-07 -.48027E-07 -.73683E-08
            .16833E-11
         8 -.11337E-03 -.12738E-03 -.51261E-07  .29642E-04  .34437E-04 -.48662E-07
            .57556E-11  .32205E-05

                    STATE NUMBER          STATE
                           1            X POSITION
                           2            Y POSITION
                           3            Z POSITION
                           4            X VELOCITY
                           5            Y VELOCITY
                           6            Z VELOCITY
                           7            DRAG(KD)
                           8            LIFT(KS)

      CORRELATION COEFFICIANTS

         1    1.0000000
         2    -.8394152   1.0000000
         3     .4461017   -.4349528   1.0000000
         4    -.7408629    .5717737   -.0646999   1.0000000
         5     .5556353   -.7416694    .0611226   -.7005019   1.0000000
         6    -.2246190    .2195873   -.8435272   -.1307540    .1237408   1.0000000
         7    -.4359857    .4243397    .1485706    .8497656   -.8079443   -.3375793
              1.0000000
         8    -.1649738   -.2125211   -.0001079    .3206526    .4188271   -.0016118
               .0024720   1.0000000

----------------------------------------------------------------------------------------------
             SECTION  5       03/21/78   15.20.27            PAGE   7
```

```
                AN/FPS-16 155 MM REAL DATA ANALYSIS
------------------------------------------------------------------------------

          SECTION  6 - LAUNCH CONDITIONS AND WEIGHTED RESIDUAL STATISTICS

     RUN  VO     QE     AZF  T FIRE   QR      QA      QE     QRDOT   Q TOT FIT NITER
          M/S    DEG    DEG   SEC

       1 560.3 39.57 129.6      .19  2.313 10.627   5.271   0.000 18.211  0     4
       2 558.2 39.68 129.9      .18   .953  1.779   2.945   0.000  5.678  0     4
       3 562.2 39.65 130.2      .17  1.104   .865   2.491   0.000  4.461  0     4
       4 559.8 39.59 130.2      .20  1.681  4.278   4.304   0.000 10.263  0     4
       5 563.6 39.62 130.2      .19  1.867  5.223   5.200   0.000 12.289  0     4
       6 560.5 39.59 130.3      .19  2.161  3.655  10.044   0.000 15.859  0     4
       7 567.9 39.37 130.3      .25  4.721  6.069  13.762   0.000 24.553  0     4
       8 563.0 39.53 130.3      .20  2.113  1.975   7.993   0.000 12.081  0     4
       9 564.9 39.50 130.2      .21   .842  4.739   2.928   0.000  8.510  0     4
      10 561.0 39.60 130.3      .25  1.939  3.502   5.530   0.000 10.972  0     4


     AVE 562.1 39.57 130.1      .20  1.969  4.271   6.047   0.000 12.288        4.0
     SIG   2.7   .08    .2      .03  1.044  2.623   3.404   0.000  5.687        0.0

     THE ABOVE STATISTICS IS BASED ON  10 OUT OF 10 RUNS













------------------------------------------------------------------------------
              SECTION  6      03/21/78  15.25.50            PAGE   8
```

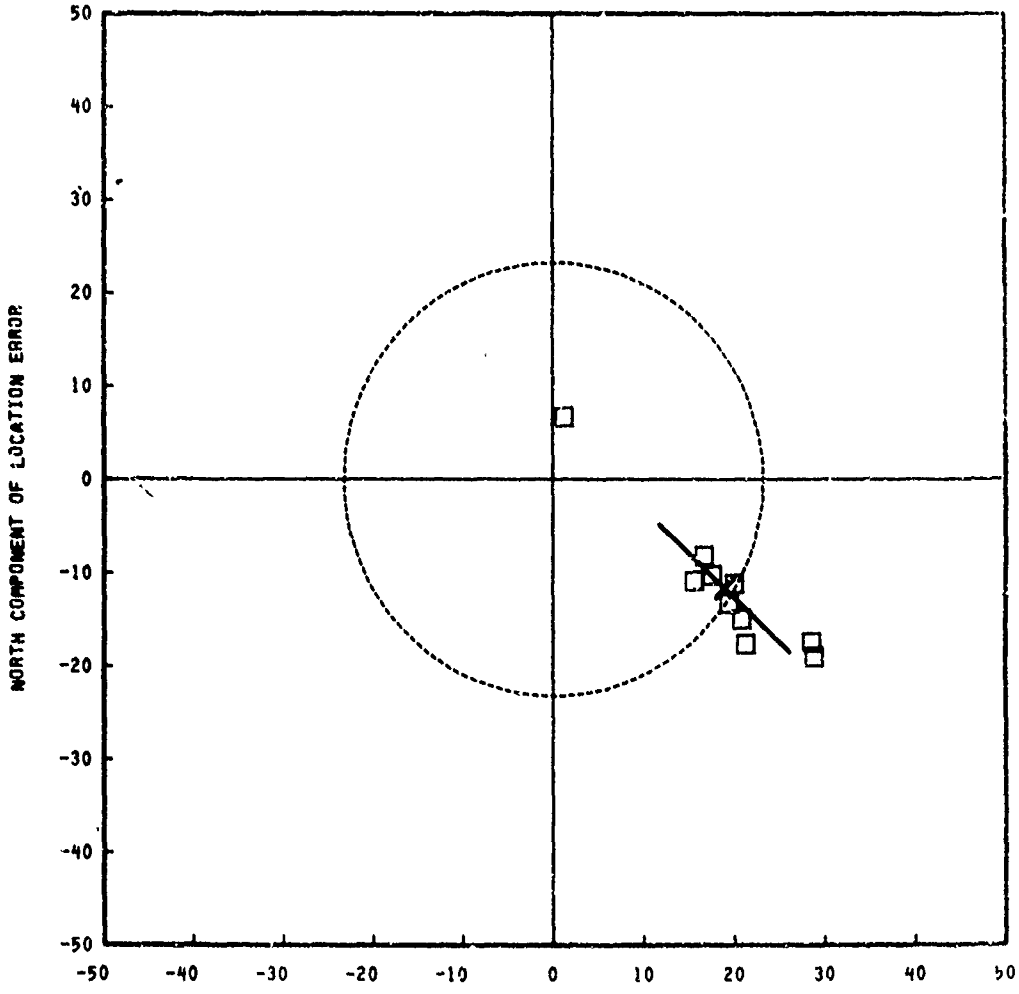
```
                AN/TPS-16 155 MM REAL DATA ANALYSIS
--------------------------------------------------------------------------------
    SECTION    7 - TRACK RESIDUALS FOR RUN NUMBER   1

    NPT  TIME     RM     DR     AM       DA       EM       DE       RRM   DRR   IDRP

      1 20.000  7625.   4.9  2.2753   -.001    .4874   -.009     0.0   0.0    0
      2 21.000  7889.   3.3  2.2755   -.025    .4771   -.022     0.0   0.0    0
      3 22.000  8147.   2.1  2.2757    .033    .4665   -.007     0.0   0.0    0
      4 23.000  8402.   2.1  2.2760    .000    .4555    .017     0.0   0.0    0
      5 24.000  8651.    .5  2.2762    .022    .4443    .009     0.0   0.0    0
      6 25.000  8897.   1.1  2.2764   -.093    .4328    .065     0.0   0.0    0
      7 26.000  9137.    .3  2.2767   -.035    .4210    .167     0.0   0.0    0
      8 27.000  9374.   1.1  2.2776    .527    .4087   -.090     0.0   0.0    0
      9 28.000  9606.    .1  2.2773   -.072    .3964    .009     0.0   0.0    0
     10 29.000  9834.  -1.2  2.2774   -.267    .3838    .033     0.0   0.0    0
     11 30.000 10060.  -1.5  2.2779   -.096    .3709    .090     0.0   0.0    0
     12 31.000 10283.  -1.4  2.2782   -.142    .3577    .030     0.0   0.0    0
     13 32.000 10502.  -1.3  2.2787    .021    .3443    .010     0.0   0.0    0
     14 33.000 10718.  -2.5  2.2790   -.039    .3307   -.009     0.0   0.0    0
     15 34.000 10933.  -2.4  2.2794    .004    .3169   -.032     0.0   0.0    0
     16 35.000 11145.  -2.8  2.2797   -.073    .3028   -.066     0.0   0.0    0
     17 36.000 11356.  -2.1  2.2802    .001    .2885   -.065     0.0   0.0    0
     18 37.000 11564.  -1.7  2.2806    .115    .2741    .038     0.0   0.0    0
     19 38.000 11769.  -3.7  2.2809   -.008    .2593   -.181     0.0   0.0    0
     20 39.000 11977.  -1.7  2.2814    .093    .2445   -.075     0.0   0.0    0
     21 40.000 12181.  -2.3  2.2816   -.029    .2295   -.057     0.0   0.0    0
     22 41.000 12385.  -1.7  2.2820   -.029    .2143   -.054     0.0   0.0    0
     23 42.000 12587.  -2.5  2.2825    .062    .1989   -.123     0.0   0.0    0
     24 43.000 12792.   -.6  2.2828    .051    .1834   -.107     0.0   0.0    0
     25 44.000 12994.   -.2  2.2831   -.023    .1677   -.166     0.0   0.0    0
     26 45.000 13198.   1.0  2.2837    .104    .1519   -.100     0.0   0.0    0
     27 46.000 13401.   1.5  2.2840    .023    .1362    .033     0.0   0.0    0
     28 47.000 13604.   1.5  2.2844    .080    .1200   -.106     0.0   0.0    0
     29 48.000 13809.   3.0  2.2847   -.018    .1041    .037     0.0   0.0    0
     30 49.000 14013.   2.5  2.2850   -.045    .0877   -.095     0.0   0.0    0
     31 50.000 14217.   1.7  2.2855    .014    .0716    .044     0.0   0.0    0
     32 51.000 14423.   1.3  2.2856   -.162    .0554    .170     0.0   0.0    0
     33 52.000 14630.    .2  2.2862    .008    .0395    .650     0.0   0.0    0
     34 53.000 14838.   0.0  2.2864   0.000    .0237   0.000     0.0   0.0    4

                          TRACK RESIDUAL STATISTICS RUN    1

                   RANGE(M)   AZIMUTH(MR)   ELEVATION(MR)   DOPPLER(M/S)

         AVRGE       -.040        .000          .001            0.000
         SIGMA       2.046        .121          .140            0.000




--------------------------------------------------------------------------------
          SECTION  7        03/21/78  15.20.27            PAGE   9
```



+MC 1 DEMONSTRATION RUN 1

```
                AN/FPS-16 155 MM REAL DATA ANALYSIS
---------------------------------------------------------------------------------

              SECTION   8 - ESTIMATION STATISTICS (EST-TRUE)
 MC          KD        KS    WE    WN    FE    AE    EE    DE    AM      BM        CM

  1   .566326E-03    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .663256E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  2   .562591E-03    .22  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .625913E-04    .22  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  3   .565083E-03    .21  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .650827E-04    .21  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  4   .557303E-03    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .573026E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  5   .567288E-03    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .672877E-04    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  6   .565820E-03    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .658198E-04    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  7   .570528E-03    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .705282E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  8   .564491E-03    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .644906E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

  9   .572542E-03    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .725419E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

 10   .557705E-03    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .500000E-03   0.00  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .577054E-04    .24  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.


      ESTIMATION STATISTICS BASED ON  10 OUT OF   10 RUNS

         KD        KS    WE    WN    FE    AE    EE    DE    AM      BM        CM
      .649676E-04    .23  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.
      .462194E-05    .01  0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.               0.

---------------------------------------------------------------------------------
           SECTION  8       03/21/78   15.25.50           PAGE  19
```

```
           AN/FPS-16 155 MM REAL DATA ANALYSIS
-------------------------------------------------------------------------------
                SECTION  9 INTERCEPT ROUTINE

INTERCEPT  1 OPTION -2(SPECIFIED ALTITUDE  )VALUE=      3.83000
                 STATISTICS BASED ON  10 OUT OF  10 RUNS

     MC        X(M)      Y(M)       Z(M)      R(M)   GOOD FIT= 0

      1        19.4     -13.2        -.0      23.5      0
      2        28.8     -19.0        -.0      34.5      0
      3        28.5     -17.5        -.0      33.5      0
      4        20.8     -15.0        -.0      25.7      0
      5        21.2     -17.7        -.0      27.6      0
      6        17.6     -10.3        -.0      20.4      0
      7         1.3       6.6         .0       6.7      0
      8        16.7      -8.2        -.0      18.6      0
      9        15.6     -10.9        -.0      19.0      0
     10        20.0     -11.2        -.0      22.9      0

    AVE        19.0     -11.6        -.0
    SIG         9.9       1.5        0.0
    AVERAGE R=      23.2 M, SIGMA R=     7.6 M, CEP        23.2 M




-------------------------------------------------------------------------------
     SECTION  9       03/21/78  15.26.03           PAGE  20
```



DEMONSTRATION RUN 1
AN/FPS-16 155 MM REAL DATA ANALYSIS

```
COV CEP OF PROB .5=    6.7 M  CEP=   23.2 M
XBAR EAST=   19.0 M   YBAR NORTH=  -11.6 M
ELLIPSE AXIS   MAJOR=    9.9 M   MINOR=    1.5 M   THETA= 133.8 DEG
```

7.1.3 Results Summary

Demonstration example 1 depicts LOCATER working in a real environment. The significant features and results of each output SECTION are noted below.

SECTION 1	This is a listing of the LOCATER input cards.
SECTION 2	This is a simulated trajectory computed by LOCATER according to the nominal launch parameters and system geometry presented in Figure 7-1.
SECTION 3	The state vector convergence criterion, .5 meter in each position, allowed convergence in 2 iterations for the first round (Monte Carlo run number 1). A data edit test was invoked after iteration #2 resulting in 1 measurement being declared bad. The initial perturbation (the line starting with -4.6 3.8 etc.) demonstrates that the initial state vector as computed only from the measurements was very close to the real weapon launch point.
SECTION 4	This section presents the track file: measurement time, measurements and weights, signal noise ratio and weighted track residual for each track time. Measurement #34 with TIME=53 seconds qualified as a bad point from the data editing test as the weighted residual Q=306.7. The SNR is computed as the measured quantity is unavailable.
SECTION 5	The ability to estimate different states of the system depends upon their functional relationship and the radar measuring capabilities. The array of correlation coefficients indicate the degree to which variables are related, hence their separability, with high correlation = +1 and no correlation = 0. The drag state and lift state are relatively independent as CC(8,7) = .002 with drag being the 7th state and lift being the 8th state.
SECTION 6	This section presents launch parameter statistics. The standard deviations of the initial velocities (2.7 m/s), quadrant elevations (.08 degree) and azimuth of fire (.2 degree) indicate the high quality of the gun crew. The increasing of the azimuth of fire is most likely due to barrel repositioning from recoil.
SECTION 7	The standard deviations of the measurement residuals: range (2 m), azimuth (.12 mr) and elevation (.14 mr) indicate the exceptional quality of this data. The last measurement, TIME = 53 seconds, was probably dropped as the projectile splashed or skipped on the water. The range residuals plot indicate a systematic error as the residuals do not exhibit just random noise.
SECTION 8	The std. dev. of the drag estimate based on 10 runs is .462194E-5 which indicates that drag can be estimated to .82%. This error when extrapolated back to the launch point is responsible for most of the location error in the trajectory plane.
SECTION 9	After each trajectory is back extrapolated 20 seconds to the ground, there is a bias of 19.0 meters East and -11.9 meters North for the mean launch location of the howitzer. The equivalent ellipsoid, which is computed by diagonalizing the miss distance covariance matrix, has a semi-major axis of 9.9 m and a semi-minor axis of 1.2 m. The CEP is 23.2 m.

Possible errors which really can not be removed result from (1) radar - weapon surveying inaccuracies, (2) the dynamic model, (3) the radar noise error model, and (4) the meteorological conditions were recorded at every 300 m in altitude which may have been too coarse.

7.2 Complete Simulation

7.2.1 Problem - Illustration

The previous example used LOCATER'S dynamics to estimate a fitted trajectory through real data. The purpose of this run is to explore the effects of substituting the real measurements by simulated measurements. These are produced by extrapolating the state vector (generated from the data in Figure 7-1) to the measurement times, and adding radar noise. All other parameters: the radar model and meteorological conditions (Table 7-2), are identical to the example in section 7.1.

7.2.2 Sample Output

```
              SIMULATION AN/FPS-16 155 MM HOWITZER
------------------------------------------------------------------------------

                          ----INPUT DATA CARDS----

              SIMULATION AN/FPS-16 155 MM HOWITZER
MISSION   01
    $RUN 10 MONTE CARLO RUNS, PROGRAM RUN MODE 1  ( COMPLETE
    SIMULATION)  $
METRO     01  METEOROLOGICAL CONDITIONS FOR ROUNDS 5124 TO 5169
    THE FOLLOWING TABLE IS A LAYERED METEOROLOGICAL MESSAGE.
    THE COLUMNS ARE: 1. HEIGHT(METERS) OF TEMP AND DENSITY
    2. TEMPERATURE (KELVIN), 3. DENSITY (KG/M**3), 4. HEIGHT
    (METERS) OF WINDS, 5. EAST WIND COMPONENT (M/S), 6. NORTH
    WIND COMPONENT.
    $USE TYPE 3 METRO PACKET (LAYERED), THE FORMAT IS $
(6F10.0)
       0.0    300.73   1.16797       0.0    -3.7495    1.1118          1
     304.8    299.83   1.13433     304.8    -2.5638   -1.3424          2
     609.6    297.39   1.10590     609.6    -1.3125   -2.5714          3
     914.4    293.96   1.08120     914.4    -0.1536   -3.0598          4
    1219.2    292.43   1.04967    1219.2     0.1701   -2.9015          5
    1524.0    290.49   1.02037    1524.0    -0.0444   -2.5546          6
    1828.8    288.63   0.99163    1828.8    -0.3735   -2.4936          7
    2133.6    286.99   0.96250    2133.6    -0.8256   -2.9002          8
    2438.4    285.23   0.93493    2438.4    -1.0068   -3.4127          9
    2743.2    283.73   0.90670    2743.2    -1.0664   -3.5984         10
    3048.0    282.16   0.87890    3048.0    -1.2161   -3.5510         11
    3352.8    280.59   0.85177    3352.8    -1.5483   -3.2232         12
    3657.6    279.19   0.82483    3657.6    -2.0625   -3.1227         13
    3962.4    277.43   0.79957    3962.4    -2.2255   -3.0280         14
    4267.2    276.06   0.78370    4267.2    -2.2891   -3.4152         15
    6096.0    276.06   0.78370    6096.0    -2.2891   -3.4152         16

TRACK     01
    $WEAPON PACKET 1, RADAR PACKET 1, 1 INTERVAL,
    TIME OPTION 3 OF 20.0 SECONDS TO TIME OPTION 3 OF 53.0 SECONDS.
    THE PRI IS 1.0 SECONDS.  $
WEAPON    01  155 MM HOWITZER
    $TAG TIME OF 0 SECONDS
    POSITIONS ARE 254.62 METERS EAST, -266.833 METERS NORTH,
    AT ALTITUDE OF 3.83 METERS.
    INITIAL VELOCITY IS 564 M/S
    AZIMUTH OF FIRE IS 2311 MILS
    QUADRANT ELEVATION IS 700 MILS
    SHELL DIAMETER .155 METERS, MASS 43.18182 KG
    DRAG FACTOR IS 1.0, DRAG CURVE NUMBER IS 1
    USE METRO CONDITIONS SPECIFIED IN PACKET 1.
    RCS OPTION 0 (CONSTANT) VALUE OF -10 DBSM
    SPIN CONSTANT IS .25 M/SS
    DRAG UNCERTAINTY 0, SPIN UNCERTAINTY 0 $
RADAR     01  AN/FPS-16
    THE AN/FPS-16 IS AN INSTRUMENTATION TYPE RADAR LOCATED
    AT WALLOPS ISLAND, VA.
------------------------------------------------------------------------------
            SECTION  1      03/21/78  15.31.17          PAGE   1
```

```
               SIMULATION AN/FPS-16 155 MM HOWITZER
-----------------------------------------------------------------------------
     $LOCATION IS 0 METERS EAST, 0 METERS NORTH AT ALTITUDE
     14.06 METERS. LONGITUDE 4.965721776 LATITUDE .6604552782
     MEASUREMENT SPACE IS RANGE 1, AZIMUTH 1, ELEVATION 1,
           BUT NO DOPPLER 0 OR SIGNAL NOISE RATIO 0.
     RADAR BIASES 0 METERS RANGE, 0 RADIANS AZIMUTH, 0 RADIANS
          ELEVATION, 0 METERS DOPPLER
     THERMAL ERROR SIGMAS ARE 50 METERS RANGE, .00078 RADIANS AZIMUTH,
          .00078 RADIANS ELEVATION AND 0.0 M/S DOPPLER
     JITTER ERROR SIGMAS ARE 1.344 METERS RANGE, .000037 RADIANS AZIMUTH,
          .000061 RADIANS ELEVATION AND 0.0 M/S DOPPLER
     REFERENCE RANGE( RANGE AT WHICH A ZERO DBSM TARGET RETURNS A SNR OF
          ZERO DB) IS 556000 METERS.
     SIGNAL NOISE RATIO THRESHOLD IS 13 DB
     FREQUENCY IS 5600000000 HZ, ELEVATION BEAMWIDTH IS .0108 RADIANS.
     NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ,0RAD EL,0 M/S DOPPLER
     NO REMOVABLE MULTIPATH PARAMETERS  A=0, B=0, C=0  $
 OUTPUT     03
     $PRINT CONVERGENCE REPORT 1 ONLY FOR THE FIRST RUN 1 $
 OUTPUT     07
     $PRINT TRACK RESIDUALS 1, WRITE THEM TO TAPE 1, FOR
     ALL RUNS 0  $
 OUTPUT     09
     $EXTRAPOLATE THE FITTED STATE VECTORS TO THE GROUND
     OPTION -2 AT LAUNCH 0 METERS. PRODUCE MISS DISTANCE PLOTS 1$
 ESTIMATOR 01
     $USE MAXIMUM LIKELY ESTIMATOR 1, USE RADAR 0 FOR WEIGHT
     COMPUTATION. STATE VECTOR INITIALIZATION IS -1 (USE
     TRUE STATE VECTOR). MAXIMUM NUMBER OF ITERATIONS IS 10,
     CONVERGENCE OPTION 1 (POSITIONAL) VALUE IS .5 METERS.
     NO A PRIORI VALUES 0
     ESTIMATE POSITIONS 1 EAST 1 NORTH 1 HEIGHT
              VELOCITIES 1 EAST 1 NORTH 1 HEIGHT
              DRAG, SPIN 1 1
              NO WIND 0 0
              BIASES 0 0 0 0
              MULTIPATH 0 0 0
     $
 END




-----------------------------------------------------------------------------
         SECTION  1       03/21/78  15.31.17           PAGE   2
```

```
                SIMULATION AN/FPS-16 155 MM HOWITZER
------------------------------------------------------------------------------------
                   SECTION   3  -  ITERATIONS

                   MONTE CARLO RUN NUMBER    1
     X          Y          Z        VX      VY       VZ          KD          KS     WE    WN
    DX         DY         DZ       DVX     DVY      DVZ         DKD         DKS    DWE   DWN
   FB    AE    EB    DE    A          B                C
  DFB   DAE   DEB   DDE   DA         DB               DC           QTOTAL

---- ITERATION    1
    5168.7  -4465.0    3601.3  207.0 -180.9    56.2   .556368E-03    .25  0.0  0.0
        .2       -.6       -.1     .0     .1      .0   .217552E-06    .00  0.0  0.0
   0.0   0.0   0.0   0.0   0.0  0.              0.
   0.0   0.0   0.0   0.0   0.0  0.              0.              3.3231

---- ITERATION    2
    5168.9  -4465.7    3601.2  207.0 -180.9    56.2   .556586E-03    .25  0.0  0.0
        .0       -.0       -.0    -.0     .0      .0  -.114717E-09    .00  0.0  0.0
   0.0   0.0   0.0   0.0   0.0  0.              0.
   0.0   0.0   0.0   0.0   0.0  0.              0.              3.0137

---- ITERATION    3
    5168.9  -4465.7    3601.2  207.0 -180.9    56.2   .556586E-03    .25  0.0  0.0
       -.0        .0       -.0     .0    -.0     -.0   .622980E-13    .00  0.0  0.0
   0.0   0.0   0.0   0.0   0.0  0.              0.
   0.0   0.0   0.0   0.0   0.0  0.              0.              3.0137























------------------------------------------------------------------------------------
              SECTION  3      03/21/78  15.32.53          PAGE   3
```

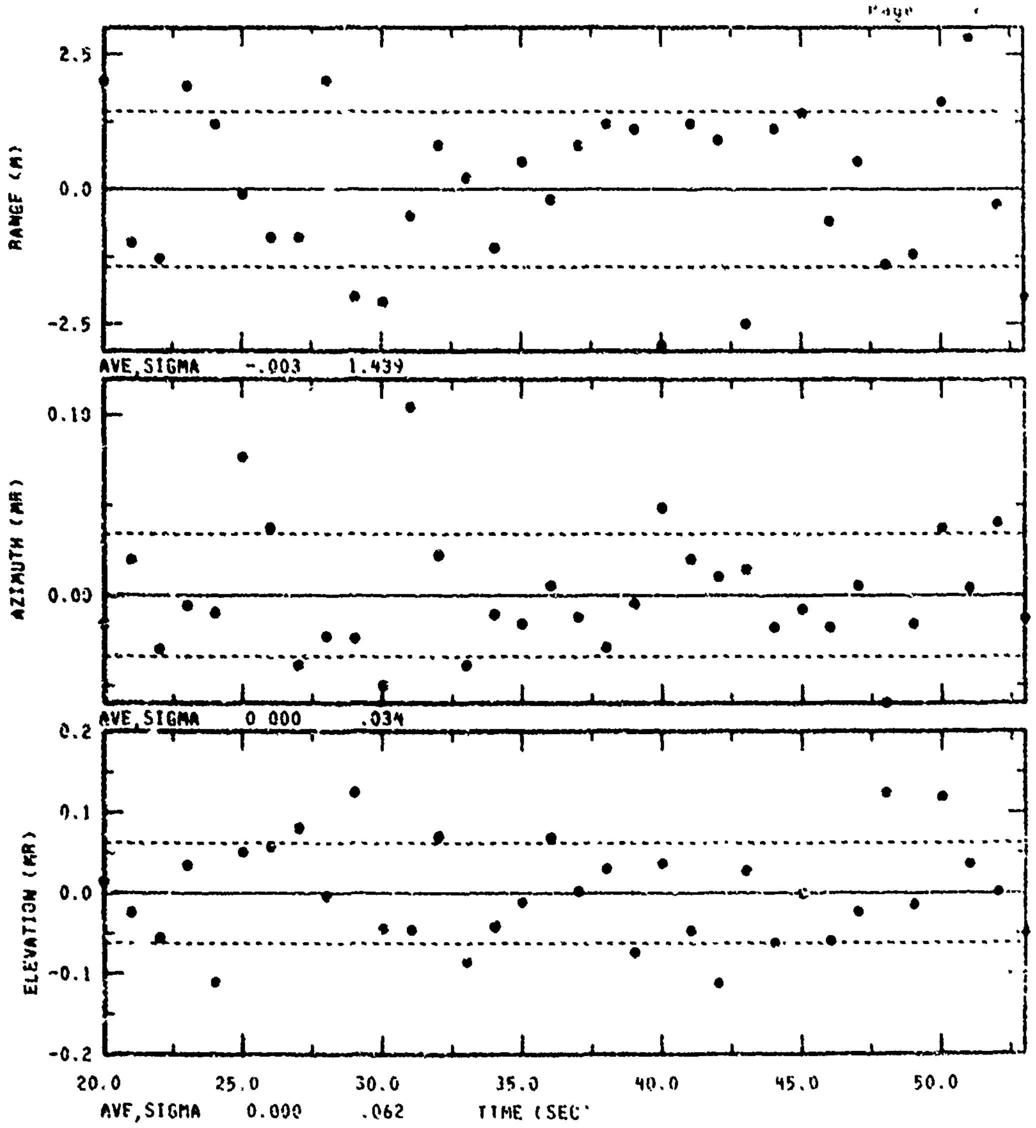
```
                    SIMULATION AN/FPS-16 155 MM HOWITZER
---------------------------------------------------------------------------

      MEASUREMENTS, WEIGHTS FOR RUN    1

      NPT  TIME     RANGE   AZIMUTH    ELEVTN  DOPPLER   SNR      (NPT)
                   WEIGHT   WEIGHT    WEIGHT   WEIGHT   RADAR     DROP

        1  20.000   7724.0 2.283312   .485184   269.41  64.29  2.44766
                 .553E+00 .730E+09 .269E+090.             1        0
        2  21.000   7987.7 2.283581   .474813   264.03  63.71   .93739
                 .553E+00 .730E+09 .269E+090.             1        0
        3  22.000   8248.8 2.283789   .464124   258.87  63.15  2.36869
                 .553E+00 .730E+09 .269E+090.             1        0
        4  23.000   8508.3 2.284089   .453243   253.96  62.61  2.32214
                 .553E+00 .730E+09 .269E+090.             1        0
        5  24.000   8759.2 2.284378   .441827   249.28  62.11  4.14151
                 .553E+00 .730E+09 .269E+090.             1        0
        6  25.000   9004.9 2.284773   .430428   244.83  61.62  4.90821
                 .553E+00 .730E+09 .269E+090.             1        0
        7  26.000   9246.7 2.285057   .418596   240.62  61.16  2.39294
                 .553E+00 .730E+09 .269E+090.             1        0
        8  27.000   9485.3 2.285316   .406511   236.64  60.72  3.33964
                 .553E+00 .730E+09 .269E+090.             1        0
        9  28.000   9723.0 2.285680   .394055   232.90  60.30  2.48053
                 .553E+00 .730E+09 .269E+090.             1        0
       10  29.000   9950.1 2.286035   .381557   229.39  59.89  6.84811
                 .553E+00 .730E+09 .269E+090.             1        0
       11  30.000  10177.7 2.286375   .368516   226.11  59.49  4.89319
                 .553E+00 .730E+09 .269E+090.             1        0
       12  31.000  10403.8 2.286904   .355401   223.07  59.11  8.57106
                 .553E+00 .730E+09 .269E+090.             1        0
       13  32.000  10626.8 2.287204   .342169   220.26  58.75  2.04520
                 .553E+00 .730E+09 .269E+090.             1        0
       14  33.000  10845.1 2.287532   .328440   217.68  58.39  3.06679
                 .553E+00 .730E+09 .269E+090.             1        0
       15  34.000  11060.2 2.287954   .314691   215.34  58.05  1.23512
                 .552E+00 .730E+09 .269E+090.             1        0
       16  35.000  11276.1 2.288348   .300713   213.23  57.72   .37815
                 .552E+00 .730E+09 .269E+090.             1        0
       17  36.000  11487.6 2.288773   .286581   211.36  57.39  1.28161
                 .552E+00 .730E+09 .269E+090.             1        0
       18  37.000  11699.1 2.289163   .272105   209.72  57.08   .44829
                 .552E+00 .730E+09 .269E+090.             1        0
       19  38.000  11908.4 2.289556   .257531   208.31  56.77  1.62459
                 .552E+00 .730E+09 .269E+090.             1        0
       20  39.000  12116.0 2.289994   .242643   207.13  56.47  2.13426
                 .552E+00 .730E+09 .269E+090.             1        0
       21  40.000  12318.6 2.290461   .227794   206.17  56.18  6.58113
                 .552E+00 .730E+09 .269E+090.             1        0
       22  41.000  12528.5 2.290850   .212587   205.44  55.89  1.65610
                 .552E+00 .730E+09 .269E+090.             1        0
       23  42.000  12733.4 2.291258   .197241   204.94  55.61  3.91303
                 .552E+00 .730E+09 .269E+090.             1        0
---------------------------------------------------------------------------
              SECTION  4       03/21/78  15.31.27           PAGE    4
```

```
                SIMULATION AN/FPS-16 155 MM HOWITZER
-------------------------------------------------------------------------------

     MEASUREMENTS, WEIGHTS FOR RUN    1

     NPT  TIME     RANGE    AZIMUTH    ELEVTN   DOPPLER    SNR    C(NPT)
                  WEIGHT    WEIGHT     WEIGHT   WEIGHT    RADAR    DROP

      24  43.000  12934.6 2.291680   .181953    204.64  55.33  3.88078
                 .551E+00 .730E+09 .269E+090.               1        0
      25  44.000  13142.8 2.292067   .166298    204.56  55..    .92583
                 .551E+00 .729E+09 .269E+090.               1        0
      26  45.000  13347.7 2.292495   .150666    204.69  54.79  1.18368
                 .551E+00 .729E+09 .269E+090.               1        0
      27  46.000  13550.5 2.292903   .134799    205.01  54.52  1.37581
                 .551E+00 .729E+09 .269E+090.               1        0
      28  47.000  13756.8 2.293342   .118921    205.53  54.26   .31398
                 .551E+00 .729E+09 .269E+090.               1        0
      29  48.000  13960.7 2.293692   .103059    206.23  54.00  7.77663
                 .551E+00 .729E+09 .269E+090.               1        0
      30  49.000  14167.5 2.294148   .086832    207.10  53.75  1.07796
                 .550E+00 .729E+09 .269E+090.               1        0
      31  50.000  14377.9 2.294611   .070806    208.13  53.50  6.13165
                 .550E+00 .729E+09 .269E+090.               1        0
      32  51.000  14587.8 2.294986   .054510    209.28  53.25  4.64292
                 .550E+00 .729E+09 .269E+090.               1        0
      33  52.000  14794.5 2.295427   .038222    210.51  53.00  1.20972
                 .550E+00 .729E+09 .269E+090.               1        0
      34  53.000  15003.9 2.295777   .021900    211.71  52.75  2.93251
                 .550E+00 .729E+09 .269E+090.               1        0

-------------------------------------------------------------------------------
              SECTION  4       03/21/78   15.31.28           PAGE    5
```

```
                SIMULATION AN/FPS-16 155 MM HOWITZER
------------------------------------------------------------------------

    SECTION   5 - STATE COVARIANCE MATRIX AND CORRELATION COEFFICIANTS MC RUN   1

       1  .14168E+00
       2 -.10465E+00  .11091E+00
       3  .42580E-01 -.36802E-01  .69038E-01
       4 -.13717E-01  .92609E-02 -.68170E-03  .24164E-02
       5  .91646E-02 -.10938E-01  .57837E-03 -.14987E-02  .19615E-02
       6 -.12054E-02  .10449E-02 -.36426E-02 -.13543E-03  .11610E-03  .27337E-03
       7 -.19309E-06  .16668E-06  .49342E-07  .49141E-07 -.42245E-07 -.72773E-08
          .14016E-11
       8 -.11167E-03 -.11995E-03  .18093E-06  .28377E-04  .31711E-04 -.92081E-07
          .13285E-10  .29362E-05

                        STATE NUMBER          STATE
                             1              X POSITION
                             2              Y POSITION
                             3              Z POSITION
                             4              X VELOCITY
                             5              Y VELOCITY
                             6              Z VELOCITY
                             7              DRAG(KD)
                             8              LIFT(KS)

    CORRELATION COEFFICIANTS

       1    1.0000000
       2    -.8347892   1.0000000
       3     .4305359   -.4205665   1.0000000
       4    -.7413319    .5656870   -.0527794   1.0000000
       5     .5497485   -.7415887    .0497013   -.6883993   1.0000000
       6    -.1936864    .1897636   -.8384732   -.1666327    .1585495   1.0000000
       7    -.4332952    .4227436    .1586211    .8443964   -.8056962   -.3717716
            1.0000000
       8    -.1731409   -.2101909    .0004019    .3368950    .4178556   -.0032501
             .0065487   1.0000000
```

```
          SIMULATION AN/FPS-16 155 MM HOWITZER
-------------------------------------------------------------------------------

       SECTION  6 - LAUNCH CONDITIONS AND WEIGHTED RESIDUAL STATISTICS

 RUN  VO     QE     AZF   T FIRE   QR      QA      QE    QRDOT   Q TOT FIT NITER
      M/S    DEG    DEG    SEC

   1 564.0 39.38 130.0     .00   1.143    .831   1.040   0.000   3.014  0     3
   2 563.2 39.40 130.0    -.01    .905   1.392    .770   0.000   3.067  0     2
   3 564.0 39.38 130.0    -.00    .847    .840    .877   0.000   2.564  0     3
   4 564.3 39.36 130.0     .00   1.322    .804    .689   0.000   2.815  0     3
   5 564.3 39.37 130.0     .00   1.290   1.014    .665   0.000   2.970  0     2
   6 563.2 39.40 130.0    -.00    .871   1.326    .533   0.000   2.731  0     2
   7 565.0 39.34 130.0     .01   1.253    .989    .856   0.000   3.099  0     2
   8 564.9 39.34 130.0     .01    .844   1.183   1.139   0.000   3.166  0     2
   9 562.9 39.41 130.0    -.01   1.015   1.008    .960   0.000   2.983  0     3
  10 563.1 39.41 130.0    -.01    .659   1.013    .919   0.000   2.591  0     3


 AVE 563.9 39.38 130.0    -.00   1.015   1.040    .845   0.000   2.900       2.5
 SIG    .7   .02    .0     .01    .214    .192    .174   0.000    .202        .5

 THE ABOVE STATISTICS IS BASED ON  10 OUT OF 10 RUNS




-------------------------------------------------------------------------------
          SECTION  6      03/21/78  15.32.53          PAGE   7
```

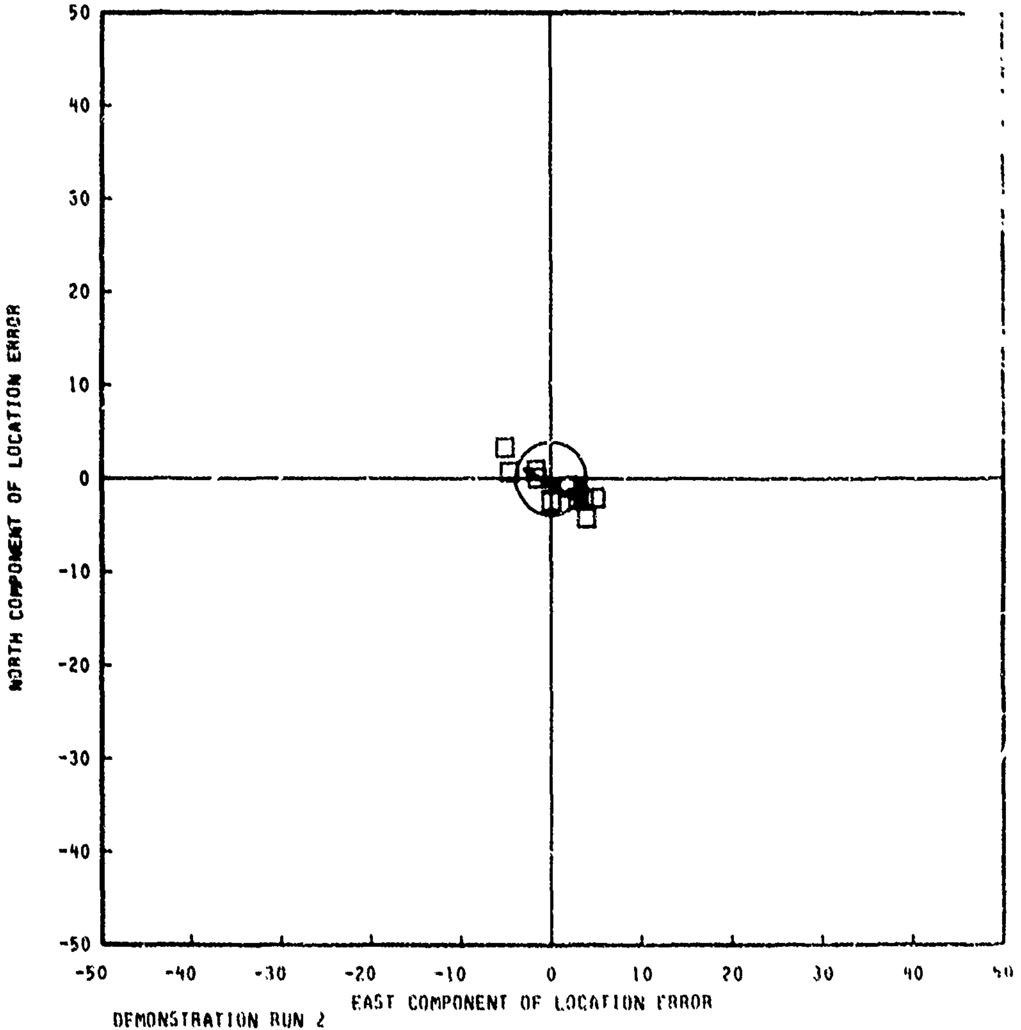
```
                SIMULATION AN/FPS-16 155 MM HOWITZER
-----------------------------------------------------------------------------------------
    SECTION    7 - TRACK RESIDUALS FOR RUN NUMBER    1

    NPT  TIME      RM    DR      AM        DA       EM         DE       REM    DRR    IDRP

      1 20.000   7724.   2.0  2.2833    -.016    .4952      .014   269.4    0.0     0
      2 21.000   7988.  -1.0  2.2836     .019    .4748     -.035   264.0    0.0     0
      3 22.000   8249.  -1.3  2.2838    -.030    .4641     -.056   258.9    0.0     0
      4 23.000   8508.   1.9  2.2841    -.006    .4532      .034   254.0    0.0     0
      5 24.000   8759.   1.2  2.2844    -.010    .4418     -.111   249.3    0.0     0
      6 25.000   9005.   -.1  2.2848     .076    .4304      .050   244.8    0.0     0
      7 26.000   9247.   -.9  2.2851     .037    .4186      .057   240.6    0.0     0
      8 27.000   9485.   -.9  2.2053    -.039    .4065      .080   236.6    0.0     0
      9 28.000   9723.   2.0  2.2857    -.023    .3941     -.004   232.9    0.0     0
     10 29.000   9950.  -2.0  2.2860    -.024    .3816      .124   229.4    0.0     0
     11 30.000  10178.  -2.1  2.2864    -.050    .3685     -.044   226.1    0.0     0
     12 31.000  10404.   -.5  2.2869     .104    .3554     -.046   223.1    0.0     0
     13 32.000  10627.    .8  2.2872     .022    .3422      .070   220.3    0.0     0
     14 33.000  10845.    .2  2.2875    -.039    .3284     -.085   217.7    0.0     0
     15 34.000  11060.  -1.1  2.2880    -.011    .3147     -.041   215.3    0.0     0
     16 35.000  11276.    .5  2.2883    -.016    .3007     -.012   213.2    0.0     0
     17 36.000  11488.   -.2  2.2888     .005    .2866      .068   211.4    0.0     0
     18 37.000  11699.    .8  2.2892    -.012    .2721      .002   209.7    0.0     0
     19 38.000  11908.   1.2  2.2896    -.029    .2575      .030   208.3    0.0     0
     20 39.000  12116.   1.1  2.2900    -.005    .2426     -.074   207.1    0.0     0
     21 40.000  12319.  -2.9  2.2905     .040    .2278      .036   206.2    0.0     0
     22 41.000  12528.   1.2  2.2908     .020    .2126     -.047   205.4    0.0     0
     23 42.000  12733.    .9  2.2913     .010    .1972     -.112   204.9    0.0     0
     24 43.000  12935.  -2.5  2.2917     .014    .1820      .027   204.6    0.0     0
     25 44.000  13143.   1.1  2.2921    -.018    .1663     -.062   204.5    0.0     0
     26 45.000  13348.   1.4  2.2925    -.008    .1507     -.001   204.7    0.0     0
     27 46.000  13551.   -.6  2.2929    -.010    .1348     -.060   205.0    0.0     0
     28 47.000  13757.    .5  2.2933     .005    .1189     -.024   205.5    0.0     0
     29 48.000  13961.  -1.4  2.2937    -.060    .1031      .123   206.2    0.0     0
     30 49.000  14167.  -1.2  2.2941    -.016    .0868     -.014   207.1    0.0     0
     31 50.000  14378.   1.6  2.2946     .037    .0708      .118   208.1    0.0     0
     32 51.000  14588.   2.8  2.2950     .004    .0545      .036   209.3    0.0     0
     33 52.000  14795.   -.3  2.2954     .040    .0382      .001   210.5    0.0     0
     34 53.000  15004.  -2.0  2.2958    -.013    .0219     -.049   211.7    0.0     0

                       TRACK RESIDUAL STATISTICS RUN    1

                  RANGE(M)   AZIMUTH(MR)   ELEVATION(MR)   DOPPLER(M/S)

         AVRGE     -.003         .000          .000            0.000
         SIGMA     1.439         .034          .062            0.000




-----------------------------------------------------------------------------------------
              SECTION  7       03/21/78   15.31.28            PAGE    8
```



FMC 1 DEMONSTRATION RUN 2

```
           SIMULATION AN/FPS-16 155 MM HOWITZER
-------------------------------------------------------------------------------

             SECTION   8 - ESTIMATION STATISTICS (EST-TRUE)
 MC        KD         KS    WE    WN    RE    AE    EB    DB    AM     BM        CM

  1   .556586E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .217438E-06   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  2   .554984E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
     -.138417E-05  -.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  3   .556619E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .250664E-06  -.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  4   .556974E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .605175E-06   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  5   .556943E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .574574E-06   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  6   .554895E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
     -.147293E-05  -.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  7   .558052E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .168310E-05   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  8   .557870E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .150207E-05   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  9   .554390E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
     -.197813E-05   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

 10   .554872E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .556368E-03   .25   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
     -.149632E-05  -.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.


      ESTIMATION STATISTICS BASED ON  10 OUT OF   10 RUNS

           KD         KS    WE    WN    RE    AE    EB    DB    AM     BM        CM
     -.149853E-06   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
      .126129E-05   .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

-------------------------------------------------------------------------------
         SECTION  8      03/21/78  15.32.53          PAGE  18
```

```
              SIMULATION AN/FPS-16 155 MM HOWITZER
-----------------------------------------------------------------------------
                 SECTION  9 INTERCEPT ROUTINE

     INTERCEPT  1 OPTION -2(SPECIFIED ALTITUDE  )VALUE=      3.83000
                  STATISTICS BASED ON  10 OUT OF  10 RUNS

       MC        X(M)      Y(M)       Z(M)       R(M)    GOOD FIT= 0

        1         -.0      -2.3         .0        2.3      0
        2         3.6      -2.1        -.0        4.2      0
        3         1.9       -.9         .0        2.1      0
        4        -1.6        .9         .0        1.9      0
        5        -1.5        .1         .0        1.5      0
        6         2.9      -2.2        -.0        3.7      0
        7        -5.1       3.3         .0        6.0      0
        8        -4.6        .7         .0        4.7      0
        9         3.9      -4.2        -.0        5.8      0
       10         4.9      -2.1        -.0        5.3      0

      AVE          .4       -.9         .0
      SIG         3.9        .9        0.0
      AVERAGE R=      3.7 M, SIGMA R=     1.6 M, CEP        3.9 M




-----------------------------------------------------------------------------
          SECTION  9      03/21/78  15.32.58          PAGE  19
```



```
     DEMONSTRATION RUN 2
     SIMULATION AN/FPS-16 155 MM HOWITZER

COV CEP OF PROB .5=    2.7 M  CEP=    3.9 M
XBAR EAST=     .4 M  YBAR NORTH=    -.9 M
ELLIPSE AXIS   MAJOR=    3 8 M   MINOR=     .9 M   THETA= 119.5 DEG
```

7.2.3 Results Summary

The track residuals, SECTION 7, shows the standard deviations in range to be 1.4 m, azimuth .034 mr, and elevation .062 mr for the first monte carlo run. This is to be expected by referring to the radar model in SECTION 1 output. The track residual standard deviations from example 1 show larger errors: 4 to 1 in azimuth and 2 to 1 in elevation. This could be the result of (1) not adding enough radar noise in example 2 or (2) the inadequacy of the dynamic model. Also, note that the track residuals have only characteristic random noise with no systematic errors present.

The drag estimate based on 10 runs is .23% as compared to .82% for example 1. This indicates that the launch point position estimations in example 2 should have approximately a 30% decrease in the semi-major axis ellipsoid length. One would therefore expect 30% of 9.9 m = 3 meters. The results in SECTION 9 shows a semi-major axis of 3.9 m - a much tighter grouping.

The mean launch location errors are relatively unbiased, .4 m East and -.9 m North based on 10 runs. The CEP for this example is 3.9 meters.

7.3 Simulation With External Trajectory

7.3.1 Problem Illustration

In the design of LOCATER it was imperative that comparisons could be made of the internal dynamics and other dynamic models, e.g., 3 degrees of freedom modified point mass simulation or a 6 degree of freedom rigid body simulation. This run mode of LOCATER as presented in section 6.4 would help differentiate between radar model errors and dynamic model errors assuming that the higher level dynamics are in fact a closer representation of real data.

The alternate simulation used in this example is the Modified Point Mass Trajectory Simulation (MPMTS)[9] developed by the USA Ballistics Research Laboratory. This program is chiefly used for generation of the ARMY Firing tables which contain final trajectory range data for a matrix of charges and firing quadrant elevations for domestic weapons.

The MPMTS is executed using the weapon launch parameters from Fig. 7-1 and meteorological conditions from Table 7-1. The output from MPMTS, time, positions, and velocities is then placed in the LOCATER input card deck (see SECTION 1) according to rules specified in section 6.4.

Ten Monte Carlo runs on this trajectory will be simulated; the difference between each is the random radar noise.

7.3.2 Sample Output

```
               AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
-------------------------------------------------------------------------------------

                              ----INPUT DATA CARDS----

               AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
MISSION    01
    THE PURPOSE OF THIS RUN IS TO COMPARE THE EFFECTS OF USING
    DIFFERENT DYNAMICS FOR MEASUREMENT GENERATION AND TRAJECTORY
    ESTIMATION.  THE SOURCE OF THE EXTERNAL TRAJECTORY IS FROM THE
    BALLISTICS RESEARCH LABORATORY'S MODIFIED POINT MASS TRAJECTORY
    SIMULATION. THE INPUT DATA TIME , POSITIONS X,Y,Z, VELOCITIES
    XDOT ,YDOT,ZDOT FOLLOW THE LOCATER INPUT DATA DECK ON CARDS.

    $ RUN 10 MONTE CARLO RUNS, SIMULATION ON AN EXTERNALLY INPUT
    TRAJECTORY  (MODE -2) WITH DATA ON CARDS $
METRO      01  METEOROLOGICAL CONDITIONS FOR ROUNDS 5124 TO 5169
    THE FOLLOWING TABLE IS A LAYERED METEOROLOGICAL MESSAGE.
    THE COLUMNS ARE: 1. HEIGHT(METERS) OF TEMP AND DENSITY
    2. TEMPERATURE (KELVIN), 3. DENSITY (KG/M**3), 4. HEIGHT
    (METERS) OF WINDS, 5. EAST WIND COMPONENT (M/S), 6. NORTH
    WIND COMPONENT.
    $USE TYPE 3 METRO PACKET (LAYERED), THE FORMAT IS $
(6F10.0)
      0.0     300.73   1.16797       0.0   -3.7495     1.1118           1
    304.8     299.83   1.13433     304.8   -2.5638    -1.3424           2
    609.6     297.39   1.10590     609.6   -1.3125    -2.5714           3
    914.4     293.96   1.08120     914.4   -0.1536    -3.0598           4
   1219.2     292.43   1.04967    1219.2    0.1701    -2.9015           5
   1524.0     290.49   1.02037    1524.0   -0.0444    -2.5546           6
   1828.8     288.63   0.99163    1828.8   -0.3735    -2.4936           7
   2133.6     286.99   0.96250    2133.6   -0.8256    -2.9002           8
   2438.4     285.23   0.93493    2438.4   -1.0068    -3.4127           9
   2743.2     283.73   0.90670    2743.2   -1.0664    -3.5904          10
   3048.0     282.16   0.87890    3048.0   -1.2161    -3.5510          11
   3352.8     280.59   0.85177    3352.8   -1.5483    -3.2232          12
   3657.6     279.19   0.82483    3657.6   -2.0625    -3.1227          13
   3962.4     277.43   0.79957    3962.4   -2.2255    -3.0280          14
   4267.2     276.06   0.78370    4267.2   -2.2891    -3.4152          15
   6096.0     276.06   0.78370    6096.0   -2.2891    -3.4152          16

TRACK      01
    $USE WEAPON 1 TRACKED BY RADAR 1 $
WEAPON     01   155 MM HOWITZER
    $TAG TIME OF 0 SECONDS
    POSITIONS ARE 254.62 METERS EAST, -266.833 METERS NORTH,
    AT ALTITUDE OF 3.83 METERS.
    INITIAL VELOCITY IS 564 M/S
    AZIMUTH OF FIRE IS 2311 MILS
    QUADRANT ELEVATION IS 700 MILS
    SHELL DIAMETER .155 METERS, MASS 43.18182 KG
    DRAG FACTOR IS 1.0, DRAG CURVE NUMBER IS 1
    USE METRO CONDITIONS SPECIFIED IN PACKET 1.
    RCS OPTION 0 (CONSTANT) VALUE OF -10 DBSM
-------------------------------------------------------------------------------------
          SECTION  1       03/22/78   17.04.52           PAGE   1
```

```
          AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
----------------------------------------------------------------------------------
       SPIN CONSTANT IS .25 M/SS
       DRAG UNCERTAINTY .05, SPIN UNCERTAINTY 0  $
   RADAR      01  AN/FPS-16
       THE AN/FPS-16 IS AN INSTRUMENTATION TYPE RADAR LOCATED
       AT WALLOPS ISLAND, VA.
       $LOCATION IS 0 METERS EAST, 0 METERS NORTH AT ALTITUDE
       14.06 METERS. LONGITUDE 4.965721776 LATITUDE .6604552782
       MEASUREMENT SPACE IS RANGE 1, AZIMUTH 1, ELEVATION 1,
            BUT NO DOPPLER 0 OR SIGNAL NOISE RATIO 0.
       RADAR BIASES 0 METERS RANGE, 0 RADIANS AZIMUTH, 0 RADIANS
           ELEVATION, 0 METERS DOPPLER
       THERMAL ERROR SIGMAS ARE 50 METERS RANGE, .00078 RADIANS AZIMUTH,
           .00078 RADIANS ELEVATION AND 0.0 M/S DOPPLER
       JITTER ERROR SIGMAS ARE 1.344 METERS RANGE, .000037 RADIANS AZIMUTH,
           .000061 RADIANS ELEVATION AND 0.0 M/S DOPPLER
       REFERENCE RANGE( RANGE AT WHICH A ZERO DBSM TARGET RETURNS A SNR OF
           ZERO DB) IS 556000 METERS.
       SIGNAL NOISE RATIO THRESHOLD IS 13 DB
       FREQUENCY IS 5600000000 HZ, ELEVATION BEAMWIDTH IS .0108 RADIANS.
       NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ,0RAD EL,0 M/S DOPPLER
       NO REMOVABLE MULTIPATH A=0, B=0, C=0
       $
   OUTPUT     03
       $PRINT CONVERGENCE REPORT 1 ONLY FOR THE FIRST RUN 1 $
   OUTPUT     07
       $PRINT TRACK RESIDUALS 1, WRITE THEM TO TAPE 1, FOR
       ALL RUNS 0  $
   OUTPUT     09
       $EXTRAPOLATE THE FITTED STATE VECTORS TO THE GROUND
       OPTION -2 AT LAUNCH 0 METERS. PRODUCE MISS DISTANCE PLOTS 1$
   ESTIMATOR 01
       $USE MAXIMUM LIKELY ESTIMATOR 1, USE RADAR 0 FOR WEIGHT
       COMPUTATION. STATE VECTOR INITIALIZATION IS -3 (USE
       MEASUREMENTS. MAXIMUM NUMBER OF ITERATIONS IS 10,
       CONVERGENCE OPTION 1 (POSITIONAL) VALUE IS .5 METERS.
       NO A PRIORI VALUES 0
       ESTIMATE POSITIONS 1 EAST 1 NORTH 1 HEIGHT
                VELOCITIES 1 EAST 1 NORTH 1 HEIGHT
                DRAG, SPIN 1 1
                NO WIND 0 0
                BIASES 0 0 0 0
                MULTIPATH 0 0 0
       $
   ORIGIN     01
       $LOCATION OF EXTERNAL TRAJECTORY ORIGIN IS 254.62 M EAST,
       -266.833 M NORTH AT ALTITUDE OF 3.83 METERS $
   END
   (F10.5,3F10.2,3F10.3)
         MODIFIED POINT MASS SIMULATION
     20.00000    4888.95  -4187.41    3598.72    205.476  -180.625    56.065
     21.00000    5093.63  -4367.57    3649.75    203.893  -179.693    46.019
     22.00000    5296.74  -4546.80    3690.78    202.340  -178.789    36.044
----------------------------------------------------------------------------------
           SECTION  1       03/22/78  17.04.52            PAGE   2
```

```
                 AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
------------------------------------------------------------------------------------------
         23.00000    5498.31  -4725.15    3721.86    200.814  -177.908     26.138
         24.00000    5698.37  -4902.62    3743.06    199.312  -177.048     16.297
         25.00000    5896.94  -5079.25    3754.46    197.832  -176.205      6.520
         26.00000    6094.04  -5255.04    3756.11    196.371  -175.377     -3.196
         27.00000    6289.69  -5430.00    3748.08    194.927  -174.560    -12.852
         28.00000    6483.90  -5604.16    3730.42    193.498  -173.752    -22.450
         29.00000    6676.69  -5777.51    3703.19    192.082  -172.950    -31.989
         30.00000    6868.07  -5950.06    3666.45    190.677  -172.149    -41.471
         31.00000    7058.04  -6121.81    3620.26    189.280  -171.350    -50.896
         32.00000    7240.63  -6292.75    3564.67    187.891  -170.547    -60.262
         33.00000    7433.83  -6462.90    3499.75    186.506  -169.739    -69.569
         34.00000    7619.64  -6632.23    3425.54    185.125  -168.923    -78.816
         35.00000    7804.08  -6800.74    3342.13    183.746  -168.095    -88.001
         36.00000    7987.14  -6968.42    3249.55    182.366  -167.256    -97.123
         37.00000    8168.81  -7135.25    3147.89    180.984  -166.401   -106.179
         38.00000    8349.10  -7301.22    3037.20    179.596  -165.530   -115.167
         39.00000    8528.00  -7466.30    2917.57    178.203  -164.638   -124.082
         40.00000    8705.51  -7630.49    2789.05    176.799  -163.724   -132.922
         41.00000    8881.60  -7793.75    2651.73    175.383  -162.785   -141.683
         42.00000    9056.27  -7956.05    2505.70    173.953  -161.818   -150.359
         43.00000    9229.51  -8117.38    2351.03    172.507  -160.822   -158.946
         44.00000    9401.28  -8277.69    2187.82    171.043  -159.793   -167.440
         45.00000    9571.59  -8436.96    2016.16    169.558  -158.729   -175.834
         46.00000    9740.40  -8595.15    1836.16    168.051  -157.627   -184.121
         47.00000    9907.69  -8752.21    1647.92    166.518  -156.486   -192.294
         48.00000   10073.43  -8908.11    1451.58    164.958  -155.306   -200.346
         49.00000   10237.60  -9062.82    1247.24    163.366  -154.085   -208.267
         50.00000   10400.17  -9216.28    1035.05    161.734  -152.814   -216.041
         51.00000   10561.07  -9368.45     815.16    160.047  -151.483   -223.646
         52.00000   10720.26  -9519.24     587.76    158.286  -150.075   -231.054
         53.00000   10877.66  -9668.61     353.03    156.397  -148.541   -238.180
         54.00000   11033.11  -9816.38     111.30    154.285  -146.782   -244.861
```

```
------------------------------------------------------------------------------------------
              SECTION  1       03/22/78   17.04.52            PAGE   3
```

```
            AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
--------------------------------------------------------------------------------
                      SECTION   3  -  ITERATIONS

                      MONTE CARLO RUN NUMBER    1
       X           Y           Z         VX      VY      VZ        KD          KS    WE   WN
      DX          DY          DZ        DVX     DVY     DVZ       DKD         DKS   DWE  DWN
     RB    AE    EB    DB    A            B               C
    DRB   DAE   DEB   DDB   DA           DB              DC         QTOTAL

 ---- ITERATION    1
      5144.6  -4455.4    3588.6  205.3 -180.1   55.2   .500000E-03  0.00  0.0  0.0
        -3.6      3.7      -4.6     .6   -1.0    1.7   .826514E-04   .29  0.0  0.0
    0.0   0.0   0.0   0.0   0.0  0.              0.
    0.0   0.0   0.0   0.0   0.0  0.              0.            25619.0385

 ---- ITERATION    2
      5141.0  -4451.7    3584.0  205.9 -181.1   56.9   .582650E-03   .29  0.0  0.0
          .0      -.0       -.0     .0    -.0     .0   .366836E-06   .00  0.0  0.0
    0.0   0.0   0.0   0.0   0.0  0.              0.
    0.0   0.0   0.0   0.0   0.0  0.              0.                9.4526

 ---- ITERATION    3
      5141.0  -4451.7    3584.0  205.9 -181.1   57.0   .583018E-03   .29  0.0  0.0
         -.3       .4       -.7    -.0    -.0     .0  -.498452E-06  -.00  0.0  0.0
    0.0   0.0   0.0   0.0   0.0  0.              0.
    0.0   0.0   0.0   0.0   0.0  0.              0.                7.9271

 ---- ITERATION    4
      5140.6  -4451.3    3583.3  205.9 -181.1   57.0   .582520E-03   .29  0.0  0.0
          .0      -.0       -.0    -.0     .0     .0  -.173861E-08   .00  0.0  0.0
    0.0   0.0   0.0   0.0   0.0  0.              0.
    0.0   0.0   0.0   0.0   0.0  0.              0.                7.7363
```

```
          AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
------------------------------------------------------------------------------

     MEASUREMENTS, WEIGHTS FOR RUN    1

     NPT  TIME      RANGE   AZIMUTH    ELEVTN  DOPPLER    SNR    C(NFT)
                   WEIGHT   WEIGHT   WEIGHT   WEIGHT   RADAR     DROP

       1  20.000    7694.9 2.284500   .485241    268.13   64.36 45.85984
                 .553E+00 .730E+09 .269E+090.              1        4
       2  21.000    7957.3 2.284838   .474894    262.72   63.77 21.02248
                 .553E+00 .730E+09 .269E+090.              1        0
       3  22.000    8217.1 2.285115   .464232    257.55   63.21  7.52758
                 .553E+00 .730E+09 .269E+090.              1        0
       4  23.000    8475.3 2.285487   .453379    252.61   62.68 20.87236
                 .553E+00 .730E+09 .269E+090.              1        0
       5  24.000    8724.8 2.285849   .441993    247.91   62.18 10.60135
                 .553E+00 .730E+09 .269E+090.              1        0
       6  25.000    8969.1 2.286319   .430627    243.44   61.69  5.61942
                 .553E+00 .730E+09 .269E+090.              1        0
       7  26.000    9209.6 2.286680   .418829    239.20   61.23   .56594
                 .553E+00 .730E+09 .269E+090.              1        0
       8  27.000    9446.7 2.287016   .406780    235.20   60.79  3.73846
                 .553E+00 .730E+09 .269E+090.              1        0
       9  28.000    9682.9 2.287460   .394361    231.44   60.37  5.92209
                 .553E+00 .730E+09 .269E+090.              1        0
      10  29.000    9908.6 2.287896   .381903    227.90   59.96  6.02832
                 .553E+00 .730E+09 .269E+090.              1        0
      11  30.000   10134.7 2.288319   .368901    224.61   59.57 14.24256
                 .553E+00 .730E+09 .269E+090.              1        0
      12  31.000   10359.3 2.288932   .355827    221.54   59.19 11.11207
                 .553E+00 .730E+09 .269E+090.              1        0
      13  32.000   10580.7 2.289316   .342637    218.71   58.82   .50175
                 .553E+00 .730E+09 .269E+090.              1        0
      14  33.000   10797.5 2.289729   .328950    216.12   58.47 12.48201
                 .553E+00 .730E+09 .269E+090.              1        0
      15  34.000   11011.0 2.290236   .315241    213.76   58.13 11.01015
                 .552E+00 .730E+09 .269E+090.              1        0
      16  35.000   11225.3 2.290715   .301305    211.64   57.80  4.64774
                 .552E+00 .730E+09 .269E+090.              1        0
      17  36.000   11435.2 2.291225   .287212    209.75   57.47  4.29760
                 .552E+00 .730E+09 .269E+090.              1        0
      18  37.000   11645.1 2.291699   .272776    208.09   57.16  2.99148
                 .552E+00 .730E+09 .269E+090.              1        0
      19  38.000   11852.8 2.292177   .258240    206.66   56.85  1.54102
                 .552E+00 .730E+09 .269E+090.              1        0
      20  39.000   12058.8 2.292696   .243390    205.47   56.55  5.22982
                 .552E+00 .730E+09 .269E+090.              1        0
      21  40.000   12259.7 2.293244   .228575    204.50   56.26 20.68347
                 .552E+00 .730E+09 .269E+090.              1        0
      22  41.000   12467.9 2.293712   .213401    203.76   55.97  3.99218
                 .552E+00 .730E+09 .269E+090.              1        0
      23  42.000   12671.0 2.294197   .198086    203.24   55.69  6.14131
                 .552E+00 .730E+09 .269E+090.              1        0
------------------------------------------------------------------------------
           SECTION  4      03/22/78  17.05.08          PAGE   5
```

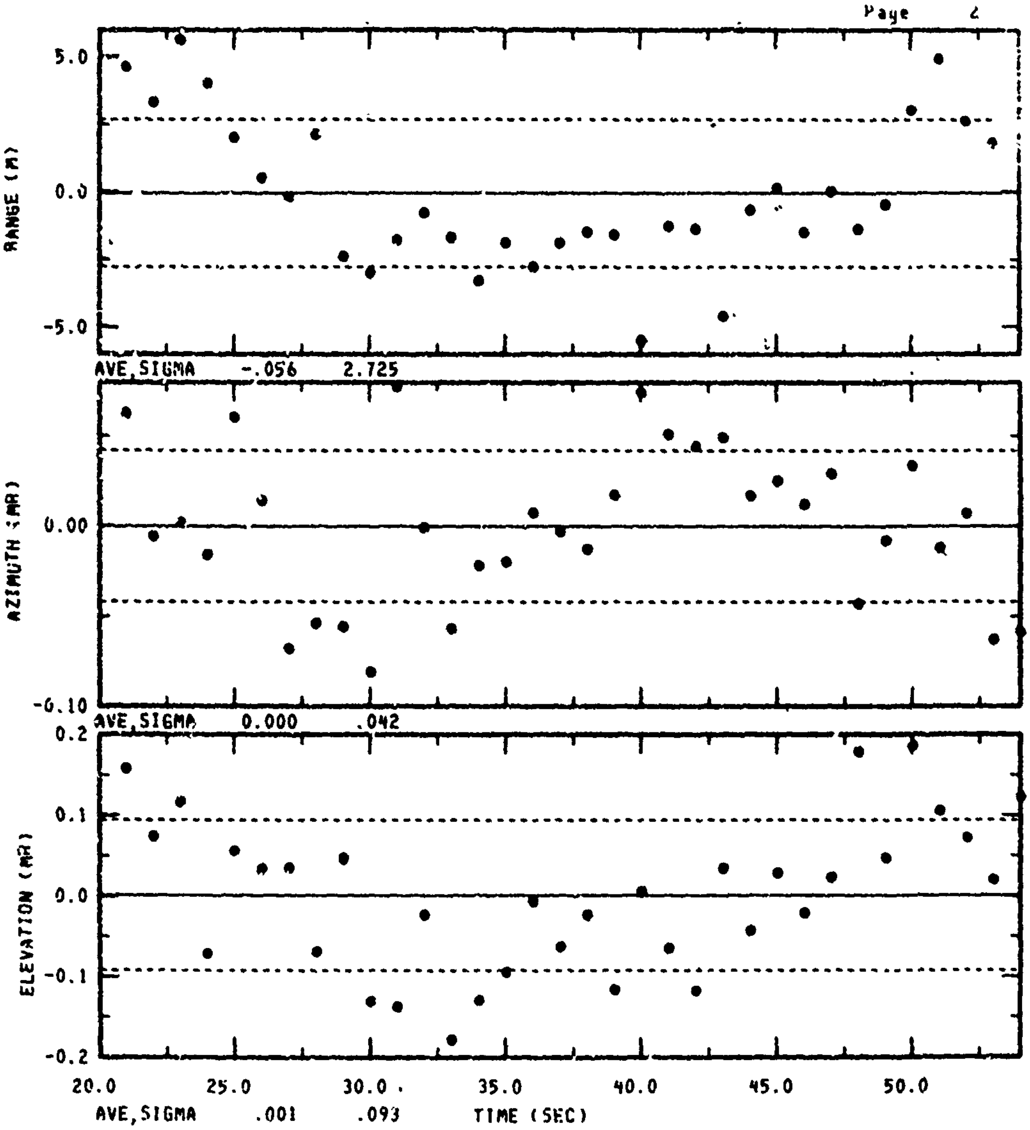
```
          AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
-------------------------------------------------------------------------------

    MEASUREMENTS, WEIGHTS FOR RUN    1

    NPT  TIME     RANGE    AZIMUTH    ELEVTN   DOPPLER   SNR     Q(NET)
                  WEIGHT   WEIGHT    WEIGHT    WEIGHT   RADAR     DROP

     24  43.000   12870.6 2.294695   .182825    202.93   55.42 13.59088
                 .551E+00 .730E+09 .269E+090.              1       0
     25  44.000   13077.1 2.295155   .167197    202.83   55.14   .95010
                 .551E+00 .729E+09 .269E+090.              1       0
     26  45.000   13280.3 2.295654   .151587    202.95   54.88   .67087
                 .551E+00 .729E+09 .269E+090.              1       0
     27  46.000   13481.3 2.296131   .135740    203.26   54.61  1.51017
                 .550E+00 .729E+09 .269E+090.              1       0
     28  47.000   13685.9 2.296635   .119878    203.76   54.35   .76463
                 .551E+00 .729E+09 .269E+090.              1       0
     29  48.000   13888.0 2.297048   .104030    204.46   54.10 10.86971
                 .551E+00 .729E+09 .269E+090.              1       0
     30  49.000   14093.0 2.297565   .087813    205.33   53.84   .81113
                 .550E+00 .729E+09 .269E+090.              1       0
     31  50.000   14301.6 2.298085   .071793    206.36   53.59 14.74778
                 .550E+00 .729E+09 .269E+090.              1       0
     32  51.000   14509.7 2.298516   .055498    207.52   53.34 16.28329
                 .550E+00 .729E+09 .269E+090.              1       0
     33  52.000   14714.8 2.299008   .039207    208.78   53.09  5.19575
                 .550E+00 .729E+09 .269E+090.              1       0
     34  53.000   14922.5 2.299408   .022871    210.06   52.85  4.80974
                 .550E+00 .729E+09 .269E+090.              1       0
     35  54.000   15133.7 2.299877   .006684    211.21   52.60 12.05928
                 .549E+00 .729E+09 .269E+090.              1       0

-------------------------------------------------------------------------------
          SECTION  4       03/22/78  17.05.08            PAGE   6
```

```
          AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
--------------------------------------------------------------------------------

     SECTION   5 - STATE COVARIANCE MATRIX AND CORRELATION COEFFICIANTS MC RUN   1

        1  .17263E+00
        2 -.12406E+00  .13667E+00
        3  .40544E-01 -.35125E-01  .77954E-01
        4 -.16909E-01  .11018E-01  .89126E-04  .77045E-02
        5  .10875E-01 -.13634E-01 -.89693E-04 -.16219E-02  .22150E-02
        6 -.75693E-03  .65936E-03 -.41179E-02 -.21021E-03  .18089E-03  .29843E-03
        7 -.23596E-06  .20427E-06  .69102E-07  .51446E-07 -.44338E-07 -.87443E-08
           .13748E-11
        8 -.15559E-03 -.15966E-03  .97857E-06  .33302E-04  .35693E-04 -.21131E-06
           .29667E-10  .31341E-05

                      STATE NUMBER          STATE
                            1            X POSITION
                            2            Y POSITION
                            3            Z POSITION
                            4            X VELOCITY
                            5            Y VELOCITY
                            6            Z VELOCITY
                            7            DRAG(KD)
                            8            LIFT(KS)

     CORRELATION COEFFICIANTS

        1    1.0000000
        2    -.8076734    1.0000000
        3     .3495000    -.3402923    1.0000000
        4    -.7825745     .5730694     .0061383    1.0000000
        5     .5561123    -.7835795    -.0068410    -.6626818    1.0000000
        6    -.1054556     .1032430    -.8537497    -.2339864     .2224905    1.0000000
        7    -.4841429     .4712452     .2110832     .8437218    -.8034775    -.4317016
             1.0000000
        8    -.2115315    -.2439424     .0019798     .3617252     .4283867    -.0069095
              .0142923    1.0000000







--------------------------------------------------------------------------------
          SECTION  5       03/22/78  17.05.08           PAGE   7
```

```
               AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
---------------------------------------------------------------------------------------

         SECTION  6 - LAUNCH CONDITIONS AND WEIGHTED RESIDUAL STATISTICS

   RUN   VO     QE     AZF   T FIRE   QR       QA       QB     QRDOT   Q TOT FIT NITER
         M/S    DEG    DEG    SEC

     1 571.7 39.22 130.1     .20   4.100    1.305    2.331   0.000   7.736  0     4
     2 570.1 39.28 130.1     .18   3.850    1.272    2.189   0.000   7.311  0     3
     3 571.6 39.23 130.1     .20   4.748    1.299    2.788   0.000   8.835  0     3
     4 571.0 39.24 130.1     .19   4.534    1.348    2.206   0.000   8.088  0     3
     5 571.3 39.24 130.1     .20   5.226    2.169    2.542   0.000   9.937  0     3
     6 571.5 39.23 130.1     .20   4.988    2.073    2.538   0.000   9.599  0     3
     7 571.5 39.23 130.0     .20   5.348    1.789    3.050   0.000  10.187  0     3
     8 571.8 39.22 130.1     .21   3.502    2.529    2.156   0.000   8.187  0     4
     9 571.5 39.23 130.1     .20   4.620    1.383    2.606   0.000   8.609  0     3
    10 571.1 39.25 130.1     .19   4.183    1.441    2.550   0.000   8.175  0     3



   AVR 571.3 39.24 130.1     .20   4.510    1.661    2.496   0.000   8.666        3.2
   SIG    .5   .02    .0     .01    .569     .428     .271   0.000    .913         .4

   THE ABOVE STATISTICS IS BASED ON  10 OUT OF 10 RUNS

---------------------------------------------------------------------------------------
             SECTION  6       03/22/78  17.06.54           PAGE   8
```

```
         AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
-------------------------------------------------------------------------------
   SECTION    7 - TRACK RESIDUALS FOR RUN NUMBER    1


   NPT  TIME     RM     DR     AM       DA      EM      DE       RRM    DRR    IDRP

     1 20.000   7695.   0.0  2.2845   0.000   .4852   0.000   268.1    0.0     4
     2 21.000   7957.   4.6  2.2848    .062   .4749    .157   262.7    0.0     0
     3 22.000   8217.   3.3  2.2851   -.006   .4642    .073   257.6    0.0     0
     4 23.000   8475.   5.6  2.2855    .002   .4534    .115   252.6    0.0     0
     5 24.000   8725.   4.0  2.2858   -.016   .4420   -.072   247.9    0.0     0
     6 25.000   8969.   2.0  2.2863    .060   .4306    .055   243.4    0.0     0
     7 26.000   9210.    .5  2.2867    .014   .4188    .033   239.2    0.0     0
     8 27.000   9447.   -.2  2.2870   -.068   .4068    .034   235.2    0.0     0
     9 28.000   9683.   2.1  2.2875   -.054   .3944   -.069   231.4    0.0     0
    10 29.000   9909.  -2.4  2.2879   -.056   .3819    .046   227.9    0.0     0
    11 30.000  10135.  -3.0  2.2883   -.081   .3689   -.131   224.6    0.0     0
    12 31.000  10359.  -1.8  2.2889    .077   .3558   -.138   221.5    0.0     0
    13 32.000  10581.   -.8  2.2893   -.001   .3426   -.024   218.7    0.0     0
    14 33.000  10797.  -1.7  2.2897   -.057   .3289   -.178   216.1    0.0     0
    15 34.000  11011.  -3.3  2.2902   -.022   .3152   -.130   213.8    0.0     0
    16 35.000  11225.  -1.9  2.2907   -.020   .3013   -.095   211.6    0.0     0
    17 36.000  11435.  -2.8  2.2912    .007   .2872   -.007   209.7    0.0     0
    18 37.000  11645.  -1.9  2.2917   -.003   .2728   -.063   208.1    0.0     0
    19 38.000  11853.  -1.5  2.2922   -.013   .2582   -.024   206.7    0.0     0
    20 39.000  12059.  -1.6  2.2927    .017   .2434   -.116   205.5    0.0     0
    21 40.000  12260.  -5.5  2.2932    .074   .2286    .005   204.5    0.0     0
    22 41.000  12468.  -1.3  2.2937    .051   .2134   -.065   203.8    0.0     0
    23 42.000  12671.  -1.4  2.2942    .044   .1981   -.118   203.2    0.0     0
    24 43.000  12871.  -4.6  2.2947    .049   .1828    .034   202.9    0.0     0
    25 44.000  13077.   -.7  2.2952    .017   .1672   -.043   202.8    0.0     0
    26 45.000  13280.    .1  2.2957    .025   .1516    .028   202.9    0.0     0
    27 46.000  13481.  -1.5  2.2961    .012   .1357   -.021   203.3    0.0     0
    28 47.000  13686.    .0  2.2966    .029   .1199    .023   203.8    0.0     0
    29 48.000  13888.  -1.4  2.2970   -.043   .1040    .179   204.5    0.0     0
    30 49.000  14093.   -.5  2.2976   -.008   .0878    .047   205.3    0.0     0
    31 50.000  14302.   3.0  2.2981    .033   .0718    .185   206.4    0.0     0
    32 51.000  14510.   4.9  2.2985   -.012   .0555    .105   207.5    0.0     0
    33 52.000  14715.   2.6  2.2990    .007   .0392    .072   208.3    0.0     0
    34 53.000  14923.   1.8  2.2994   -.063   .0229    .020   210.1    0.0     0
    35 54.000  15134.   3.2  2.2999   -.059   .0067    .122   211.2    0.0     0

                          TRACK RESIDUAL STATISTICS RUN    1

                     RANGE(M)    AZIMUTH(MR)    ELEVATION(MR)   DOPPLER(M/S)

       AVRGE          -.056         .000           .001            0.000
       SIGMA          2.725         .042           .093            0.000



-------------------------------------------------------------------------------
            SECTION  7        03/22/78   17.05.09            PAGE   9
```

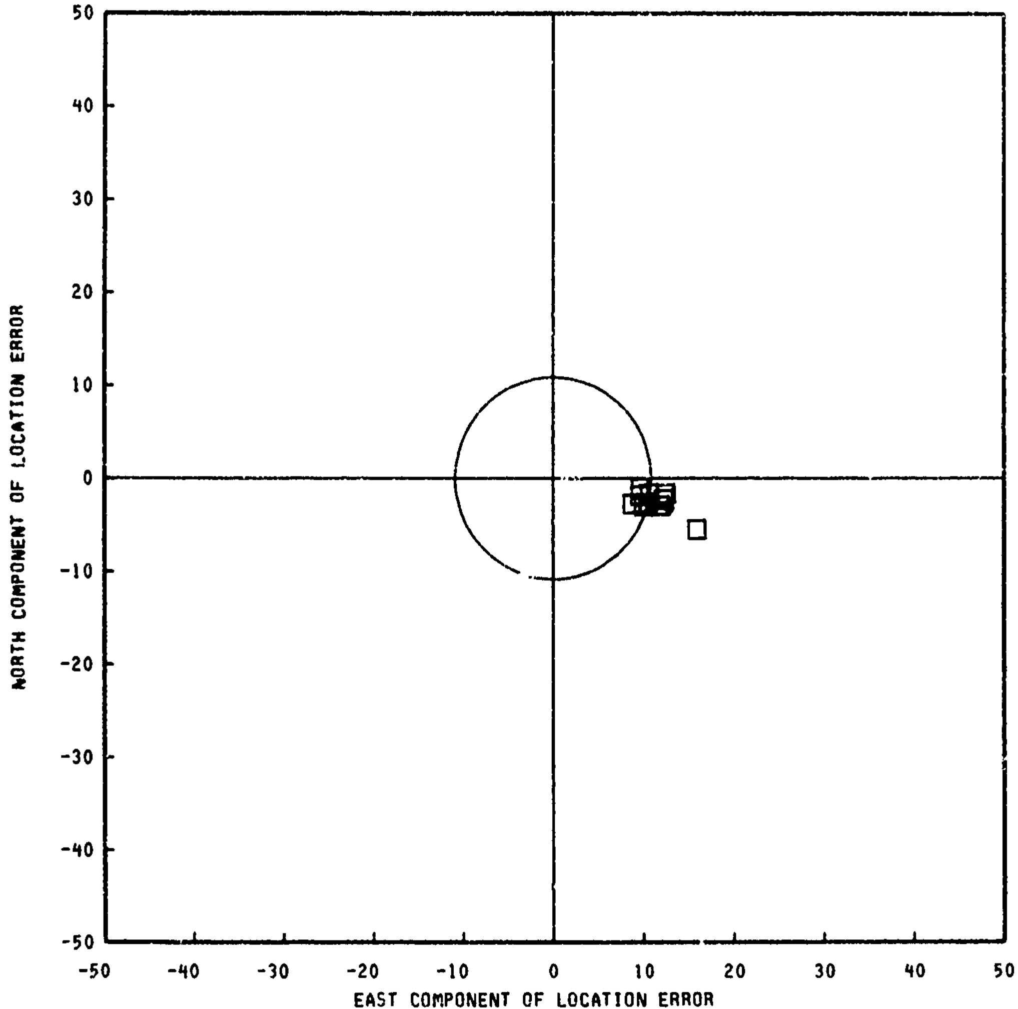
Page 2



+MC 1 DEMONSTRATION RUN 3

```
             AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
--------------------------------------------------------------------------------

             SECTION   8 - ESTIMATION STATISTICS (EST-TRUE)
 MC          KD         KS    WE    WN    RE    AE    EB    DB    AM      BM        CM

  1    .582520E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .825198E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  2    .579569E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .795692E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  3    .582711E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .827109E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  4    .580899E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .808990E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  5    .581743E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .817433E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  6    .581873E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .818734E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  7    .581948E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .819481E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  8    .582722E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .827216E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

  9    .581988E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .819882E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

 10    .581404E-03     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .500000E-03    0.00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .814036E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.



       ESTIMATION STATISTICS BASED ON  10 OUT OF   10 RUNS

          KD          KS    WE    WN    RE    AE    EB    DB    AM      BM        CM
       .817377E-04     .29   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.
       .903876E-06     .00   0.0   0.0   0.0   0.0   0.0   0.0   0.0 0.            0.

--------------------------------------------------------------------------------
            SECTION  8      03/22/78  17.06.55          PAGE  19
```

```
        AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT
---------------------------------------------------------------------------
                    SECTION  9 INTERCEPT ROUTINE

     INTERCEPT  1 OPTION -2(SPECIFIED ALTITUDE  )VALUE=       3.83000
                    STATISTICS BASED ON  10 OUT OF  10 RUNS

          NO        X(M)      Y(M)      Z(M)      R(M)    GOOD FIT= 0

           1        10.0      -2.9       -.0      10.4     0
           2        15.9      -5.5       -.0      16.8     0
           3        10.7      -1.7       -.0      10.9     0
           4        12.5      -1.7       -.0      12.6     0
           5        10.5      -2.7       -.0      10.8     0
           6         9.7      -1.1       -.0       9.7     0
           7         8.8      -2.8       -.0       9.2     0
           8        12.3      -2.3       -.0      12.5     0
           9         9.6      -1.9       -.0       9.8     0
          10        11.9      -3.0       -.0      12.3     0

         AVE        11.2      -2.6       -.0
         SIG         2.1        .8       0.0
         AVERAGE R=      11.5 M, SIGMA R=     2.1 M, CEP        10.8 M




---------------------------------------------------------------------------
          SECTION  9       03/22/78  17.06.59          PAGE  20
```



DEMONSTRATION RUN 3
AN/FPS-16 155 MM DATA ANALYSIS--EXTERNAL TRAJECTORY INPUT

```
COV CEP OF PROB .5=    1.6 M  CEP=   10.8 M
XBAR EAST=   11.2 M   YBAR NORTH=   -2.6 M
ELLIPSE AXIS   MAJOR=    2.1 M   MINOR=     .8 M   THETA= 115.3 DEG
```

7.3.3 Results Summary

The results of simulation on an externally generated trajectory closely parallel the results of real data analysis. This was expected as the 3 degree of freedom simulation, MPMTS, represents a closer dynamic model to reality than LOCATER'S dynamics. One would immediately question why isn't the dynamic model of MPMTS used in LOCATER. The answer lies in the fact that MPMTS relies on several coefficient curves which are dependent on Mach number and shell type. This a priori information is quite unavailable to LOCATER in its tactical environment as it normally doesn't know what projectile is being observed. LOCATER does not address the problem of directly determining the shell diameter but does estimate the inverse ballistic coefficient. This could be used in conjunction with range and velocity information to classify the projectile type.

The range residual plots (SECTION 7) for the first run demonstrate the same type model differences as was evident in example 1. This is reflected by probable drag curve uncertainty errors as the range measurement direction is almost coplanar with the down-range (drag) direction.

The drag estimate based on the 10 Monte Carlo runs is .14%. This results in the tight grouping of launch point locations as shown in the plot in SECTION 9.

The average location error components, 11.2 m East and -2.6 m North exhibit the same bias as evident in example 1. This again is due to dynamic model errors, specifically the drag curve. The CEP of the system is 10.8 m.

Some conclusions may be reached from the following table about the quantitative errors involved of dynamic modeling.

Dynamic model	Noise model	Example #	CEP(m)
LOCATER	LOCATER	2	3.9
MPMTS	LOCATER	3	10.8
REAL	REAL	1	23.2

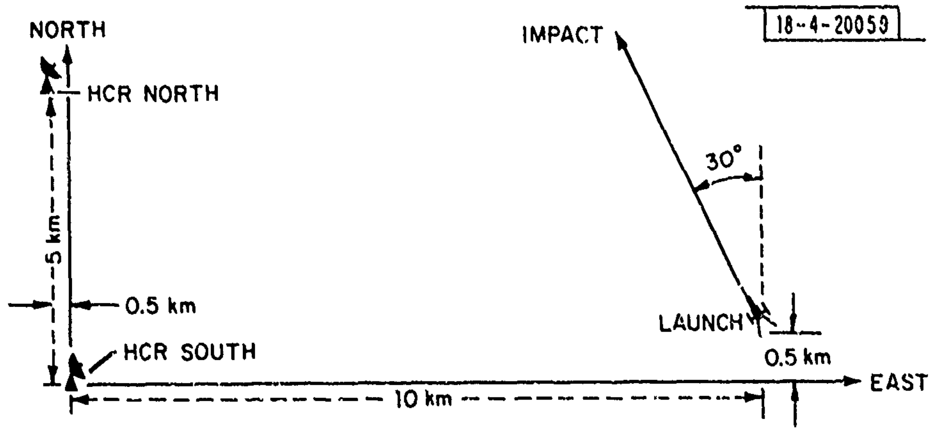
From the 3 examples, 6.9 m may be attributed to dynamic model error between LOCATER and MPMTS and 12.4 m to a combination of dynamic model errors, radar noise errors and survey errors between MPMTS and the real world.

These results, however, only pertain to this radar-weapon system and quantitative conclusions may not be applicable to other systems.

7.4 Multiple Radar Simulation

7.4.1 Problem Illustration

Example 4 considers the problem of a netted type radar tracking a low quadrant elevation 105 mm howitzer. Each radar in the net is a hemispheric coverage radar (HCR) and has a baseline of approximately 5 km. The problem is to calculate the radars performance in determining the launch point location with the system geometry and parameters specified in Figure 7-2.



WEAPON

TYPE	105-mm HOWITZER
CHARGE	6
INITIAL VELOCITY	393 m/sec
QUADRANT ELEVATION	300 mils
AZIMUTH OF FIRE	330° CLOCKWISE FROM NORTH
FLIGHT TIME	20 sec
LAUNCH ALTITUDE	30 m
LOCATION (UTM)	10,000 m EAST, 500 m NORTH

RADAR

NAME	HCR NET
MEASUREMENTS	RANGE, AZIMUTH, ELEVATION, DOPPLER
PRI	2 sec
HCR SOUTH	
LOCATION (UTM)	0 m EAST, 0 m NORTH
ALTITUDE	40 M
HCR NORTH	
LOCATION (UTM)	−500 m EAST, 5000 m NORTH
ALTITUDE	40 m

ATMOSPHERE

WIND SPEED	5 m/sec
WIND DIRECTION	45° (from the NE)
DENSITY	1.15 kg/m^3
TEMPERATURE	−6.66° C

Fig. 7-2. System parameters of multiple HCR simulation. Locations of radars and weapon.

7.4.2 Sample Output

```
                          MULTIPLE HEMISPHERIC COVERAGE RADAR
-------------------------------------------------------------------------------

                               ----INPUT DATA CARDS----

                          MULTIPLE HEMISPHERIC COVERAGE RADAR
      MISSION   01
          USING 2 HEMISPHERIC COVERAGE RADARS WITH A BASELINE
          OF 5 KM, TRACK A LOW QE 105 MM MORTAR SHOT.
          $RUN 20 MONTE CARLO RUNS. COMPLETE SIMULATION MODE 1 $
      WEAPON     01  LOW QE 105 MM MORTAR
          $TAG TIME OF 0 SECONDS, POSITIONS ARE 10000 METERS EAST,
          500 METERS NORTH AT ALTITUDE OF 30 METERS.
          INITIAL VELOCITY (CHARGE THREE) IS 393 M/S.
          AZIMUTH OF FIRE IS 5867 MILS CLOCKWISE FROM NORTH.
          QUADRANT ELEVATION 300 MILS.
          SHELL DIAMETER .105 METERS, MASS 15 KG.
          DRAG FACTOR 1.0, USE DRAG CURVE 1
          USE METRO PACKET NUMBER 4
          RCS OPTION 0 (CONSTANT VALUE) WHICH IS -12 DBSM.
          SPIN CONSTANT IS .15 M/SS
          DRAG UNCERTAINTY IS .05 (FIVE PERCENT). SPIN
          UNCERTAINTY IS 0  $
      RADAR     01      HCR SOUTH
          THE SENSOR IS A COMPOSITE OF 2 HCR RADARS, WITH
          THE SOUTHERNMOST RADAR TO BE CONSIDERED THE BASE.
          NON-SIMULTANEOUS MEASUREMENTS ARE TAKEN.
          $LOCATION 0 METERS EAST, 0 METERS NORTH, AT ALTITUDE
          OF 40 METERS. LONGITUDE IS .17453293 RADIANS,
          LATITUDE IS .87266463 RADIANS.
          RADAR MEASUREMENT SPACE IS RANGE (1), AZIMUTH (1)
              ELEVATION(1) AND DOPPLER(1).
              SNR WAS NOT TAKEN 0.
          BIAS ERRORS FOR MEASUREMENT GENERATION ARE
               1.0 METERS RANGE, .0009 RAD AZ, .00058 RAD EL,
               AND .2 M/S DOPPLER
          THERMAL ERROR SIGMAS 50 M RANGE,.0925 RAD AZ,
               .0925 RAD EL, AND  9.7 M/S DOPPLER
          JITTER ERROR SIGMAS 5 M RANGE, .001 RAD AZ,
               .001 RAD EL, AND .5 M/S DOPPLER
          REFERENCE RANGE IS 159000 METERS.
          MEASUREMENT THRESHOLD IS 13 DB.  FREQUENCY 3300000000 HZ
          ELEVATION BEAMWIDTH IS .0873 RADIANS.
          NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ, 0 RAD EL,
               0 M/S DOPPLER.
          NO REMOVABLE MULTIPATH PARAMETERS A IS 0, B IS 0
          C IS 0  $
      RADAR      02      HCR NORTH
          $LOCATION -500 METERS EAST, 5000 METERS NORTH, AT ALTITUDE
          OF 40 METERS. LONGITUDE IS COMPUTED INTERNALLY 0.0
          LATITUDE IS COMPUTED INTERNALLY 0.0
          RADAR MEASUREMENT SPACE IS RANGE (1), AZIMUTH (1)
              ELEVATION(1) AND DOPPLER(1).
              SNR WAS NOT TAKEN 0.
-------------------------------------------------------------------------------
               SECTION  1      03/21/78  15.34.53          PAGE  1
```

```
                      MULTIPLE HEMISPHERIC COVERAGE RADAR
------------------------------------------------------------------------------------
         BIAS ERRORS FOR MEASUREMENT GENERATION ARE
              1.0 METERS RANGE, .0009 RAD AZ, .00058 RAD EL,
              AND .2 M/S DOPPLER
         THERMAL ERROR SIGMAS 50 M RANGE,.0925 RAD AZ,
              .0925 RAD EL, AND  9.7 M/S DOPPLER
         JITTER ERROR SIGMAS 5 M RANGE, .001 RAD AZ,
              .001 RAD EL, AND .5 M/S DOPPLER
         REFERENCE RANGE IS 159000 METERS.
         MEASUREMENT THRESHOLD IS 13 DB.  FREQUENCY 3300000000 HZ
         ELEVATION BEAMWIDTH IS .0873 RADIANS.
         NO REMOVABLE BIASES 0 M RANGE, 0 RAD AZ, 0 RAD EL,
              0 M/S DOPPLER.
         NO REMOVABLE MULTIPATH PARAMETERS A IS 0, B IS 0
         C IS 0  $
     TRACK      01  MULTIPLE RADAR COVERAGE LIMITS
         $USE WEAPON PACKET 1
         RADAR NUMBER 1, 1 TRACK INTERVAL,
         PRE-APOGEE ELEVATION OPTION -4 VALUE OF .008 RADIANS
              TO POST-APOGEE ELEVATION OPTION 4 VALUE OF
              .008 RADIANS. THE PRI IS 2.0 SECONDS.
         RADAR 2, 1 TRACK INTERVAL
              TIME OPTION 3 OF .2 SECONDS TO POST APOGEE
              ELEVATION OPTION 4, VALUE OF .008 RADIANS.
              THE PRI IS 2.0 SECONDS.
         $
     ESTIMATOR 01
         $USE FILTER 1, USE SIGMAS IN RADAR PACKET 1 FOR WEIGHTS,
         USE TRUE STATE VECTOR FOR INITIALIZATION -1, MAXIMUM
         NUMBER OF ITERATIONS IS 20, POSITIONAL CONVERGENCE
         OPTION 1, VALUE = .5 METERS, NO APRIORI DATA 0,
         ESTIMATE POSITIONS EAST 1 NORTH 1 HEIGHT 1
                   VELOCITIES EAST 1 NORTH 1 HEIGHT 1
                   DRAG 1 NO SPIN 0
                   NO WIND 0 0
                   NO BIASES 0 0 0 0
                   NO MULTIPATH PARAMETERS 0 0 0
         $
     MEASURE   01  ERROR GENERATION
         $IN SIMULATING RADAR MEASUREMENTS INCLUDE
         BIASES 1,THERMAL ERRORS 1, JITTER ERRORS 1,
         AND TROPOSPHERIC REFRACTION 1, NO MULTIPATH 0 $
     METRO      04  GROUND CONDITIONS
         $METRO PACKET TYPE 2 (GROUND CONDITIONS)
         AIR DENSITY IS 1.15 KG/MMM
         WIND SPEED IS 5 M/S ( ABOUT TEN KNOTS)
         WIND IS COMING FROM THE N.E. ( 45 DEGREES)
         GROUND TEMPERATURE IS 266.5 DEG KELVIN$
     OUTPUT     02  NOMINAL TRAJECTORY
         $COVERAGE OPTION 1, RADAR 1, WEAPON 1
         TIME INITIAL OF 0 SECONDS EVERY .5 SEC TO IMPACT
         OPTION -999. PRINTOUT IN POLAR COORDINATES
         OPTION 2, NO TAPE PRINTOUT 0  $
------------------------------------------------------------------------------------
            SECTION  1      03/21/78  15.34.53           PAGE   2
```

```
                        MULTIPLE HEMISPHERIC COVERAGE RADAR
--------------------------------------------------------------------------------
    OUTPUT     03  CONVERGENCE
        $GENERATE SECTION THREE OF THE LOCATER TEST REPORT
        1 FOR ONLY 1 RUN $
    OUTPUT     07
        $PRINT TRACK RESIDUALS 1, WRITE THEM TO TAPE FOR PLOTTING 1,
        FOR ALL RUNS 0   $
    RANDOM     01  RANDOM NUMBER SEED INITIALIZATION
        $RANDOM NUMBER SEED IS 3674231 $
    END





--------------- RANDOM NUMBER SEED INITIALIZATION -------------------------------
          SECTION  1      03/21/78  15.34.53          PAGE   3
```

```
                MULTIPLE HEMISPHERIC COVERAGE RADAR
------------------------------------------------------------------------------
                          RADAR  1 TRACKING WEAPON  1

   TIME(SEC)   R(M)    AZ(MR)   EL(MR)    RDOT  AZDOT    ELDOT    VEL   SNR(DB)

     0.000  10012.5 1520.84    -1.79 -171.6   -33.43    10.36  393.0  36.03
      .500   9929.3 1504.19     3.75 -161.4   -33.17    10.78  382.1  36.18
     1.000   9851.0 1487.67     9.00 -151.8   -32.90    10.20  371.7  36.32
     1.500   9777.4 1471.29    13.95 -142.7   -32.63     9.61  361.8  36.45
     2.000   9708.2 1455.04    18.61 -134.1   -32.35     9.02  352.5  36.57
     2.500   9643.2 1438.94    22.97 -126.0   -32.08     8.43  343.7  36.69
     3.000   9582.0 1422.96    27.03 -118.3   -31.82     7.84  335.5  36.80
     3.500   9524.6 1407.11    30.80 -111.2   -31.59     7.25  328.0  36.90
     4.000   9470.9 1391.36    34.29 -104.5   -31.41     6.68  321.5  37.00
     4.500   9420.2 1375.68    37.48  -98.4   -31.31     6.12  316.0  37.09
     5.000   9372.4 1360.04    40.41  -92.7   -31.26     5.57  311.5  37.18
     5.500   9327.4 1344.41    43.05  -87.3   -31.26     5.02  307.7  37.27
     6.000   9285.1 1328.78    45.42  -82.1   -31.29     4.47  304.4  37.34
     6.500   9245.3 1313.13    47.52  -77.1   -31.32     3.93  301.6  37.42
     7.000   9208.0 1297.45    49.35  -72.1   -31.37     3.37  299.0  37.49
     7.500   9173.2 1281.76    50.90  -67.3   -31.41     2.82  296.6  37.56
     8.000   9140.7 1266.05    52.17  -62.6   -31.44     2.26  294.4  37.62
     8.500   9110.6 1250.32    53.16  -57.9   -31.46     1.70  292.4  37.67
     9.000   9082.8 1234.59    53.86  -53.3   -31.46     1.13  290.5  37.73
     9.500   9057.3 1218.86    54.29  -48.7   -31.45      .56  288.6  37.78
    10.000   9034.1 1203.14    54.43  -44.2   -31.43     -.01  286.9  37.82
    10.500   9013.1 1187.44    54.28  -39.7   -31.39     -.58  285.4  37.86
    11.000   8994.4 1171.75    53.85  -35.3   -31.34    -1.15  283.9  37.90
    11.500   8977.8 1156.10    53.14  -30.9   -31.28    -1.71  282.5  37.93
    12.000   8963.5 1140.48    52.14  -26.5   -31.19    -2.28  281.2  37.96
    12.500   8951.3 1124.91    50.86  -22.2   -31.10    -2.85  280.0  37.98
    13.000   8941.2 1109.38    49.29  -18.0   -30.99    -3.41  279.0  38.00
    13.500   8933.3 1093.92    47.45  -13.7   -30.86    -3.97  278.0  38.02
    14.000   8927.5 1078.53    45.33   -9.5   -30.72    -4.52  277.1  38.03
    14.500   8923.7 1063.20    42.93   -5.4   -30.57    -5.07  276.3  38.03
    15.000   8922.1 1047.96    40.26   -1.2   -30.40    -5.61  275.6  38.04
    15.500   8922.5 1032.81    37.32    2.9   -30.22    -6.14  275.0  38.04
    16.000   8925.0 1017.75    34.12    7.0   -30.02    -6.67  274.4  38.03
    16.500   8929.4 1002.79    30.65   11.0   -29.82    -7.19  274.0  38.02
    17.000   8936.0  987.93    26.93   15.0   -29.60    -7.70  273.6  38.01
    17.500   8944.5  973.19    22.96   19.0   -29.37    -8.20  273.3  37.99
    18.000   8955.0  958.56    18.74   23.0   -29.13    -8.69  273.1  37.97
    18.500   8967.5  944.06    14.27   27.0   -28.88    -9.17  273.0  37.95
    19.000   8982.0  929.69     9.57   30.9   -28.61    -9.63  272.9  37.92
    19.500   8998.4  915.45     4.64   34.8   -28.34   -10.09  273.0  37.89
    20.000   9016.8  901.35     -.52   38.7   -28.06   -10.54  273.0  37.85




------------------------------------------------------------------------------
           SECTION  2        03/21/78  15.34.55           PAGE   4
```

```
                       MULTIPLE HEMISPHERIC COVERAGE RADAR
-------------------------------------------------------------------------------------------
                    SECTION   3   -   ITERATIONS

                    MONTE CARLO RUN NUMBER     1
         X        Y        Z       VX     VY     VZ         KD        KS    WE   WN
       DX        DY       DZ       DVX    DVY    DVZ       DKD       DKS   DWE  DWN
       RB   AB   EB   DB    A         B             C
      DRB  DAB  DEB  DDB   DA       DB            DC        CTOTAL

     ---- ITERATION   1
        9962.6    564.8      4.6 -186.2  322.7  111.1    .698250E-03   .15 -3.5 -3.5
           -.9    -10.9     16.8     .5     .5     .3    .640367E-05  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.             0.
       0.0  0.0  0.0  0.0  0.0  0.             0.              7.3330

     ---- ITERATION   2
        9961.7    554.0     21.4 -185.7  323.2  111.3    .704654E-03   .15 -3.5 -3.5
           -.0       .0       .0    -.0     .0     .0    .371027E-07  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.             0.
       0.0  0.0  0.0  0.0  0.0  0.             0.              3.8690

     ---- ITERATION   3
        9961.7    554.0     21.4 -185.7  323.2  111.3    .704691E-03   .15 -3.5 -3.5
           -.0       .0       .0    -.0    -.0    -.0    .831187E-11  0.00  0.0  0.0
       0.0  0.0  0.0  0.0  0.0  0.             0.
       0.0  0.0  0.0  0.0  0.0  0.             0.              3.8689

-------------------------------------------------------------------------------------------
             SECTION   3     03/21/78    15.36.06           PAGE    5
```

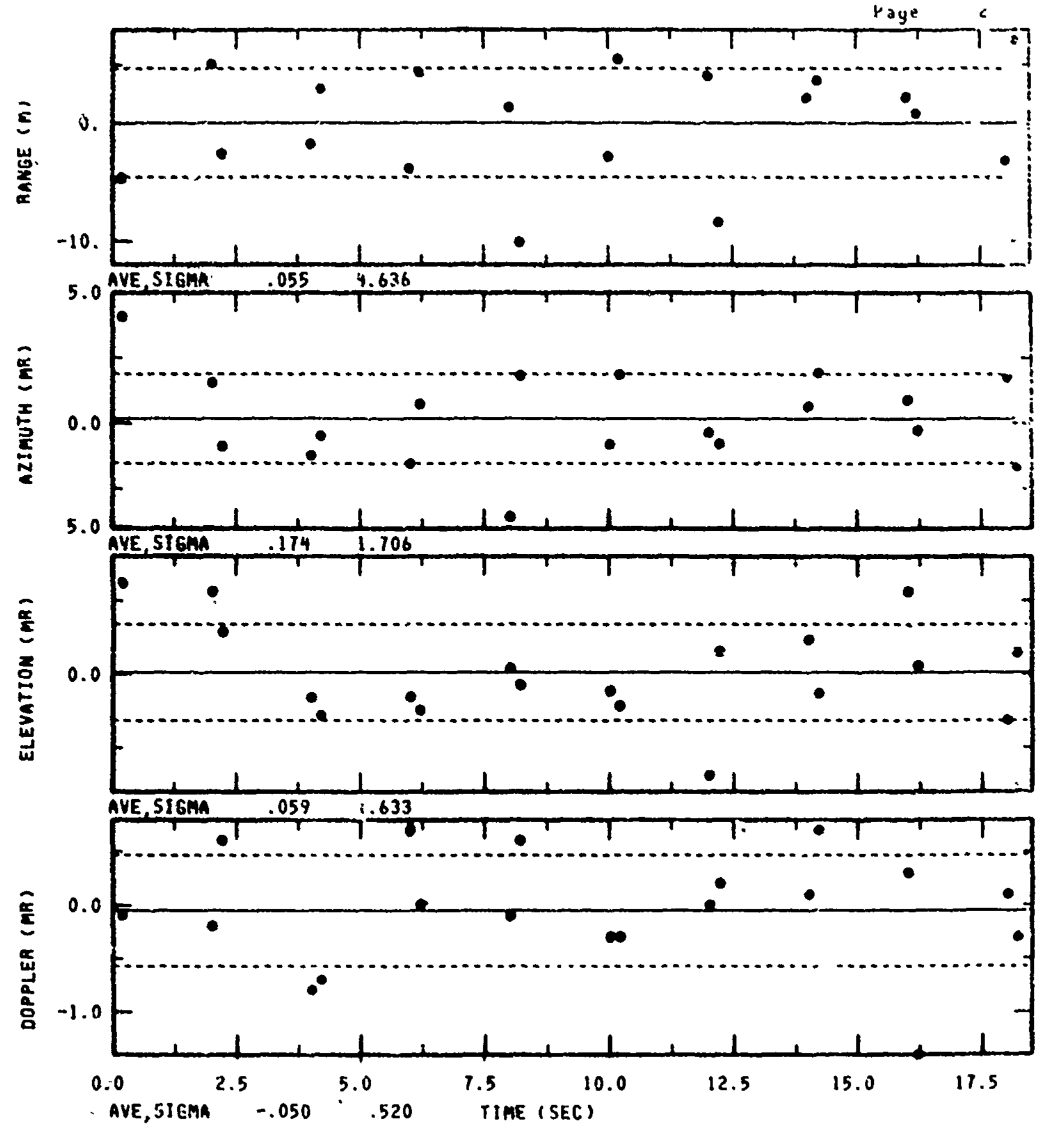
```
                   MULTIPLE HEMISPHERIC COVERAGE RADAR
---------------------------------------------------------------------------

      MEASUREMENTS, WEIGHTS FOR RUN    1

      NPT  TIME     RANGE   AZIMUTH    ELEVTN  DOPPLER   SNR     C(NET)
                   WEIGHT   WEIGHT    WEIGHT   WEIGHT   RADAR    DROP

        1    .200  11362.6 1.976615   .004739  -297.26  33.83  6.60295
                  .384E-01 .220E+06 .220E+06 .346E+01     2        0
        2   2.000   9711.6 1.457461   .023212  -134.44  36.57  4.58125
                  .391E-01 .347E+06 .347E+06 .369E+01     1        0
        3   2.200  10807.0 1.931942   .021161  -261.18  34.71  2.11070
                  .387E-01 .257E+06 .257E+06 .355E+01     2        0
        4   4.000   9467.2 1.390594   .035487  -105.44  37.00  3.20481
                  .392E-01 .370E+06 .370E+06 .372E+01     1        0
        5   4.200  10318.4 1.892059   .032926  -234.59  35.52  2.80079
                  .389E-01 .294E+06 .294E+06 .362E+01     2        0
        6   6.000   9279.4 1.327315   .046837   -81.20  37.35  3.56761
                  .393E-01 .388E+06 .388E+06 .374E+01     1        0
        7   6.200   9871.6 1.851656   .044238  -215.53  36.30  1.40342
                  .391E-01 .333E+06 .333E+06 .368E+01     2        0
        8   8.000   9140.7 1.262204   .054708   -62.35  37.62  5.30075
                  .393E-01 .403E+06 .403E+06 .376E+01     1        0
        9   8.200   9440.6 1.808741   .052662  -200.61  37.05  6.79252
                  .392E-01 .372E+06 .372E+06 .372E+01     2        0
       10  10.000   9030.7 1.201679   .056364   -43.97  37.82   .99590
                  .394E-01 .415E+06 .415E+06 .377E+01     1        0
       11  10.200   9067.4 1.761956   .055616  -187.75  37.78  3.27802
                  .393E-01 .412E+06 .412E+06 .376E+01     2        0
       12  12.000   8968.1 1.139067   .051358   -26.00  37.96  5.72229
                  .394E-01 .422E+06 .422E+06 .377E+01     1        0
       13  12.200   8692.6 1.709552   .056748  -173.26  38.49  3.44492
                  .394E-01 .452E+06 .452E+06 .380E+01     2        0
       14  14.000   8931.5 1.077673   .049279    -8.73  38.03   .92549
                  .394E-01 .426E+06 .426E+06 .378E+01     1        0
       15  14.200   8372.3 1.659522   .049791  -158.02  39.17  4.27881
                  .395E-01 .491E+06 .491E+06 .383E+01     2        0
       16  16.000   8930.8 1.016695   .039808     8.14  38.03  4.10057
                  .394E-01 .426E+06 .426E+06 .378E+01     1        0
       17  16.200   8067.7 1.601676   .039908  -144.31  39.81  7.37031
                  .396E-01 .528E+06 .528E+06 .385E+01     2        0
       18  18.000   8957.4  .957888   .020162    24.22  37.97  2.74017
                  .394E-01 .423E+06 .423E+06 .377E+01     1        0
       19  18.200   7804.8 1.541854   .023879  -126.16  40.40  4.28859
                  .396E-01 .562E+06 .562E+06 .387E+01     2        0




---------------------------------------------------------------------------
            SECTION  4       03/21/78  15.34.58          PAGE   6
```

```
                   MULTIPLE HEMISPHERIC COVERAGE RADAR
-------------------------------------------------------------------------------

    SECTION   5 - STATE COVARIANCE MATRIX AND CORRELATION COEFFICIANTS MC RUN   1

       1  .30677E+01
       2  .23086E+01  .17413E+02
       3 -.61997E+00 -.23034E+01  .65090E+02
       4 -.27172E+00 -.44509E+00 -.28462E+00  .97669E-01
       5  .33848E-01 -.79983E+00  .76611E+00 -.94410E-01  .24509E+00
       6  .65672E-01  .24188E+00 -.57626E+01 -.48793E-02 -.24864E-01  .62481E+00
       7  .10540E-05  .89176E-05  .13320E-04 -.14717E-05  .15737E-05 -.69522E-06
          .39116E-10

                 STATE NUMBER         STATE
                      1            X POSITION
                      2            Y POSITION
                      3            Z POSITION
                      4            X VELOCITY
                      5            Y VELOCITY
                      6            Z VELOCITY
                      7            DRAG(KD)

    CORRELATION COEFFICIANTS

       1   1.0000000
       2    .3158650   1.0000000
       3   -.0438736   -.0684199   1.0000000
       4   -.4964018   -.3412961   -.1128851   1.0000000
       5    .0390349   -.3877601    .1918100   -.6102038   1.0000000
       6    .0474350    .0733315   -.9036298   -.0197517   -.0635375   1.0000000
       7    .0962158    .3416913    .2639798   -.7529465    .5082596   -.1406291
           1.0000000




-------------------------------------------------------------------------------
              SECTION  5      03/21/78   15.34.58          PAGE   7
```

```
         SECTION  6 - LAUNCH CONDITIONS AND WEIGHTED RESIDUAL STATISTICS

RUN  VO     QE     AZF   T FIRE    QR       QA       QE     QRDOT   Q TOT FIT NITER
     M/S    DEG    DEG    SEC

  1 396.4 17.10 330.1    -.13    .844    1.051     .963    1.011   3.869  0     3
  2 396.5 16.89 330.1    -.12   1.627     .790     .776    1.497   4.690  0     3
  3 392.6 16.93 330.0     .01    .863     .964     .885    1.022   3.735  0     3
  4 392.0 16.83 330.0     .05    .867     .631    1.001     .881   3.380  0     3
  5 393.2 16.89 330.0    -.00   1.425     .849     .858    1.176   4.308  0     3
  6 395.7 16.92 329.9    -.12    .749     .631     .784     .829   2.994  0     3
  7 394.7 16.97 330.0    -.08    .525     .794    1.069     .658   3.046  0     3
  8 392.1 16.89 330.1     .05   1.849     .862     .833    1.304   4.847  0     3
  9 391.6 16.83 329.9     .09    .828     .687    1.302     .604   3.421  0     3
 10 397.4 16.95 330.0    -.13   1.243     .994    1.025     .520   3.783  0     3
 11 394.2 16.85 330.0    -.07   1.265    1.314     .863     .869   4.310  0     3
 12 392.5 16.87 330.0    -.04   1.398    1.291     .924     .859   4.472  0     3
 13 392.3 16.85 329.9     .04   1.210     .965    1.487    1.163   4.826  0     3
 14 392.9 16.70 330.1    -.02    .539     .848     .570     .676   2.633  0     3
 15 394.9 16.96 330.0    -.09   1.528     .984    1.401    1.006   4.920  0     3
 16 391.9 16.87 330.1     .04    .641     .463     .811    1.002   2.917  0     3
 17 386.7 16.86 330.0     .26   1.197    1.048     .803     .959   4.008  0     3
 18 395.6 16.80 329.9    -.12   1.280    1.058     .846    1.461   4.644  0     3
 19 390.5 16.99 330.0     .12   1.427    1.325    1.114    1.026   4.892  0     3
 20 389.6 16.88 330.0     .16    .728    1.069    1.621    1.081   4.499  0     3



AVE 393.2 16.89 330.0    -.01   1.102     .931     .997     .980   4.010        3.0
SIG   2.5   .08    .1     .11    .374     .226     .261     .255    .722        0.0

THE ABOVE STATISTICS IS BASED ON  20 OUT OF 20 RUNS
```

```
                    MULTIPLE HEMISPHERIC COVERAGE RADAR
--------------------------------------------------------------------------------
    SECTION   7 - TRACK RESIDUALS FOR RUN NUMBER   1

    NPT  TIME     RM     DR     AM       DA       EM      DE      RRM   DRR   IDRP

      1    .200 11363.   -4.7  1.9766   4.045   .0047   3.059 -297.3    -.1    0
      2   2.000  9712.    5.0  1.4575   1.531   .0232   2.782 -134.4    -.2    0
      3   2.200 10807.   -2.6  1.9319   -.887   .0212   1.422 -261.2     .6    0
      4   4.000  9467.   -1.8  1.3906  -1.247   .0355   -.820 -105.4    -.8    0
      5   4.200 10348.    2.9  1.8921   -.495   .0329  -1.418 -234.6    -.7    0
      6   6.000  9279.   -3.9  1.3273  -1.551   .0468   -.794  -81.2     .7    0
      7   6.200  9872.    4.3  1.8517    .706   .0442  -1.237 -215.5     .0    0
      8   8.000  9141.    1.3  1.2622  -3.583   .0547    .170  -62.3    -.1    0
      9   8.200  9441.  -10.1  1.8087   1.795   .0527   -.387 -200.6     .6    0
     10  10.000  9031.   -2.9  1.2017   -.830   .0564   -.590  -44.0    -.3    0
     11  10.200  9067.    5.4  1.7620   1.833   .0556  -1.091 -187.7    -.3    0
     12  12.000  8968.    4.0  1.1391   -.369   .0514  -3.447  -26.0    -.0    0
     13  12.200  8693.   -8.4  1.7096   -.803   .0567    .754 -173.3     .2    0
     14  14.000  8931.    2.1  1.0777    .628   .0493   1.160   -8.7     .1    0
     15  14.200  8372.    3.6  1.6595   1.905   .0498   -.660 -158.0     .7    0
     16  16.000  8931.    2.2  1.0167    .888   .0398   2.790    8.1     .3    0
     17  16.200  8068.     .8  1.6017   -.290   .0399    .272 -144.3   -1.4    0
     18  18.000  8957.   -3.2   .9579   1.727   .0202  -1.564   24.2     .1    0
     19  18.200  7805.    7.0  1.5419  -1.697   .0239    .713 -126.2    -.3    0

                        TRACK RESIDUAL STATISTICS RUN   1

                   RANGE(M)   AZIMUTH(MR)   ELEVATION(MR)   DOPPLER(M/S)

          AVRGE       .055         .174          .059            -.052
          SIGMA      4.636        1.706         1.633             .516




--------------------------------------------------------------------------------
           SECTION  7        03/21/78  15.34.59           PAGE   9
```

Page c

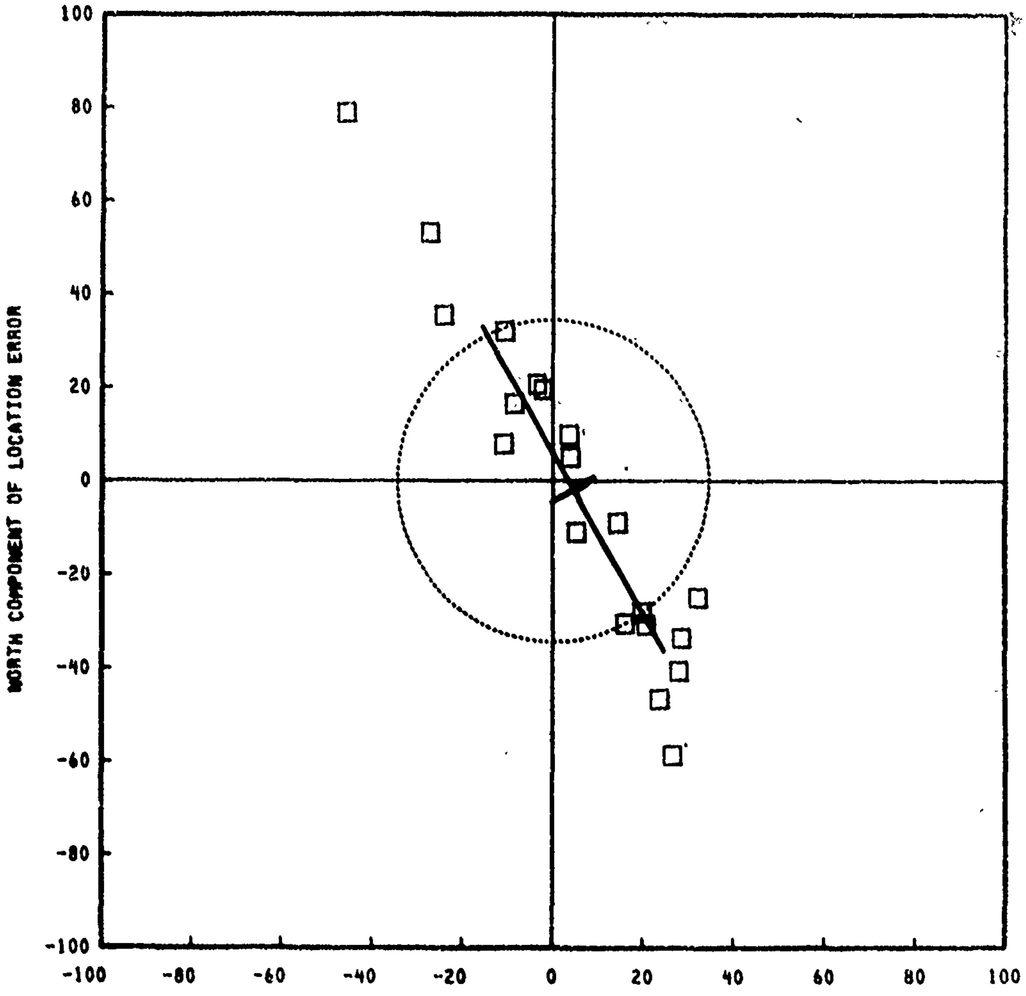


+MC 1 DEMONSTRATION RUN 4

```
                   MULTIPLE HEMISPHERIC COVERAGE RADAR
--------------------------------------------------------------------------------

         SECTION   8 - ESTIMATION STATISTICS (EST-TRUE)
MC         KD          KS    WE    WN    RE    AE    EB    DB    AM     BM        CM

 1    .704691E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .698250E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .644077E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 2    .705662E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .702118E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .354375E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 3    .699769E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .705987E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.621791E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 4    .704946E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .709855E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.490930E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 5    .714591E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .713724E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .867220E-06   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 6    .717946E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .717592E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .354375E-06   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 7    .721396E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .721461E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.646028E-07   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 8    .717070E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .725329E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.825911E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

 9    .731880E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .729197E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .268254E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

10    .754352E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .733066E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .212861E-04   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

11    .735866E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .736934E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.106810E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.

12    .721989E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
      .740803E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.             0.
     -.188140E-04   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.             0.


--------------------------------------------------------------------------------
         SECTION  8      03/21/78   15.35.42          PAGE  29
```

```
                         MULTIPLE HEMISPHERIC COVERAGE RADAR
------------------------------------------------------------------------------------------
   RC        KD          KS    WE    WN    RP    AE    EB    DB    AM       BM        CM

   13   .747244E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .744671E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .257263E-05   0.00  0.0 -0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   14   .745087E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .748539E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.345199E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   15   .748880E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .752408E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.352774E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   16   .748684E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .756276E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.759224E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   17   .751107E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .760145E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.903763E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   18   .765876E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .764013E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .186241E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   19   .761268E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .767802E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.661375E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.

   20   .769969E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .771750E-03    .15 -3.5 -3.5   0.0   0.0   0.0   0.0   0.0 0.                 0.
       -.178109E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.



        ESTIMATION STATISTICS BASED ON  20 OUT OF   20 RUNS

             KD          KS    WE    WN    RE    AE    ED    DE    AM       BM        CM
       -.158639E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.
        .765393E-05   0.00  0.0  0.0   0.0   0.0   0.0   0.0   0.0 0.                 0.




------------------------------------------------------------------------------------------
           SECTION  8      03/21/78  15.36.06           PAGE  30
```

```
                    MULTIPLE HEMISPHERIC COVERAGE RADAR
------------------------------------------------------------------------------
                 SECTION  9 INTERCEPT ROUTINE


     INTERCEPT   1 OPTION -2(SPECIFIED ALTITUDE  )VALUE=      30.00000
                  STATISTICS BASED ON  20 OUT OF  20 RUNS

        MC        X(M)      Y(M)       Z(M)       R(M)   GOOD FIT= 0

         1        26.3     -58.5       -.0        64.1     0
         2        23.6     -46.6       -.0        52.3     0
         3         3.6       9.7       -.0        10.4     0
         4        -3.5      20.5        .0        20.7     0
         5         3.8       5.0       -.0         6.3     0
         6        32.0     -24.9       -.0        40.5     0
         7        19.7     -28.1       -.0        34.3     0
         8        -8.6      16.4        .0        18.5     0
         9       -10.8      31.8        .0        33.6     0
        10        27.8     -40.6       -.0        49.2     0
        11        15.9     -30.5       -.0        34.4     0
        12        14.3      -9.1       -.0        16.9     0
        13        -2.2      19.4        .0        19.5     0
        14         5.2     -10.9       -.0        12.1     0
        15        20.5     -30.8       -.0        37.0     0
        16       -10.9       7.8        .0        13.4     0
        17       -45.8      78.6        .1        91.0     0
        18        28.3     -33.6       -.0        44.0     0
        19       -24.2      35.3        .0        42.8     0
        20       -27.3      53.0        .0        59.6     0

       AVE         4.4      -1.8       -.0
       SIG        40.2       5.3       0.0
       AVERAGE R=      35.0 M, SIGMA R=     20.9 M, CEP       34.3 M











------------------------------------------------------------------------------
             SECTION  9      03/21/78  15.36.07          PAGE  31
```



DEMONSTRATION RUN 4
MULTIPLE HEMISPHERIC COVERAGE RADAR

COV CEP OF PROB .5= 27.1 M CEP= 34.4 M
XBAR EAST= 4.4 M YBAR NORTH= -1.8 M
ELLIPSE AXIS MAJOR= 40.2 M MINOR= 5.3 M THETA= 149.9 DEG

7.4.3 Results Summary

This example demonstrates a multiple radar tracking a low quadrant elevation 105 mm howitzer.

SECTION 2 output is the ballistic trajectory based on the parameters specified in FIGURE 6. The radar used in the coverage is the southernmost sensor - HCR South. Note that the maximum projectile elevation angle is approximately 54 mr or 3 degrees at the time of 10 seconds.

SECTION 4 output is a dump of the track file which consists of both radar's measurements sorted in time. The measurements with track times of 2 to 18 seconds every 2 seconds are those of radar 1 while those times of .2 to 18.2 seconds are from radar 2.

SECTION 7 reports the file of track residuals for monte carlo run 1. The fit state vector is extrapolated to each track time, transformed to the appropriate radar coordinate system and the quantity, measurement minus estimated, is printed and plotted. The measurement residuals standard deviations are range 4.6 m, azimuth 1.7 mr, elevation 1.6 mr and doppler .5 m/s.

The statistics on drag estimation (KD) indicate a standard deviation of .765E-5 mm/kg, which corresponds to a drag estimate of 1.04 %.

The output from SECTION 9 plots the fitted state vector extrapolated to the terrain, with respect to the true launch location at coordinates (0 m East, 0 m North). The mean miss distance location, 4.4 m East and -1.8 m North, is relatively unbiased based on 20 Monte Carlo runs. The equivalent ellipsoid has a semi-major axis of 40.2 m inclined at approximately 150 degrees. The semi -major axis is almost inclined in the same direction as the down range axis. The cross range accuracies at 8.5 km is about 14.5 m; This error is largely responsible for the elongated scatter diagram. The equivalent CEP is 34.4 m.

System errors such as surveying accuracies, axes alignment and biases have not been included in this analysis but are nonetheless important and should be included for practical applications.

8.0 LOCATER PROGRAMMER'S GUIDE

The programmer's guide for LOCATER contains the following:

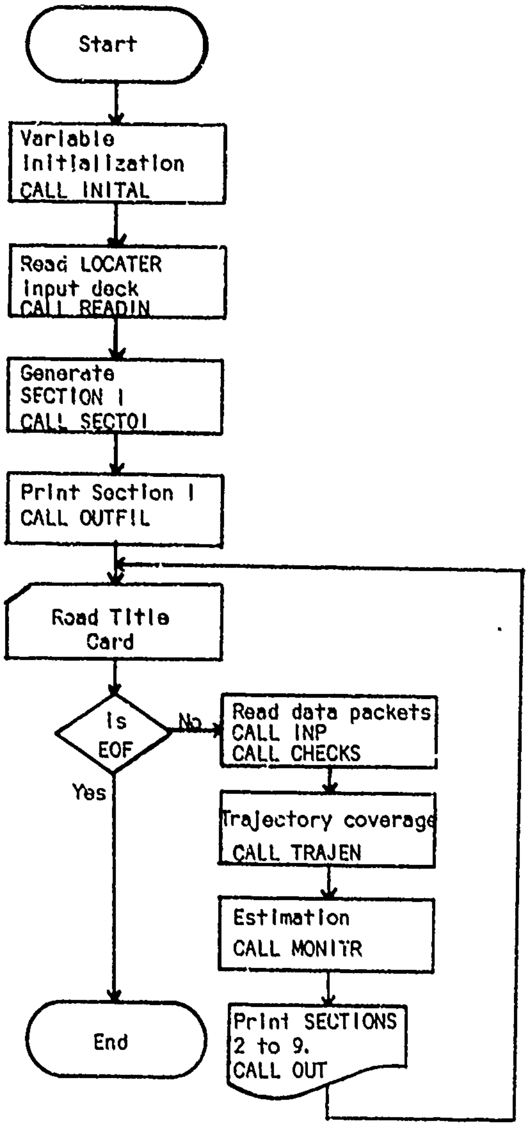
1. Flow charts of the main control routines.
2. Subroutine calling sequence and level number.
3. Alphabetical subroutine list, calling routine, and purpose.
4. Labelled common variable description, values, units, and cross reference list.
5. Information for modifying LOCATER - input storage array lengths and addition of new data packets.
6. Information for the modifying equations of motion.
7. LOCATER input/output units, purpose and contents.

8.1 Flow Charts

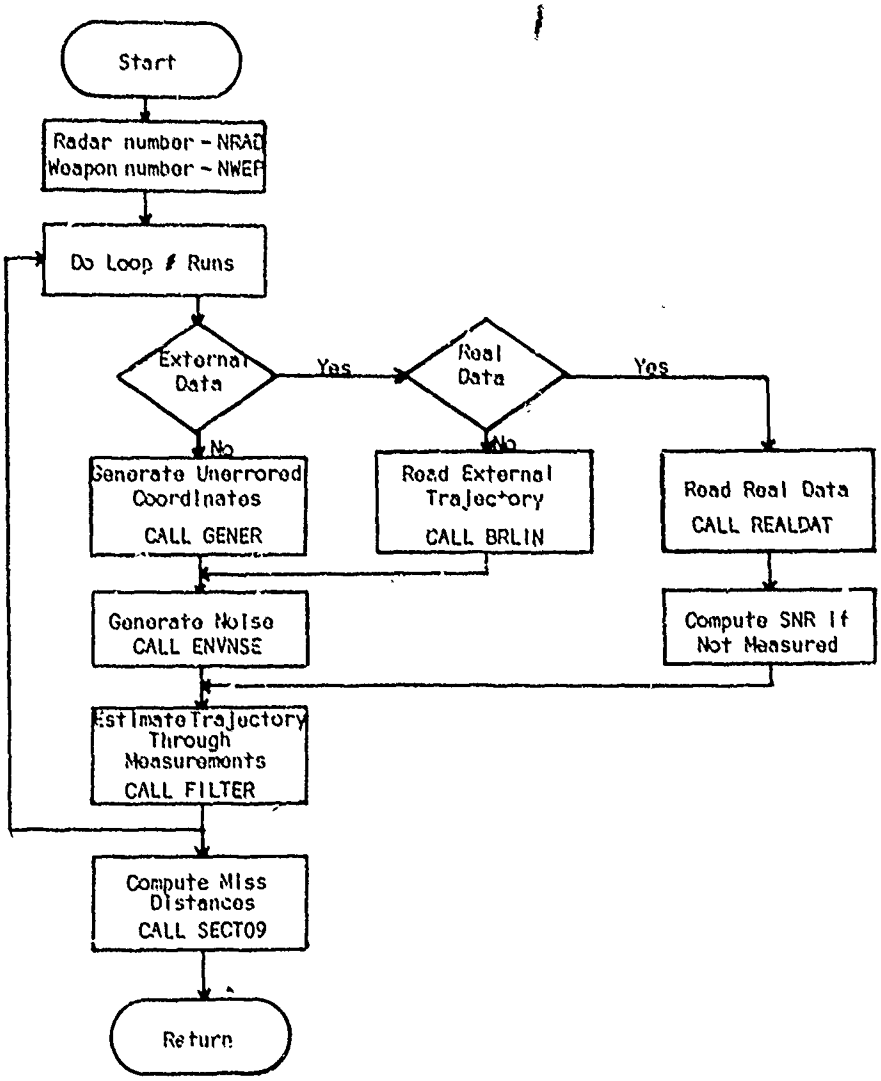
The following routines are flow charted in Section 8.1.

1. LOCATER Main program
    1. Variable initialization
    2. Reads in data packets
    3. Call MONITR the control program
    4. Outputs all data files
2. MONITR Main control subroutine
    1. Determines program run mode - either simulation or real data analysis
    2. Generates unerrored trajectory coordinates
    3. Computes radar noise for measurement simulation
    4. Calls the state vector estimator routine MAXLIK
    5. Determines covariance of estimated state vectors
3. MAXLIK Estimator subroutine
    1. Generates measurement weights
    2. Determines starting state vector
    3. Solves the maximum likely equation
    4. Generates SECTION 3-8 of the LOCATER REPORT
4. ACCEL Equations of motion
    Refer to section 5.3 for description

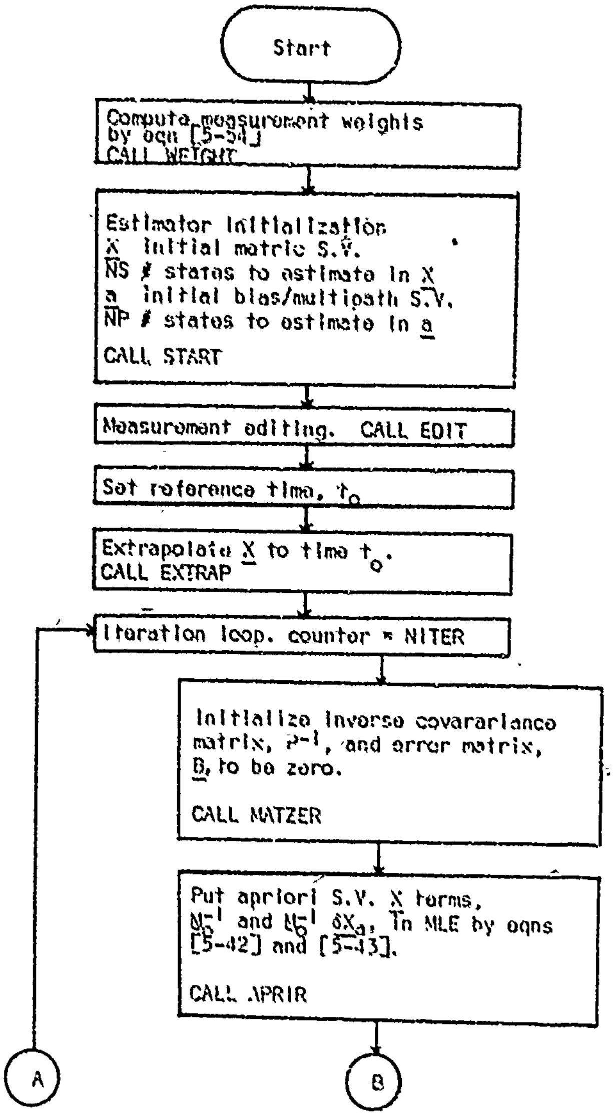
8.1.1 LOCATER FLOW CHART

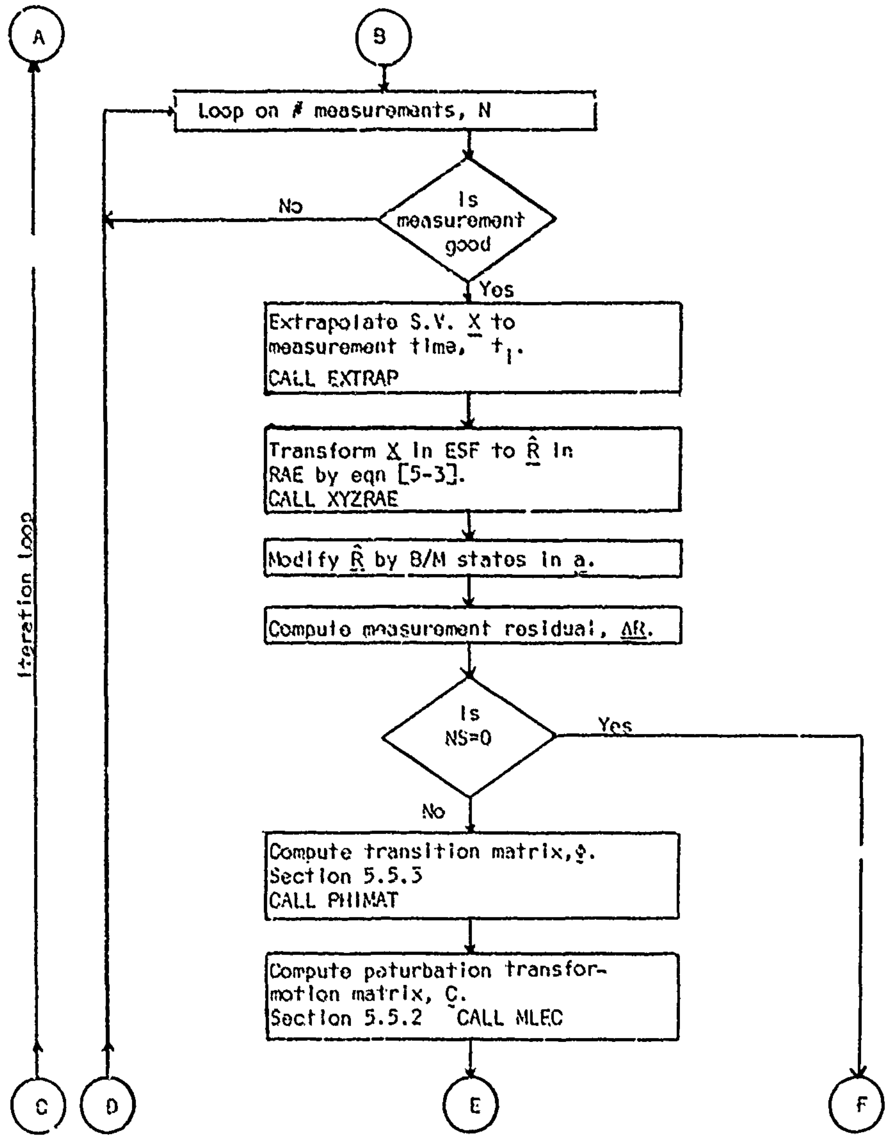


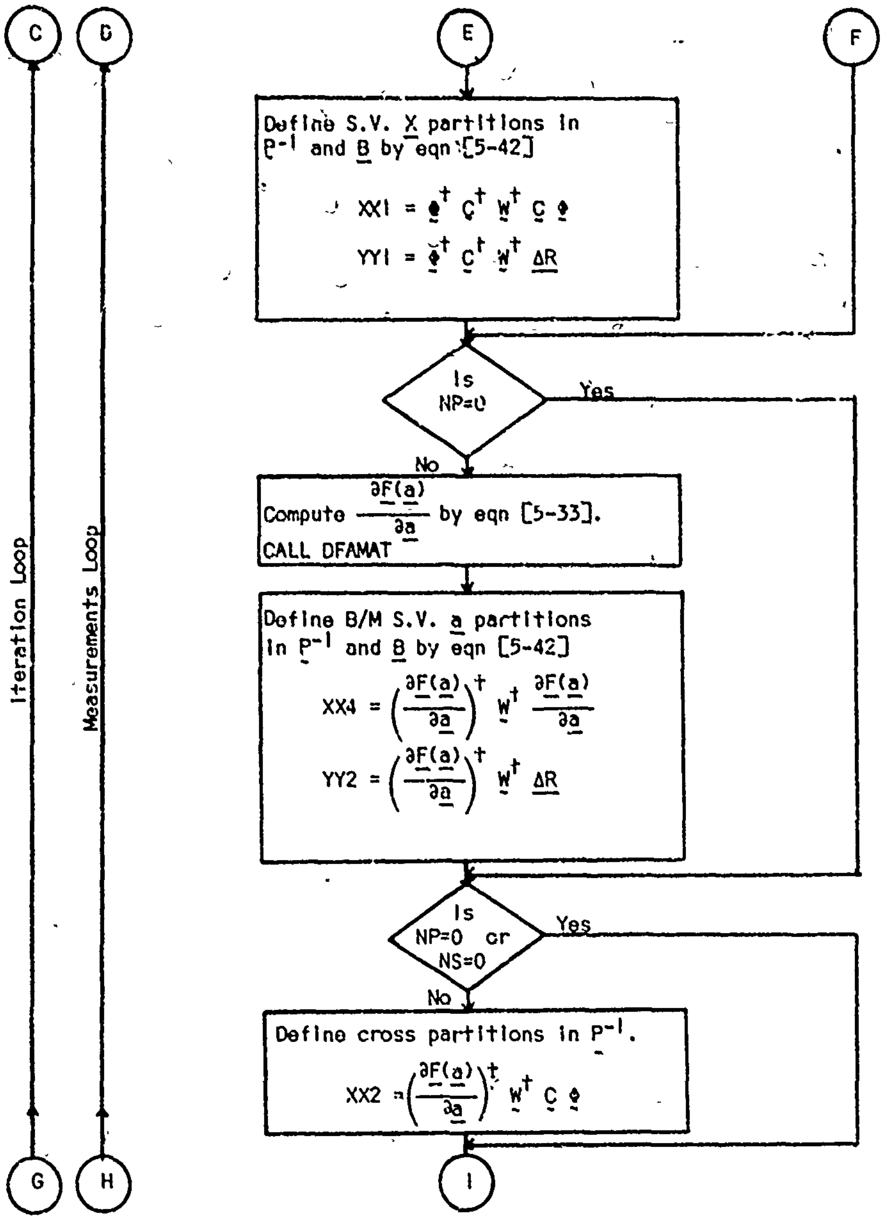
8.1.2 MONITR FLOW CHART

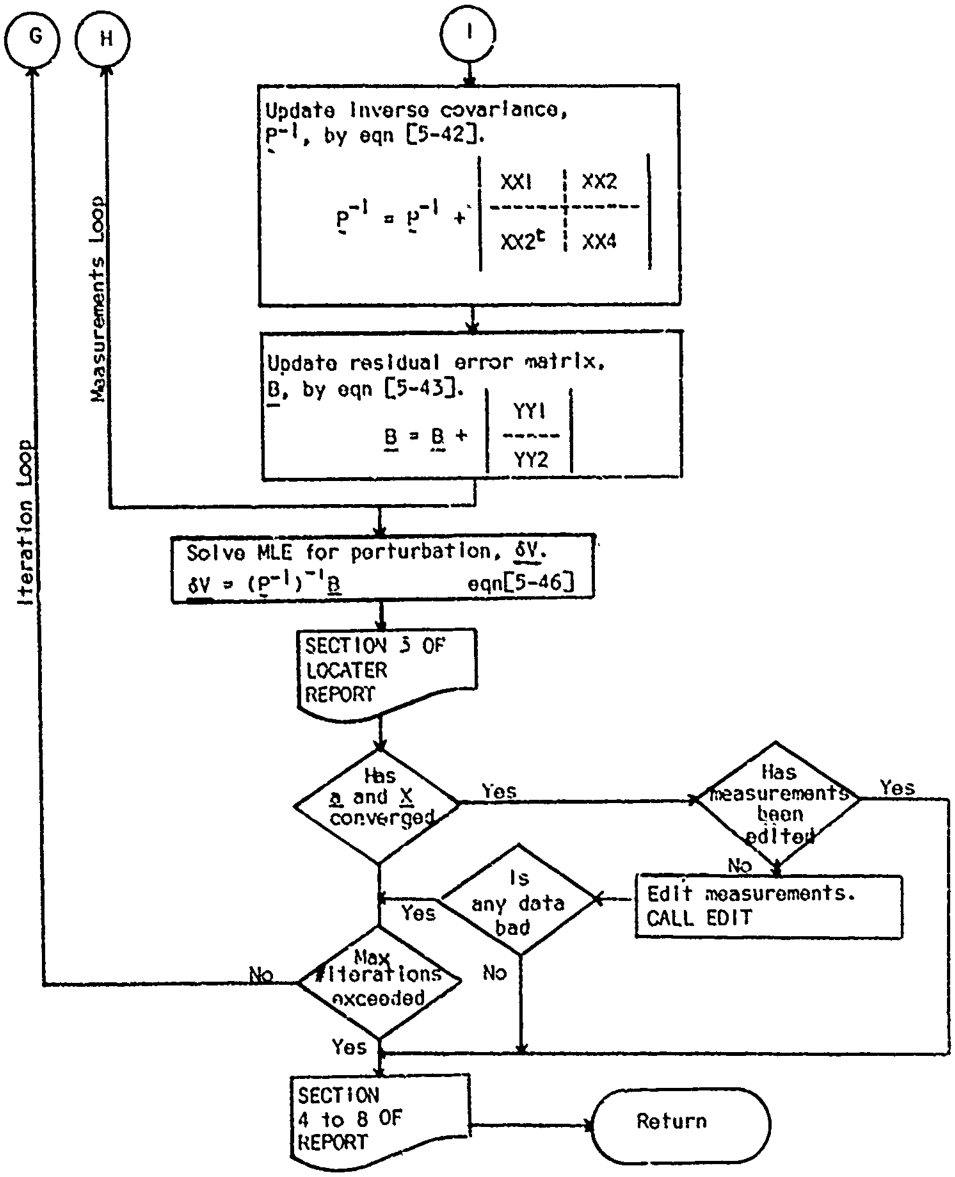


8.1.3 MAXLIK FLOW CHART

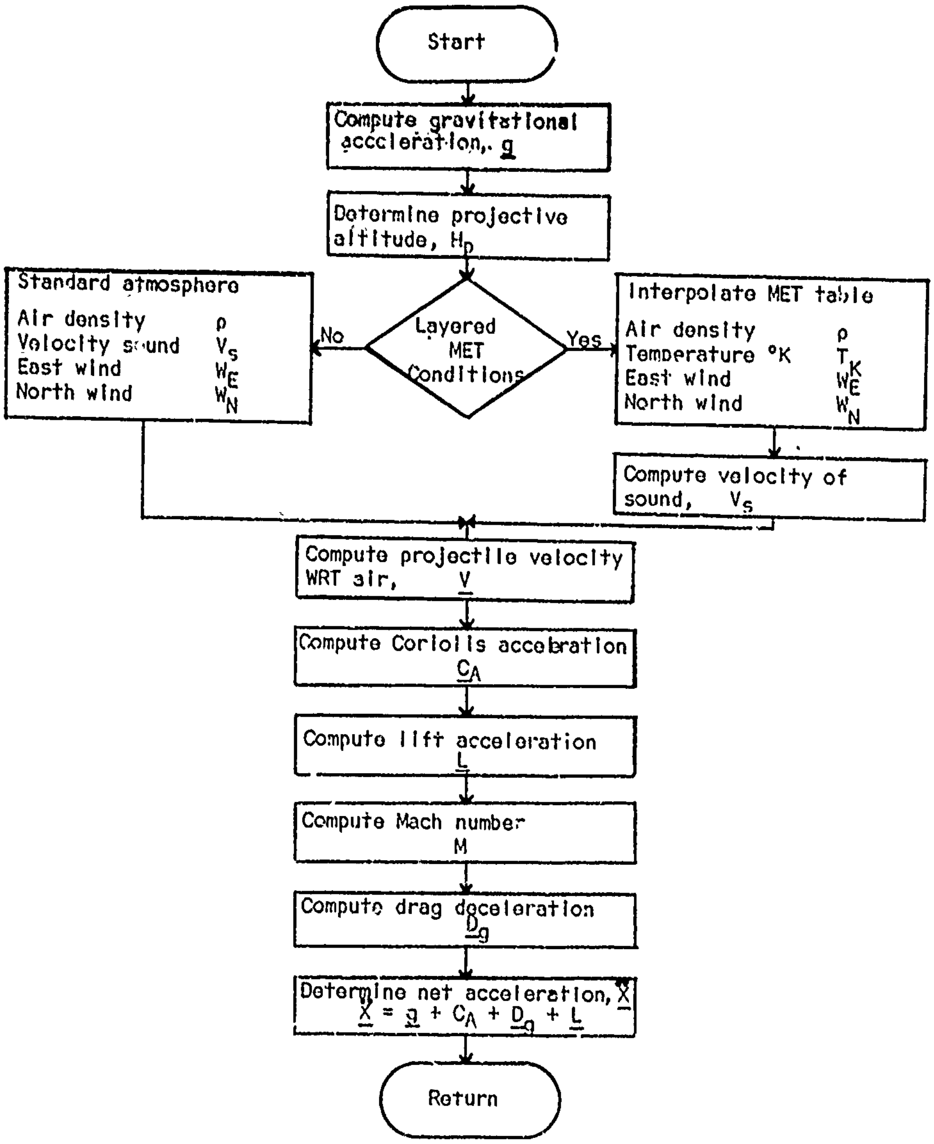



A
B
Loop on # measurements, N
Is measurement good
No
Yes
Extrapolate S.V. X to measurement time, t_i.
CALL EXTRAP
Transform X in ESF to $\hat{R}$ in RAE by eqn [5-3].
CALL XYZRAE
Modify $\hat{R}$ by B/M states in a.
Compute measurement residual, ΔR.
Is NS=0
Yes
No
Compute transition matrix, Φ.
Section 5.5.3
CALL PHIMAT
Compute perturbation transformation matrix, C.
Section 5.5.2 CALL MLEC
Iteration Loop
C
D
E
F


C
D
E
F
Define S.V. X partitions in P⁻¹ and B by eqn [5-42]
XX1 = Φᵗ Cᵗ Wᵗ C Φ
YY1 = Φᵗ Cᵗ Wᵗ ΔR
Is NP=0
Yes
No
Compute ∂F(a)/∂a by eqn [5-33].
CALL DFAMAT
Define B/M S.V. a partitions in P⁻¹ and B by eqn [5-42]
XX4 = (∂F(a)/∂a)ᵗ Wᵗ ∂F(a)/∂a
YY2 = (∂F(a)/∂a)ᵗ Wᵗ ΔR
Is NP=0 or NS=0
Yes
No
Define cross partitions in P⁻¹.
XX2 = (∂F(a)/∂a)ᵗ Wᵗ C Φ
Iteration Loop
Measurements Loop
G
H
I


G
H
I
Update inverse covariance, P^{-1}, by eqn [5-42].
$P^{-1} = P^{-1} + \left|\begin{array}{c|c} XX1 & XX2 \\ \hline XX2^t & XX4 \end{array}\right|$
Update residual error matrix, B, by eqn [5-43].
$B = B + \left|\begin{array}{c} YY1 \\ \hline YY2 \end{array}\right|$
Measurements Loop
Iteration Loop
Solve MLE for perturbation, δV.
$\delta V = (P^{-1})^{-1} B$ eqn[5-46]
SECTION 3 OF LOCATER REPORT
Has a and X converged
Yes
Has measurements been edited
Yes
No
Edit measurements. CALL EDIT
Is any data bad
Yes
No
Max iterations exceeded
No
Yes
SECTION 4 to 8 OF REPORT
Return

8.1.4 ACCEL FLOW CHART



8.1.5 Subroutine Calling Sequence

LEVEL NUMBER	ROUTINE NAME
0	LOCATER
1	INITAL
1	READIN
1	SECT01
1	OUTFIL
1	INP
2	FREAD
2	COPCHK
2	TABLIN
2	SETUP
2	OUTFIL
1	CHECKS
2	DMPOUT
1	TRAJEN
2	SETRND
2	REACH*
2	SECT02
3	RCST
3	TLUXY
3	SGNR
3	XYZRAE
2	EXTRAP$
1	MONITR
2	GENER
3	SETRND
3	MEASTR
3	REACH*
3	EXTRAP$
3	XYZXYZ
3	XYZRAE
3	RCST
4	TLUXY
3	SORT
2	BRLIN
3	SETUP
3	XYZECF
3	ECFXYZ
3	XYZRAE
3	RCST
4	TLUXY
2	REALDAT
3	SGNR
3	SORT
2	ENVNSE
3	GAUSS
3	MULPTH
4	TLUXY
3	TRPSH
3	SGNR
2	FILTER
3	MAXLIK
4	WEIGHT
4	START
5	SETRND
5	MEASTR
5	XMEAS
6	POLREG
7	SIMEQN
6	POLYVL
6	DIFPOL

```
4                               EDIT
5                                   AVRGE
4                               EXTRAP$
4                               PHIMAT
5                                   EXTRAP
4                               MATZER
4                               APRIR
4                               XYZXYZ
5                                   XYZECF
5                                   ECFXYZ
4                               XYZRAE
4                               RAEERR
4                               MLEC
4                               MATMUL
4                               DFAMAT
4                               TRNPSE
4                               MATINV
4                               COPMAT
4                               EXLPSE
4                               CONVRG
4                               SECT03
4                               SECT04
4                               SECT05
4                               SECT06
5                                   GRND21
5                                   REACH*
4                               SECT07
4                               SECT08
2                       SECT09
3                           EIGEN
3                           GRND21
3                           REACH*
3                           SORT
1               OUT
2                   OUTFIL
```

```
* SUBROUTINE EXTRAP

   LEVEL    ROUTINE
   BIAS     NAME

     0      EXTRAP
     1          ACCEL
     2              AMAG
     2              ALTUD
     2              TLUXY
     2              AXB
     2              KDD
```

```
$ SUBROUTINE REACH

   LEVEL    ROUTINE
   BIAS     NAME

     0      REACH
     1          EXTRAP
     1          XYZXYZ
     2              XYZECF
     2              ECFXYZ
     1          XYZRAE
```

1	ALTUD
1	GRND21
1	GRUND
1	NEXTX

All subroutines, SECT01 to SECT09, call subroutines TOP and BOT.

8.2 Subroutine Description

ROUTINE NAME	DESCRIPTION	CALLING ROUTINE	#OF CALLS
ACCEL	Equations of motion	EXTRAP	3
ADOTB	Vector dot product	RCST	1
ALTUD	Altitude of projectile	ACCEL	1
		REACH	5
AMAG	Vector magnitude	ACCEL	4
		ALTUD	1
		RCST	2
		SECT02	1
		SECT06	1
		SECT09	1
		SETRND	1
APRIR	Apriori information for MLE	MAXLIK	1
AVRGE	Average of an array	EDIT	1
AXB	Vector cross product	ACCEL	2
BOT	Writes bottom of each page	SECT01	2
		SECT02	2
		SECT03	3
		SECT04	2
		SECT05	2
		SECT06	3
		SECT07	3
		SECT08	5
		SECT09	5
BRLIN	Read external trajectory	MONITR	1
CHECKS	Input data consistency check	LOCATER	1
CONVRG	MLE covergence test	MAXLIK	1
COPCHK	Transfer input to storage arrays	INP	15
COPMAT	Matrix copy	MAXLIK	1
DFAMAT	B/M perturbation transformation in MLE	MAXLIK	1
DIFPOL	Polynomial differentiation	XMEAS	1
DMPOUT	Dump input data packet arrays	CHECKS	15
ECFXYZ	Coordinate transformation from ECF to ESF	BRLIN	1
		XYZXYZ	1
EDIT	Measurement editing	MAXLIK	3
EIGEN	Eigenvalues of symmetric matrix	SECT09	1
ENVNSE	Add radar noise to trajectory	MONITR	1
EXLPSE	MLE state vector expansion/collapse	MAXLIK	2
EXTRAP	State vector extrapolation	GENER	1
		MAXLIK	2
		PHIMAT	2
		REACH	6
		TRAJEN	2
FILTER	Filter choice routine	MONITR	1
FREAD	Read free format data packet	INP	1
GAUSS	Random number generator	ENVNSE	2
		MONITR	1
GENER	Generates unerrored trajectory coordinates for simulation	MONITR	1
GRND21	Determines ground height if no	REACH	1

	digital terrain map has been input.
INITAL	Variable initialization
INIT	Block data initialization
INP	Main input routine
KDO	Zero yaw drag coefficient curve
LOCATER	Main program
MATINV	Matrix inversion
MATMUL	Matrix multiplication
MATZER	Matrix initialization to 0
MAXLIK	Determines best fit trajectory through measurements
MEASTR	Defines true state vector
MLEC	Perturbation transformation from ECF to RAE
MONITR	Control program for measurement generation and trajectory estimation
MULPTH	Generate multipath errors
NEXTX	Roots of nonlinear equations
OUT	Main output routine
OUTFIL	Transfers output from SECT01 to SECT09 to line printer
PHIMAT	State transition matrix
POLREG	Polynomial regression
POLYVL	Polynomial evaluation
RAEERR	Modify measurement estimates by bias multipath errors
RCST	Compute RCS
REACH	Extrapolate state vector to a specified condition
READIN	Transfers input cards to disk
REALDAT	Read real data
SECT01	Print input data cards
SECT02	Radar-Weapon trajectory coverage
SECT03	MLE convergence performance
SECT04	Dump measurements array
SECT05	Print covariance matrix and correlation coefficients
SECT06	Launch parameters of estimated state vectors
SECT07	Print track residuals
SECT08	Estimation statistics
SECT09	Launch point determination
SETRND	Define initial state vector and integration constants
SETUP	Define transformations from ECF and ESF
SETUP2	Determines longitude and latitude of an ESF origin relative to another ESF origin
SGNR	Compute signal noise ratio
SIMEQN	Simultaneous equations
SORT	Sort measurements as function of time for multiple radar data

SECT06	1
SECT09	1
LOCATER	1
LOCATER	1
ACCEL	1
MAXLIK	1
MAXLIK	9
DFAMAT	1
MAXLIK	3
FILTER	1
GENER	1
START	1
MAXLIK	1
LOCATER	1
ENVNSE	1
REACH	1
LOCATER	1
COPCHK	2
INP	2
LOCATER	2
OUT	2
TABLIN	4
MAXLIK	2
XMEAS	1
XMEAS	1
MAXLIK	1
BRLIN	1
GENER	1
SECT02	1
GENER	2
SECT06	1
SECT09	2
LOCATER	1
MONITR	1
LOCATER	1
TRAJEN	4
MAXLIK	1
MAXLIK	1
MAXLIK	1
MAXLIK	1
MAXLIK	1
MAXLIK	1
MAXLIK	1
GENER	1
START	4
TRAJEN	1
BRLIN	1
INP	1
BRLIN	1
GENER	1
REALDAT	1
ENVNSE	1
REALDAT	1
SECT02	1
POLREG	1
GENER	1
REALDAT	1

		SECT09	1
START	Get state vector to initialize MLE	MAXLIK	1
TABLIN	Read a table in a data packet	INP	1
TLUXY	2-D table interpolation	ACCEL	4
		MULPTH	1
		RCST	1
TOP	Writes LOCATER title at top of each output page	BOT	1
		SECT01-09	1
TRAJEN	Nominal trajectory generation	LOCATER	1
TRNPSE	Matrix transpose	MAXLIK	2
TRPSH	Trophospheric refraction errors	ENVNSE	1
WEIGHT	Measurement weights in MLE	MAXLIK	1
XMEAS	Compute initial state vector from measurements	START	1
XYZECF	Coordinate transform from ESF to ECF	BRLIN	1
		XYZXYZ	1
XYZRAE	Coordinate transform from ESF to RAE	BRLIN	1
		GENER	1
		MAXLIK	1
		REACH	4
		SECT02	1
XYZXYZ	Coordinate transform between 2 radar ESF systems	GENER	1
		MAXLIK	1
		REACH	4

8.3 Labelled Common

The FORTRAN source of LOCATER uses 22 labelled common areas with each common being implemented as a COMDECK in the CDC UPDATE form of source storage. This implementation allows global common redefinitions.[7]

The purpose of this section is to familiarize the programmer with each common variable. The subsections of 8.3 are:

8.3.1 Input Data Packet Storage
arrays and dimensions

8.3.2 FORTRAN Common Statements

8.3.3 Variable Cross Reference
variable list

8.3.4 Common Variable Description
values, units, and defining subroutine

8.3.1 Input Data Packet Storage Arrays

Each LOCATER data packet has an associated common storage array. All field free numeric ITEMS that were read from the data packet are stored in this array with the number of ITEMS read being stored at the end of the array. The dimensions of these arrays are also stored as variables.

For example, the WEAPON XX data packet is stored in array WEAPON(100,XX) in labelled common WEP where XX ranges from 1 to 5. The first dimension of the array WEAPON, 100, is stored in variable IDIMA(14) while the second dimension, 5, is stored in JDIMA(14).

The following is a list of packet name and storage arrays:

Packet Name	Packet Array	Dimensions	Dimension Names	Labelled Common
APRIORI	APRIOR	(20,5)	IDIMA(1) ,JDIMA(1)	APR
EDITOR	EDITOR	(20)	IDIMA(2) ,JDIMA(2)	MEAS
ESTIMATOR	ESTIMA	(70)	IDIMA(3) ,JDIMA(3)	ESTI
MEASURE	MEASUR	(20)	IDIMA(4) ,JDIMA(4)	MSGN
METRO	METRO	(10,5)	IDIMA(5) ,JDIMA(5)	MET
MISSION	MISSIO	(20)	IDIMA(6) ,JDIMA(6)	TRAC
MULTIPATH	MULTIP	(20)	IDIMA(16),JDIMA(16)	MUL
ORIGIN	ORIGIN	(10,5)	IDIMA(7) ,JDIMA(7)	ORIG
OUTPUT	OUTPT	(100,5)	IDIMA(8) ,JDIMA(8)	OUT
RADAR	RADAR	(100,5)	IDIMA(9) ,JDIMA(9)	RAD
RANDOM	RANDOM	(5)	IDIMA(10),JDIMA(10)	RAND
TOPOGRAPH	TOPOGR	(20)	IDIMA(12),JDIMA(12)	AAA
TRACK	TRACK	(100)	IDIMA(13),JDIMA(13)	TRAC
WEAPON	WEAPON	(100,5)	IDIMA(14),JDIMA(14)	WEP
VECTOR	VECTOR	(20,5)	IDIMA(15),JDIMA(15)	APR

In the above list if a variable has only 1 dimension, e.g., array MISSIO, the variable JDIMA(6) would be 1. If the dimensions of any of the above arrays are to be changed, the new dimensions of the array should be stored in arrays IDIMA and JDIMA. LOCATER will then automatically perform bookkeeping if storage is changed in this manner.

Some data packets have an optional table as input. The following list contains the packet name, table storage array name, dimensions, variables names of dimensions and the appropriate common name. The array for storage of the variable format to read the table is also included.

Packet Name	Table Array	Dimensions	Dimensions Names	Common Name	Format
METRO	METVAL	(40,6,5)	IDMET,JDMET,KDMET	MET	FMTMET(20)
MULTIPATH	MULTAB	(100,2)	IIMUL,JJMUL	MUL	FMTMUL(20)
RCSTABLE	RCSTAB	(100,2,5)	IDIMA(11),JDIMA(11)	RCSS	FMTRCS(20)

For example the METRO X data packet is stored in array METVAL(40,6,XX) where XX ranges from 1 to 5 thus allowing 5 different sets of meteorological conditions. The variables IDMET=40, IDMET=6, and KDMET=5. The array METVAL is stored in labelled common MET, with the variable format to read the table being stored in array FMTMET(20).

8.3.2 FORTRAN Labelled Common Variables

All FORTRAN labelled common blocks in LOCATER are:

COMMON NAME	VARIABLE LIST
APR	APRIOR(20,5),VECTOR(20,5)
CONST	PI,ALG10,MILRAD,PI02,TWOPI,DEGRAD
EARTH	G0,RE,HRAD,REHR,VSNDG,OMEGA, OMEG(3),ECCEN,NORPOL
ESTI	ESTIMA(70)
INFO	NRAD,NWEP,NPTMAX,NRUN,MC,MULRAD
LENGTH	IDIMA(20),JDIMA(20),WORDS(20),NPACKS, IDMET,JDMET,KDMET,KDRCS,LXHAT, LAHAT,INDX(12)
MEAS	RMEAS(300,14),IIRM,JJRM,EDITOR(20), RSED(300,4)
MET	NMET,METNO,NMETC,METRO(10,5), METVAL(40,6,5),FMTMET(20)
MLE1	XOUT(20),DXOUT(10),AHAT(7),AOUT(7), DAOUT(7),ISTAT1(10),ISTAT2(7),Q(4), QSUM,COVAR(17,17)
MLE2	IFIT,NITER,NS,NSX,NP,NPX, NM,NMX,NSP,NSPX,NDROP,NUSED,IEXL(17), STNAM(17)
MSGN	MEASUR(20)
MUL	MULTIP(20),MULTAB(100,2),IIMUL,JJMUL, FMTMUL(20)
ORIG	ORIGIN(10,5),FMT1(20)
OUT	OUTPT(100,10)
RAD	RADAR(100,5),FMTDAT(20,5)
RAND	ISTART,RANDOM(5)
RCSS	RCSTAB(100,2,5),FMTRCS
REPORT	TITLE(20),NLINE,LNMAX,DASHES(22), NPAGE,NPGMX,DAY,TOD
TAPES	ITAPE(20),KTAPE(20),KIN,KOUT, KDAT,KREAL,KCARD
TRAC	MISSIO(20),TRACK(100)
WEP	WEAPON(100,5)

The description of each variable is in section 8.3.4.

8.3.3 Cross Reference Variable Name List

VARIABLE NAME	COMMON BLOCK	VARIABLE NAME	COMMON BLOCK	VARIABLE NAME	COMMON BLOCK
AHAT	MLE1	KCARD	TAPES	NS	MLE1
ALG10	CONST	KDATA	TAPES	NSP	MLE2
AOUT	MLE1	KDMET	LENGTH	NSPX	MLE2
APRIOR	APR	KDRCS	LENGTH	NSX	MLE2
COVAR	MLE1	KIN	TAPES	NUSED	MLE2
DAOUT	MLE1	KOUT	TAPES	NWEP	INFO
DASHES	REPORT	KREAL	TAPES	OMEG	EARTH
DAY	REPORT	KTAPE	TAPES	OMEGA	EARTH
DEGRAD	CONST	LAHAT	LENGTH	ORIGIN	ORIG
DXOUT	MLE1	LNMAX	REPORT	OUTPT	OUT
ECCEN	EARTH	LXHAT	LENGTH	PI	CONST
EDITOR	MEAS	MC	INFO	PIO2	CONST
ESTIMA	ESTI	MEASUR	MSGN	Q	MLE1
FMTDAT	RAD	METNO	MET	QSUM	MLE1
FMTMET	MET	METRO	MET	RADAR	RAD
FMTMUL	MUL	METVAL	MET	RANDOM	RAND
FMTRCS	RCSS	MILRAD	CONST	RCSTAB	RCSS
FMT1	ORIG	MISSIO	TRAC	RE	EARTH
GRND	AAA	MULRAD	INFO	REHR	EARTH
GRNDM	AAA	MULTAB	MUL	RHOG	EARTH
G0	EARTH	MULTIP	MUL	RMEAS	MEAS
HRAD	EARTH	NDROP	MLE2	RSED	MEAS
IDIMA	LENGTH	NITER	MLE2	STNAM	MLE2
IDMET	LENGTH	NLINE	REPORT	TITLE	REPORT
IEXL	MLE2	NM	MLE2	TOD	REPORT
IFIT	MLE2	NMET	MET	TOPOGR	AAA
IIMUL	MUL	NMETC	MET	TRACK	TRAC
IIRM	MEAS	NMX	MLE2	TWOPI	CONST
INDX	LENGTH	NORPOL	EARTH	VECTOR	APR
ISTART	RAND	NP	MLE2	VSNDG	EARTH
ISTAT1	MLE1	NPACKS	LENGTH	WEAPON	WEP
ISTAT2	MLE1	NPAGE	REPORT	WORDS	LENGTH
ITAPE	TAPES	NPGMX	REPORT	XGR	AAA
JDIMA	LENGTH	NPTMAX	INFO	XOUT	MLE1
JDMET	LENGTH	NPX	MLE2	YGR	AAA
JJMUL	MUL	NRAD	INFO		
JJRM	MEAS	NRUN	INFO		

8.3.4 Labelled Common Variable Description

This section describes every labelled common variable; its dimensions, contents, any unused storage and the routine that defines the variable. All variables follow the convention: I-N integer, otherwise real, except where noted.

APR LABELLED COMMON

Variable	Description, Value, Units
APRIOR(20,5)	Storage for APRIORI packet. Section 6.2.1. Elements 11-19 of each column is unused.
VECTOR(20,5)	Storage for VECTOR packet. Section 6.2.16. Elements 12-19 of each column is unused.

The second dimension refers to the packet number.

CONST LABELLED COMMON

Variable	Description, Value, Units
ALG10	Natural log of 10.0 = 2.302585
DEGRAD	Pi/180.0
MILRAD	Pi/3200.0 (real)
PI	3.1415926536
PI02	Pi/2.0
TWOPI	2.0*pi

Variables in CONST are defined in subroutine INITAL.

EARTH LABELLED COMMON

Variable	Description, Value, Units
ECCEN	Earth eccentricity = .0822719
GO	Gravitational constant times radius of earth squared = 9.80665*RE*RE
HRAD	Radar altitude above sea level
NORPOL	Radius of earth at north pole= 6356583.0 meters (real)
OMEG(3)	Components of earth spin resolved onto ESF system at radar location
OMEGA	Earth spin rate= 7.2921E-5 (rad/sec)
RE	Radius of earth at sea level
REHR	RE+HRAD.
RHOG	Atmospheric density (kg/mmm)
VSNDG	Velocity sound (m/s)

Variables in EARTH are defined in SETRND and INITAL.

ESTI LABELLED COMMON

Variable	Description, Value, Units
ESTIMA(70)	Storage for ESTIMATOR packet. Elements 25-69 are unused

INFO LABELLED COMMON

Variable	Description, Value, Units
MC	Number of runs-defined in MONITR=MISSIO(1)
MULRAD	0 single radar flag 1 multiple radar flag
NRAD	Packet # of base radar from 1 to 5 =MISSIO(3)
NRUN	Current run number. 1 to MC
NPTMAX	# of observations in track file.
NWEP	Weapon packet from 1 to 5. If real data mode NWEP may be 0. =MISSIO(2)

Variables in INFO are defined in MONITR,GENER,BRLIN and REALDAT.

LENGTH LABELLED COMMON

Variable	Description, Value, Units
IDIMA(20)	First dimension of packet storage arrays. section 8.3.1
JDIMA(20)	Second dimension of packet storage arrays
IDMET	First dimension of array METVAL=40
JDMET	Second dimension of METVAL=6
KDMET	Third dimension of METVAL=5
INDX(12)	(INDX(I)) is the index of the I'th estimated state in the state vector X.
KDRCS	Second dimension of RCSTAB=2
LAHAT	Length of B/M state vector=7
LXHAT	Length of metric state vector=20
NPACKS	Number of data packet types=16
WORDS(20)	First 4 letters of each PACKET NAME stored as left justified Hollerith.

Variables in LENGTH are defined in INITAL and BLOCK DATA.

MEAS LABELLED COMMON

Variable	Description, Value, Units
RMEAS(300,14)	Measurements file. For observation I,RMEAS(I,K) contains: K= 1 Measurement time(sec) 2 Range measurement(m) 3 Azimuth measurement(rad) 4 Elevation measurement(rad) 5 Doppler measurement(m/s) 6 Range weight 7 Azimuth weight 8 Elevation weight 9 Doppler weight 10 Signal noise ratio(db) 11 Radar number 12 Point drop code 0 Good point 1 Dropped from pre-fit edit 2 Dropped from low SNR 4 Dropped from post-fit edit 13 Weighted squared residual for observation 14 Unused

Cols. 1-5,10 are defined in GENER,BRLIN,or REALDAT
Cols. 6-9 are defined in WEIGHT
Col. 12 is defined in EDIT
Col. 13 is defined in MAXLIK

IIRM	First dimension of RMEAS=300
JJRM	Second dimension of RMEAS=14
RSED(300,4)	Track residual array (measured-estimate). For observation I, RSED(I,K) contains K=1 Range residual (m) K=2 Azimuth residual (rad) K=3 Elevation residual (rad) K=4 Doppler residual (m/s)
EDITOR(20)	Storage for EDITOR data packet. Elements 5-19 are unused

MET LABELLED COMMON

Variable	Description, Value, Units
METRO(10,5)	Real storage for METRO packet.
METNO	METRO packet number to be used defined in SETRND.
NMET	METRO type: 1 Default atmosphere 2 Specified ground conditions 3 Specified layered atmosphere
NMETC	# layers in type 3 METRO packet= METVAL(IDMET,1,METNO)

METVAL(40,6,5)	Storage for layered METRO table. For packet # METNO, and layer I, METVAL(I,K,METNO) contains:
	K=1 Height (m) of temp/den
	K=2 Temperature(deg Kelvin)
	K=3 Density(kg/mmm)
	K=4 Height of winds(m)
	K=5 East wind (m/s)
	K=6 North wind (m/s)

FMTMET(20)	Variable format to read 1 MET layer

MLE1 LABELLED COMMON

Variable	Description, Value, Units
XOUT(20)	Output estimated state vector. See section 5.3 for description.
DXOUT(10)	State vector perturbation
AHAT(7)	B/M state vector . Section 5.5.1
AOUT(7)	B/M state vector output in SECTION 3
DAOUT(7)	B/M state vector perturbation. output in SECTION 3
ISTAT1(10)	Estimation switches for metric SV. See section 5.5.1 Implementation
ISTAT2(7)	Estimation switches for B/M state vector. See Section 5.5.1 Implementation.
Q(4)	Average weighted squared residual over # of observations for each measurement component.
QSUM	Sum of Q components
COVAR(17,7)	Covariance matrix output in SECTION 5.

MLE2 LABELLED COMMON

Variable	Description, Value, Units
IFIT	0 Good fit flag 1 Bad fit (divergence)
NITER	Iteration # of estimator
NDROP	# of dropped measurements from editing
NUSED	# of good measurements
NSX	Max # of metric states to estimate=10
NS	# of metric states to estimate
NPX	Max # of B/M states to

	estimate
NP	# of B/M states to estimate
NSP	NS+NP
NSPX	NSX+NPX
NMX	# of radar measurement components=4
NM	# measurement components
IEXL(17)	For the I'th estimated state
STNAM(17)	STNAM(IEXL(I)) is name of state.

MSGN LABELLED COMMON

Variable	Description, Value, Units
MEASUR(20)	MEASURE packet storage array. See section 6.2.4.

MUL LABELLED COMMON

Variable	Description, Value, Units
MULTIP(20)	MULTIPATH packet storage array. See section 6.2.7
MULTAB(100,2)	Real storage for MULTIPATH table Column 1 is unerrored elevation (rad) Column 2 is errored elevation (rad)
IIMUL	First dimension of MULTAB=100
JJMUL	Second dimension of MULTAB=2
FMTMUL(20)	Variable format to read 1 row of the multipathtable

ORIG LABELLED COMMON

Variable	Description, Value, Units
ORIGIN(10,5)	Storage array of ORIGIN packet. See section 6.2.8
FMT1(20)	Variable format to read external data

OUT LABELLED COMMON

Variable	Description, Values, Units
OUTPT(100,10)	Storage array for OUTPUT data packet. The packet number is the same as the column #.

RAD LABELLED COMMON

Variable	Description, Value, Units
RADAR(100,5)	Storage for RADAR data packet. The packet # is stored in the same column. Elements 34-49, 63-99 of each column in unused. Elements 50-61 contain transformation matrices from ECF to ESF. Element 62 contains radius of earth(m)
FMTDAT(20,5)	Variable format to read real data

RAND LABELLED COMMON

Variable	Description, Value, Units
RANDOM(5)	Storage array for RANDOM packet. See section 6.2.11
ISTART	Starting random # seed

RCSS LABELLED COMMON

Variable	Description, Value, Units
RCSTAB(100,2,5)	Storage array for static RCS vs. aspect angle table
FMTRCS	Variable format to read RCS TABLE

REPORT LABELLED COMMON

Variable	Description, Value, Units
TITLE(20)	LOCATER title card (20A4)
NLINE	The current print line #
LNMAX	Max # of print lines/page Set at 55 in BLOCK DATA
NPGMX	Physical page size in lines=60
NPAGE	Page # of LOCATER REPORT
DASHES(22)	Array of dashes
DAY	Date in form bXX/YY/ZZb XX is numeric month 1-12 YY day of month ZZ year, b is blank
TOD	Time of day in form bXX,YY,ZZb XX is hour, YY is min, ZZ is sec

TAPES LABELLED COMMON

All tape units, variable names and contents are in section 8.6

TRAC LABELLED COMMON

Variable	Description, Value, Units
MISSIO(20)	Real storage array for MISSION data packet. See section 6.2.6
TRACK(100)	Storage array for the TRACK data packet. See section 6.2.14

WEP LABELLED COMMON

Variable	Description, Value, Units
WEAPON(100,5)	Storage array for the WEAPON data packet. See section 6.2.15. The packet # is stored in the same column.

8.4 Program Modification Techniques

Section 8.4 is primarily concerned with instructing the programmer how to make necessary program changes without getting too involved in the structure of LOCATER. The following problems are considered:

1. Increasing the length of the measurements file.
2. Increasing the length of tables: RCS vs Aspect angle, Layered Meteorological profile and multipath table.
3. Add more RADAR or WEAPON data packets.
4. Add new data packets or tables.
5. Change equations of motion.

8.4.1 Measurements File

The measurement file length is currently set at a maximum of 300 measurements. This includes all measurements from all radars tracking the weapon.

To change the length to N measurements the following changes are necessary:

1. Variable IIRM must be set to N in routine INITAL (line 147).
2. The first dimension of arrays RMEAS and RSED in COMMON/MEAS/ must be changed to RMEAS(N,14) and RSED(N,4) respectively. If the program run mode is +2 (external trajectory input) the array STORE in routine BRLIN must be dimensioned STORE(N,5). (line 12).

   If the maximum number of measurements is exceeded, LOCATER will print an appropriate error message.

8.4.2 RCS vs. Aspect Angle Table

The Radar cross section vs. aspect angle table is stored in array RCSTAB located in labelled common/RCSS/.

The limits are 5 tables with a maximum of 99 values per table. To increase the number of tables:

1. Change the variable JDIMA(11) to the maximum number of tables in routine BLOCK DATA INIT.
2. Change the third dimension of RCSTAB to the maximum number of tables.

To change the length of the table to M entries

1. Change the first dimension of array RCSTAB to M+1.
2. Change the variable JDIMA(11) to M+1 in BLOCK DATA INIT.

8.4.3 Layered Meteorological Profile

The layered meteorological profile is stored in array METVAL located in labelled common BLOCK/MET/. The current table limits are 5 tables with a maximum of 39 layers for each table. To increase the number of tables:

1. Change the variable KDMET to the number of tables by an assignment statement in routine INITAL. (line 50)
2. Change the third dimension of array METVAL to the number of tables.

To increase the size of the table to M layers:

1. Change variable IDMET to M+1 by an assigment statement in routine INITAL. (line 48).
2. Change the first dimension of array METVAL to M+1.

For each layer 6 items are required. They are:

1. Height (meters) of temperature and density
2. Temperature (deg Kelvin)
3. Density (kg/mmm)
4. Height (meters) of wind
5. East wind component (m/s)
6. North wind component (m/s).

To add an additional item:

1. Increase variable JDMET in routine INITAL (line 49) to the number of values for each layer.
2. Change the second dimension of array METVAL to the number of values for each layer.
3. Change the variable format card to read the required number of items.

8.4.4 Multipath Table

The multipath table relates unerrored elevation to errored elevation measurements. This table is stored in array MULTAB located in labelled common/MUL/ and is currently limited at 99 entries. To increase the table length to M entries:

1. Change variable IIMUL to M+1 by an assignment statement in routine INITAL. (line 228).
2. Change the first dimension of array MULTAB to M+1.

8.4.5 Number of Weapon and Radar Packets

The WEAPON data packet is stored in array WEAPON located in labelled common block/WEP/. The second dimension of array WEAPON refers to the maximum number of WEAPON packets. To increase the number of packets to M:

1. Change the second dimension of array
   WEAPON to M.
2. Change variable JDIMA(14) to M by
   a data statement in BLOCK DATA INIT.

The RADAR data packet is stored in array RADAR located in labelled common /RAD/. The second dimension of array RADAR refers to the maximum number of RADAR packets while the first dimension is the maximum number of parameters for the radar model. To increase the number of maximum packets to M:

1. Change the second dimension of array
   RADAR to M.
2. Change variable JDIMA(9) to M
   by a data statement in BLOCK DATA INIT.

8.4.6 Equations of Motion Modification

The equations of motion used by LOCATER are defined in routine ACCEL which is flow charted in section 8.1.4 and described mathematically in section 5.3. The method of describing the dynamics is to define the projectile's accelerations as a function of positions, velocities and atmospheric conditions and then using a modified prediction corrector algorithm (routine EXTRAP) to extrapolate the present state.

Routine SETRND defines the initial state vector array X, meteorological conditions and integration constants. The elements of X are

X(1)	Tag time of state
X(2),X(3),X(4)	Positions (meters)
X(5),X(6),X(7)	Velocities (m/s)
X(11)	Drag state (mm/kg)
X(12)	Spin state (m/s)
X(13)	East wind component (m/s)
X(14)	North wind component (m/s). Element 13 and 14 are 0.0 for layered type atmospherics
X(15)-X(20)	Unused

The function of routine ACCEL is to compute the accelerations and store them in array locations X(8),X(9),X(10).

At present the dynamics includes gravity, zero yaw drag with an approximation for yaw, coriolis, and lift accelerations in the medium of a standard or layered type atmosphere.

To utilize additional states in the dynamics, one should consider to which type of packet (WEAPON, RADAR or METRO) the parameters should be included with. Refer to section 8.3.4 for unused parts of these storage arrays. The change might be large enough in scope to make a new type of data packet and common. These parameters should then be made available in routine

SETRND and put in the state vector array X in the unused array locations (15 to 20). Routine ACCEL would then be modified to reflect the new dynamic model.

8.4.7 Addition of New Data Packets

LOCATER at present will recognize 16 types of data packets. See section 8.3.1 for a list. Each new packet will include:

1. A PACKET NAME card with a packet number.
2. List of numeric ITEMS delimited by two $.
3. An optional table preceded by a variable format card and followed by a blank card.

For an example of a new data packet consider 3 different types of earth model's.

1. flat
2. spherical
3. WGS-72 ellipsoidal model(3)

At present only type 3 is utilized by LOCATER.

The following steps allow the recognition of the new packet by LOCATER.

1. Choose a unique PACKET NAME up to 10 alphanumeric characters long. Example, "EARTH"

2. Increase variable NPACKS by 1 in routine INITAL (line 46). Example, NPACKS=17.

3. Take the first 4 letters of the PACKET NAME and add the Hollerith representation to the end of array WORDS. Example, DATA WORDS(17)/4HEART/

4. Decide what specific variables should be input for each type of model.

Example - Model 1

Item #	Value and Description
1	1 signifying flat

Example - Model 2

Item #	Value and Description
1	2 signifying spherical
2	0 earth not rotating
	1 earth rotating
3	radius of earth (m)

Example - Model 3

Item #	Value and Description
1	3 signifying ellipsoidal
2	0 earth not rotating
	1 earth rotating
3	radius of earth at north pole
4	eccentricity

5. Chose a unique array name, dimensions and labelled common for the storage of the data packet.
   Example: COMMON/MODEL/SHAPE(10)
   Hence the data packet will be stored in array SHAPE.

6. Store the first dimension of the array at the end of array IDIMA in routine BLOCK DATA INIT and the second dimension at the end of array JDIMA.
   If the second dimension is nonexistant set it to 1.
   Example: DATA IDIMA(17)/10/,JDIMA(17)/1/.

7. If the number of data packets is greater than 20, change the dimensions of arrays WORDS, IDIMA and JDIMA to the appropriate number in labelled common block/LENGTH/.

8. Decide on a default model or require the user to specify a model.
   To choose a default model (say type 2) with the earth rotating the following code should be implemented common block/LENGTH/.

```
COMMON/MODEL/SHAPE(10)
.
.
.
SHAPE(1 )=2.0
SHAPE(2)=1.0
SHAPE(3)=6356760.0
IL=IDIMA(17)
SHAPE(IL)=3.0
.
.
.
```

   The last line of code signifies that 3 variables were defined.

   To require the user to specify an input packet, the following code would be implemented

```
.
.
COMMON/MODEL/SHAPE(10)
.
.
.
IL=IDIMA(17)
SHAPE(IL)=0.0
.
.
```

   This signifies that no variables were defined and a packet must be input.

9. The following code would be added to routine INP.

   Add a 17th branch (say label 260) to the multiple GO TO at line 48.

```
      COMMON/MODEL/SHAPE(10)
      .
      .
      .
  260 CONTINUE
      CALL COPCHK (FREE,SHAPE,NUMBER,NUM,NNVAR)
      GO TO 30
      .
      .
      .
```

This code assigns the values read by the free format reading routine to array SHAPE.

An example of an EARTH data packet follows:

```
     EARTH     01
     $ USE ELLIPSOID MODEL TYPE 3, THE
      EARTH IS ROTATING 1, THE RADIUS
      OF THE NORTH POLE RADIUS IS 6356760
      METERS, ECCENTRICITY IS .08181 $
```

The above example of adding a new data packet only considers the input of the variables, not what changes are necessary to make them functional. For example, the earth model type would affect gravitation, Coriolis acceleration and appropriate coordinate system transformations.

8.5 LOCATER Input/Output Units

The I/O of LOCATER is carried out by 20 units, most of which are scratch for the LOCATER REPORT. For each unit i used by FORTRAN, the local file TAPEi must be declared on the PROGRAM statement card. The labelled common block TAPES contain the variable names for each unit.

The following table equates tape unit number with variable name and describes the contents.

UNIT #	VARIABLE NAME	DEFINING ROUTINE	CONTENTS
1	KIN	INITAL	LOCATER data cards
2	KDAT	INITAL	Real or external data if on tape
3	KTOP	INITAL	Digital topographic map
4			Scratch for MAXLIK
5	KCARD	INITAL	Systems input (card reader)
6	KOUT	INITAL	Systems printer
11	ITAPE(1)	BLOCK DATA	SECTION 1 of LOCATER output
12	ITAPE(2)	BLOCK DATA	SECTION 2
13	ITAPE(3)	BLOCK DATA	SECTION 3
14	ITAPE(4)	BLOCK DATA	SECTION 4
15	ITAPE(5)	BLOCK DATA	SECTION 5
16	ITAPE(6)	BLOCK DATA	SECTION 6
17	ITAPE(7)	BLOCK DATA	SECTION 7
18	ITAPE(8)	BLOCK DATA	SECTION 8
19	ITAPE(9)	BLOCK DATA	SECTION 9
22	KTAPE(2)	BLOCK DATA	SECTION 2 tape output
27	KTAPE(7)	BLOCK DATA	SECTION 7 tape output
29	KTAPE(9)	BLOCK DATA	SECTION 9 tape output

Tape unit numbers 7-10, 20, 21, 23-26 and 28 are unused.

REFERENCES

1. M.E. Austin and E.T. Bayliss, "A Maximum Likelihood Weapon Location Algorithm for Use With Projectile Tracking Radars," Technical Note 1977-15, Lincoln Laboratory, M.I.T. (21 July 1977), DDC AD-3022299L.
2. B.L. Diamond and M.E. Austin, "The ARIES Program: Coordinates, Transformations, Trajectories and Tracking," Technical Note 1975-15, Lincoln Laboratory, M.I.T. (5 September 1975), DDC AD-A015815/4.
3. Department of the Army Technical Manual TM 5-241-4/1 (Volume 1 - Transformation Coordinates from Geographic to Grid), Army Map Service, July 1958.
4. R.F. Lieske and A.M. MacKensie, "Determination of Aerodynamic Drag from Radar Data," MR-2210, Ballistic Research Laboratory (August 1972).
5. *Handbook of Physics and Chemistry*, 46th Edition, Chemical Rubber Company, 1965.
6. The U.S. Air Force, U.S. Standard Atmosphere, 1962, Washington, U.S. Government Printing Office, 1962.
7. *Update Reference Manual*, Publication #60342500, CDC Publications and Graphics Division, 1975.
8. Control Data Corporation, *Scope Reference Manual*, Version 3.4, Publication #60307200, CDC Software Documentation, Sunnyvale, CA, 1972.
9. J. Hurff and P. Ward, "A Modified Point Mass Trajectory Model for TACFIRE", USA Ballistics Research Laboratory, (3 March 1964).
10. "Wallops Station Radar Information Handbook," NASA (1975).
11. R.F. Lieske and M.L. Reiter, "Equations of Motion for a Modified Point Mass Trajectory," Report 1314, Ballistics Research Laboratories (March 1966), DDC AD-485869.
12. D.K. Barton and H.R. Ward, *Handbook of Radar Measurement*, (Prentice-Hall Inc., 1969).
13. E.T. Bayliss, "Improvement of the ANITPQ-31H Projectile Tracking Radar Weapon Location Algorithm," Project Report TT-23, Lincoln Laboratory, M.I.T. (15 July 1977).

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

⑲ **REPORT DOCUMENTATION PAGE**

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ⑱ ESD-TR-78-377

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE *(and Subtitle)* ⑥ HOWLS LOCATER Computer Program: Description and User's Guide.

5. TYPE OF REPORT & PERIOD COVERED ⑨ Project ~~Report~~. 10

6. PERFORMING ORG. REPORT NUMBER Project Report TT-14

7. AUTHOR(s) ⑩ Edward T. Bayliss ~~and~~ James H. Cosgrove

8. CONTRACT OR GRANT NUMBER(s) ⑮ F19628-78-C-~~0002~~, ARPA Order-2752

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Lincoln Laboratory, M.I.T.
P.O. Box 73
Lexington, MA 02173

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

Program Element No. 62702E
Project Code 9G10
ARPA Order 2752

11. CONTROLLING OFFICE NAME AND ADDRESS

Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

12. REPORT DATE ⑪ 26 Dec~~ember 1~~978

13. NUMBER OF PAGES 228

14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*

Electronic Systems Division
Hanscom AFB
Bedford, MA 01731

⑫ 227p.

15. SECURITY CLASS. *(of this report)* Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

⑭ TT-14

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

None

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

projectile tracking
FORTRAN
weapon locations

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

LOCATER is a computer program used to simulate projectile tracking radar estimation of weapon locations from real or simulated projectile tracking data. A complete mathematical description of the modified point mass trajectory modeling, radar random errors, wind, refraction, multipath and the likelihood estimator is included. Detailed user instruction and samples are covered. A programmer's guide to modification of the 7000 line FORTRAN program is included.

207 650

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*