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THESIS

SIMULATION OF A TRACK-WHILE-SCAN RADAR

by

William Frederick Delaney

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SIGNATURE OF A TRACE-WHITE-SCAN RADAR

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

A model of a TWS radar is developed that provides a realistic computer simulation for comparing various radar tracking methods.

Prediction accuracy of a simplified alpha - beta tracker is compared to that of an adaptive filter. In addition, the effect on radar tracking of a variable gate size correlation technique is investigated.

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CHAPTER I

INTRODUCTION

A need exists for more extensive use of computer simulations as an aid for defining and obtaining the solutions to systems engineering problems. To gain some insight and experience in this field a computer simulation of a hypothetical point defense radar system is carried out.

The criteria for defining the radar parameters and method of operation were derived from the following situation.

A destroyer class ship should be able to provide itself with adequate protection against a multiple aircraft raid while transiting singly. In order to provide timely detection and adequate intelligence for launch of a defensive weapon the shipboard radar must be capable of the following functions:

1. Full hemispherical coverage.
2. Medium range search i.e. 50-100 n.m.
3. Multiple target track while scan.
4. High data rates in critical threat sectors.

In addition, to minimize costs the radar design should be compatible with existing weapons. To provide a realistic approach, only those designs and techniques capable of being implemented with currently available components were allowed.

A phased array antenna with a monopulse beam was chosen to meet the requirement of high data rates on multiple targets. Phased arrays are inherently limited in scan. To meet the requirement of full 360° coverage it was necessary to rotate the antenna mechanically in azimuth. Formulation of the problem in this way led to the selection of two modes of operation. The first is characterized by complete

radar coverage with mechanical rotation in azimuth and electronic scanning in elevation, with monopulse in elevation angle only. This mode has limited tracking capability due to a relatively low revisit rate. Mode 2, a sector scan with an electronically steered beam in azimuth and elevation and monopulsing in two coordinates, is capable of providing 0° to 90° elevation coverage and $\pm 45^\circ$ in relative azimuth.

It is felt that the two-mode solution is justified since one can assume with some confidence that the raid will be radially inbound with little or no intentional maneuvering at ranges greater than twenty-five nautical miles. Once the raid has been detected and evaluated as such by the observer, Mode 2 can be selected to provide a high data rate to track the target, whose probability of maneuver increases as the range to the target decreases and as his weapon launch point is approached.

The switching range is not critical and can be assumed to be a function of the maximum range of the expected weapon available to the enemy aircraft (of the order of 5 to 15 n.m.) plus some safety time.

Once the radar was modeled and the computer program written, the simulation became a convenient vehicle for investigation of the radar tracking equations which are a critical facet of a TWS system. A comparison of prediction accuracy and resolution of target tracks between a classical alpha/beta tracker and an adaptive technique was pursued as an extension of the basic premise of utilizing the computer as a device for design and analysis.

CHAPTER II

RADAR MODEL

A discussion of some assumptions which affected the choice of the type of radar to be modeled was presented in the introduction. This chapter presents some of the reasoning and methods used to select basic parameters for the radar necessary to establish a reasonable time scale for the simulation. This initial section is followed by a discussion of a few of the more important subroutines in enough detail to supplement the flow diagrams of appendix II where necessary.

Choice of Basic Parameters.

- Assume:
- (1) Target velocity = 500 m.p.h.
 - (2) Attack profile shown in Fig. 1
 - (3) Target weapon release point ≤ 10 m.m. max.
 - (4) Defensive weapon = missile (max 3).
 - (5) Missile requires a high data rate for command guidance.
 - (6) Antenna height (h_a) = 50 ft.

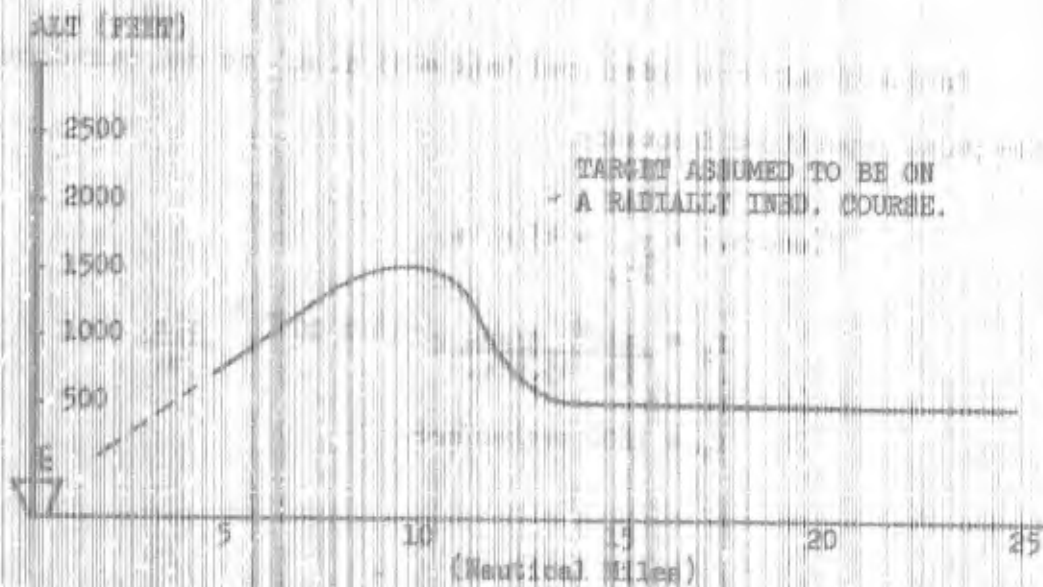


Fig. 1 ATTACK PROFILE

Desiring a 10 second sector scan in which to fire and control the defensive missile, we must commence sector scan at a minimum range of 20 n. m. This ensures an impact point of approximately 15 n. m., providing adequate time for a second attempt before the attacking aircraft reaches his weapon launch point. Arbitrarily assuming twice this range (40 n. m.) will provide adequate time for threat evaluation. Based on the radar horizon given by the following equation, 50 n. m. was chosen as the range at which a probability of detection, equal to 90% on a single scan, would provide sufficient initial detection capability.

$$r = \sqrt{2h_a} + \sqrt{2h_c} \quad (\text{miles})$$

h_c = height of target A/C.

given : $h_a = 50 \text{ n. m.}$

$r \approx 41 \text{ miles } h_c = 300 \text{ ft.}$

$r \approx 54 \text{ miles } h_c = 1000 \text{ ft.}$

Having obtained an idealized $R_{max} = 45 \text{ n. m.}$, we can calculate the pulse repetition frequency.

$$R(\text{unamb.}) = \frac{c}{2r_p} = 45 \text{ n. m.}$$

$$f_p = \frac{3 \times 10^8 \text{ m/sec}}{2 \times 45 \text{ n.m.}} \times 9.4 \times 10^{-4} \frac{\text{n.m.}}{\text{m.}}$$

$$f_p = 1800 \text{ cycles/sec.}$$

Assuming a fan shaped antenna (beam width by 5.5° in elevation) and requiring the equivalent of integrating 4 pulses per scan we determine the time for one revolution of the antenna in note 1.

$$\frac{1}{1800 \text{ cycles/sec.}} \times \frac{4 \text{ cycles}}{1^\circ \text{ Beam Position}} \times \frac{360^\circ}{\text{REV.}} = 0.8 \frac{\text{SEC.}}{\text{REV.}}$$

This figure must be multiplied by the number of 5.5° sections in elevation that must be covered. Taking into account the target profiles and realizing the advantages of short revisit rates a compromise value of 52.5° coverage in elevation requiring 8 sec. total scan time was selected.

To simulate the continuous motion of the antenna, azimuth is divided into 0.02° increments. The following diagram describes the antenna motion.

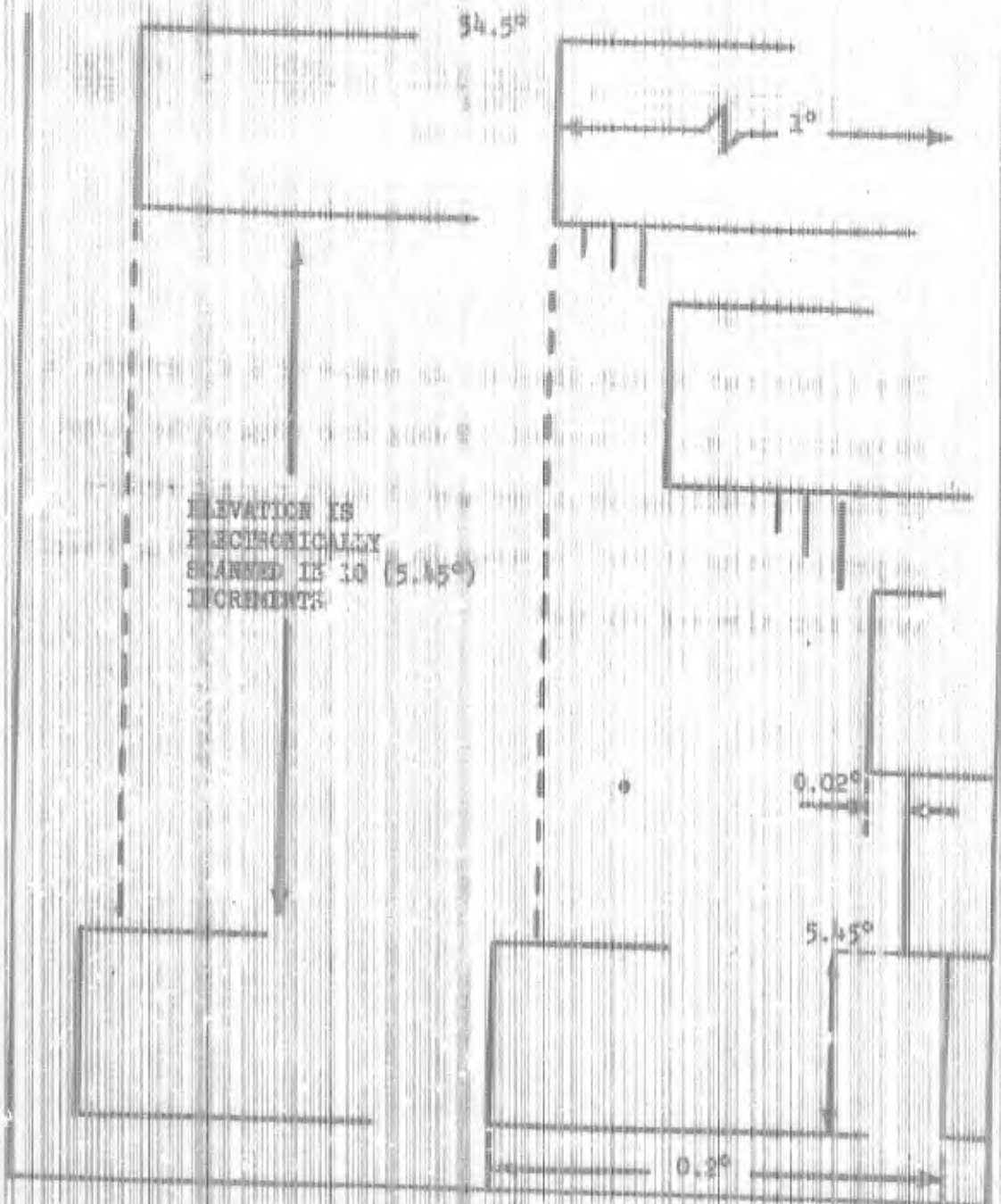


Fig. 2. SIMULATED ANTENNA MOTION -- MODE 1

Turning now to a discussion of mode 2 or full electronic sector scan the following assumptions were made:

(1) Defensive missile has a 20 millisecond command guidance requirement repeated at intervals of 1 second.

(2) Special purpose beam steering computer capable of:

- (a) Calculating 200 beam positions per second.
- (b) Superimposing collimation commands on the beam position to obtain variable beam shape.
- (c) Beam shape = $2^\circ \times 2^\circ$ pencil beam.

(3) 5 ms. illumination time per beam position except 25 ms. illumination time for beam positions where targets are predicted to be present.

(4) 10 - target capability, maximum.

The above assumptions lead to the establishment of the following table:

TABLE 1. Search Beam Positions vs. known targets

Targets	Search Beam Positions Remaining Per 1 Second Interval.
0	200
2	190
4	180
6	170
8	160
10	150

In a $\pm 45^\circ$ AZ. by 60° EL. sector we have $45 \times 50 \approx 1350$ ($2^\circ \times 2^\circ$) beam positions. For the worst case of 10 targets engaged the revisit rate to a "same" search position would be $\frac{1350}{150} =$ approximately 9 seconds. This scan interval is reduced to 6.75 seconds for the case of 0 targets engaged.

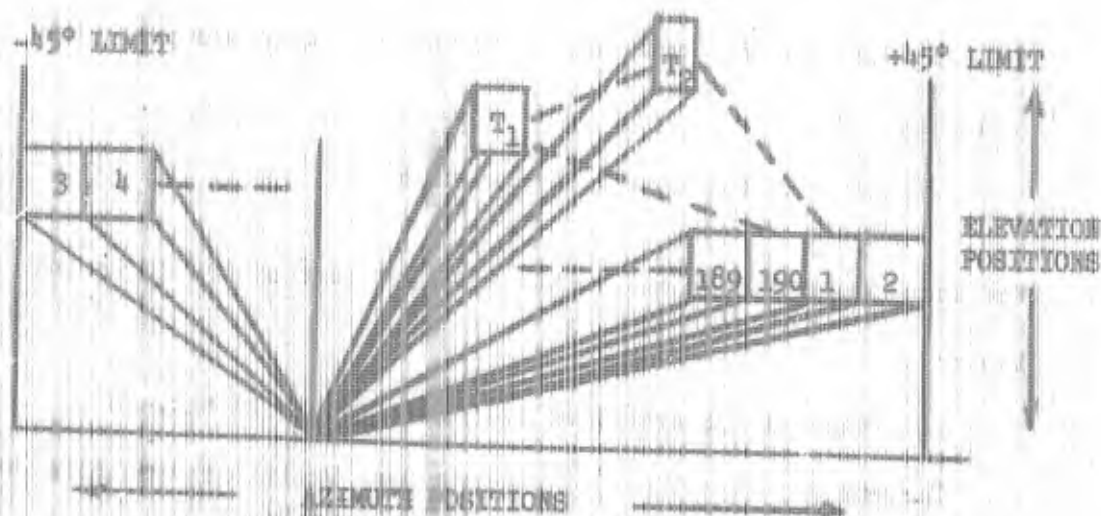


Fig. 1. BEAM SCANNING SEQUENCE FOR 2 TARGETS ENGAGED. MODE 2.

The target detection model for mode I and mode II are essentially identical and can be described in the following way. If the radar beam passes over a target the target range as given by the target generator is compared to the values in Table 2 to determine the probability of detection for that range. If Random, the result of calling the uniform random number generator RAN1, is less than the probability of detection, we assume a detection; otherwise a miss or noise return.

TABLE 2. Probability of detection vs. range.

Prob. of Det.	Target Range
0.22	60.0
0.5	55.0
0.6	54.0
0.7	53.0
0.8	52.0
0.85	51.0
0.9	50.0
0.95	49.0
0.99	48.0
0.999	47.0

Having established a radar target the radar range RADRNG is computed by the equation $RADRNG = TARGRNG + RANERR$ where RANERR is obtained by calling the GAUSSIAN random number generator and using the equation:

$$RANERR = DEV * 0.3$$

We can see from the above equations that the radar range is equal to the true range plus an error term with a standard deviation by choice, of 0.3 n. m.

It should be noted at this point that all radar measurements are computed in essentially the same manner. That is RADRNG, AZRAD and ELRAD are computed as noisy observations of the "true" target position, as given by the target generation subroutine, TARGEN.

CORRELATION:

To correlate current radar observations with tracks established from predictions on previous observations, a subroutine corras was devised. Current radar observations are stored in the matrices RADRG, AZRAD, ELRAD. While predicted values from the tracker are stored similarly. Once during each revolution of the antenna each track is compared with each observation, for each observation that a track agrees with, a one is placed in the corresponding location of the $O(I,J)$ correlation matrix. The columns of the correlation matrix correspond to tracks and the rows correspond to observations. For a track to agree with an observation certain tolerances were assumed: range must be within $\pm X$ n.m., azimuth and elevation angles must be within $\pm Y$ degrees.

X and Y are determined as follows:

(1) Alpha - Beta filter.

Range gate ≈ 2.5 n.m.

Azimuth gate ≈ 2.5 n.m.

Elevation gate ≈ 1.5 n.m.

(2) Kalman Filter.

Range gate $\approx 2.0 * \text{SQRT} [P(1,1)]$ n.m.

Azimuth gate $\approx 1.0 * \text{SQRT} [P(3,3)]$ n.m.

Elevation gate $\approx 2.5 * \text{SQRT} [P(5,5)]$ n.m.

After this initial correlation several observations may correlate with one track or several tracks may correlate with one observation. In these situations, a set of four association rules are applied to

the correlation matrix, $C(I, J)$, to assign observations to the proper tracks.

These rules implemented by subroutine ASSOC, are as follows:

(1) A track which correlates with several observations rejects any observation held in common with another track, if the common observation is the only observation correlating with the second track.

(2) A track correlating with several observations, some of which are not held in common with other tracks, rejects observations which are held in common with other tracks.

(3) When several observations correlate with one track, the closest observation is associated with that track.

(4) When several tracks correlate with one observation, the observation is associated with the closest track.

Rules 3 and 4 are based on the value of range since it has the smallest σ^2 for measurement noise. The above correlation and association routine is essentially the same as that given by [7].

CHAPTER III

FILTERS

Smoothing of raw radar reports and prediction of future observations, basic functions of an automatic tracking system, can be performed conveniently by a set of equations implemented on a computer. In this simulation two distinct schemes were chosen to perform these functions. In the simplest case target tracks are based on smoothing and prediction of an alpha-beta tracker operating in a cartesian coordinate reference frame.

The smoothing equation is:

$$\Lambda_{pn} = \Lambda_{pn} + \alpha (\tilde{X}_p - \Lambda_{pn})$$

The prediction equations:

$$\dot{\Lambda}_p = \dot{\Lambda}_{p-1} + \beta (\tilde{X}_p - \Lambda_{pn})$$

$$\Lambda_{p+1} = \Lambda_{pn} + \dot{\Lambda}_p \Delta t$$

- Where:
- Λ_{pn} = Smooth value of X, Y or Z for the nth scan.
 - Λ_{pn} = Predicted value of X, Y or Z for the nth scan.
 - \tilde{X}_p = Noisy observation of X, Y or Z for the nth scan.
 - $\dot{\Lambda}_p$ = Smooth prediction of X, Y or Z component of velocity for the nth scan.

Vector A_{i+1} = Predicted X,Y or Z coordinate for the $i+1$ scan.

T = Time between looks which is essentially constant.

T = 1 second for sector scan.

T = 0 seconds for full scan.

α = The smoothing parameter.

$\beta = \frac{\sigma^2}{2\alpha T}$ for optimum filtering.

Normally associated with the alpha-beta smoothing prediction equations are a set of rules for determining bin size. The rules are usually based on track firmness, length of time since last correlation and radar range. Basically this set of rules for varying the correlation gate size is an attempt to make the system adaptive to target dynamics.

Experimentation with the simple alpha-beta tracker indicated that given a reasonable fixed gate size based only on accuracy of the radar measurements, tracks could be maintained on targets with mild maneuvers, i.e., less than $3^\circ/\text{sec.}$ turns, with little difficulty given a suitable value of alpha. An important result observed from these simulations was that the real problem associated with tracking is the time delay before sensing a target's maneuver initiation.

Investigation of a criterion for detecting target maneuvers seemed to be the next logical step. Changes in the magnitude and angle of the target velocity vector in the X - Y plane were looked at briefly as one possibility. From the data accumulated, incidental to other tasks being performed, the changes in angle appeared to be an unlikely candidate due to extraneous noise caused by measurement errors of the radar. The magnitude of the vector, on the other hand, appeared to be rather insensitive to target maneuvers.

In lieu of providing this somewhat uncertain correlation, it was decided to use techniques that were in comparison well defined. The Kalman filter was chosen as the best solution to the problem for the following reasons:

(1) While the Kalman filter can not predict target maneuvers, the P matrix generated by the filter equation is directly influenced by target maneuverability (Q matrix) and at the same time is a measure of our confidence in predicted values. It seemed reasonable, therefore, to make the correlation gate size proportional to the corresponding values of the P matrix.

(2) If an observation is missed due to a target maneuver we can expand the gate size to some larger value to increase the probability of correlation on the next scan without automatic gate size reduction if we succeed.

The Kalman Filter Equations as given in (4):

$$G_n = P_{n/n-1} H^T [H P_{n/n-1} H^T + R]^{-1}$$

$$\hat{x}_{n/n} = \hat{x}_{n/n-1} + G_n (z_n - H \hat{x}_{n/n-1})$$

$$P_{n/n} = P_{n/n-1} - G_n H P_{n/n-1}$$

$$\hat{x}_{n+1/n} = \hat{x}_{n/n}$$

$$P_{n+1/n} = \hat{x}_{n/n}^T + Q$$

These equations represented in block diagram form appear in fig. 4.

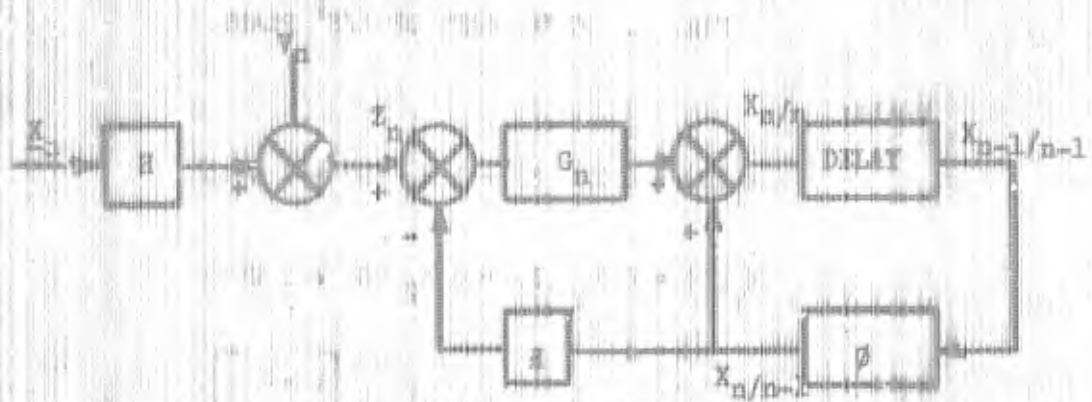


Fig. 4. BLOCK DIAGRAM OF FILTER EQUATIONS.

where: $Z = H X + V$

or $Z = \begin{bmatrix} \text{Radar Range} \\ \text{Radar Azimuth} \\ \text{Radar Elevation} \end{bmatrix}$

V represents the noise associated with the radar measurement of the three observables and is gaussian.

H = observability matrix.

or $H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{bmatrix}$

ϕ = The state transition matrix that represents the dynamics of the aircraft target. Assuming the aircraft can be represented as pure inertia of a $\frac{1}{s^2}$ plant.

We have



Fig. 5. FLOW GRAPH OF $1/s^2$ PLANT.

Yields:

$$\dot{X}_1(s) = 0 X_1(s) + 1 X_2(s) + 0 U(s)$$

$$\dot{X}_2(s) = 0 X_1(s) + 0 X_2(s) + 1 U(s)$$

hence:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \Rightarrow [sI - A] = \begin{bmatrix} s & -1 \\ 0 & 1/s \end{bmatrix}$$

where: $\Delta_A = \frac{1}{s^2}$

$$[sI - A]^{-1} = \frac{\begin{bmatrix} s & 0 \\ 0 & 1/s \end{bmatrix}^T}{\Delta_A} = \frac{\begin{bmatrix} s & 1 \\ 0 & s \end{bmatrix}}{\Delta_A} = \begin{bmatrix} 1/s & 1/s^2 \\ 0 & 1/s \end{bmatrix}$$

we know: $\Phi(s) = [sI - A]^{-1} = \begin{bmatrix} 1/s & 1/s^2 \\ 0 & 1/s \end{bmatrix}$

hence: $\Phi(t) = \begin{bmatrix} 1 & t \\ 0 & 1 \end{bmatrix}$

Assuming the components of the X vector are uncoupled.

$$\Phi(t) = \begin{bmatrix} 1 & t & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & t & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

R = The covariance of the measurement noise is by definition $R = E[y y^t]$

In this case the standard deviation of the measurement

range, azimuth, and elevation are known to within
 specified values.

$$\sigma_R = 0.3 \text{ m.}$$

$$\sigma_{AZ} = 0.5 \text{ deg.}$$

$$\sigma_{EI} = 0.5 \text{ deg.}$$

hence:

$$R = \begin{bmatrix} 0.09 & 0 & 0 \\ 0 & 0.25 & 0 \\ 0 & 0 & 0.25 \end{bmatrix}$$

$\hat{X}_{n/n-1}$ represents the predicted states of a radar target.

To initialize the filter for a particular target, that is specify

$\hat{X}_{1/0}$, the following method is used.

$$\hat{X}_{1/0} = \begin{bmatrix} \text{Radar Range} \\ R = -0.166 \\ \text{Radar Azimuth} \\ AZ = 0.0 \\ \text{Radar Elevation} \\ EI = 0.0 \end{bmatrix}$$

This method assumes the target is closing the radar radially
 ($AZ = 0.0$) at a low altitude ($EI \approx 0.0$) with a velocity of approx-
 imately 600 n.m. /hr.

$P_{n/n-1}$ represents the amount of uncertainty in the predicted
 values of target states $\hat{X}_{n/n-1}$.

$$P = E \{ (\hat{X}_n - \hat{X}_{n/n-1}) (\hat{X}_n - \hat{X}_{n/n-1})^T \}$$

where: \hat{X}_n is the true state.

$\hat{X}_{n/n-1}$ is the predicted value.

To initialize the filter we must provide:

$\hat{X}_{1/0}$ Given $\hat{X}_{1/0}$ defined previously and R the covariance of the meas-
 urement noise.

$P(1,1)$, $P(3,3)$, $P(5,5)$ are known.

Again relying on the assumption of a radially closing target at low

altitude with a speed of 600 m.m./hr. we can assume the remaining diagonal elements of P which represent $\frac{\sigma_x^2}{R}$, $\frac{\sigma_y^2}{R^2}$, $\frac{\sigma_z^2}{R^2}$ will be small. Actual values were determined empirically and as a result the initial covariance of error matrix is determined.

$$P = \begin{bmatrix} 1.09 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0278 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.25 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.00100 \end{bmatrix}$$

It should be noted here that $F_{1/0}(3.3) = 2.5$ is used in place of 0.25 to aid tracking maneuvering targets. If an observation fails to correlate with an established track the P matrix for that track is set equal to the above values. The gate sizes, and in particular, the Azimuth gate, are directly related to the P matrix values. This procedure enlarges the gate size thus increasing the probability of correlation on the next scan.

Lastly but certainly not of the least importance is the Q matrix specification. The Q matrix which represents perturbations to the state vector due to target maneuvers must be representative of the full range of movements the target is expected to use.

Values for Q were estimated by assuming a "worst" case such as 6000 ft./min. rate of climb, 1 g. linear acceleration and 12° / second turning rates. One half these "worst" case values were actually used in an attempt to average the Q matrix over the full range of expected maneuvers.

Estimation of $Q(1,1)$

Assume the aircraft can vary speed by (100 n.m. / hr. max.)

$$\approx \pm 0.027 \text{ n.m./sec.}$$

$Q = E [\underline{w} \underline{w}^t]$ where \underline{w} is a random signal caused by target maneuvers.

Taking $1/2$ (0.027) implies

$$Q(1,1) = (0.013) (0.013) = 0.0169$$

Estimation of $Q(2,2)$

Assume the aircraft can accelerate at $(1g)$ max.

$$\text{Taking } 1/2 (1g) \approx .0027 \frac{\text{ft.}}{\text{sec}^2} \times 1 \text{ sec.}$$

$$\text{implies that } Q(2,2) = (.0027) (.0027) \approx .00001$$

Estimation of $Q(3,3)$

Assume the aircraft can make a $(12^\circ / \text{second})$ max. turn.

Taking $1/2$ $(12^\circ/\text{sec}) = 6^\circ/\text{sec.}$ and using fig. 6

We have:

$$\text{chord length} = 2r \sin \theta/2$$

$$\text{or } \theta = 2 \sin^{-1} \frac{.02}{30} \approx 0.083^\circ$$

Hence,

$$Q(3,3) = (.083) (.083) = .00692$$

Estimates for the remaining terms of Q were obtained in a like manner with Q taking the following form.

$$Q \text{ est.} = \begin{bmatrix} 0.0169 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.00001 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0069 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0011 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.0011 \end{bmatrix}$$

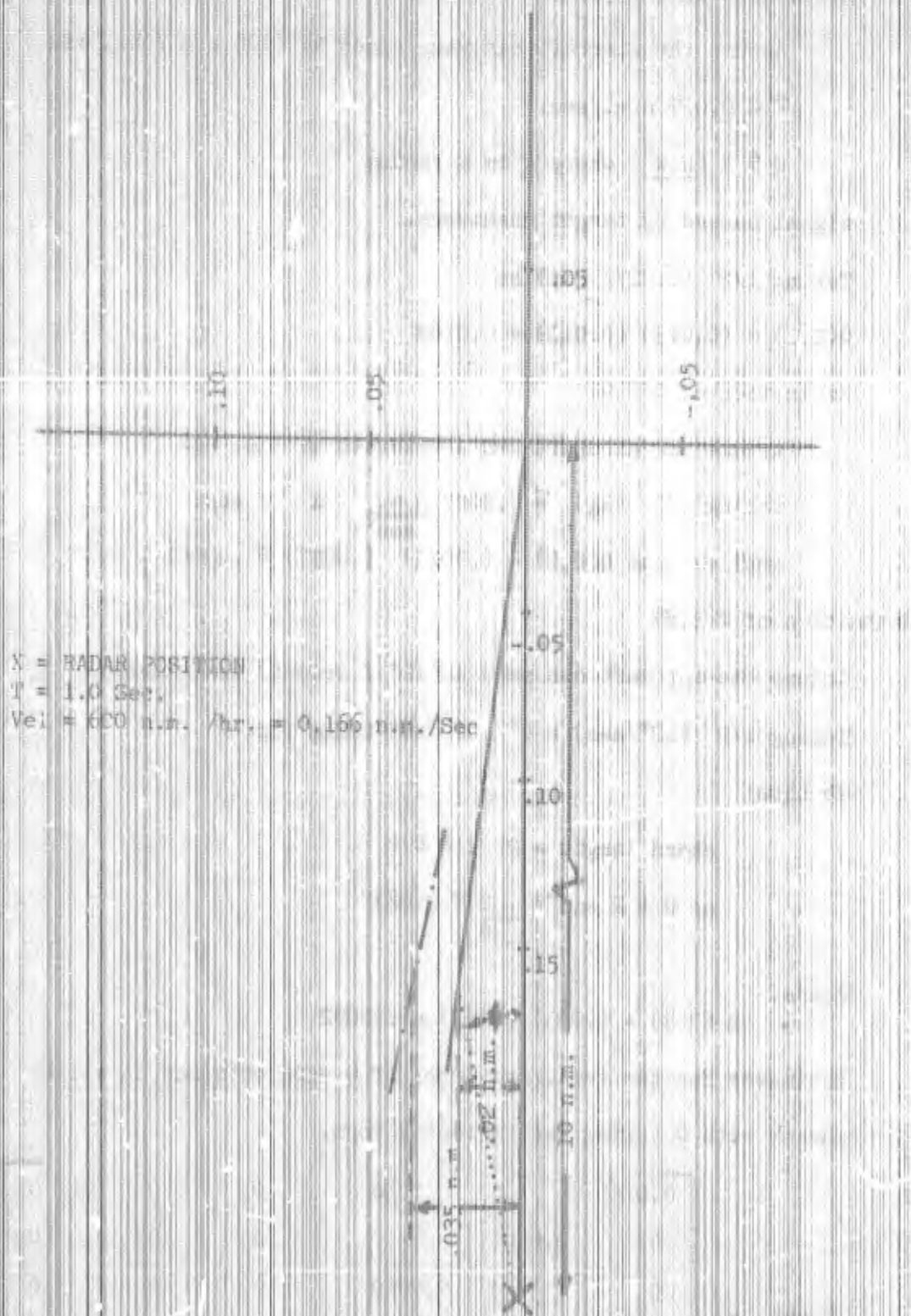


Fig. 6. CHANGE IN RADAR AZIMUTH DUE TO A TURNING TARGET.

Simulations were run to optimize the Q values in order to obtain the best filter response over the range of 0°, 3°, 6°, and 12° /sec.

targets with constant speed targets:

$$Q_{exp} = \begin{bmatrix} 0.00169 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0030 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.015 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.10 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.0001 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.00001 \end{bmatrix}$$

The Q_0 matrix values were not increased in magnitude as might at first be expected but were set equal to Q_1 for the following reasons:

(1) The eight second scan time applies to targets of fairly long range compared to target ranges anticipated for sector scan, and as such the targets are expected to maneuver as little as possible in an attempt to close the ship.

(2) It is intuitively felt that T(ave.) for aircraft maneuvers for this type of target might be expected to be 3-4 seconds vice 8 seconds.

(3) The effect of maneuvers acting on a spherical coordinate system decreases with increasing range.

CHAPTER IV CONCLUSIONS

The radar system simulation presented in this paper is felt overall to be a simplified but realistic model of a sophisticated system which could be implemented with current "state of the art" hardware.

The basic main program / subroutine organization divides the system into easily recognized functions capable of being extended in scope, modified in part, or replaced entirely with a new concept, while maintaining the integrity of the remainder of the program. Any portion of the model can be reworked to meet special requirements of a particular problem of interest.

By the addition of new subroutines which might include phenomena associated with clutter, target scintillations, and atmospheric attenuation a more realistic detection probability, given a set of initial conditions, could be achieved.

Hence the original objective of building a model for simulation of a hypothetical radar system as a tool for analysis of a variety of radar system problems has been met.

As an exercise with practical significance, the simulation was used to investigate the relative effectiveness of several types of radar tracking filters.

While no pretension of an extensive analysis is implied, the author feels that a reasonable and unequivocal comparison of the filters can be made from the material presented.

Based on the ensemble average of the squared difference between predicted and actual positions the Kalman filter obviously provides a somewhat better tracking response for all target tracks tested.

The tracking ability of both filters appears to be about equal for "look alike" targets in close proximity. The ability of the tracking routine to resolve these targets depends on using relevant gate size. The gate size in turn is directly related to the accuracy of the radar measurement of range, and angles, and to the extent of maneuver capability of the target. The minimum gate size allowable without inducing excessive non-correlation due to observation noise would thus be essentially the same for both filters.

The most significant advantage of Kalman Filter tracking appears to be in its ability to track maneuvering targets without dropping tracks. This advantage is a result of its ability to automatically increase the gate size if a firm track fails to correlate, thus improving the probability of correlation on the next scan.

The requirement for peripheral tracking functions such as track fitness and quality would surely be reduced in a system using Kalman filtering since the (P) matrix can be used as a measure of this type of information. This feature affects somewhat the disadvantage of increased computation time due to the recursive algebraic equations required to calculate the G and F matrices.

Finally, the dependence of the Kalman filter on the Q matrix dictates that an efficient and reliable method for estimating Q for a particular target is essential.

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APPENDIX 1

GRAPHICAL OUTPUT

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Kalman filter	Crossing targets T = 1 sec.	49

Interpretation and conclusions

(1) The first eight graphs provide a comparison of the prediction accuracy of each of the two filters investigated.

The following rules apply:

(a) Four different target tracks are employed i.e. 0° , 3° , 6° and $12^\circ/\text{sec}$.

(b) Target turning rates are initiated at $T = 6$ sec.

(c) Each graph represents the results in range (R), azimuth (X), and elevation (A) of a "Monte Carlo" ensemble average of 100 runs.

(d) Sample rate = 1 sec. appropriate to Mode 2 operation.

(e) Alpha-beta filtering is performed in a cartesian coordinate reference frame while Kalman filtering is done in spherical coordinates.

Filtering of the azimuth coordinate, which happens to be changing most rapidly, is about equal for both filters. The Kalman filter is obviously superior in range and elevation predictions.

The following symbol table applies for all succeeding graphs.

_____	true track
X	predicted position target one.
A	predicted position target two.

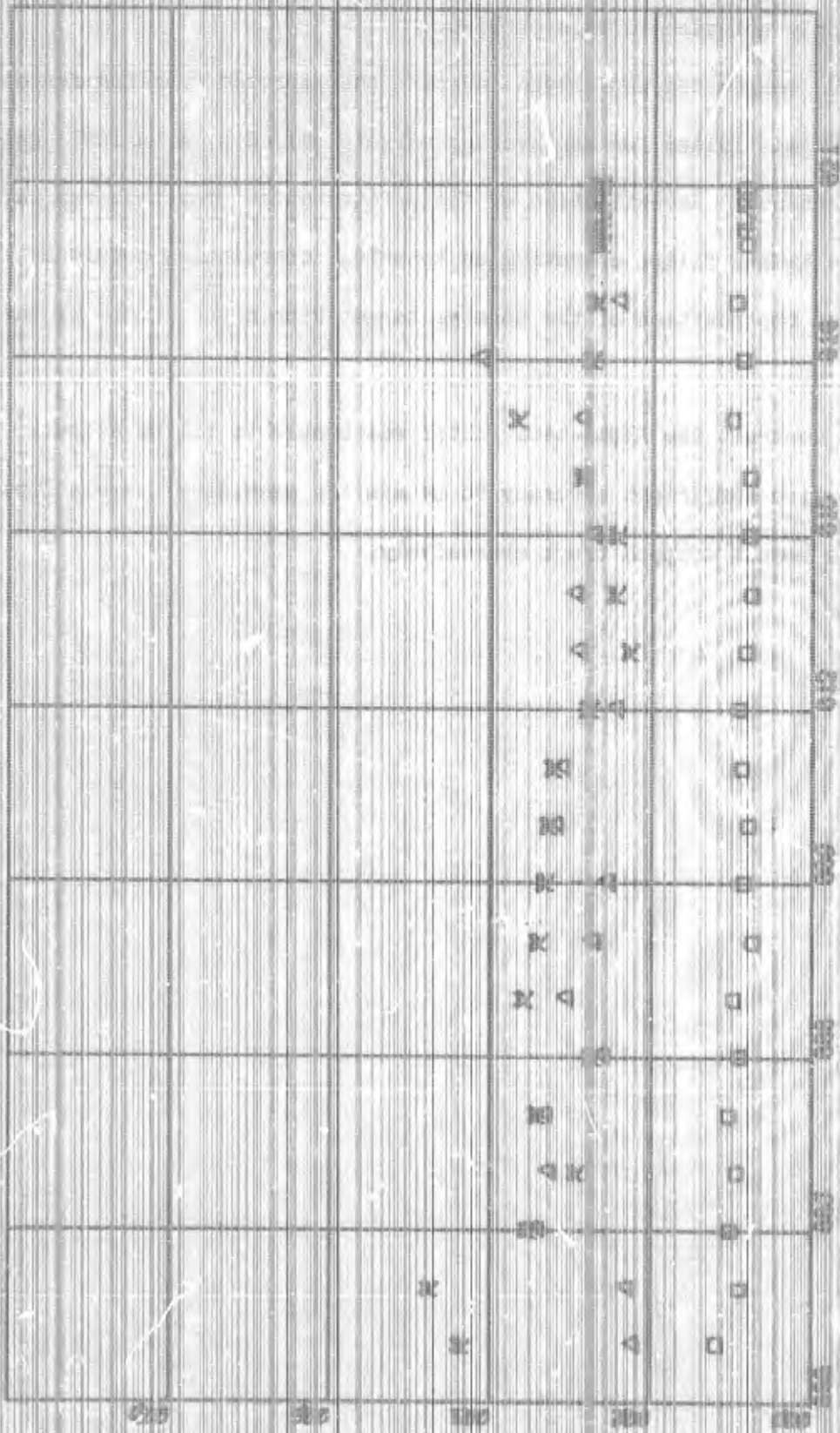
(2) Graphs nine and ten represent filtering ability for "look alike" targets, i.e. similar range, elevation, and azimuth.

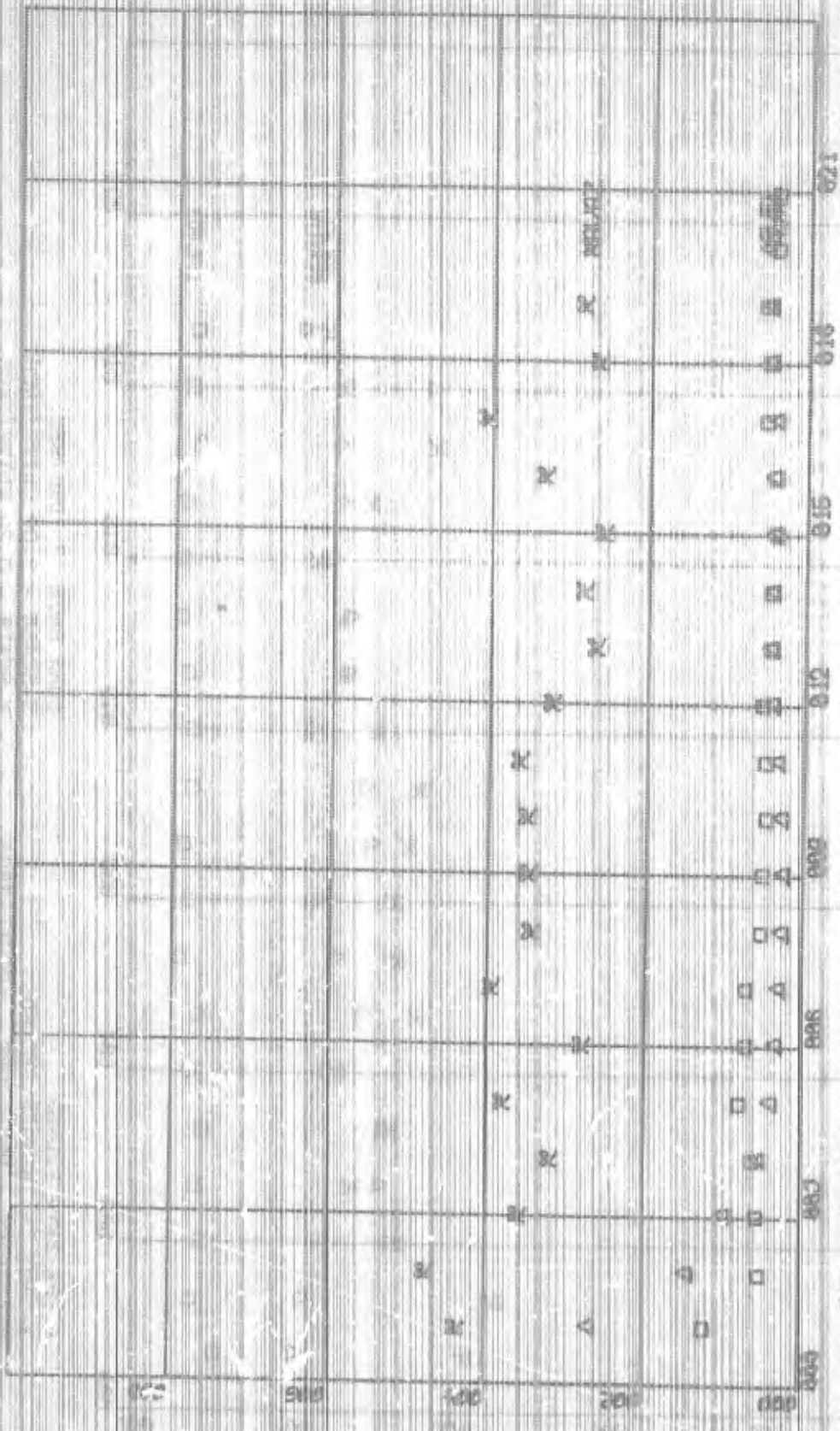
The ability of both filters, supplemented by a set of correlation and association rules, to distinguish between similar targets in close proximity leaves something to be desired. A reduced revisit rate i.e. (1 sec vice 3 sec.) has little or no effect. (see graphs 13 and 14).

It seems reasonable therefore to assume that a higher resolution radar is the only solution to this problem.

(3) Graphs ten and eleven indicate the improved tracking response of the Kalman filter for maneuvering targets, aided by a variable gate size technique. Investigation of the printed output for this run shows that the Kalman filter operating on spherical coordinates consistently predicted the position of the turning target within the limits of the gate size.

In contrast the Alpha-beta filter was unable to follow azimuth changes with sufficient accuracy to obtain the necessary correlations and as a result dropped track extensively.







ALPHA-BETA FILTER

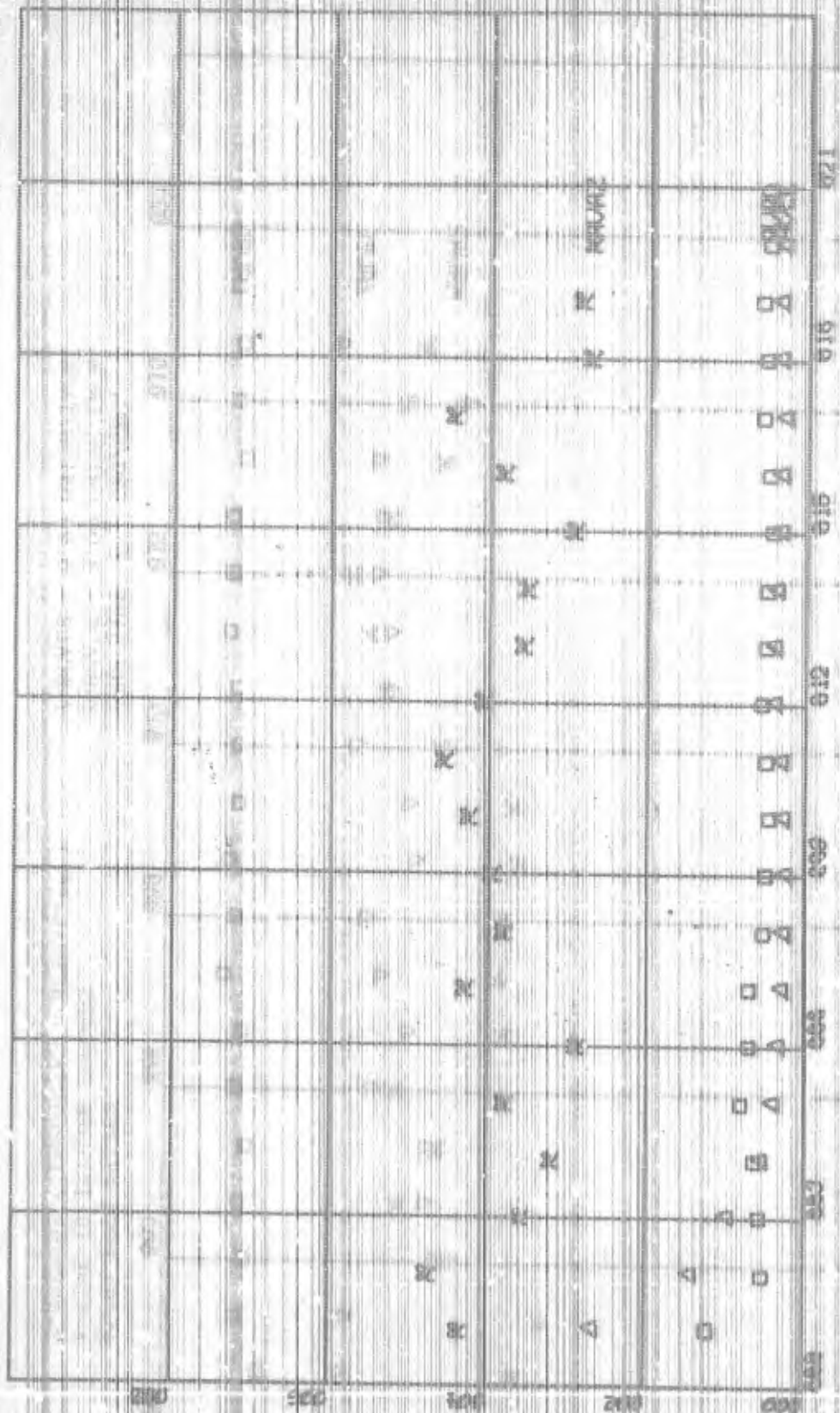
X-TIME IN INTEGER SECONDS

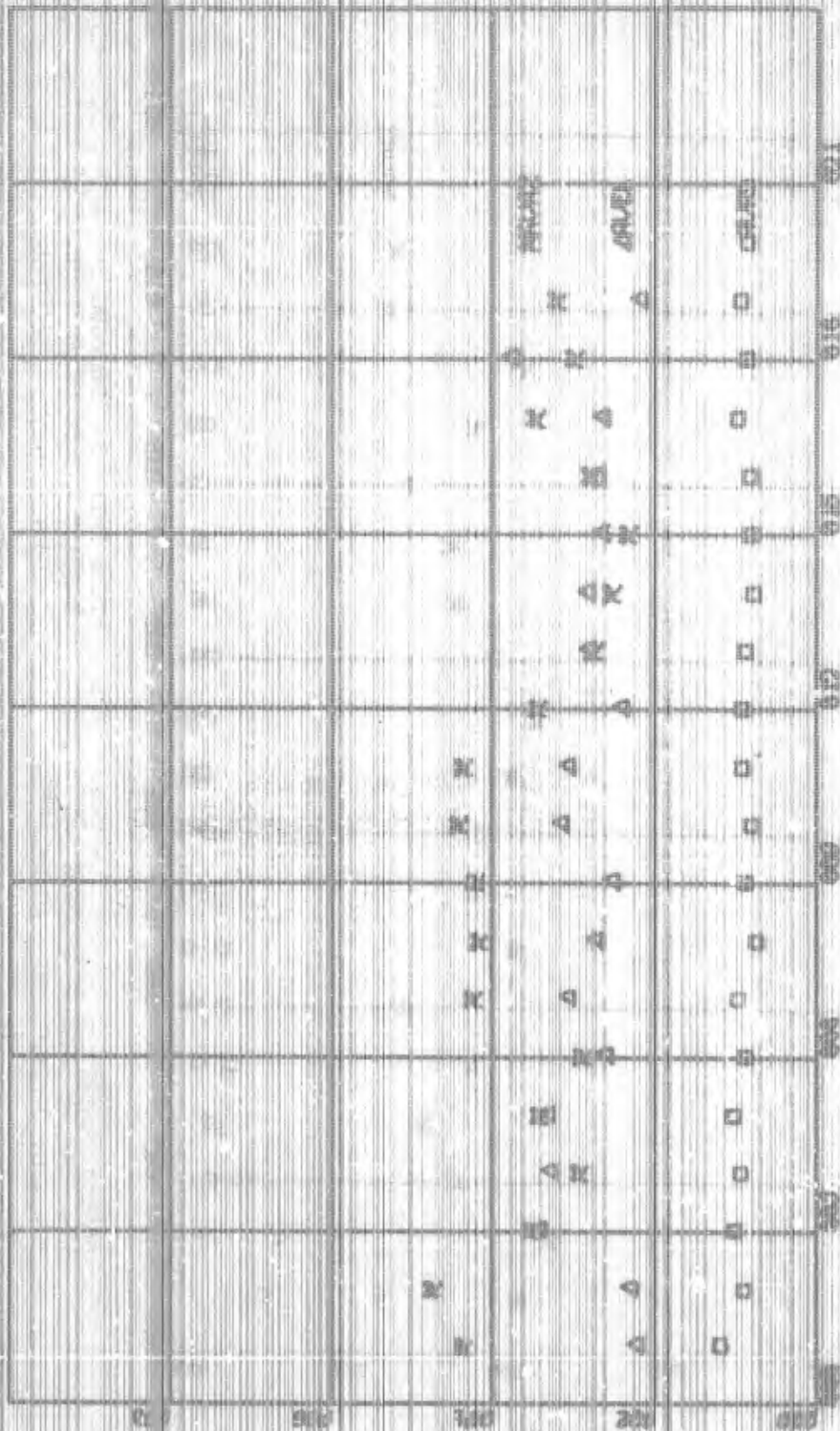
Y-AVERAGE ((PREDICTED - ACTUAL)**2)

TURF RATE 3 DEG/SEC.

X-SCALE - 3.00 UNITS/INCH.

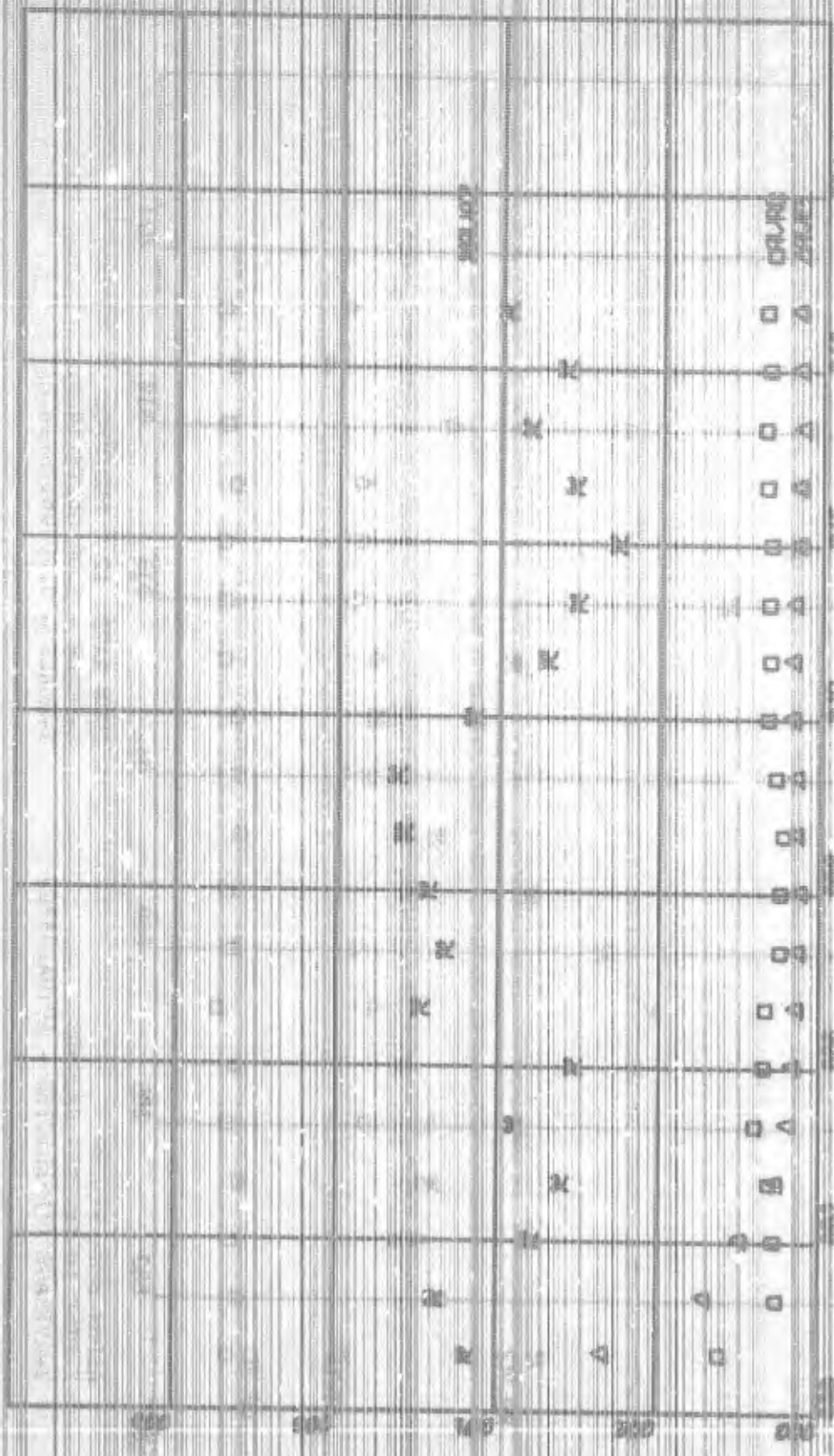
Y-SCALE - 0.20 UNITS/INCH.





ALPHA-BETA FILTER
 X-TIME IN INTEGER SECONDS
 Y-POSITION ((POSITION - ACTUAL)*52)

TURN RATE 6 DEG/SEC.
 X-SCALE - 3.00 UNITS/INCH.
 Y-SCALE - 0.20 UNITS/INCH.



KAMMAR FILTER

X - TIME IN INTCHEG SECONDS

Y - AVG. ((PRELIMIDED - ACTUAL) * 2)

TURW RATE 6 DEG/SEC.

X-SCALE - 3.00 UNITS/INCH.

Y-SCALE - 0.20 UNITS/INCH.

011

016

015

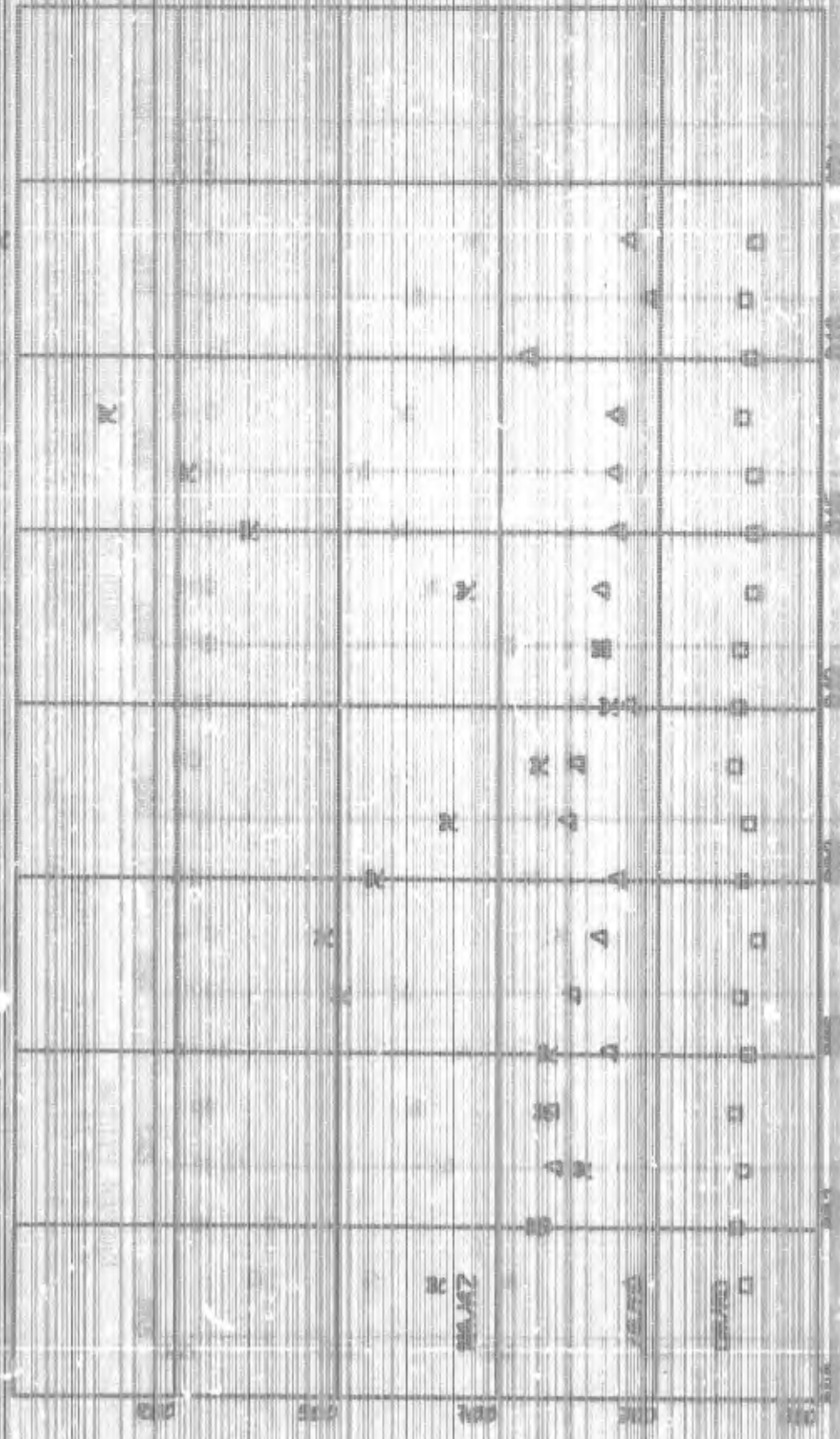
012

005

000

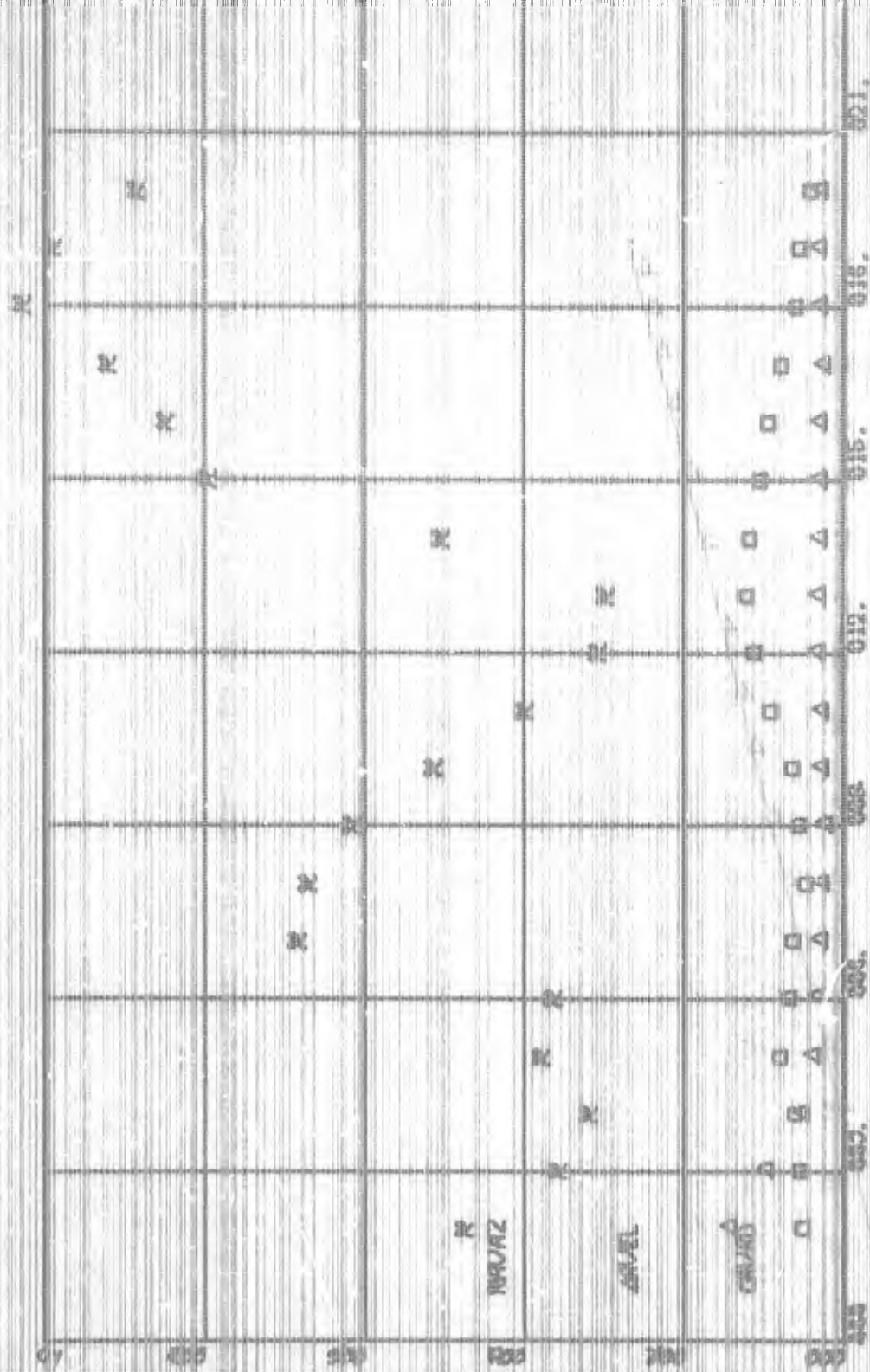
003

000



ALPHA-BETA FILTER
 X-TIME IN INTEGER SECONDS
 Y-AVERAGE ((PREDICTED - ACTUAL)**2)

TURN RATE 12 DEG/SEC.
 X-SCALE - 3.00 UNITS/INCH.
 Y-SCALE - 0.20 UNITS/INCH.



KALMAN FILTER

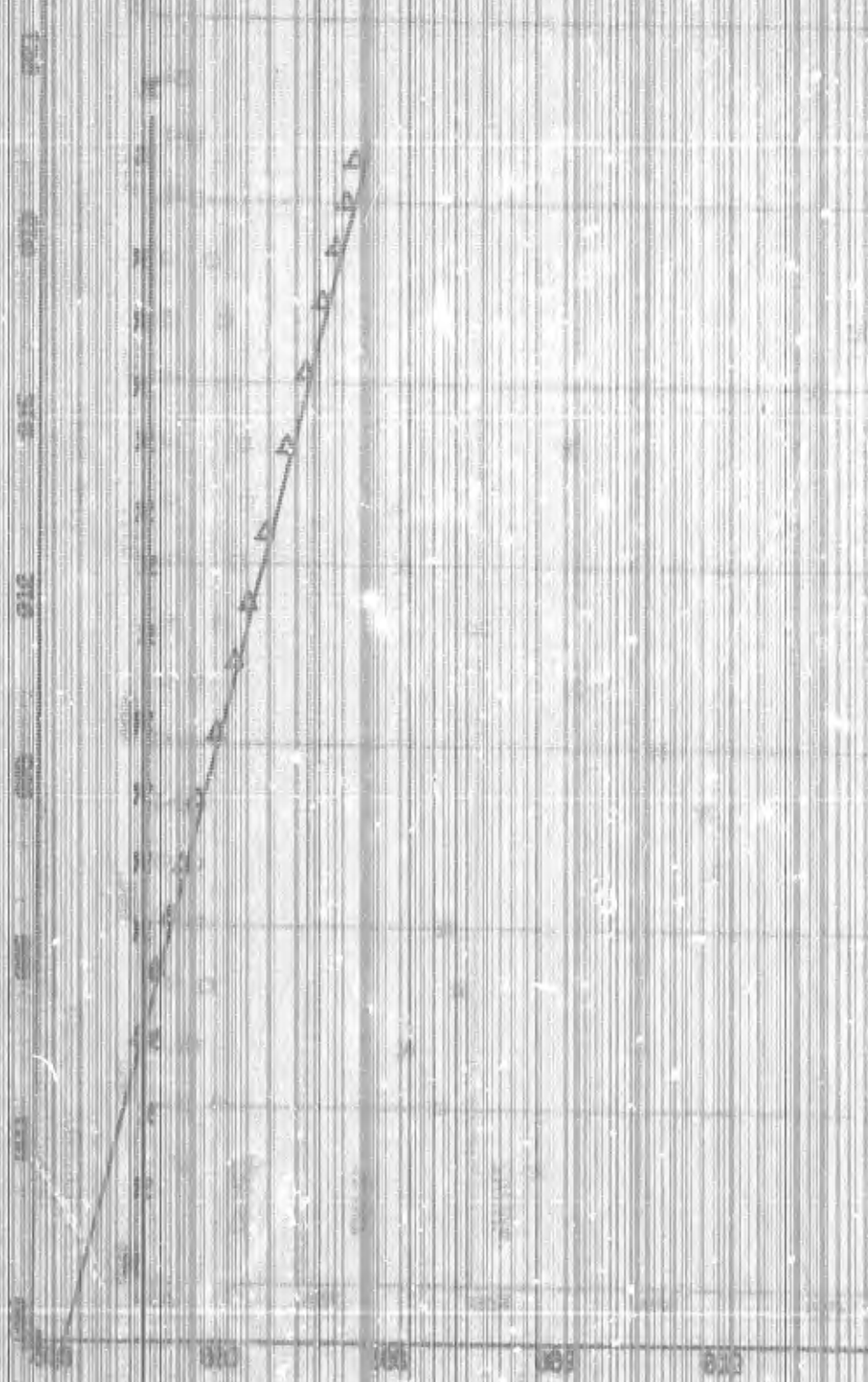
X - TIME IN INTEGER SECONDS

Y - AVG. ((PREDICTED - ACTUAL)**2)

TURN RATE 12 DEG/SEC.

X-SCALE = 3.00 UNITS/INCH.

Y-SCALE = 0.20 UNITS/INCH.



ALPHA-BETA FILTER

$K = 1 = 0.4$

K SCALE = 1 SCALE = 2.0 UNITS/INCH

NON MANEUVERING

$T = 8$ SEC.



KALMAN FILTER

K = Y = N.M.

K SCALE = Y SCALE = 3.00 UNITS/INCH

NON MANEUVERING

T = 8 SEC



ALPHA-BETA FILTER
 $X = Y = N.M.$
 $X \text{ SCALE} = Y \text{ SCALE} = 3.00 \text{ UNITS/INCH}$

DEG/SEC



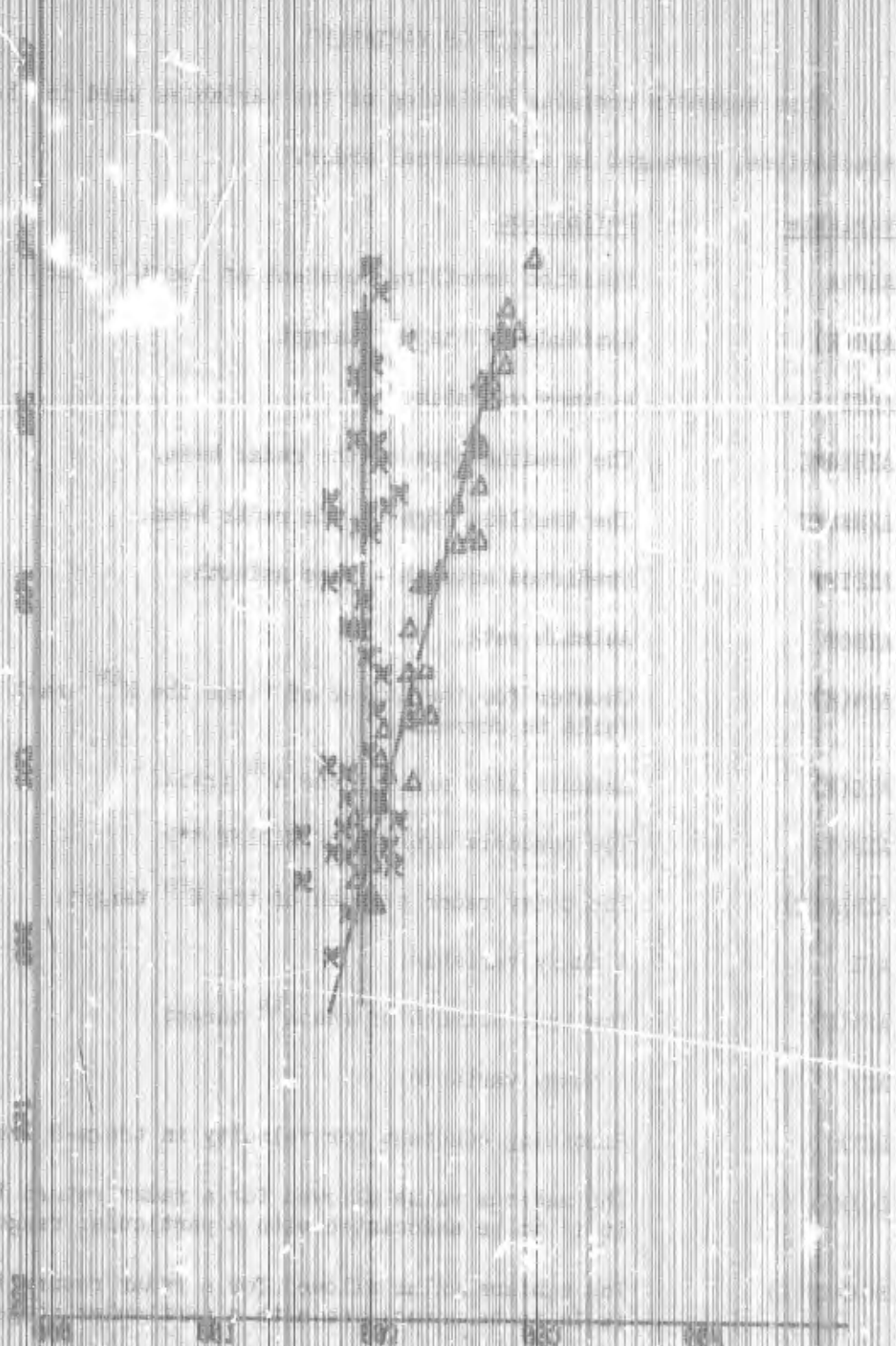
GAMMA FIELD
 (= Y = X)
 X SCALE = Y SCALE = 3.00 UNIT / INCH.

3.000 / SEC



ALPHA-BETA FILTER
 $\tau = \gamma = 0.1$
 X SCALE = Y SCALE = 1.00 UNITS/INCH

NON-MANIPULATED
 $T = 1$ SEC.



KALMAN FILTER

X = Y = N.M.

X SCALE - Y SCALE = 1.00 UNITS/INCH

NOT MANEUVERING

T = 1 SEC.

APPENDIX II

LIST OF VARIABLES

This appendix contains a listing of the variables used in the simulations, arranged in alphabetical order.

<u>Variable</u>	<u>Definition</u>
ALPHA	Position smoothing constant of the d-B tracker.
ALT(K)	Altitude of the K^{th} target.
ALTA	A dummy variable.
AZBRML	The leading edge of the radar beam.
AZBRMT	The trailing edge of the radar beam.
AZDIFF	Predicted azimuth - true azimuth.
AZDOT	Azimuth rate.
AZ4(K)	Counter for the number of times the K^{th} track fails to correlate.
AZG(K)	Azimuth gate size of the K^{th} track.
AZ2(I)	The ensemble average of ELDIFF **2
AZRAD(K)	The noisy radar azimuth of the K^{th} target.
AZI	A dummy variable.
AZT(K)	The true azimuth of the K^{th} target.
AZY	A dummy variable.
BETA	Smoothing constant for velocity in the c-d tracker
BOUNMAX (I)	The maximum value allowed for a radar return if it is to be associated with a particular range box.
BOUNMIN(I)	The minimum value allowed for a radar return if it is to be associated with a particular range box.
C(I,J)	Observation / track correlation matrix.
CONF(K)	Azimuth of the leading edge of the radar beam on initial detection of the K^{th} target.
DELTA	Normalized velocity vector.

<u>Variable</u>	<u>Definition</u>
DOT1	A dummy variable.
DOT2	The predicted velocity components of the K^{th} target as given by the α - β tracker.
DOT3	
DOT4	
ELBANS	Bottom extremity of the radar beam.
ELBAMS	Top extremity of the radar beam.
ELDIFF	Predicted elevation - true elevation.
ELDOT	Elevation angle rate.
ELERR	Radar measurement noise added to the true elevation angle.
ELG(K)	Elevation gate size of the K^{th} track.
ELRAD(K)	Noisy radar value of target elevation.
ELT(K)	True target elevation angle.
ELTEST	Parameter for distinguishing between range boxes by elevation angle.
FLAG	Flag is set by MOVAVE if a target is detected.
G(I,J)	Gain matrix for the Kalman filter equations.
GO	Used by SCAN 360 to compress full scan.
H(I,J)	Observability matrix for Kalman filter equations.
HD(K)	Heading of the K^{th} aircraft in degrees.
HPNT	A dummy variable.
HT(I,J)	The transpose of the observability matrix.
IA	Range box index.
IAZ(I)	Used as a counter in conjunction with IAZ.
IAZ(I)	Radar return signal counter which is compared to a threshold value to determine whether or not a detection has occurred.
IAZREF	Reference azimuth of sector scan.

<u>Variable</u>	<u>Definition</u>
CI	Elevation beam position indicator.
IEDE(I)	IEDE INDEX (I)
IEDEK (I)	IEDEK in conjunction with IEDE determine when a track falls two consecutive times, to correlate then initiating drop track procedure.
TEFL	The fixed point form of TEL.
TEFLI	A dummy variable.
TEMP	The fixed point form of TMP.
TEMPI	A dummy variable.
IF(I)	A flag used to initialize the Kalman filter for a particular observation.
KIR	Flag to indicate an improper matrix-inverse operation.
LISS	Lower limit of the sector scan.
LIML	Port limit of the sector scan.
LIMS	Starboard limit of the sector scan.
LIMP	Upper limit of the sector scan.
ME	The number of bins.
MET	Number of discrete times.
NO	Counter for the number of target bins currently active.
NS(I)	Flag to indicate known targets in sector scan.
NT	Number of targets.
SDR	Sector scan counter.
SDCI	Dummy variable.
SDSE	
SDSI	
SDSCAL	The number of 30 degree scans of the radar.
SDSTK	Number of current active tracks.

<u>Variable</u>	<u>Definition</u>
PRAD	A dummy variable for the noisy radar observations (Range, Azimuth or Elevation.)
P(I,J)	The covariance of error matrix.
PRAD	The predicted radar azimuth of the target.
PAZ	A dummy variable.
PD(I)	A discrete value of probability from the probability of detection table.
PDET	Probability of decision.
PELRAD	Predicted value of the target elevation.
PHI(I,J)	The state transition matrix used in the Kalman filter.
PHI1(I,J)	The state transition matrix for the one second case.
PHI8(I,J)	The state transition matrix for the eight second case.
PHIT(I,J)	Transpose of the PHI matrix.
PITCH(K)	Value of the nose altitude of the K th target in degrees.
PITCH1	A dummy variable.
PHI...9(I,J)	Storage for P matrix associated with each track.
PHARNG	Predicted radar range of a target.
PHYD	A dummy variable used in the Alpha-Beta tracker for the predicted value of range, azimuth or elevation.
PXEND	Predicted X,Y,Z, components of target position.
PYRAD	
PZRAD	
Q(I,J)	Matrix representing target maneuver capability.
QA(I,J)	Q may be set equal to Q1 or Q8 as required by the appropriate scan time.
QB(I,J)	
R(I,J)	Covariance matrix of the observation noise.

<u>Variable</u>	<u>Definition</u>
RADDEG	Constant used to convert radians to degrees.
RADIFF	Predicted range - true range.
RANDOM	Uniformly distributed random number.
RAUER	Error in measuring target range.
RANGE(I)	Discrete value of range used to enter the probability of detection table.
RADRNG(K)	Noisy target range as given by the radar.
RADRNG1	A dummy variable.
RDOT	Range rate.
RG(K)	Range gate size for the K^{th} track of the correlation routine.
S(I)	A dummy variable used for temporary storage.
SMOOTH	The filtered radar observation in range, azimuth or elevation.
SUM	Temporary value of the radar beam leading edge.
T	Time interval for updating targets equal to scan time.
T1	Dummy variables.
T2	
TANGRNG	True value of target range as given by the target generator.
TEL	Temporary sector span beam reference.
TEST	
TESTT	
TET	
THETA	Value of target heading in radians with reference to the positive X-axis.
VEL(K)	Speed of the K^{th} target in n.m./hr.
VMAG2(I)	Insemble average of radiff.

<u>Variable</u>	<u>Definition</u>
VHS	Fixed point form of MB.
VPEI2(I)	Ensemble average of azdiff.
XP(I,J)	Predicted state vector.
XPI	A dummy variable.
KRAD(K)	X coordinate of the K^{th} target as given by the radar.
KRAD1(K)	Stored radar track quantity for graphical output.
KRAD2(K)	.
XS	Smooth state vector.
XF(K)	The true X coordinate of the K^{th} target
XFL(K)	Stored target track quantity for graphical output.
XY2(K)	.
YRAD(K)	Radar Y coordinate of the K^{th} target.
YRAD1(K)	Stored radar track quantity for graphical output.
YRAD2(K)	.
YS(K)	The true Y coordinate of the K^{th} target.
YFL(K)	Stored target track quantity for graphical output.
YT2(K)	.
Z(I,J)	Measurable quantities input to the Kalman filter equations.
ZRAD(K)	The radar Z coordinate of the K^{th} target.
ZF(K)	The true Z coordinate of the K^{th} target.

2

Notes: Variables associated with the following input/output and matrix algebra subroutines, have not been defined, since they are essentially dummy variables.

1. AID
2. PRINTF
3. PROD
4. READ
5. RECF
6. TRANS

APPENDIX III

LOGIC FLOW DIAGRAMS

This appendix contains a series of Logic Flow diagrams as listed below.

MAIN PROGRAM

SUBROUTINE RANGE

SUBROUTINE SCAN 160

SUBROUTINE DETECT

SUBROUTINE MOVE

SUBROUTINE CORRASS

SUBROUTINE ASSOC

SUBROUTINE ASFILE

SUBROUTINE KALFILT

SUBROUTINE SETUP

SUBROUTINE YVS

SUBROUTINE MONTE

FLOW CHART SYMBOLS



A connector or terminal.



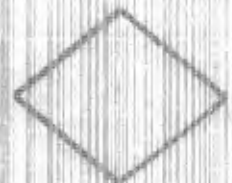
An offpage connector.



A predefined process or module/subroutine.
A more detailed flow chart of this subroutine
is also included.



Input/output other than display.

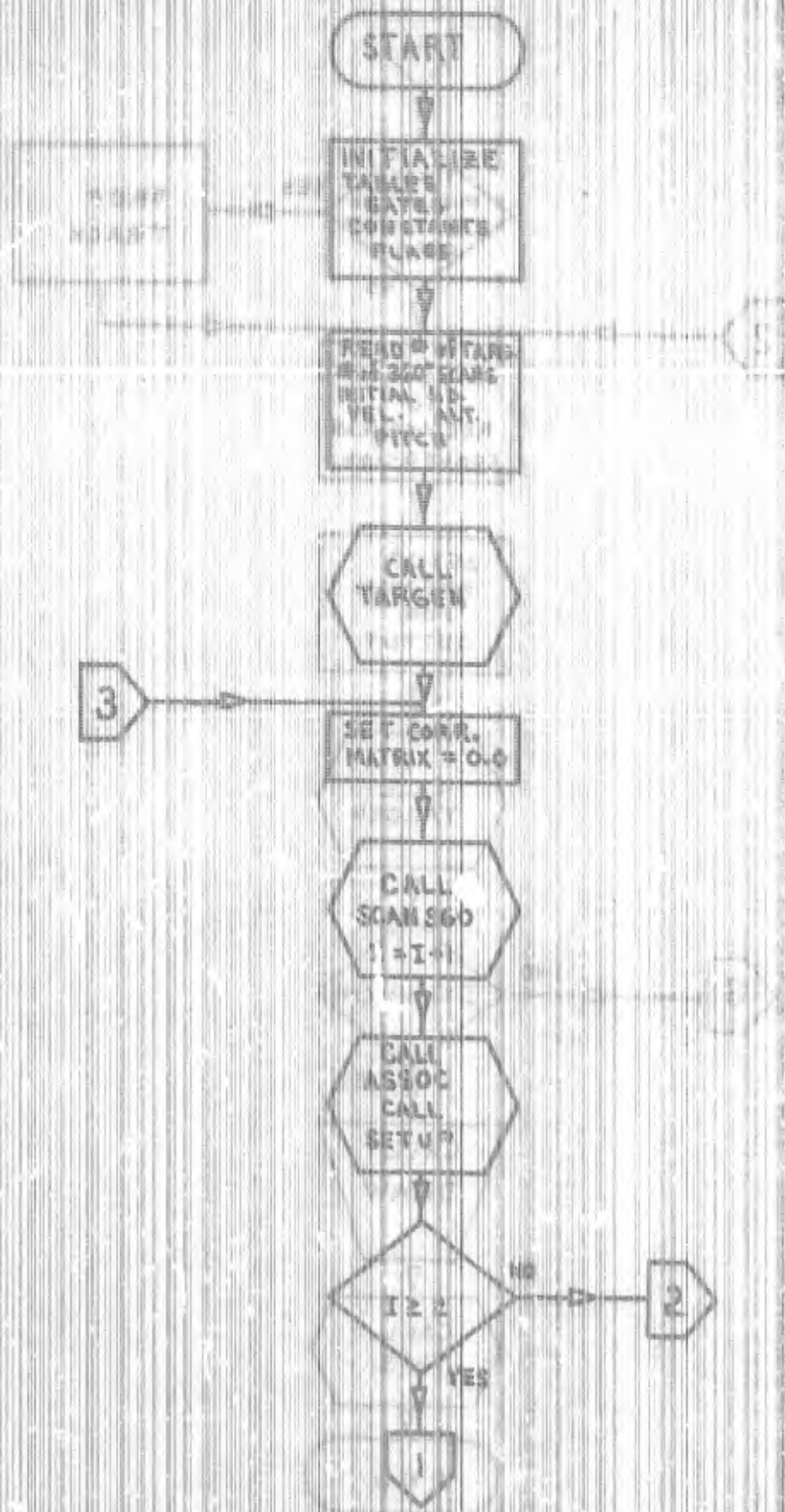


Decision.

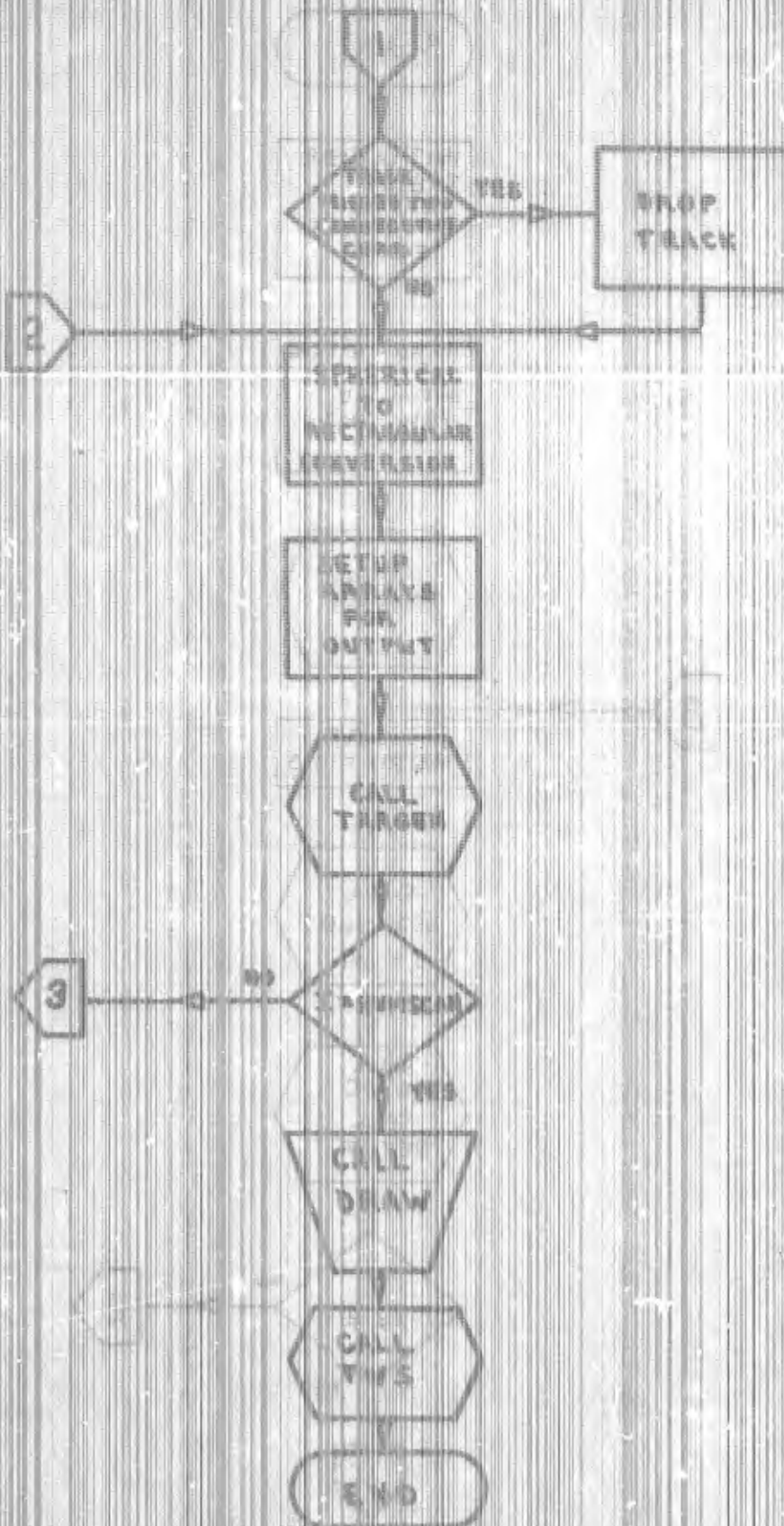


Processing, annotation.

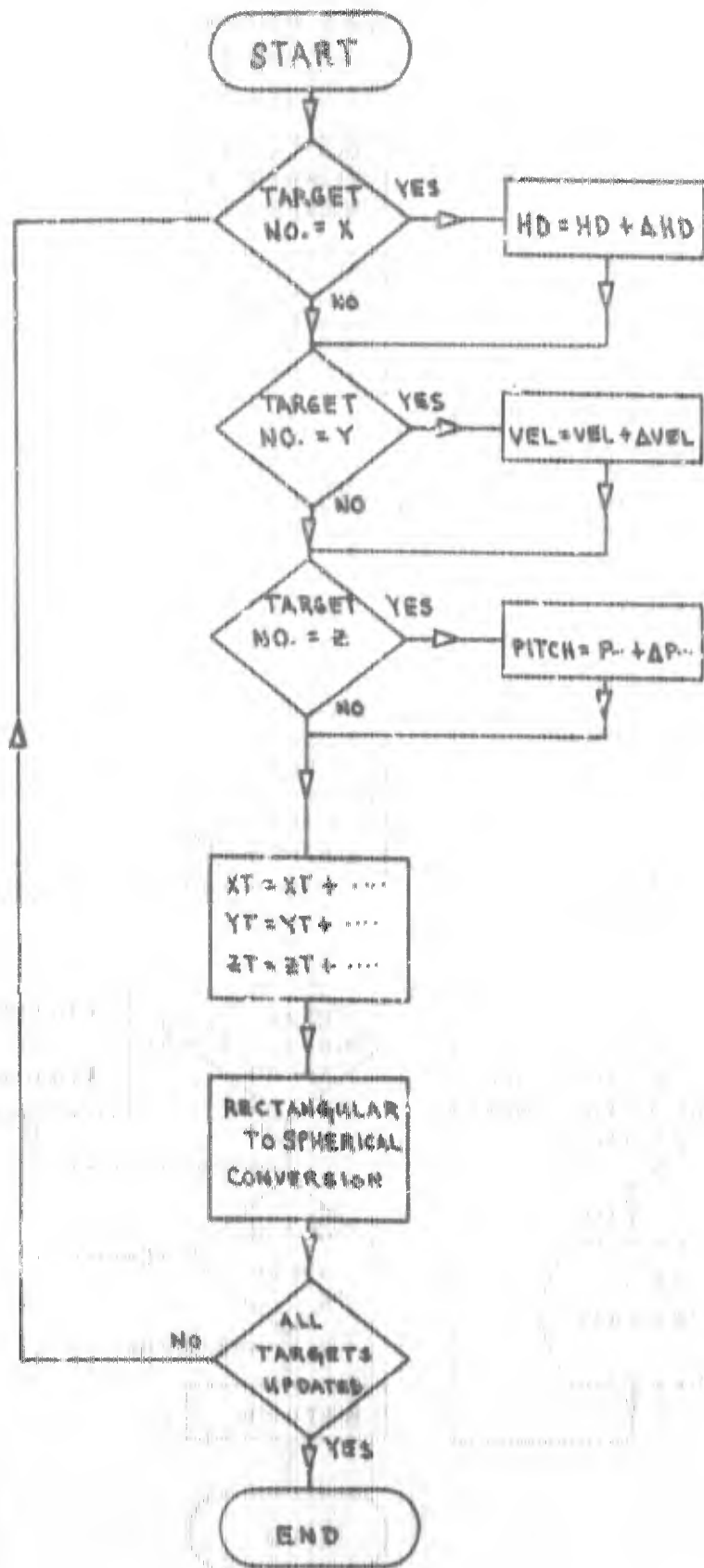
MAIN PROGRAM



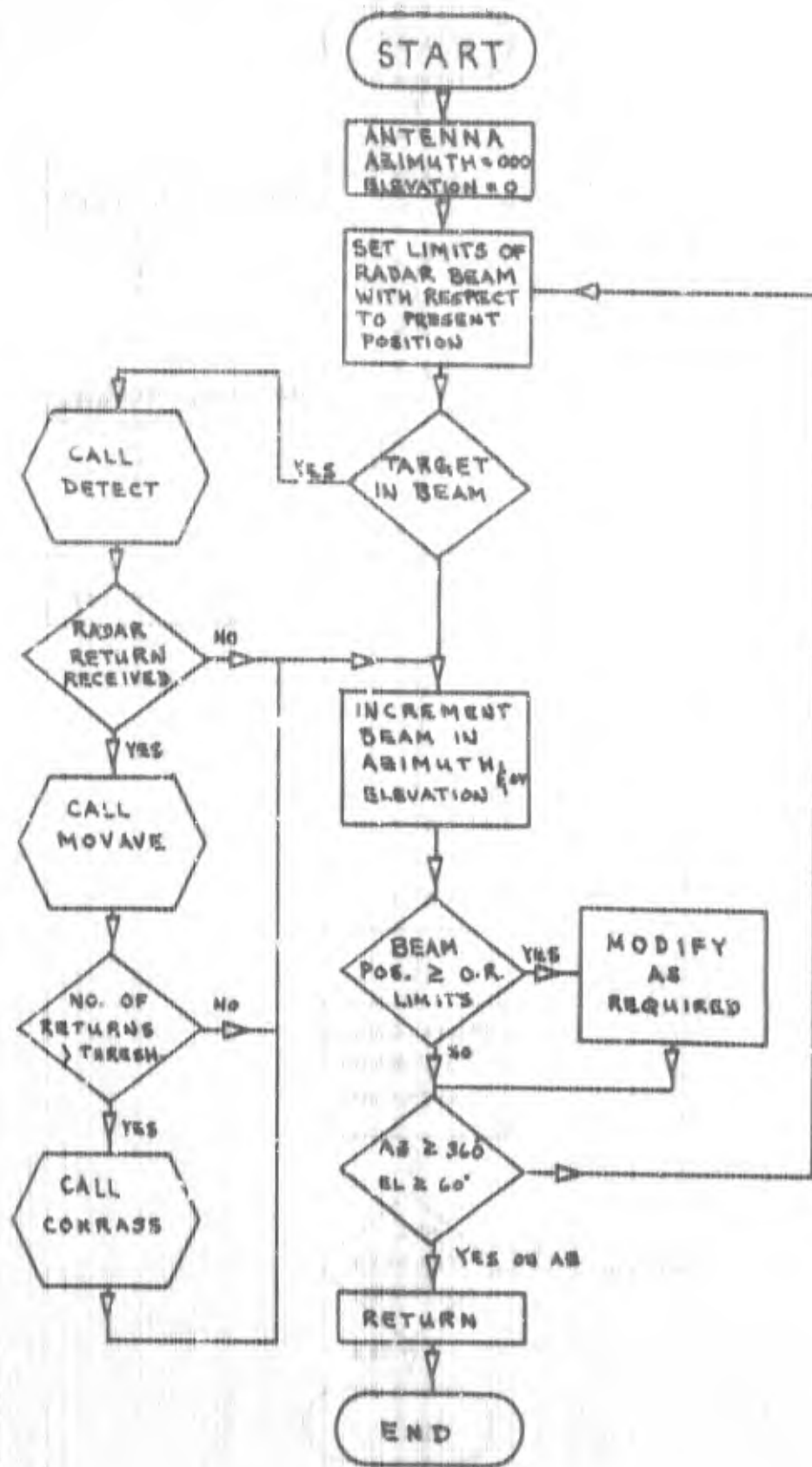
MAIN PROGRAM



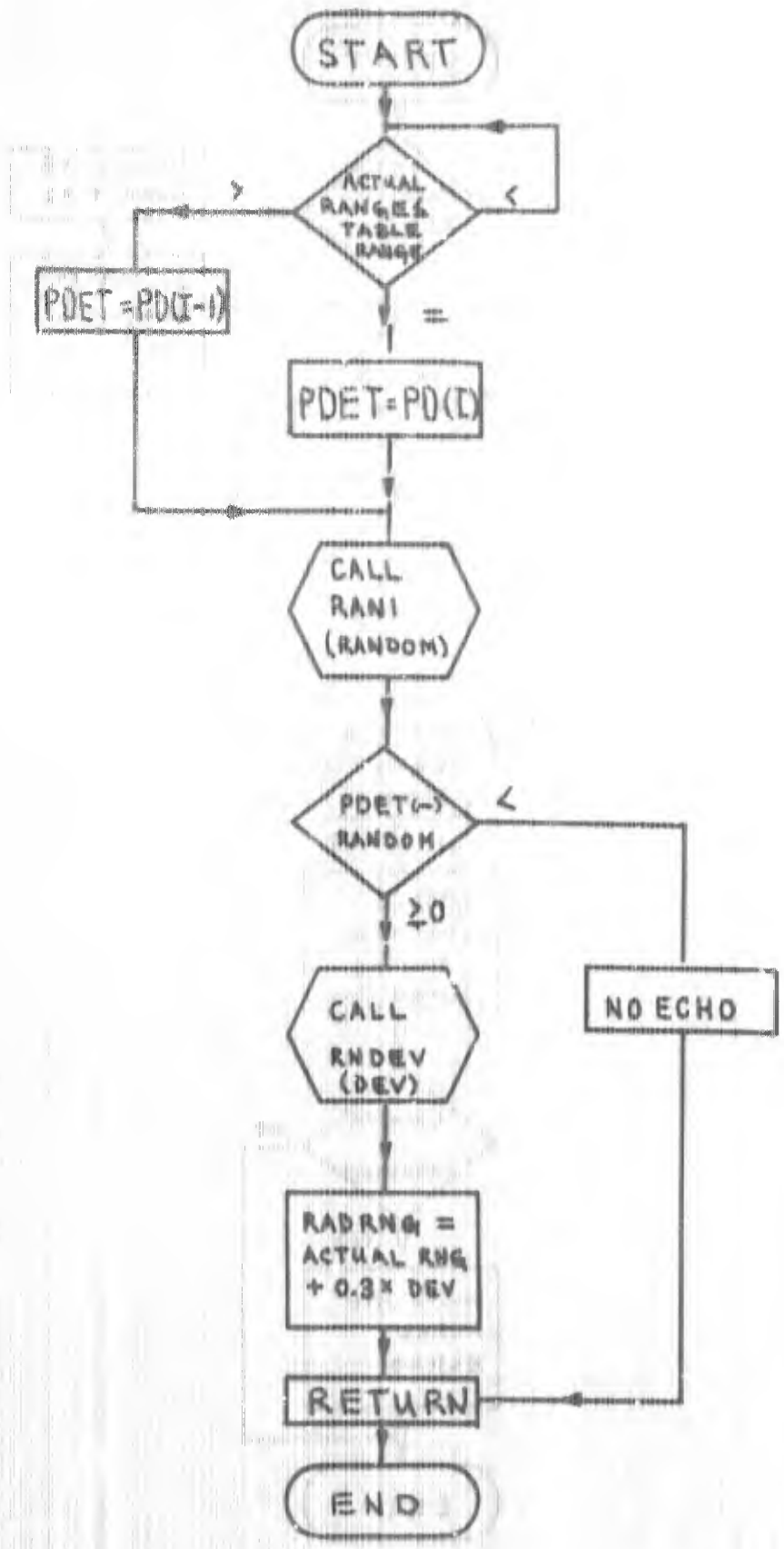
TARGEN



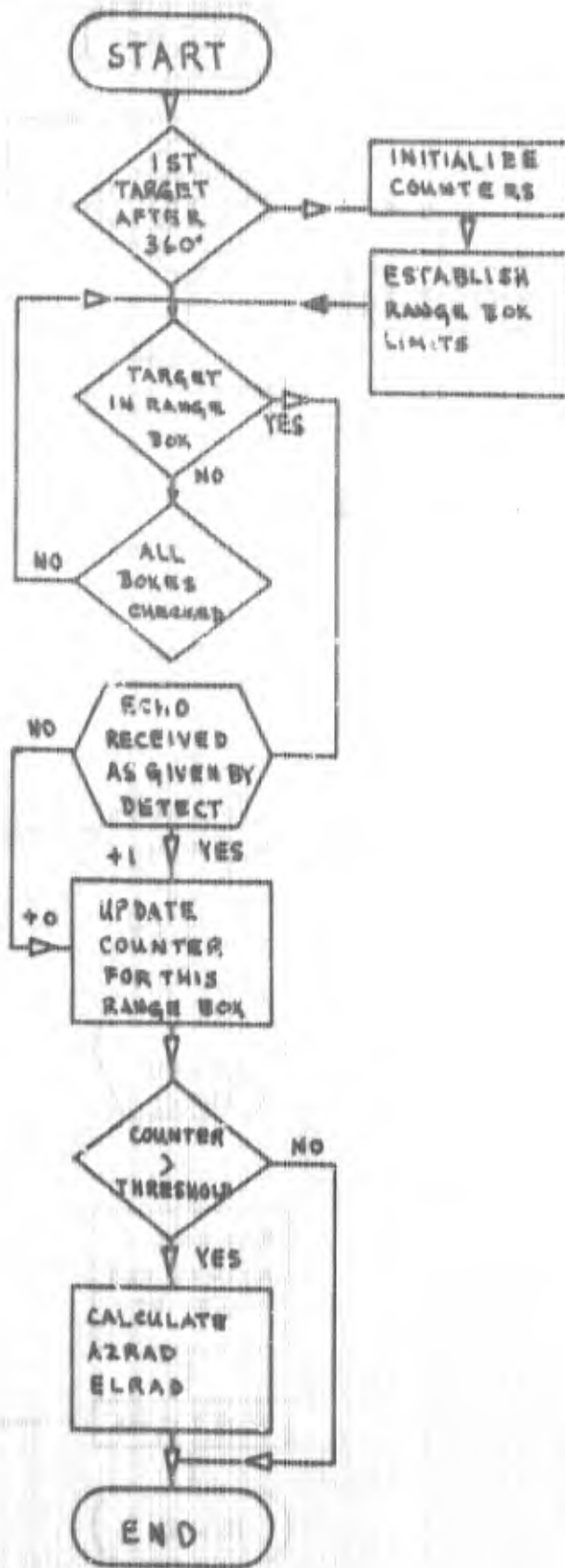
SCAN360



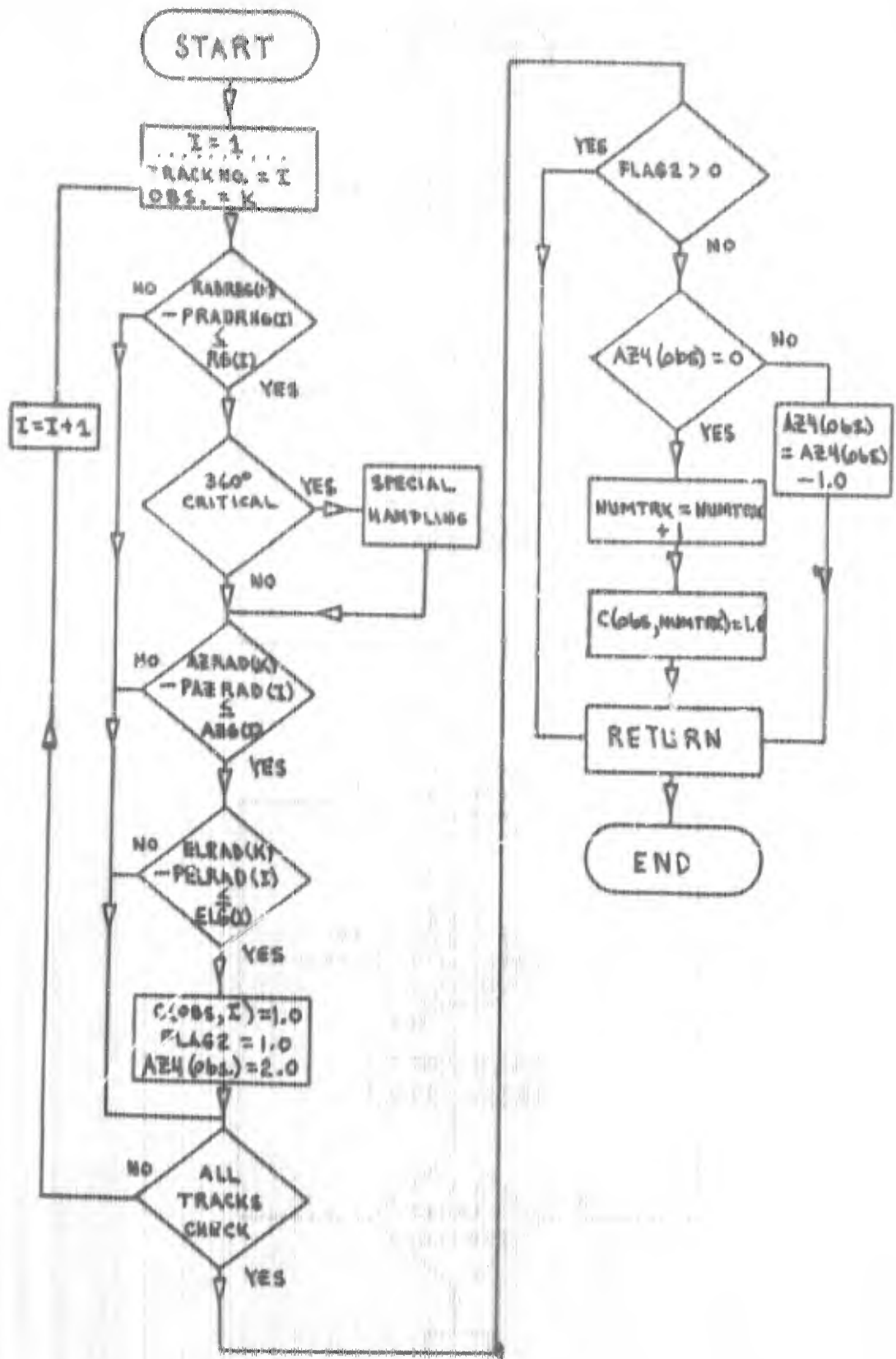
DETECT



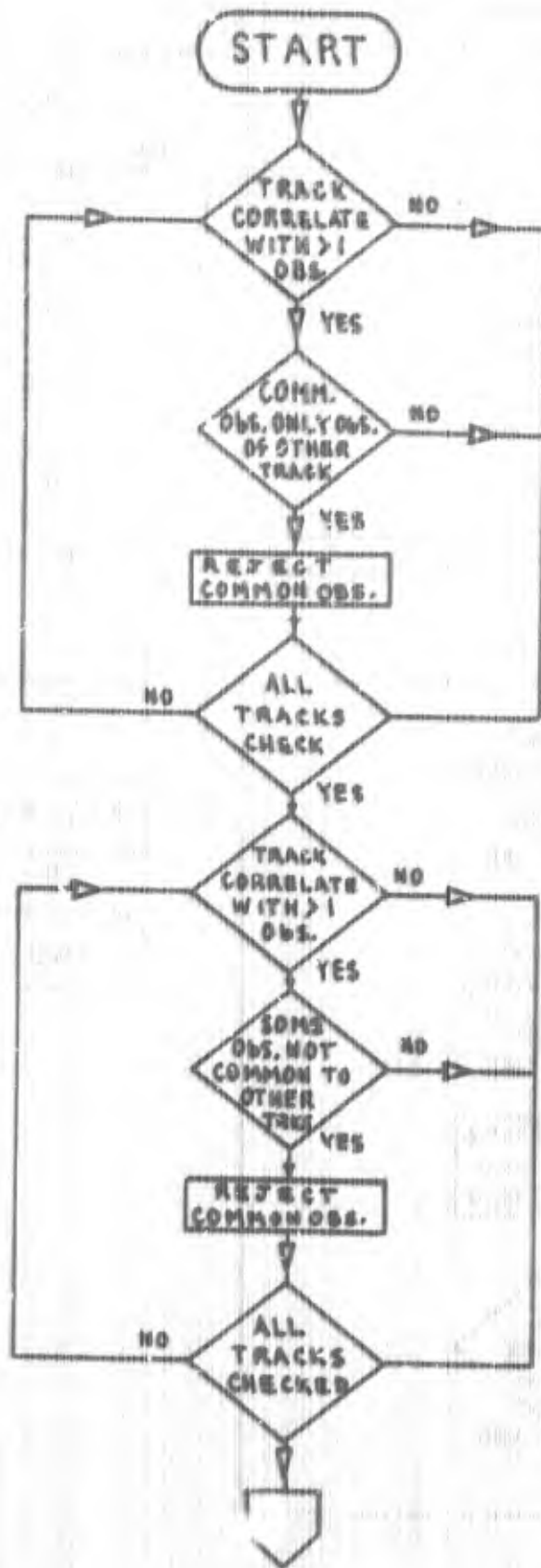
MOVAVE



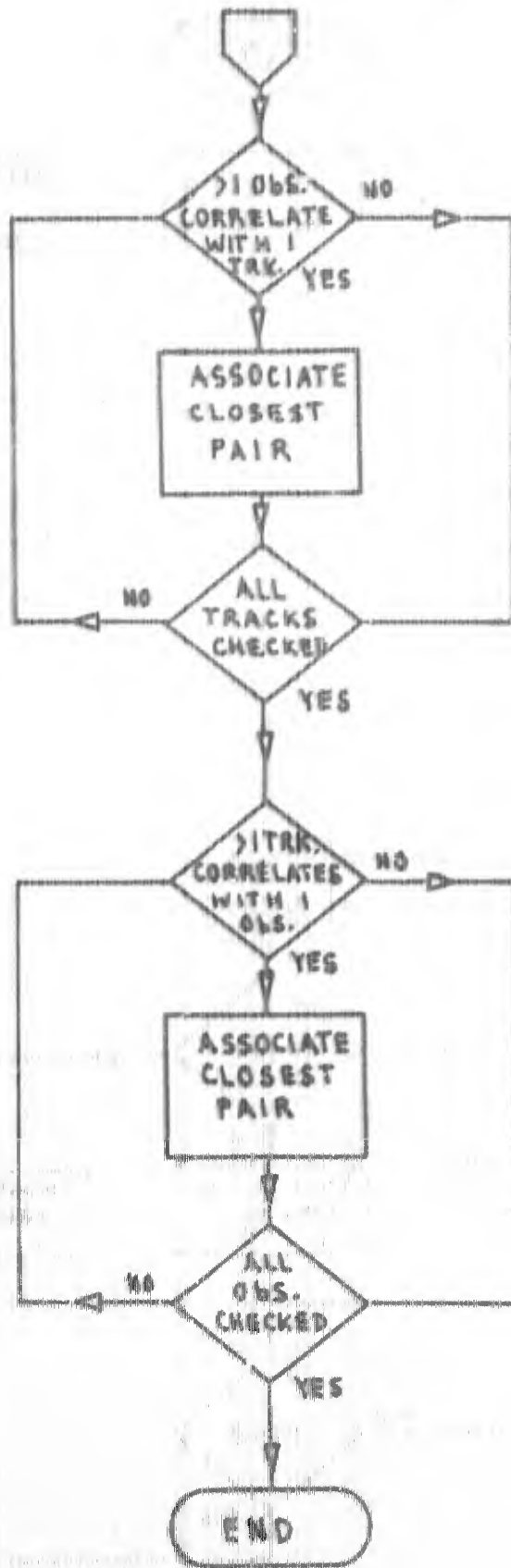
CORRASS



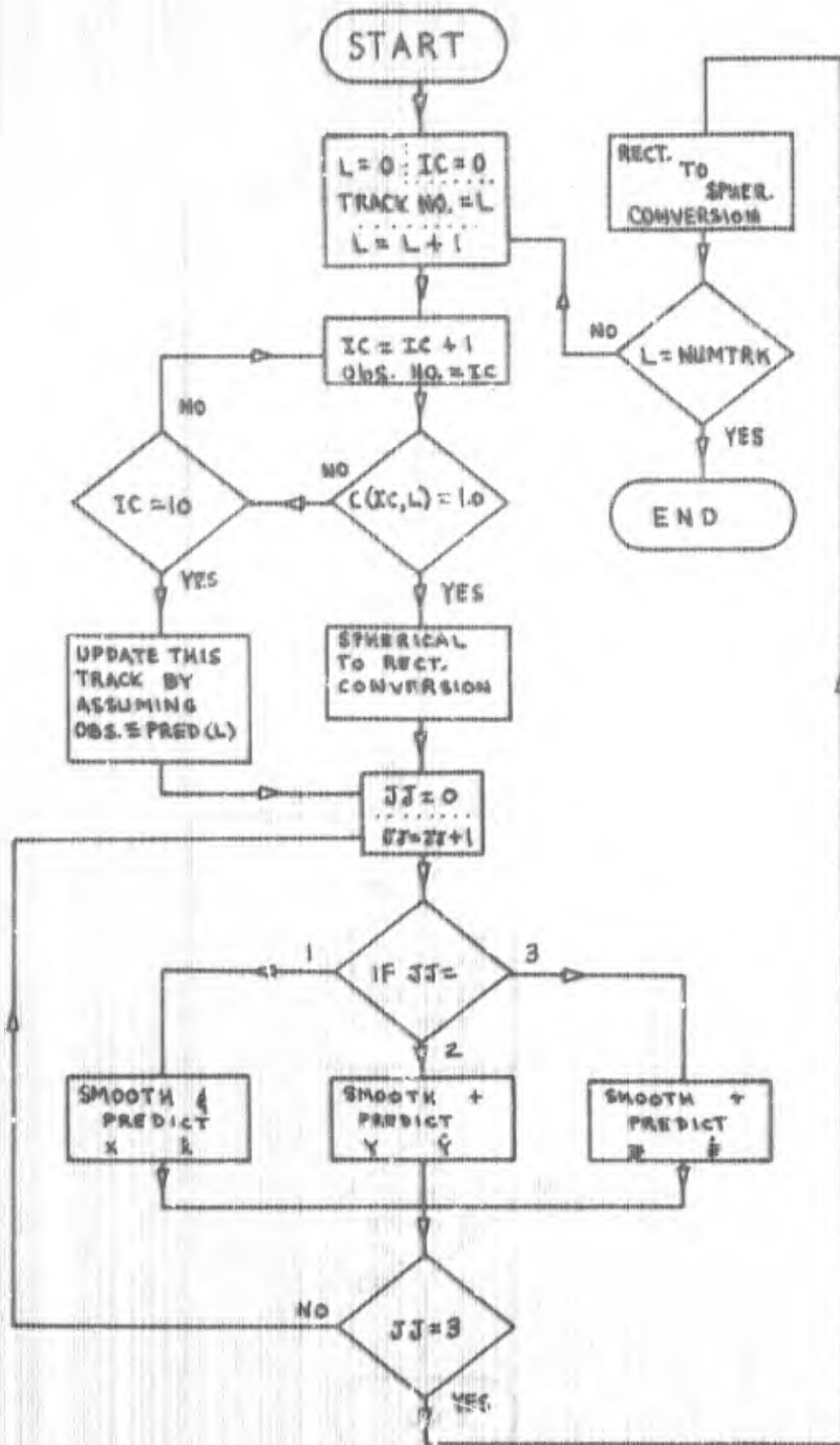
ASSOC



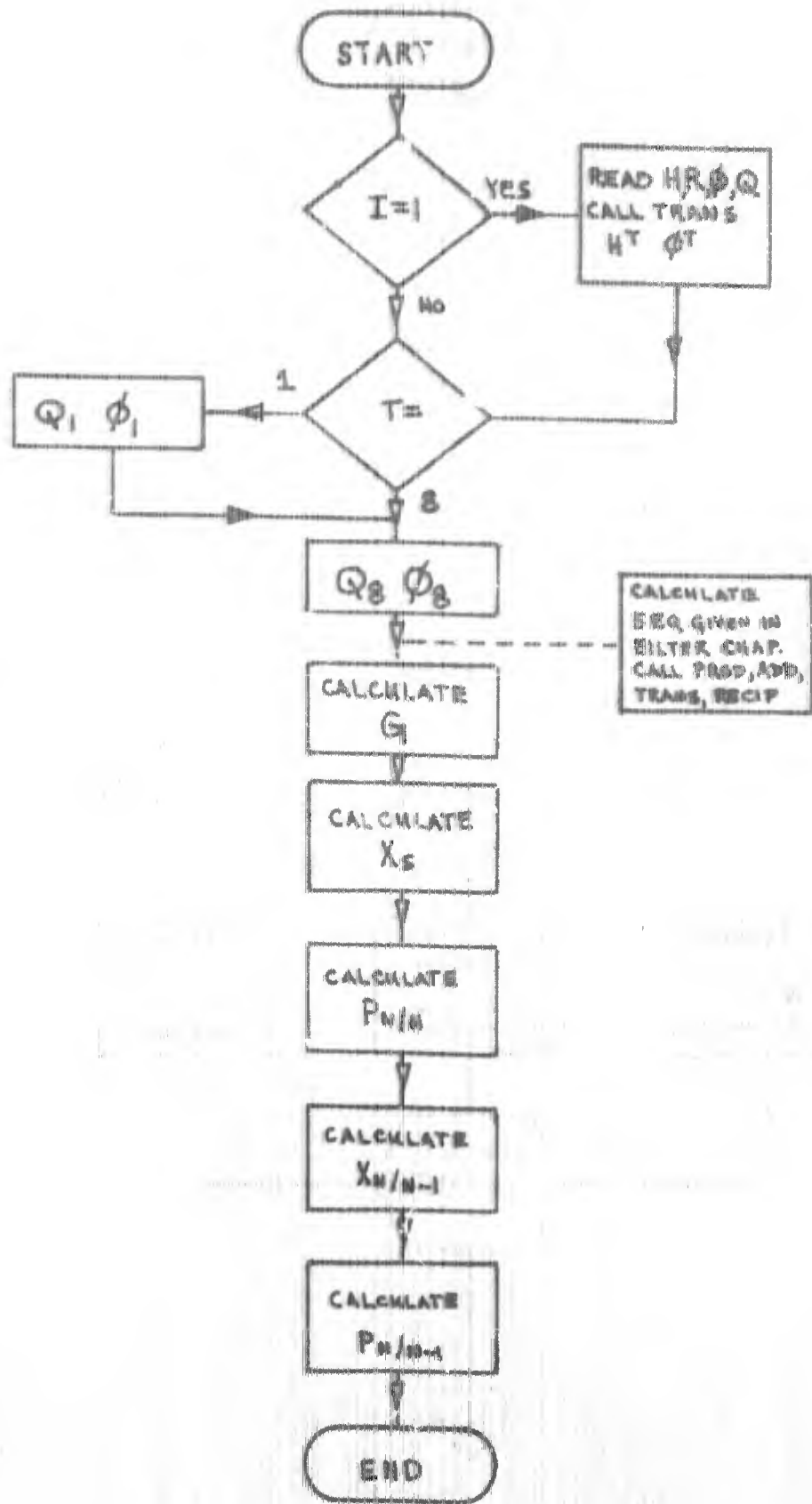
ASSOC (CONT)



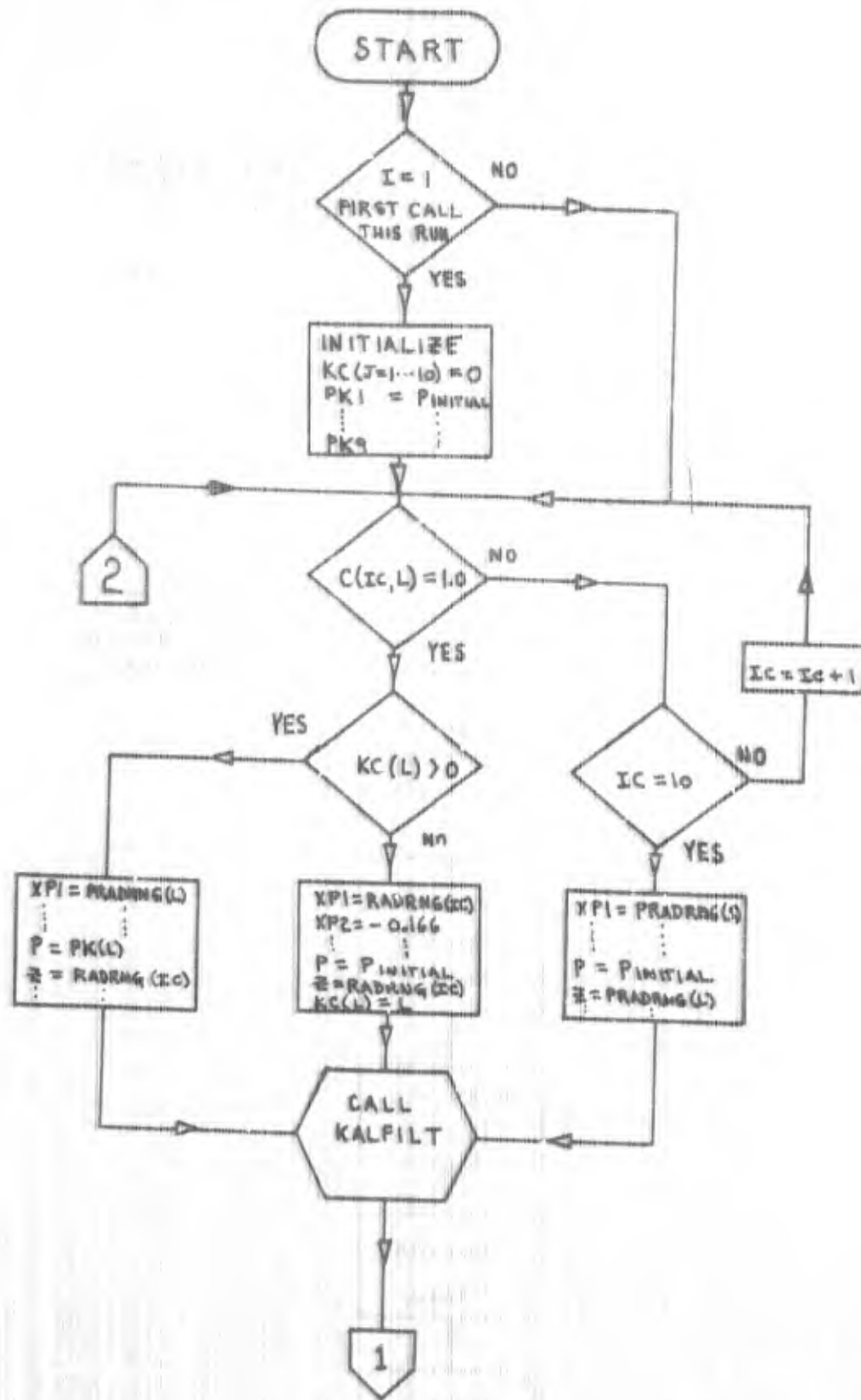
ABFILT



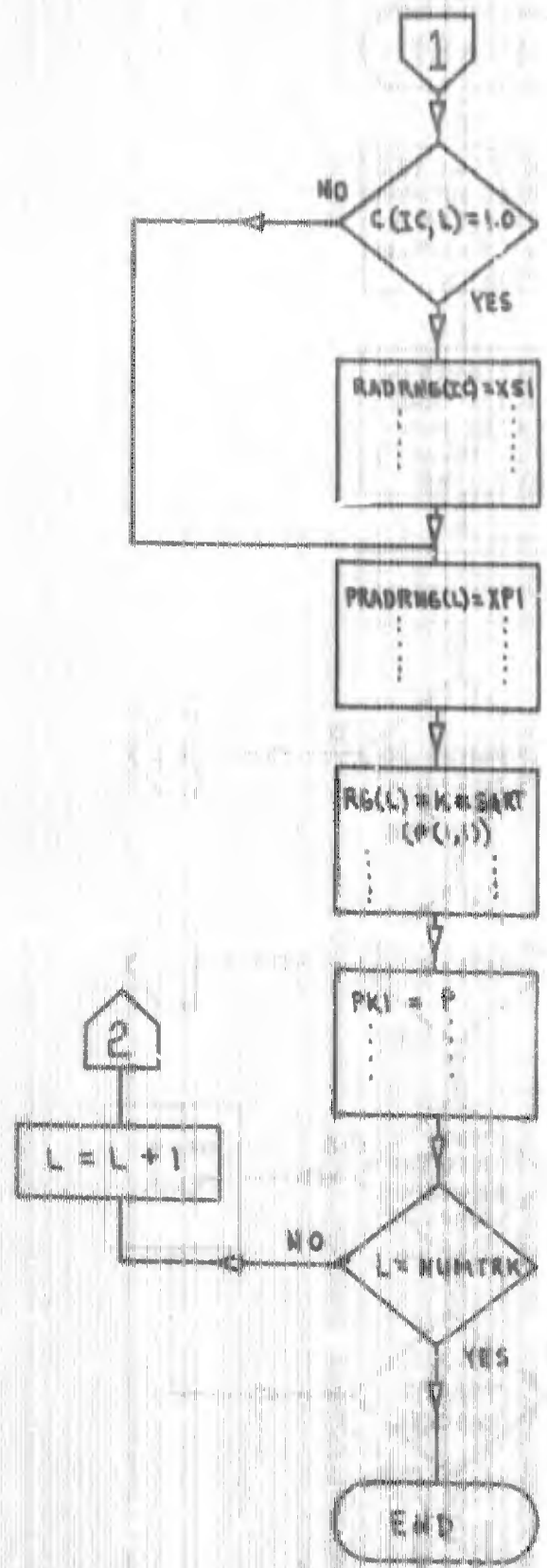
KALFILT



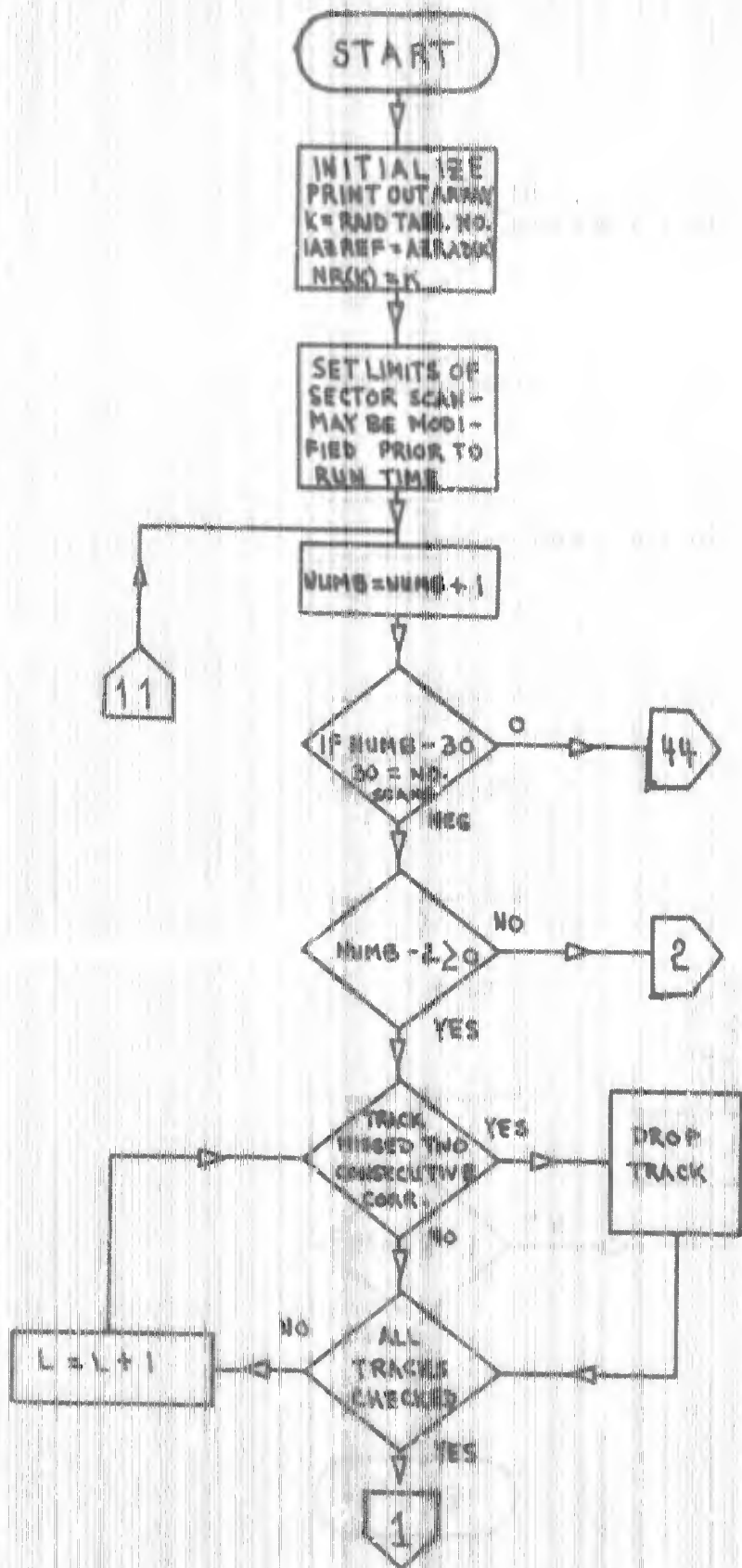
SETUP

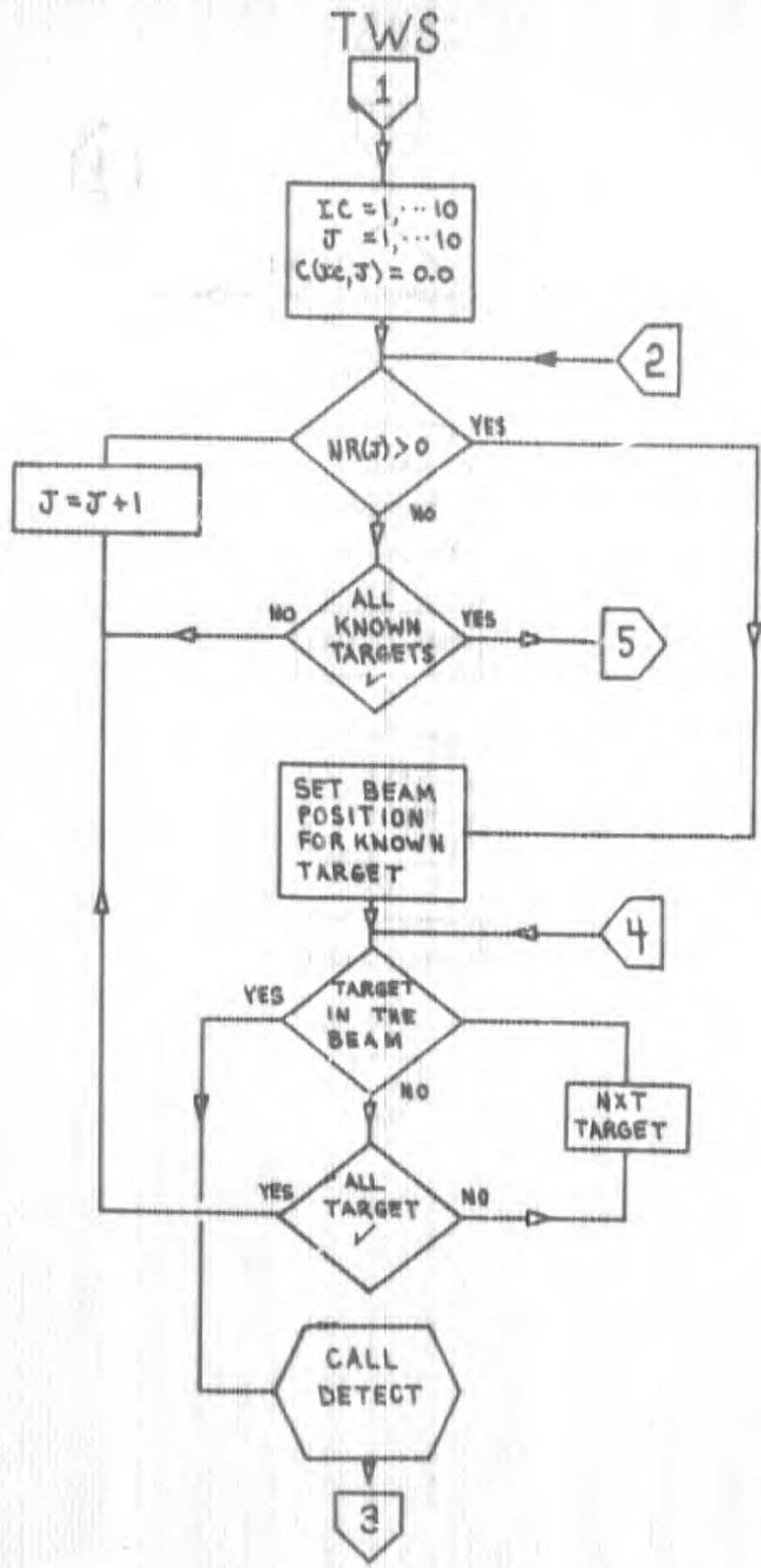


SETUP (CONT)

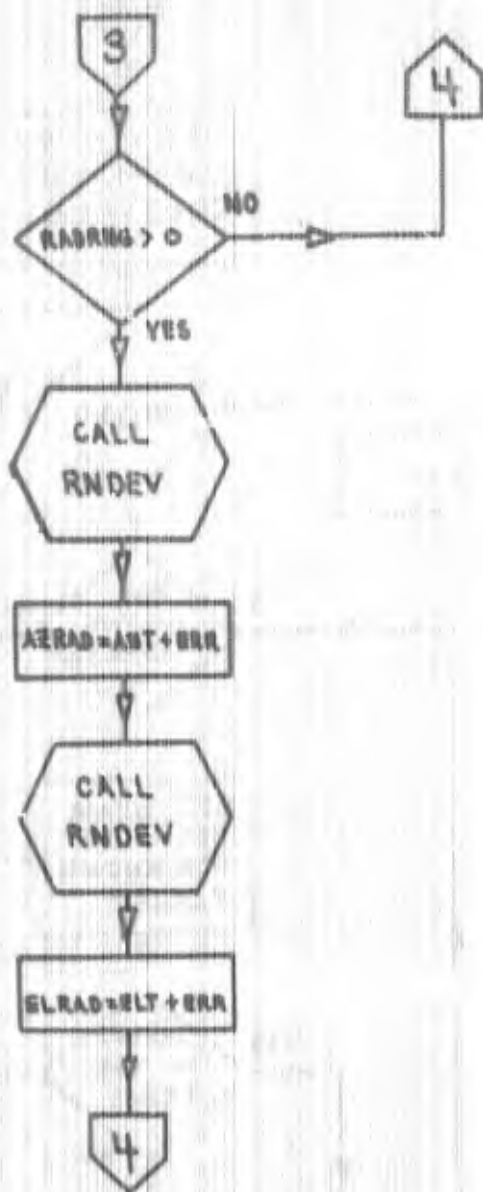


TWS

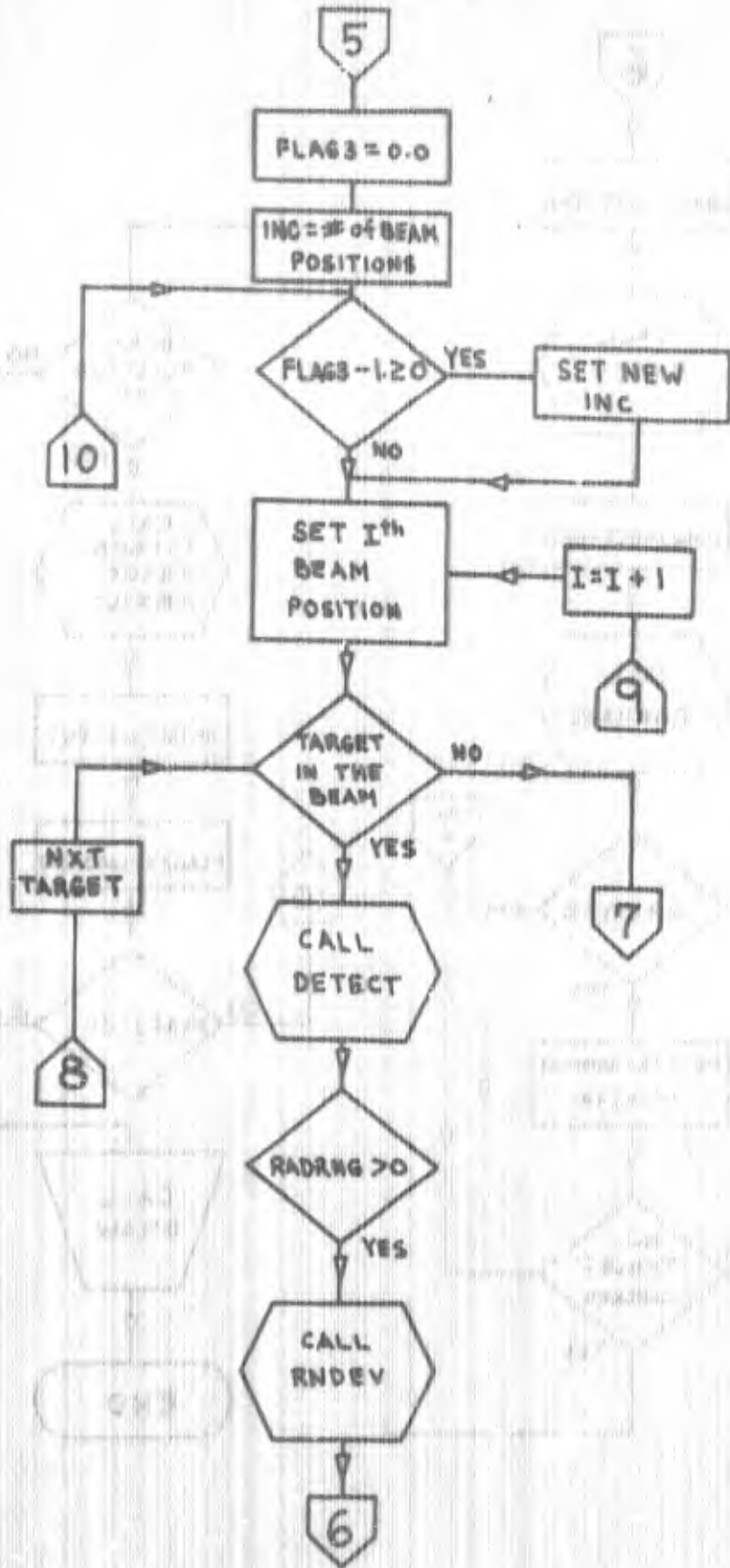




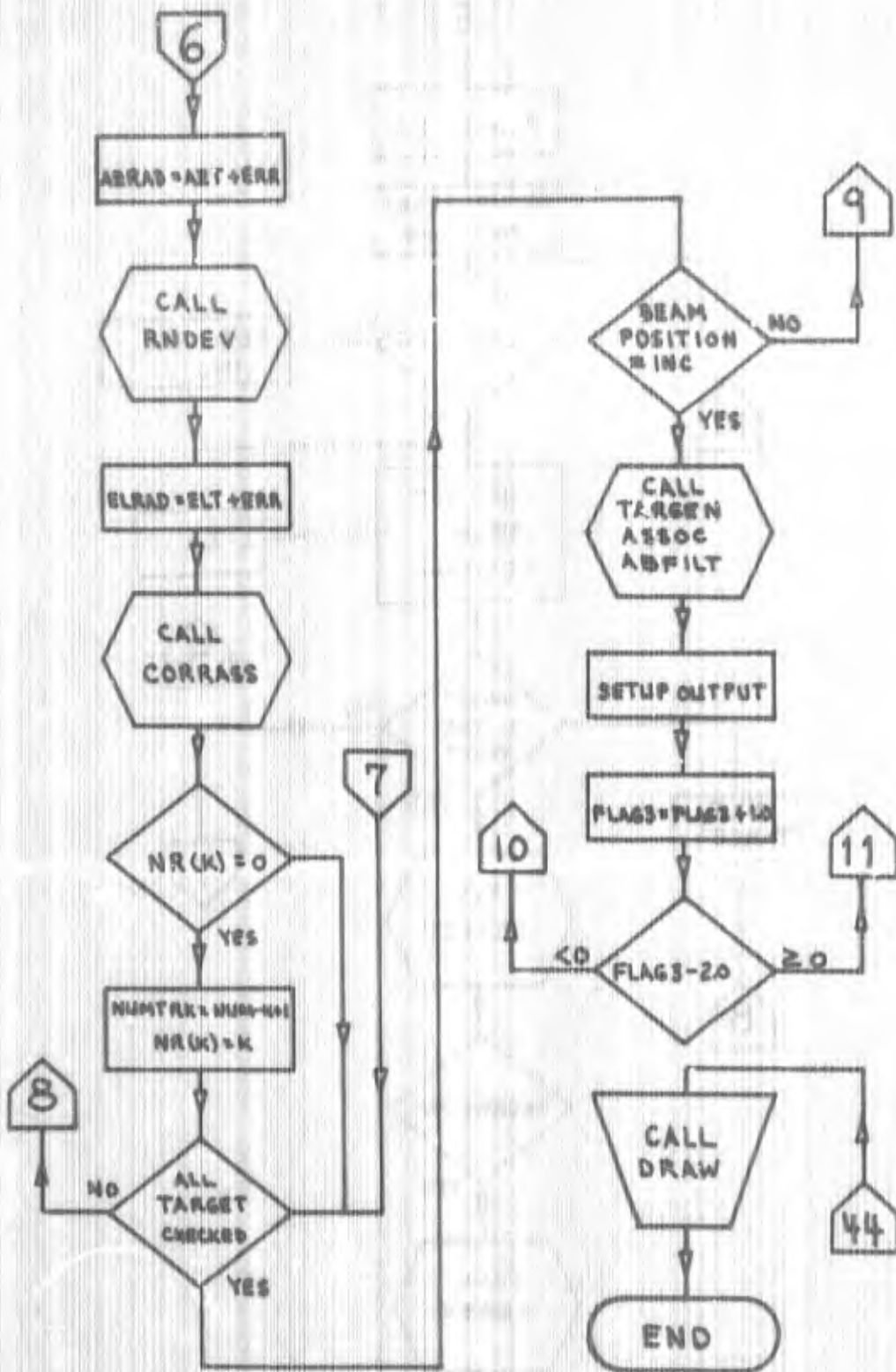
TWS



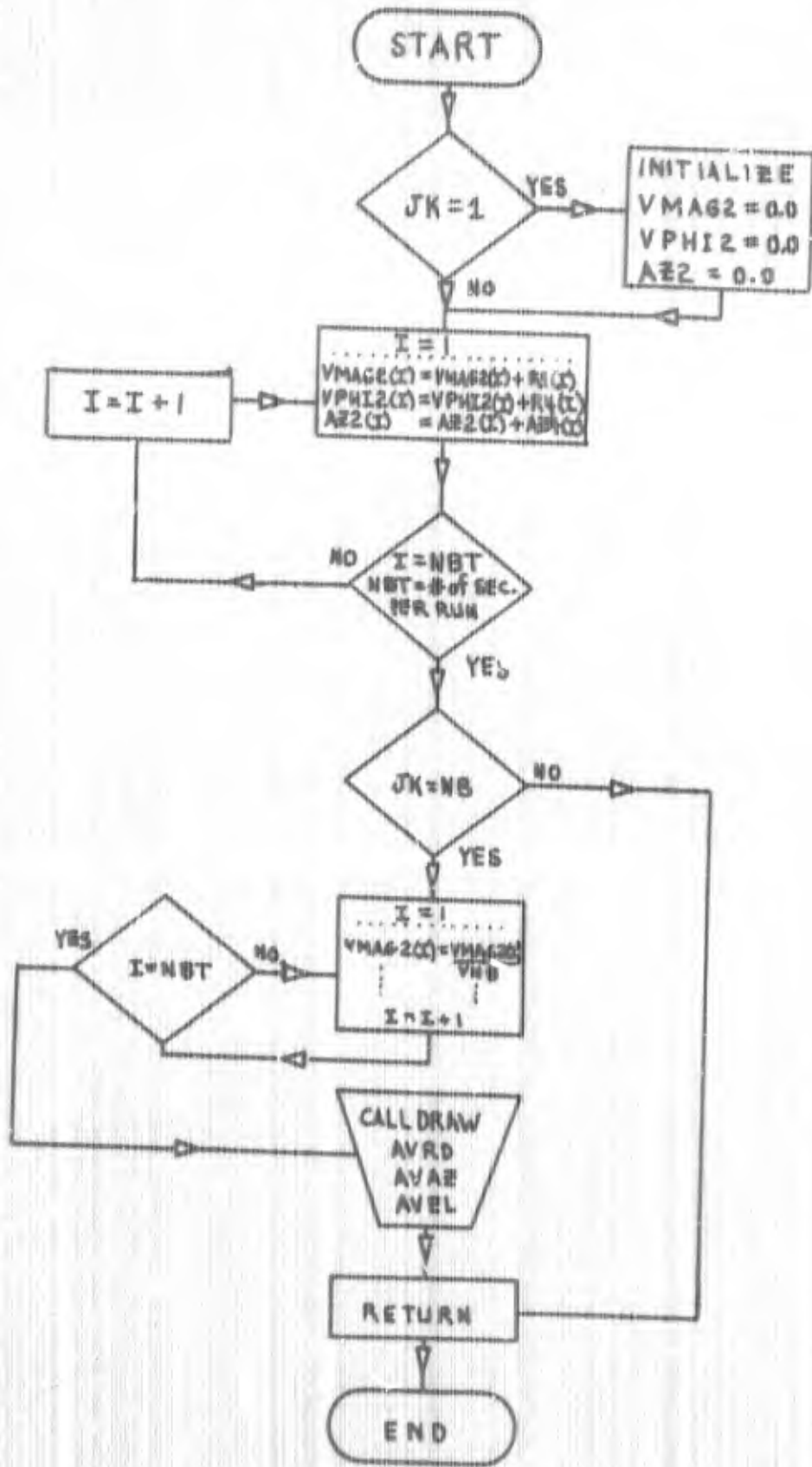
TWS



TWS



MONTE



APPENDIX IV

PROGRAM LISTING

PROGRAM LISTING
PAGE 1 OF 1
DATE 11/11/77
TIME 11:11 AM



PROGRAM KA2TVGS

```

DIMENSION RANGE(10),TARGRNG( 10 ),PD(10),
1YTILE(12),MD(10),VEL(10),ALT(10),PITCH(10),XT( 10 ),YT( 10 ),
2ZT(10),AZT(10),C(10,10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4PRADRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XT1(200),YT1(200),
5XRAD1(200),YRAD1(200),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
6(10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOY(10),NR(10),HDFIX(
710),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(20),R2(20),
8R3(20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
9,XT2(30),YT2(30),XRAD2(30),YRAD2(3 )
DIMENSION HPHT(6,6),X(6,6),VNI(6,6),Z(6,6),PHT(6,6),
1PHIT(6,6), P1(6,6 ),H(6,6),HT(6,6),PHI(6,6),R(6,6),Q(6,6),P(6,6),
2XS(6,6),XP(6,6),XPL(6,6),T1(6,6),T2(6,6),Q1(6,6),Q8(6,6),PHI1(6,6),
3,PHI8(6,6)
DIMENSION RDOT(10),AZDOT(10),ELDOT(10),
1KC(10),PK1(6,6),PK2(6,6),PK3(6,6),PK4(6,6),PK5(6,6),PK6(6,6),
2PK7(6,6),PK8(6,6),PK9(6,6)
COMMON RANGE,TARGRNG,PDET,PD,IR,RANDOM,NUNIF,DEV,
1 RANERR, RADRNG,MD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
2 AZT , ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TF ,I,AZRADI,
3RADRNG1,ELRADI, AZRAD ,C,S,DOTT,ZT,PAZRAD,ELBEAMT
4,FLAG, NUMTRK, NUM1 ,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
5, XRAD,YRAD,ZRAD,CONT,PRADRNG,PELRAD,XT1,YT1,XRAD1,YRAD1,INDEX,IN
6 DE,IAT,PXRAD,PYRAD,PZRAD,DOIX,DOIZ,DOY,NR,HDFIX,PITFIX,VELFIX
7 ,ALPHA ,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
8,XS,XP,P,KC

```

KALMAN FILTER IN POLAR COORDINATES

HEADING = DEGREES VELOCITY = N.M./ HR. ALTITUDE = FEET

FORMAT STATEMENTS

C
C
C
C
C
C
C
C

```

100 FORMAT(4 F10.4)
101 FORMAT(/,3X,11H HEADING = ,F10.4, 7HDEGREES, 3X,10HVELOCITY = ,
    1F10.4, 8HN.M./HR,3X,11HALTITUDE = ,F10.4, 4HFEET,3X, 7HPITCH = ,
    2F10.4, 7HDEGREES )
102 FORMAT( 2F10.4)
103 FORMAT(10X, F10.4 )
106 FORMAT(10F7.3 )
108 FORMAT(/, 9X,11HPROB OF DET, 9X,12HTARGET RANGE,/,10X,F10.4,
    110X, F10.4 )
109 FORMAT(/,10X,F10.4,10X,F10.4)
110 FORMAT(10X, 110 )
120 FORMAT( F10.4)
122 FORMAT(/, 15,1X,5F10.4,15)
123 FORMAT(/,4X,3H K ,3X, 8H RDRNG ,2X,6H AZRAJ, 4X, 6H ELRAD, 4X,
    15H XRAD, 5X, 5H YRAD, 5X, 5H ZRAD, 5X, 4H I )
161 FORMAT(/,10X,5MLL = ,12,5X,6HXT1 = ,F10.4,5X, 4MYT1 = , F10.4 )
162 FORMAT(/,10X, 5HLL = ,12,5X,8HXRAD1 = ,F10.4,5X, 9HYRAD1 = ,F10.4)
191 FORMAT(/,5X,5H K = ,12, 5X, 7H AZI = ,F10.4,5X,7H SLT = ,F10.4,
    15H XT = ,F10.4, 5HYI = , F10.4 ,5X,10HTARGRNG = ,F10.4)

```

C
C
C
C

CONSTANTS AND FLAGS

```

RADDEG = 57.2957795131
NUMIF = 12207003125.
IR=71625307
READ 106,(PD(I),J=1,10)
READ 106,(RANGE(J),J=1,10)
PRINT 108,PD(1),RANGE(1)
DO 3 J=2,10
3 PRINT 109, PD(J),RANGE(J)
READ 110, NT
READ 110, NUMSCAN
LL=
DO 4 K=1,NT
AZ4(K)= 0.0

```

```

RG(K) =2.5
AZG(K)= 2.5
ELG(K)=1.5
READ 100, HD(K), VEL(K), ALT(K), PITCH(K)
PRINT 101, HD(K), VEL(K), ALT(K), PITCH(K)
4 READ 102, XT(K), YT(K)
DO 2 J=1,12
2 TITLE(J) = 8H
DO 53 J=1,10
INDET(J)=0
53 INDEX(J)=0
I=8.0
NUM1=0
NUMTRK = 0
CORR=0.0
TESTT=1.0
PRINT 8
8 FORMAT(/,20X,37HCOVARIANCE OF THE ERROR OR P MATRIX )
CALL READD(6,6,P)
CALL TARGEN
DO 1 I=1,NUMSCAN
TEST = 0.0
JA=1
DO 55 IC=1,10
DO 55 J=1,10
55 C(IC,J)=0
CALL SCAN360
IF(I - 1) 61,61,60
60 NUM1 = 1
CALL ASSOC
61 CALL SETUP
IF(I-2)160,158,158
158 DO 150 J= 1,NUMTRK
TOTAL = 0.0
DO 151 IC = 1,10
151 TOTAL =TOTAL+ C(IC,J)

```

```

IF(TOTAL) 152,152,150
152 IF(INDEX(J)) 156,156,153
153 IF(1-(INDEX(J)+1)) 150,150,156
156 INDEX(J) = 1
INDEX(J) = 1
GO TO 150
154 DO 155 JB=J,NUMTRK
    C(I,C,JB) = C(I,C,JB+1)
    PRADRNG(JB)=PRADRNG(JB+1)
    PAZRAD(JB)=PAZRAD(JB+1)
    PELRAD(JB)=PELRAD(JB+1)
    INDEX(JB)=INDEX(JB+1)
    INDE(JB)=INDE(JB+1)
157 PELRAD(JB)=PELRAD(JB+1)
155 CONTINUE
121 FORMAT(//,10X,11HDROP TRACK ,I2)
    PRINT 121,J
    NUMTRK =NUMTRK -1
150 CONTINUE
160 DO 50 K= 1,NT
    XRAD(K) =(RADRNG(K) ) *COSF( ELRAD(K) /57.29577) *
15 INFIAZRAD(K) / 57.29577)
    YRAD(K) =(RADRNG(K) ) *COSF(ELRAD(K) /57.29577) *
1 COSFIAZRAD(K) / 57.29577)
    LL= I
    IF(K-1)200,200,201
200 XT1(LL)= X1(K)
    YT1(LL)= Y1(K)
    IF(1-1) 97,97,98
57 XRADI(LL)=XRAD(K)
    YRADI(LL)=YRAD(K)
60 TO 96
58 CC= 0
DO 51 J=1,10
51 CC=CC+C(K,J)

```

```

51 IF(CC) 54,54,52
52 XRAD1(LL)=XRAD(K)
   YRAD1(LL)=YRAD(K)
   GO TO 56
54 XRAD1(LL)=0.0
   YRAD1(LL)=0.0
   GO TO 56
201 XT2(LL)= XT(K)
   YT2(LL)= YT(K)
   IF(I-I) 557,557,558
557 XRAD2(LL)=XRAD(K)
   YRAD2(LL)=YRAD(K)
   GO TO 56
558 CC= .0
50 551 J=I,10
   CC=CC+C(K,J)
551 IF(CC) 554,554,552
552 XRAD2(LL)=XRAD(K)
   YRAD2(LL)= YRAD(K)
   GO TO 56
554 XRAD2(LL)= 0.0
   YRAD2(LL)= 0.0
56 PRINT 123
   PRINT 122, X,RAD(RNG(K),AZRAD(K),ELRAD(K),XRAD(K),YRAD(K),
   I),ZRAD(K),I)
   PRINT 161,LL,XT1(LL),YT1(LL)
   PRINT 162,LL,XRAD1(LL),YRAD1(LL)
50 CONTINUE
   CALL TARGEN
1 CONTINUE
ITITLE(1)= 8HFULL SCA
ITITLE(2)=8HN MANUEV
ITITLE(3)=8HING TARG
ITITLE(4)=8H3 DEG/SE
ITITLE(5)=8HC
ITITLE(6)=8H

```



```

SUM=0.00
8 11=1
ELBEAMB=0.0
ELBEAMT=5.454545
11 AZBEAML = SUM
AZBEAMT = SUM -1.0
NA = 0
IF(AZBEAMT 160,61,61
60 AZBEAMT =360.0+AZBEAMT
NA = 1
61 DO 63 K=1,NT
IF(NA) 12,13,12
12 IF(AZTIK ) -1.0) 21,20,20
20 IF(AZTIK ) - AZBEAMT)63,63,5
21 IF(AZTIK ) - AZBEAML)5,63,63
13 IF(AZTIK )-AZBEAML)4,63,63
4 IF(AZBEAMT - AZTIK )15,63,63
5 IF(ELTIK )-ELBEAMB)63,6,6
6 IF(ELBEAMT - ELTIK )163,7,7
7 NUM3 = K
CALL DETECT
CALL MOVAVE
IF(FLAG) 63,63,52
52 NUM3 = K
CALL CORRASS
63 CONTINUE
11=11+1
SUM = SUM + .02
ELBEAMB = ELBEAMT
ELBEAMT=ELBEAMT+5.454545
IF(IGO -1.0) 15,16,16
15 IF( 90.0-SUM) 14,14,10
14 SUM=270.0
60=1.0
GO TO 10
16 IF( 360.0- SUM) 9,9,10

```

```

10 IF(11-11) 11,8,8
9 GO TO 0
RETURN
END
SUBROUTINE DETECT
DIMENSION
1 TITLE(12),HD(10),VEL(10),ALT(10),PITCH(10),XT( 10 ),YT( 10 ),
2 ZT(10),AZT(10),C(10,10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3 ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4 PRAD(10),PELRAD(10),PAZRAD(10),RADRNG(10),XT1(200),YT1(200),
5 XRAD1(200),YRAD1(200),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
6 (10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
7 10),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(20),R2(20),
8 R3(20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
COMMON RANGE,TARGRNG,PDET,PD,IR,RANDOM,NUMIF,DEV,
1 RANERR, RADRNG,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
2 AZT , ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TESTT,AZRADI,
3 RADRNG1,ELRAD1, AZRAD ,C,S,DOTT,ZT,PAZRAD,ELBEAMT
4 ,FLAG, JUMTRK, NUM1 ,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
5 ,XRAD,YRAD,ZRAD,CONT,PRADRNG,PELRAD,XT1,YT1,XRAD1,YRAD1,INDEX,IN
6 DE,IAT,PXRAD,PYRAD,PZRAD,DOTX,DOTZ,DOTY,NR,HDFIX,PITFIX,VELFIX
7 ,ALPHA ,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
8 ,XS,XP,P,KC
K=NUM3
IF(RANGE(1)- TARGRNG(K )) 20,20,21
20 PDET= PD(1)
GO TO 5
21 DO 1 J=1,10
IF(RANGE(J) -TARGRNG(K )) 2,3,1
3 PDET=PD(J)
GO TO 5
2 PDET=PD(J-1)
GO TO 5
1 CONTINUE
PDET=PD(10)

```

```

5 CALL RAN1(IR, RANDOM)
IF(PDET - RANDOM)7,6,6
6 CALL RNDEV(NUNIF,DEV)
RANERR = (DEV*0.3)
RADRNG(K) = TARGRNG(K) + FRANERR
PRINT 412, K, RADRNG(K)
412 FORMAT(/,10X,4HK = ,12, 9HRADRNG = , F10.4,
1 ZONA GOOD RADAR TARGET )
GO TO 8
7 RADRNG(K) = 0.0
411 FORMAT(/,10X,13HTARGET NO. = , 12, 7H A MISS )
PRINT 411,K
8 RETURN
END
SUBROUTINE MOVEAVE
DIMENSION
1 ITITLE(12),HD(10),VEL(10),ALF(10),PITCH(10),XT( 10 ),YTI( 10 ),
2 ZT(10),AZT(10),C(10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3 ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4 PRADRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XT1(200),YTI(200),
5 XRAD1(200),YRAD1(200),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
6(10),PYRAD(10),PZRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
710),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(20),R2(20),
8R3(20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
COMMON
1 RANERR, RADRNG,HD,VEL,ALF,PITCH,XT,YTI,NT,JA,T,I,TEST,
2 AZT, ELI, IAZ, BOXMAX,BOXMIN,ELTEST,TESTT,AZRAD1,
3 RADRNG1,ELRAD1, AZRAD, C,S,DOTT,ZT,PAZRAD,EL,BEAMT
4 FLAG, NUMIRK, NUM1, NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
5 XRAD,YRAD,ZRAD,CONT,PRADRNG,PELRAD,XT1,YTI,XRAD1,YRAD1,INDEX,IN
6 DE,IAT,PXRAD,PYRAD,PZRAD,DOTX,DOTZ,DOTY,NR,HDFIX,PITFIX,VELFIX
7 ALPHA,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
8 XS,XP,P,KC
K=NUM3
FLAG = 0.0

```

```

IF(RADRNG(K) ) 7,1,7
1 RADRNG1=TARRNG(K)
GO TO 2
7 RADRNG1 = RADRNG(K)
2 IF( TEST ) 3,4,3
4 IA=
DO 17 K=1,5
IAZ(K) =0
17 IAT(K) =0
NO=
K = PUM3
TEST=1.0
10 NO = NO + 1
IA=IA+1
BOXMIN (IA)=RADRNG1-1.5
BOXMAX (IA) = RADRNG1 + 1.5
ELTEST (IA) = ELBEAMT
3 DO 5 J=1,NO
IF( ELTEST (J)-ELBEAMT) 5,6,5
6 IF( BOXMAX(J) - RADRNG1) 5,8,8
8 IF (RADRNG1 - BOXMIN(J)) 5,9,9
5 CONTINUE
GO TO 10
9 IF(RADRNG(K) )11,12,11
12 IAZ(K) =IAZ(K) +0
IAT(K) =IAT(K) +1
GO TO 22
11 IAZ(K) = IAZ(K) +1
IAT(K) =IAT(K) +1
IF(IAZ(K)-1) 22,21,22
21 CONT(K) =AZBEAMT+0.99
22 IF(IAT(K) -5) 14,16,14
16 IF(IAZ(K) -3) 20,15,15
20 RADRNG(K) = 0.0
GO TO 14
1, N = K

```

```

FLAG = 1.0
NUM3 = K
AZRAD(N) = CONT(K) - 0.49
CALL RNDEV(NUNIF,DEV)
ELERR = DEV * 0.5
ELRAD(N) = ELT(K) + ELERR
TEST1 = TEST1 + 1.0
PRINT 18, AZRAD(N), ELRAD(N), ELERR
18 FORMAT(/,10X,13HGO TO CORRASS,8HAZRAD = ,F10.4, 10X, 8HELRAD = ,
19 RETURN
END
SUBROUTINE CORRASS
DIMENSION
1 ITITLE(12), HD(10), VEL(10), ALI(10), PITCH(10), XT(10), YI(10),
2 ZT(10), AZT(10), C(10,10), S(10), ELT(10), XRAD(10), YRAD(10), ZRAD(10),
3 ELRAD(10), AZRAD(10), BOXMIN(10), BOXMAX(10), ELTEST(10), IAZ(10),
4 PRADRN(10), PELRAD(10), PAZRAD(10), RADRNG(10), XTI(200), YTI(200),
5 XRADI(200), YRADI(200), INDEX(10), INDE(10), COMT(10), IAT(10), PXRAD
6 I(10), PYRAD(10), PZRAD(10), DOTX(10), DOTZ(10), DOTY(10), NR(10), HDFIX(
7 I(10), PITFIX(10), VELFIX(10), RG(10), AZG(10), ELG(10), RI(20), RZ(20),
8 R3(20), R4(20), AZ1(20), AZ2(20), AZ3(20), AZ4(20)
DIMENSION XS(6,6), XP(6,6), P(6,6), KC(10)
COMMON
1 RANERR, RADRNG, HD, VEL, ALI, PITCH, XT, YI, NT, JA, TI, TEST,
2 AZT, ELT, IAZ, BOXMAX, BOXMIN, ELTEST, TEST1, AZRADI,
3 RADRNG1, ELRADI, AZRAD, C, S, DOTT, ZT, PAZRAD, ELBEAMT
4 FLAG, NUMTRK, NUM1, NUM2, NUM3, AZBEAMT, RADDEG, ELRAD
5 XRAD, YRAD, ZRAD, COMT, PRADRNG, PELRAD, XTI, YTI, XRADI, YRADI, INDEX, IN
6 DE, IAT, PXRAD, PYRAD, PZRAD, DOTX, DOTZ, DOTY, NR, HDFIX, PITFIX, VELFIX
7 ALPHA, BETA, RG, AZG, ELG, R1, R2, R3, R4, AZ1, AZ2, AZ3, AZ4
8 XS, XP, P, KC
9 NUM3
FLAG2 = 0.0

```

505 DO 18 K = 1, NUMTRK
PRINT 20, RG(K), AZG(K), ELG(K)

```

203 FORMAT(//,30X,5HRG = ,F10.6,5X,6MAZG = ,F10.6,5X, 6HELG = ,F10.6)
    IF (ABS(F(RADRNG(N))-PRADRNG(K))-RG(K)) 15,15,18
15 IF (AZRAD(N)-(360.0-AZG(K))) 302,303,303
302 IF (AZRAD(N)-AZG(K)) 300,300,304
300 IF (PAZRAD(K)-(360.0-AZG(K))) 304,3 1,301
301 AZY =AZRAD(N)+ 360.0
    IF (ABS(AZY-PAZRAD(K))-AZG(K)) 16,16,18
304 IF (ABS(AZRAD(N)-PAZRAD(K))-AZG(K)) 16,16,18
303 IF (PAZRAD(K)-AZG(K)) 305,304,304
305 PAZY=PAZRAD(K)+360.0
    IF (ABS(PAZY-AZRAD(N))-AZG(K)) 16,16,18
16 IF (ABS(ELRAD(N)-PELRAD(K))-ELG(K)) 17,17,18
17 IC=N

```

J=K

```

C(IC,J)=1
PRINT 60,(C(IC,J),J=1,10),IC=1,10)
FLAG2=1.0
AZ4(N)= 2.0

```

```

18 CONTINUE
    IF (FLAG2) 120,120,121
120 PRINT 536,N,NUMTRK
536 FORMAT(//,10X,11HTARGET NO. ,12,2X, 23MDID NOT CORRELATE WITH ,12,
1 6HTRACKS)
60 FORMAT(//10X,10F10.3)
    IF (AZ4(N)) 62,62,63
63 AZ4(N)=AZ4(N) - 1.0
    GO TO 121
62 NUMTRK= NUMTRK + 1
    KC(NUMTRK) = 0
    IF (NUMTRK -9) 123,538,538
538 NUMTRK= 9
123 C(N,NUMTRK) =1.0
121 RETURN
END

```

SUBROUTINE ASSOC
DIMENSION RANGE(10),TARGRNG(10),PD(10),

```

11 TITLE(12),HD(10),VEL(10),ALT(10),PITCH(10),XT( 10 ),YT( 10 )
22 (10),AZT(10),C(10,10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3 ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4 PRDRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XT1(200),YT1(200),
5 XRAD1(200),YRAD1(200),INDEX(10),DOIX(10),CONT(10),IAT(10),PXRAD
6 (10),PITFIX(10),VELFIX(10),RG(10),AZG(10),DOTY(10),NR(10),HDFIX(
7 (20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
8 DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
9 COMMON
10 RANGE,TARGRNG,PDET,PD,IR,RANDOM,NUNIF,DEV,
11 RANERR, RADRNG,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
12 AZT, ELT, IAZ, BO,MAX,BOXMIN,ELTEST,TESTT,AZRADI,
13 BRDRNG1,ELRADI, AZRAD, C,S,DOIT,ZT,PAZRAD,ELBEAMT
14 FLAG, NUMTRK, NUM1, NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
15 XRAD,YRAD,ZRAD,CONT,PRDRNG,PELRAD,XT1,YT1,XRAD1,YRAD1,INDEX,IN
16 DE,IAT,PXRAD,PYRAD,PZRAD,DOIX,DOITZ,DOIT,NR,HDFIX,PITFIX,VELFIX
17 ALPHA,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
18 XS,XP,P,KC
19 DO 19 J= 1,10
20 SUM1=0
21 DO 25 IC=1,10
22 SUM1=C(IC,J)+SUM1
23 IF(SUM1-1.)19,19,26
24 DO 119 IC=1,10
25 IF(C(IC,J)-1.)19,20,19
26 JPI=J+1
27 DO 21 JP2=JPI,10
28 IF(C(IC,JP2)-1.)21,22,21
29 IPI=1
30 SUM2=0
31 DO 23 IPI=1,10
32 SUM2=C(IPI,JP2)+SUM2
33 IF(SUM2-1.)21,24,21
34 G(IIC,J)=0
35 CONTINUE
36 119 CONTINUE

```

```

19 CONTINUE
   DO 31 J=1,10
   SUM3=0
   DO 32 IC=1,10
   SUM3=C(IC,J)+SUM3
   IF(SUM3-1.731,31,33
33 DO 131 IC=1,10
   IF(C(IC,J))31,31,36
36 SUM4=0
   JP3=J+1
   DO 35 JPA=JP3,10
   SUM4=SUM4+C(IC,JP4)
   IF(SUM4)31,37,31
37 DO 231 IC=1,10
   IF(C(IC,J))31,31,38
38 SUM5=0
   JP5=J+1
   DO 39 JP6=JP5,10
   SUM5=SUM5+C(IC,JP6)
   IF(SUM5)31,31,40
40 C(IC,J)=0
231 CONTINUE
131 CONTINUE
31 CONTINUE
   DO 41 J=1,10
   SUM6=0
   DO 42 IC=1,10
   SUM6=SUM6+C(IC,J)
   IF(SUM6-1.741,41,43
43 DO 44 IC=1,10
   S(IC)=210
   IF(C(IC,J))44,44,45
45 S(IC)= PRADRNG(J) - RADRNG(IC)
44 CONTINUE
   IC=1
   IA=I+1

```

```

NB=1
S(NB)=.210
DO 46 IB=1A,10
IF(S(IC)-S(IB))46,46,47
47 IF(S(NB)-S(IB))46,46,48
48 NB=IB
46 CONTINUE
DO 49 IC=1,10
C(IC,J)=0
C(NB,J)=1
41 CONTINUE
DO 51 IC=1,10
SUM7=0
DO 52 J=1,10
SUM7=SUM7+C(IC,J)
52 IF(SUM7-1.)51,51,53
53 DO 54 J=1,10
S(J)=.210
IF(C(IC,J))54,54,55
55 S(J) = PRDRNG(J) - RADRNG(IC)
54 CONTINUE
J=1
JZ = J +1
NC=1
S(NC)=101,0
DO 56 JB = JZ,10
IF(S(J)-S(JB))56,56,57
57 IF(S(NC)-S(JB))56,56,58
58 NC=JB
56 CONTINUE
DO 59 J=1,10
C(IC,J)=0
C(IC,NC) = 1
51 CONTINUE
PRINT 63
63 FORMAT(/10X,24H CORRELATION MATRIX)

```

```

PRINT 60+(IC(IC,J),J=1,10)-IC-1,10)
60 FORMAT(/10X,10F10.3)
ENC
SUBROUTINE TARGEN
DIMENSION
11 TITLE(12),HD(10),VEL(10),ALT(10),PITCH(10),XT(10),PD(10),
22 T(10),AZT(10),C(10,10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3 ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4 PRDRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XRAD(10),YRAD(10),ZRAD(10),
5 XRAD1(200),YRAD1(200),INDEX(10),INDE(10),CONT(10),IAT(10),PXPRAD
6(10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),AZG(10),ELG(10),NR(10),HDFIX(
710),PITFIX(10),VELFIX(10),RG(10),AZG(10),AZZ(10),RI(20),R2(20),
8R3(20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
COMMON
RANGE,TARGRNG,PD,IR,RANDOM,NUNIF,DEV,
1 RANERR, RADRNG,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
2 AZT, ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TESTT,AZRAD1,
3 RADRNG1,ELRAD1, AZRAD, C,S,DOIT,ZI,PAZRAD,ELBEAMT
4 FLAG, NUMTRK, NUM1, NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
5, XRAD,YRAD,ZRAD,CONT,PRDRNG,PELRAD,XT1,YT1,XRAD1,YRAD1,INDEX,IN
6 DE,IAT,PXPRAD,PYRAD,PZRAD,DOTX,DOTZ,DOIT,NR,HDFIX,PITFIX,VELFIX
7, ALPHA, BETA, RG, AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
8,XS,XP,P,KC
DO 1 K=1,NT
14 IF(HD(K)-360.0) 24,24,23
23 HD(K)=HD(K)-360.0
24 THETA=(360.0-HD(K)+90.0)/RADDEG
16 PITCH1=PITCH(K)/57.2957795131
DELTA=(VEL(K)*T)/3600.
XT(K) )=XT(K) )+(COSF(THETA))#DELTA
YT(K) )=YT(K) )+(SINF(THETA))#DELTA
ZT(K) )=ZT(K) )+(SINF(PITCH1)) # DELTA
AZ1= ATANF( YT(K) )/XT(K) ) # 57.2957795131
IF(XT(K)) 11,7,7
7 AZT(K) ) = 90.-AZ1
60 TO 8

```

```

11 ACT(K) = 270.0 - AZ1
3 TARGNG(K) = SORTF(XTK) )**2 + (YTK) )**2 +
  1/21(K) )**2)
  ELT(K) = ATANF(ZTK) )/SORTF(XTK) )**2
  1 +1Y(X) )**2) ) *RADDEG
  ALT(K) = 6076.1 * ZT(K)
1 CONTINUE
RETURN
END
SUBROUTINE SETUP
  DIMENSION RANGE(10), TARGNG( 10 ), PD(10),
  1 JTTLE(12), HD(10), VEL(10), ALI(10), PITCH(10), XT( 10 ), YI( 10 ),
  2 ZT(10), AZI(10), C(10,10), S(10), ELT(10), XRAD(10), YRAD(10), ZRAD(10),
  3 ELRAD(10), AZRAD(10), BOXMIN(10), BOXMAX(10), ELTEST(10), IAZ(10),
  4 PRADRNG(10), PELRAD(10), PAZRAD(10), RADRNG(10), XTI(200), YTI(200),
  5 XRAD1(200), YRAD1(10), INDEX(10), INDE(10), CONT(10), IAT(10), PXRAD
  6 (10), PYRAD(10), PZRAD(10), DOTX(10), DOTZ(10), DOTY(10), NR(10), HDFIX(
  7 (10), FITFIX(10), VELFIX(10), RG(10), AZG(10), ELG(10), RI(20), RZ(20),
  8 R3(20), R4(20), AZ1(20), AZ2(20), AZ3(20), AZ4(20)
  DIMENSION WPM(6,6), XI(6,6), VNI(6,6), Z(6,6), PHT(6,6),
  1 PHIT(6,6), P1(6,6), H(6,6), HT(6,6), PHI(6,6), R(6,6), Q(6,6), P(6,6),
  2 XS(6,6), XP(6,6), XPI(6,6), YI(6,6), YPI(6,6), Z(6,6), G(6,6), PHI1(6,6)
  3, PHI2(6,6)
  DIMENSION RDOT(10), AZDOT(10), ELDOT(10),
  1 INC(10), PK1(6,6), PK2(6,6), PK3(6,6), PK4(6,6), PK5(6,6), PK6(6,6),
  2 PK7(6,6), PK8(6,6), PK9(6,6)
  COMMON RANGE, TARGNG, PDET, PD, IR, RANDOM, NUMIF, EV,
  1 RANER, RADRNG, HD, VEL, ALI, PITCH, XI, YI, NI, JA, TI, I, TEST,
  2 AZI, ELI, IAZ, BOXMAX, BOXMIN, ELTEST, TESTI, AZRAD1,
  3 RADRNG1, ELRAD1, AZRAD, C, S, DOIT, ZI, PAZRAD, ELBEAMT
  4 FLAG, NUMIRK, NUMI, NUM2, NUM3, AZBEAMI, RADDEG, ELRAD
  5 XRAD, YRAD, ZRAD, CONT, PRAVRNG, PELRAD, XI1, YI1, XRAD1, YRAD1, INDEX, IN
  6 DE, IAT, PXRAD, PYRAD, PZRAD, DOTX, DOTZ, DOTY, NR, HDFIX, FITFIX, VELFIX
  7 ALPHA, BETA, RG, AZG, ELG, RI, R2, R3, R4, AZ1, AZ2, AZ3, AZ4
  8 XS, XP, P, KC
  IF(1-1) 425, 425, 61

```

```

425 DO 104 J=1,10
104 KC(J)= 0
DO 488 L=1,6
80 488 M=1,6
PK1(L,M)=P(L,M)
PK2(L,M)=P(L,M)
PK4(L,M)=P(L,M)
PK5(L,M)=P(L,M)
PK6(L,M)=P(L,M)
PK7(L,M)=P(L,M)
PK8(L,M)=P(L,M)
PK9(L,M)=P(L,M)
488 PK3(L,M)=R(L,M)
61 DO 777 L=1,NUMTRK
23 NUM2 = I
DO 21 IC= 1,10
IF(C(IC,L)) 21,21,22
21 CONTINUE
XP(1,1)= PRAORNG(L)
XP(2,1)= RDOT(L)
XP(3,1)= PAZRAD(L)
XP(4,1)= AZDOT(L)
XP(5,1)= PELRAD(L)
XP(6,1)= ELDOI(L)
DO 296 M=1,6
80 296 N=1,6
296 P(M,N)=0.0
P(1,1)=0.09
P(2,2)= 0.0278
P(3,3)= 2.0
P(4,4)=0.25
P(5,5)=0.25
P(6,6)= 0.00109
Z(1,1)= PRADRNG(L)
Z(2,1)= PAZRAD(L)
Z(3,1)= PELRAD(L)

```

```

583 DO 22 LT=L
      GO TO 267
264 IF (KC(LT)), 264,264,265
      XP(1,1)= RADRNG(IC)
      XP(2,1)= - 0.166
      XP(3,1)= AZRAD(IC)
      XP(4,1)= 0.0
      XP(5,1)= ELRAD(IC)
      XP(6,1)= 0.0
      DO 266 M=1,6
      DO 266 N=1,6
266 P(M,N)=0.0
      P(1,1)=0.09
      P(2,2)= 0.0278
      P(3,3)= 2.0
      P(4,4)=0.25
      P(5,5)=0.25
      P(6,6)= 0.00109
      Z(1,1)=FRADRNG(IC)
      Z(2,1)= AZRAD(IC)
      Z(3,1)= ELRAD(IC)
      KC(LT)= LT
      GO TO 267
265 XP(1,1)= PRADRNG(L)
      XP(2,1)= ROOT(L)
      MP(3,1)= PAZRAD(L)
      XP(4,1)= AZDOT(L)
      MP(5,1)= PELRAD(L)
      MP(6,1)= ELDOT(L)
      Z(1,1)= RADRNG(IC)
      Z(2,1)= AZRAD(IC)
      Z(3,1)= ELRAD(IC)
      IF(L=2) 268,269,270
268 DO 271 J=1,6
      DO 271 JJ=1,6
271 P(J,J)=PK1(J,J)

```

269 60 TO 267
 90 272 J=1,6
 90 272 JJ=1,6
 272 P(J, JJ)= PK2(J, JJ)
 90 TO 267
 270 IF(L-3) 288, 288, 289
 288 DO 273 J=1,6
 DO 273 JJ=1,6
 273 P(J, JJ)= PK3(J, JJ)
 GO TO 267
 289 IF(L-5) 274, 275, 276
 274 DO 277 J=1,6
 DO 277 JJ=1,6
 277 P(J, JJ)= PK4(J, JJ)
 GO TO 267
 275 DO 278 J=1,6
 DO 278 JJ=1,6
 278 P(J, JJ)= PK5(J, JJ)
 GO TO 267
 276 IF(L-6) 290, 290, 291
 290 DO 279 J=1,6
 DO 279 JJ=1,6
 279 P(J, JJ)= PK6(J, JJ)
 GO TO 267
 291 IF(L-8) 280, 281, 282
 280 DO 283 J=1,6
 DO 283 JJ=1,6
 283 P(J, JJ)= PK7(J, JJ)
 GO TO 267
 281 DO 284 J=1,6
 DO 284 JJ=1,6
 284 P(J, JJ)= PK8(J, JJ)
 GO TO 267
 282 DO 285 J=1,6
 DO 285 JJ=1,6
 285 P(J, JJ)= PK9(J, JJ)

```

267 CALL KALFIL(T,Z,XS,XP,P,NUM1,NUM2)
IF(C(IC,L)) 263,263,400
400 RADRNG(IC)= XS(1,1)
AZRAD(IC)= XS(3,1)
ELRAD(IC)= XS(5,1)
RDOT(L)= XP(2,1)
AZDOT(L)= XP(4,1)
ELDOT(L)= XP(6,1)
PRDRNG(L)=XP(1,1)
PAZRAD(L)= XP(3,1)
PELRAD(L)=XP(5,1)
RG(L)= 2.0 * SORTF(P(1,1))
AZG(L)= 1.0 * SORTF(P(3,3))
ELG(L)= 2.5 * SORTF(P(5,5))
IF(L-2) 401,402,403
401 DO 404 J=1,6
DO 404 JJ=1,6
404 PK1(J,JJ)= P(J,JJ)
GO TO 777
402 DO 405 J=1,6
DO 405 JJ=1,6
405 PK2(J,JJ)=P(J,JJ)
GO TO 777
403 IF(L-4) 406,407,408
406 DO 409 J=1,6
DO 409 JJ=1,6
409 PK3(J,JJ)=P(J,JJ)
GO TO 777
407 DO 410 J=1,6
DO 410 JJ=1,6
410 PK4(J,JJ)=P(J,JJ)
GO TO 777
408 IF(L-6) 411,412,413
411 DO 414 J=1,6
DO 414 JJ=1,6
414 PK5(J,JJ)= P(J,JJ)

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800

```

GO TO 777
412 DO 415 J=1,6
    DO 415 JJ=1,6
415 PK6(J,JJ)=P(J,JJ)
GO TO 777
413 IF(L-8) 416,417,418
426 DO 419 J=1,6
    DO 419 JJ=1,6
419 PK7(J,JJ)=P(J,JJ)
GO TO 777
417 DO 420 J=1,6
    DO 420 JJ=1,6
420 PK8(J,JJ)=P(J,JJ)
GO TO 777
418 DO 421 J=1,6
    DO 421 JJ=1,6
421 PK9(J,JJ)=P(J,JJ)
777 CONTINUE
END
SUBROUTINE TWS
DIMENSION
11 TITLE(12),HD(10),VEL(10),ALT(10),PITCH(10),XT( 10 ),YT( 10 ),
22 T(10),AZT(10),C(10,10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
3 ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
4 PRADRN(10),PELRAD(10),PAZRAD(10),RADRN(10),XTI(200),YTI(200),
5 XRADI(200),YRADI(200),INDEX(J),IMDE(10),CONT(10),IAT(10),PXRAD
6 (10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
7 10),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(20),R2(20),
8 R3(20),R4(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
9 ,YT2(30),XRAD2(30),YRAD2(3 )
DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
COMMON
1 RANGE, T,DRNG,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
2 AZT, ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TESTT,AZRADI,
3 RADRN(1),ELRADI, AZRAD ,C,S,DOTT,ZT,PAZRAD,ELBEAMT
RANGE(10),TARGRN( 10 ),PD(10),

```



```

IF(LIML) 2,4,4
2 LIML=360+LIML
4 LMR=IAZREF +44
5 LIMR=LIMR-360 6,6,5
6 LIMB=1
LIMY=29
ITEL1=LIMB
ITEMP1 = LIML
28 NUMB=NUMB+1
IF( NUMB - 30 ) 43,43,44
43 PRINT 111, NUMB
111 FORMAT(/,10X,7HNUMB = ,12)
IF(I-2)160,158,158
158 DO 150 J= 1,NUMTRK
TOTAL = 0.0
DO 151 IC = 1,10
151 TOTAL =TOTAL+ C(IC,J)
IF(TOTAL) 152,152,150
152 IF(INDEX(J)) 156,156,153
153 IF(I-INDEX(J) +1) 156,154,156
156 INDEX(J) = I
INDE(J) = I
GO TO 150
154 DO 155 JB=J,NUMTRK
DO 157 IC= 1,10
C(IC,JB )= C(IC,JB+1)
PRADRNG(JB)=PRADRNG(JB+1)
PAZRAD(JB)=PAZRAD(JB+1)
INDEX(JB)=INDEX(JB+1)
INDE(JB)=INDE(JB+1)
157 PELRAD(JB)=PELRAD(JB+1)
155 CONTINUE
PRINT 121,J
121 FORMAT(/,10X,11HDROP TRACK ,12)
NUMTRK =NUMTRK -1

```

```

150 CONTINUE
160 DO 19 J=1,NT
170 PRINT 61,J,NR(J)
180 FORMAT(/,10X,2HJ=,12,6HNR(J)=,I2 )
190 IF (NR(J)) 19,19,23
200 ITEL=ELRAD(NR(J))
210 ITEMP=AZRAD(NR(J))
220 IF (ITEL) 75,70,75
230 IF (ITEMP) 75,70,75
240 IF (ITEL) 75,70,75
250 IF (ITEMP) 75,70,75
260 IF (ITEL) 75,70,75
270 IF (ITEMP) 75,70,75
280 IF (ITEL) 75,70,75
290 IF (ITEMP) 75,70,75
300 IF (ITEL) 75,70,75
310 IF (ITEMP) 75,70,75
320 IF (ITEL) 75,70,75
330 IF (ITEMP) 75,70,75
340 IF (ITEL) 75,70,75
350 IF (ITEMP) 75,70,75
360 IF (ITEL) 75,70,75
370 IF (ITEMP) 75,70,75
380 IF (ITEL) 75,70,75
390 IF (ITEMP) 75,70,75
400 IF (ITEL) 75,70,75
410 IF (ITEMP) 75,70,75
420 IF (ITEL) 75,70,75
430 IF (ITEMP) 75,70,75
440 IF (ITEL) 75,70,75
450 IF (ITEMP) 75,70,75
460 IF (ITEL) 75,70,75
470 IF (ITEMP) 75,70,75
480 IF (ITEL) 75,70,75
490 IF (ITEMP) 75,70,75
500 IF (ITEL) 75,70,75
510 IF (ITEMP) 75,70,75
520 IF (ITEL) 75,70,75
530 IF (ITEMP) 75,70,75
540 IF (ITEL) 75,70,75
550 IF (ITEMP) 75,70,75
560 IF (ITEL) 75,70,75
570 IF (ITEMP) 75,70,75
580 IF (ITEL) 75,70,75
590 IF (ITEMP) 75,70,75
600 IF (ITEL) 75,70,75
610 IF (ITEMP) 75,70,75
620 IF (ITEL) 75,70,75
630 IF (ITEMP) 75,70,75
640 IF (ITEL) 75,70,75
650 IF (ITEMP) 75,70,75
660 IF (ITEL) 75,70,75
670 IF (ITEMP) 75,70,75
680 IF (ITEL) 75,70,75
690 IF (ITEMP) 75,70,75
700 IF (ITEL) 75,70,75
710 IF (ITEMP) 75,70,75
720 IF (ITEL) 75,70,75
730 IF (ITEMP) 75,70,75
740 IF (ITEL) 75,70,75
750 IF (ITEMP) 75,70,75
760 IF (ITEL) 75,70,75
770 IF (ITEMP) 75,70,75
780 IF (ITEL) 75,70,75
790 IF (ITEMP) 75,70,75
800 IF (ITEL) 75,70,75
810 IF (ITEMP) 75,70,75
820 IF (ITEL) 75,70,75
830 IF (ITEMP) 75,70,75
840 IF (ITEL) 75,70,75
850 IF (ITEMP) 75,70,75
860 IF (ITEL) 75,70,75
870 IF (ITEMP) 75,70,75
880 IF (ITEL) 75,70,75
890 IF (ITEMP) 75,70,75
900 IF (ITEL) 75,70,75
910 IF (ITEMP) 75,70,75
920 IF (ITEL) 75,70,75
930 IF (ITEMP) 75,70,75
940 IF (ITEL) 75,70,75
950 IF (ITEMP) 75,70,75
960 IF (ITEL) 75,70,75
970 IF (ITEMP) 75,70,75
980 IF (ITEL) 75,70,75
990 IF (ITEMP) 75,70,75

```

```

CALL DETECT
IF(RADRNG(K)) 18,18,33
33 CALL RNDEV ( NUNIF ,DEV)
  AZRAD(K)=AZT(K)+DEV*0.05
  CALL RNDEV(NUNIF,DEV)
  ELRAD(K)=ELT(K)+ DEV*0.05
  PRINT 20,K,RADRNG(K),AZRAD(K),ELRAD(K)
20 FORMAT(/,10X,7HTARGET , 12,5X, 9HRADRNG = ,F10.4,5X,8HAZRAD = ,
  IF10.4, 5X, 8HELRAD = , F10.4)
  PRINT 50
50 FORMAT(/,10X, 35HCALLING CORRASS AFTER STATEMENT 20 )
  CALL CORRASS
18 CONTINUE
19 CONTINUE
C
C THIS SECTION SCANS THE SECTOR ASTIME REMAINING PERMITS.
C IT IS DIVIDED INTO 0.5 SECONDS OF KNOWN TARGETS PLUS SCAN
C AND 0.5SECONDS OF SCAN
C
  FLAG3= 0.0
  INC= 100 -(NUMTAR *5)
102 IF( FLAG3 -1.0) 100,101,101
101 INC=(200 - NUMTAR *5)- INC
100 PRINT 81, INC
81 FORMAT(/,10X,6HINC = , I4)
  DO 80 J=1,INC
  TEL=IYELI
  TEMP=ITEMP1
37 DO 26 K=1,NT
25 IF(ABSF(TEL - ELT(K))-1.0) 25,25,26
45 NUM3=K
  CALL DETECT
  IF(RADRNG(K)) 26,26,34
34 CALL RNDEV (NUNIF,DEV)
  AZRAD(K) = AZT(K) +DEV/100.

```

```

205 CALL RNDEV (NUMIF,DEV)
206 ELRAD(K) = ELT(K)+DEV/100.
207 PRINT 20,K,RADNRG(K),AZRAD(K),ELRAD(K)
208 CALL CORRASS
209 IF( NR(K)) 106,106,26
210 NUMTAR = NUMTAR +1
211 NR(K)=K
212 CONTINUE
213 ITEMP1=ITEMP1+2
214 IF(ITEMP1-360) 91,91,90
215 ITEMP1=1
216 IF( LIMR -90)82,83,83
217 IF(ITEMP1 +90)-360) 83,80,80
218 TEMP=ITEMP1
219 ITEMP = TEMP
220 IF( LIMR-ITEMP) 84,80,80
221 ITEMP1=LIML
222 ITEL1=ITEMP1+2
223 IF( ITEL1- 29) 80,80,85
224 ITEL1=1
225 CONTINUE
226 CALL TARGEN
227 CALL ASSOC
228 CALL SETUP
229 DO 56 K=1,NT
230 XRAD(K) =(RADNRG(K) *COSF( ELRAD(K) /57.29577)) *
231 16INF(AZRAD(K) / 57.29577)
232 YRAD(K) =(RADNRG(K) *COSF(ELRAD(K) /57.29577)) *
233 16OSF(AZRAD(K) / 57.29577)
234 LL = NUMB
235 IF(K-1)200,200,201
236 XT(ILL)= XT(K)
237 YT(ILL)= YT(K)
238 CC= .0
239 DO 51 J=1,10
240 CC=CC+C(K,J)

```

```

53 IF(CC) 54,55,53
53 XRAD1(LL)=XRAD(K)
   YRAD1(LL)=YRAD(K)
54 GO TO 56
54 ARAD1(LL)=0.0
   YRAD1(LL)=0.0
55 GO TO 56
201 XT2(LL)= XT(K)
   YT2(LL)= YT(K)
558 CC= 0
559 J=1,10
551 CC=CC+C(K,J)
   IF(CC) 554,554,552
552 XRAD2(LL)=XRAD(K)
   YRAD2(LL)= YRAD(K)
56 GO TO 56
554 XRAD3(LL)= 0.0
   YRAD3(LL)= 0.0
56 CONTINUE
301 IF(LL - IXX) 301,300,301
   FLAG3=FLAG3+1.0
   FLAG3= FLAG3+1.0
   IF(FLAG3 -2.0) 102,26,28
300 CALL DRAW(LL,XT1,YT1,1.0,LABEL,ITITLE, 1, 1.0,0.0,2,2,5, 8,0,LAST)
   CALL DRAW(LL,XT2,YT2,2.0,LABEL,ITITLE, 1, 1.0,0.0,2,2,5, 8,0,LAST)
   CALL DRAW(LL,XRAD2,YRAD2,2,3,LABEL,ITITLE, 1,1.0,0.3,2,2,6,10,0,
   :LAST)
   CALL DRAW(LL,XRAD1,YRAD1,3,1,LABEL,ITITLE, 3,3.0,0.3,2,2,6,10,0,
   :LAST)
   IXX = 21
   IF( NUMB - 21) 302,44,44
302 NUMB= 0
44 GO TO 301
44 RETURN
END
SUBROUTINE KALFILT(Z,XS,XP,P,NUM1,NUM2)

```

```

C VFF 58(6,6),Z(6,6),X(6,6),VNI(6,6),Z(6,6),PHI(6,6),
C VFF DIMENSION PHIT(6,6),X(6,6),VNI(6,6),Z(6,6),PHI(6,6),
C VFF PHIT(6,6),PI(6,6),H(6,6),HT(6,6),PHI(6,6),R(6,6),Q(6,6),P(6,6),
C VFF 2XS(6,6),XP(6,6),T1(6,6),T2(6,6),Q8(6,6),Q8(6,6),PHI1(6,6),
C VFF 3*PHI8(6,6),
C VFF 3*PHI8(6,6),
C THE FIRST SECTION OF KALFILT SETS UP THE INITIAL MATRICES REQUIRED
C IN THE RECURSION EQUATIONS
C SECTION ONE IS EXECUTED IF NUM1=0
C NUM3 = K OR TARGET NUMBER
C VFF NUM2 = T I.E. 1 OR  $\beta$  ACTS AS A FLAG TO PICK THE CORRESPONDING Q
C EQUATION AND PHI MATRIX
C 58(6,6),Z(6,6),X(6,6),VNI(6,6),Z(6,6),PHI(6,6),
C 61 PRINT 1
C 1 FORMAT(//,40X,26H OBSERVABILITY OR H MATRIX )
C 1 CALL READD(3,6,H)
C 2 PRINT 2
C 2 CALL TRANS(3,6,HT)
C 3 DO 3 I=1,6
C 3 PRINT 4,HT(I,J),J=1,3)
C 4 FORMAT(//,3F13,5)
C 5 PRINT 5
C 5 FORMAT(//,20X,43HCOVARIANCE OF MEASUREMENT NOISE OR R MATRIX )
C 5 CALL READD(3,3,R)
C 6 PRINT 6
C 6 FORMAT(//,40X,28HSTATE TRANSION OR PHI MATRIX )
C 6 CALL READD(6,6,PHI1)
C 7 PRINT 7
C 7 CALL READD(6,6,PHI8)
C 7 FORMAT(//,20X,39HCOVARIANCE OF PERTURBATIONS OR Q MATRIX )
C 7 CALL READD(6,6,Q1)
C 8 PRINT 8
C 8 CALL READD(6,6,Q8)

```

```

60 IF (NUM2 - 1) 62,62,64
62 DO 63 L=1,6
63 DO 64 M=1,6
64 CALL PHIL(L,M)
65 DO 66 L=1,6
66 DO 67 M=1,6
67 CALL PHIL(L,M)
68 DO 69 L=1,6
69 DO 70 M=1,6
70 CALL PHIL(L,M)
71 DO 72 L=1,6
72 DO 73 M=1,6
73 CALL PHIL(L,M)
74 DO 75 L=1,6
75 DO 76 M=1,6
76 CALL PHIL(L,M)
77 DO 78 L=1,6
78 DO 79 M=1,6
79 CALL PHIL(L,M)
80 DO 81 L=1,6
81 DO 82 M=1,6
82 CALL PHIL(L,M)
83 DO 84 L=1,6
84 DO 85 M=1,6
85 CALL PHIL(L,M)
86 DO 87 L=1,6
87 DO 88 M=1,6
88 CALL PHIL(L,M)
89 DO 90 L=1,6
90 DO 91 M=1,6
91 CALL PHIL(L,M)
92 DO 93 L=1,6
93 DO 94 M=1,6
94 CALL PHIL(L,M)
95 DO 96 L=1,6
96 DO 97 M=1,6
97 CALL PHIL(L,M)
98 DO 99 L=1,6
99 DO 100 M=1,6
100 CALL PHIL(L,M)
101 DO 102 L=1,6
102 DO 103 M=1,6
103 CALL PHIL(L,M)
104 DO 105 L=1,6
105 DO 106 M=1,6
106 CALL PHIL(L,M)
107 DO 108 L=1,6
108 DO 109 M=1,6
109 CALL PHIL(L,M)
110 DO 111 L=1,6
111 DO 112 M=1,6
112 CALL PHIL(L,M)
113 DO 114 L=1,6
114 DO 115 M=1,6
115 CALL PHIL(L,M)
116 DO 117 L=1,6
117 DO 118 M=1,6
118 CALL PHIL(L,M)
119 DO 120 L=1,6
120 DO 121 M=1,6
121 CALL PHIL(L,M)
122 DO 123 L=1,6
123 DO 124 M=1,6
124 CALL PHIL(L,M)
125 DO 126 L=1,6
126 DO 127 M=1,6
127 CALL PHIL(L,M)
128 DO 129 L=1,6
129 DO 130 M=1,6
130 CALL PHIL(L,M)
131 DO 132 L=1,6
132 DO 133 M=1,6
133 CALL PHIL(L,M)
134 DO 135 L=1,6
135 DO 136 M=1,6
136 CALL PHIL(L,M)
137 DO 138 L=1,6
138 DO 139 M=1,6
139 CALL PHIL(L,M)
140 DO 141 L=1,6
141 DO 142 M=1,6
142 CALL PHIL(L,M)
143 DO 144 L=1,6
144 DO 145 M=1,6
145 CALL PHIL(L,M)
146 DO 147 L=1,6
147 DO 148 M=1,6
148 CALL PHIL(L,M)
149 DO 150 L=1,6
150 DO 151 M=1,6
151 CALL PHIL(L,M)
152 DO 153 L=1,6
153 DO 154 M=1,6
154 CALL PHIL(L,M)
155 DO 156 L=1,6
156 DO 157 M=1,6
157 CALL PHIL(L,M)
158 DO 159 L=1,6
159 DO 160 M=1,6
160 CALL PHIL(L,M)
161 DO 162 L=1,6
162 DO 163 M=1,6
163 CALL PHIL(L,M)
164 DO 165 L=1,6
165 DO 166 M=1,6
166 CALL PHIL(L,M)
167 DO 168 L=1,6
168 DO 169 M=1,6
169 CALL PHIL(L,M)
170 DO 171 L=1,6
171 DO 172 M=1,6
172 CALL PHIL(L,M)
173 DO 174 L=1,6
174 DO 175 M=1,6
175 CALL PHIL(L,M)
176 DO 177 L=1,6
177 DO 178 M=1,6
178 CALL PHIL(L,M)
179 DO 180 L=1,6
180 DO 181 M=1,6
181 CALL PHIL(L,M)
182 DO 183 L=1,6
183 DO 184 M=1,6
184 CALL PHIL(L,M)
185 DO 186 L=1,6
186 DO 187 M=1,6
187 CALL PHIL(L,M)
188 DO 189 L=1,6
189 DO 190 M=1,6
190 CALL PHIL(L,M)
191 DO 192 L=1,6
192 DO 193 M=1,6
193 CALL PHIL(L,M)
194 DO 195 L=1,6
195 DO 196 M=1,6
196 CALL PHIL(L,M)
197 DO 198 L=1,6
198 DO 199 M=1,6
199 CALL PHIL(L,M)
200 DO 201 L=1,6
201 DO 202 M=1,6
202 CALL PHIL(L,M)
203 DO 204 L=1,6
204 DO 205 M=1,6
205 CALL PHIL(L,M)
206 DO 207 L=1,6
207 DO 208 M=1,6
208 CALL PHIL(L,M)
209 DO 210 L=1,6
210 DO 211 M=1,6
211 CALL PHIL(L,M)
212 DO 213 L=1,6
213 DO 214 M=1,6
214 CALL PHIL(L,M)
215 DO 216 L=1,6
216 DO 217 M=1,6
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973 CALL PHIL(L,M)
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975 DO 976 M=1,6
976 CALL PHIL(L,M)
977 DO 978 L=1,6
978 DO 979 M=1,6
979 CALL PHIL(L,M)
980 DO 981 L=1,6
981 DO 982 M=1,6
982 CALL PHIL(L,M)
983 DO 984 L=1,6
984 DO 985 M=1,6
985 CALL PHIL(L,M)
986 DO 987 L=1,6
987 DO 988 M=1,6
988 CALL PHIL(L,M)
989 DO 990 L=1,6
990 DO 991 M=1,6
991 CALL PHIL(L,M)
992 DO 993 L=1,6
993 DO 994 M=1,6
994 CALL PHIL(L,M)
995 DO 996 L=1,6
996 DO 997 M=1,6
997 CALL PHIL(L,M)
998 DO 999 L=1,6
999 DO 1000 M=1,6
1000 CALL PHIL(L,M)
1001 DO 1002 L=1,6
1002 DO 1003 M=1,6
1003 CALL PHIL(L,M)
1004 DO 1005 L=1,6
1005 DO 1006 M=1,6
1006 CALL PHIL(L,M)
1007 DO 1008 L=1,6
1008 DO 1009 M=1,6
1009 CALL PHIL(L,M)
1010 DO 1011 L=1,6
1011 DO 1012 M=1,6
1012 CALL PHIL(L,M)
1013 DO 1014 L=1,6
1014 DO 1015 M=1,6
1015 CALL PHIL(L,M)
1016 DO 1017 L=1,6
1017 DO 1018 M=1,6
1018 CALL PHIL(L,M)
1019 DO 1020 L=1,6
1020 DO 1021 M=1,6
1021 CALL PHIL(L,M)
1022 DO 1023 L=1,6
1023 DO 1024 M=1,6
1024 CALL PHIL(L,M)
1025 DO 1026 L=1,6
1026 DO 1027 M=1,6
1027 CALL PHIL(L,M)
1028 DO 1029 L=1,6
1029 DO 1030 M=1,6
1030 CALL PHIL(L,M)
1031 DO 1032 L=1,6
1032 DO 1033 M=1,6
1033 CALL PHIL(L,M)
1034 DO 1035 L=1,6
1035 DO 
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100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

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CALL PROD(P,PHIT,6,6,6,6,P1)
DO 30 I=1,6
DO 30 J=1,6
30 T(I,J) = 0.0
CALL PROD(PHI,P1,6,6,6,6,T1)
CALL ADD (T1,Q,6,6,6,P)
PRINT 103
103 FORMAT(/,20X,6HPN/N-1)
65 CALL PRINT(6,6,P)
65 RETURN
END
SUBROUTINE READD (M,N,XX)
DIMENSION XX(6,6)
DO 1 I=1,M
READ 2 ,(XX(I,J), J=1,N)
2 FORMAT( 6F13,5)
1 PRINT 2,(XX(I,J), J=1,N )
END
SUBROUTINE PRINT (M,N,XX)
DIMENSION XX(6,6)
DO 1 I=1,M
1 PRINT 2,(XX(I,J), J=1,N )
2 FORMAT( /, 6F13,5)
END
SUBROUTINE TRANS(A,N,M,D)
DIMENSION A(6,6),D(6,6)
DO 153 I=1,N
DO 153 J=1,M
153 B(J,I)=A(I,J)
END
SUBROUTINE PROD:A,B,N,M,L,D)
DIMENSION A(6,6),B(6,6),D(6,6)
DO 151 I=1,N
DO 151 J=1,L
B(I,J)=0.0
DO 151 K=1,M

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151 D(I,J)=D(I,J)+A(I,K)*B(K,J)
END
SUBROUTINE ADD(A,B,N,M,D)
DIMENSION A(6,6),B(6,6),D(6,6)
DO 152 I=1,N
DO 152 J=1,M
152 D(I,J)=A(I,J)+B(I,J)
END
SUBROUTINE RECIP(N,EP,B,X,KER)
DIMENSION A(6,6),B(6,6),X(6,6)
DO 1 I=1,N
DO 1 J=1,N
11 A(I,J)=B(I,J)
12 Z=0.0
13 DO 14 K=1,N
14 Z=ABS(A(K,L))
15 X(KP,J)=Z
16 IF(L-KP)13,20,20
17 DO 18 L=1,N
18 A(L,J)=A(KP,J)
19 Z=X(L,J)
20 IF(ABS(A(L,L))-EP)50,50,30
30 IF(L=N)31,34,34
31 LPI=L+1

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00 36 K=L*P1,N
IF(A(K,L))32,36,32
32 RATIO=A(K,L)/A(L,L)
DO 33 J=L*P1,N
33 A(K,J)=A(K,J)-RATIO*A(L,J)
DO 35 J=1,N
35 X(K,J)=X(K,J)-RATIO*X(L,J)
36 CONTINUE
34 CONTINUE
40 DO 43 I=1,N
II=N+1-I
DO 43 J=1,N
S=0.0
IF(II-NI+1,43,43
41 IIP1=II+1
DO 42 K=IIP1,N
42 S=S+A(II,K)*X(K,J)
43 K(II,J)=(X(II,J)-S)/A(II,II)
K(II,J)
RETURN
50 KER=2
RETURN
END
END

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101 PROGRAM KALMON1
102 DIMENSION
103   RANGE(10),TARGRNG( 10 ),PD(10),
104   IITITLE(12),HDI(10),VEL(10),ALT(10),PITCH(10),XT( 10 ),YT( 10 ),
105   ZT(10),AZT(10),CT(10),S(10),ELT(10),XRAD(10),YRAD(10),ZRAD(10),
106   3ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZ(10),
107   4PRDRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XT1(100),YT1(100),
108   5XRAD1(100),YRAD1(100),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
109   6(10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
110   7(10),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(40),R2(40),
111   8R3(40),R4(40),AZ1(40),AZ2(40),AZ3(40),AZ4(40),VMAG1(40),VMAG2(40),
112   9VMAG3(40),VMAG4(40),VPHI1(40),VPHI2(40),VPHI3(40),VPHI4(40)
113
114 DIMENSION A(6,6),B(6,6),D(6,6),X(6,6),
115   1PHIT(6,6),PI(6,6),H(6,6),HT(6,6),PHI(6,6),R(6,6),Q(6,6),P(6,6),
116   2 XS(6,6),XP(6,6),XX(6,6),VNI(6,6),Z(6,6),PHT(6,6),HPHT(6,6),XPI(
117   3 6,6),T1(6,6),T2(6,6)
118 COMMON
119   1 KANERR, RADRNG,HD,VEL,AL1,PITC,XT,YT,NT,JA,T,I,TEST,
120   2 AZI, ELI, IAZ, BOXMAX,BOXMIN,ELTEST,TEST,T,AZRAD1,
121   3RADRNG1,ELRAD1, AZRAD ,C,S,DOIT,ZI,PAZRAD,ELBEAMT
122   4,FLAG, NUMTRK, NUM1 ,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
123   5, XRAD,YRAD,ZRAD,CONT,PRDRNG,PELRAD,XT1,YT1,XRAD1,YRAD1,INDEX,IN
124   6 DE,IAT,PXRAD,PYRAD,PZRAD,DOTX,DOTZ,DOTY,NR,HDFIX,PITFIX,VELFIX
125   7 ,ALPHA ,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4,VMAG1,VMAG2,
126   8VMAG3,VMAG4,VPHI1,VPHI2,VPHI3,VPHI4
127
128 100 FORMAT(4 F10.4)
129 101 FORMAT(7,3X,11H HEADING = ,F10.4, 7HDEGREES, 3X,10HVELOCITY =,
130   1F10.4, 8HNS-M./HR,3X,11HALTITUDE = ,F10.4, 4HFEET,3X, 7HPITCH =,
131   2F10.4, 7HDEGREES )
132 102 FORMAT( 2F10.4)

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C
C
C TEST RUN FOR MONTE CARLO AVERAGES
C THIS PROGRAM TESTS THE KALMAN FILTER FOR AN OBSERVATION TIME OF T=1.0
C VMAG2(L) = ENSEMBLE AVERAGE OF RADIFF
C VPHI2(L) = ENSEMBLE AVERAGE OF AZDIFF
C AZ2 (L) = ENSEMBLE AVERAGE OF ELDIFF

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C NB = THE NUMBER OF RUNS
C NB1 = NUMBER OF DISCRETE TIMES
NB=100
NB1=20
I=1.0
NT =1

C
C
ITITLE(1)=8HHD160/V
ITITLE(2)=8HEL600 /
ITITLE(3)=8HALT500/
ITITLE(4)=8HLEV/RT3
ITITLE(5)=8HD/5/T=1
ITITLE(6)=8H
ITITLE(7)=8H
ITITLE(8)=8H
ITITLE(9)=8HJOB0194
ITITLE(10)=8HDELANEY
ITITLE(11)=8H W. F.
ITITLE(12)=8HKALMOMI
RADDEG= 57.2957795131
NUMIF = 12207003125.
90 714 K=1,NT
READ 10C, HD(K), VEL(K), ALT(K), PITCH(K)
ZT(K)= ALT(K)/ 6076.1
714 REF? 102, XT(K),YT(K)
HEAD=HD(1)
VELOC= VEL(1)
ALTT= ALT(1)
PIT= PITCH(1)
ZTT= ZT(1)
XPOS= XT(1)
YPOS= YT(1)
NUM2=0
DO 604 JK=1,NB
HD(1)= HEAD

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017 VEL(1)= VELOC
018 ALT(1)= ALTI
019 PITCH(1)= PIT
      ZT(1)= ZIT
      XT(1)= XPOS
      YT(1)= YPOS
      CALL TARGEN
      721 DO 708 I=1,NBT
            K=1
            XRAD(1)= 1
            CALL RNDEV(NUNIF,DEV)
            RADERR=DEV*0.3
            RADRNG(K)= TARGRNG(K)+ RADERR
            CALL RNDEV(NUNIF,DEV)
            AZERR= DEV*0.5
            AZRAD(K)= AZT(K)+ AZERR
            CALL RNDEV(NUNIF,DEV)
            ELERR= DEV*0.5
            ELRAD(K)=ELT(K)+ELERR
            IF (ELRAD(K)) 300,301,301
            300 ELRAD(K)= 0.0
            301 NUMB=I
            CALL TARGEN
            K=1
            168 RADIFF=ABS(XP(1,1))-ABS(TARGRNG(K))
            AZDIFF= ABS(XP(3,1))-ABS(AZT(K))
            IF(AZDIFF-10.0) 165,165,166
            165 IF(10.0-AZDIFF) 166,265,265
            166 AZDIFF=ABS(360.0-AZDIFF)
            265 ELDIFF=ABS(XP(5,1))- ABS(ELT(K))
            R1(NUMB)=RADIFF**2
            R4(NUMB) = AZDIFF**2
            AZ4(NUMB)= ELDIFF**2
            C AZ2 REPRESENTS THE X COMPONENT OF SMOOTH POSITION.
            C AZ3 REPRESENTS THE Y COMPONENT OF SMOOTH POSITION.
            AZ2(NUMB)=(XS(1,1)*COSF(XS(5,1)/RADDEG))*SINF(XS(3,1)/RADDEG)

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VPHI2(L)= VPHI2(L) +R4(L)
AZ2(L)= AZ2(L) +AZ4(L)
806 CONTINUE
IF(JK-NB )815,814,815
814 80 810 L=1,N8Y
XRAD1(L)=L
VNB=NB
VMAG2(L)= VMAG2(L)/VNB
VPHI2(L)= VPHI2(L)/VNB
810 AZ2(L)=AZ2(L) /VNB
ITITLE(1)=RHWD160/V
ITITLE(2)=8HEL600 /
ITITLE(3)=8HALT500/
ITITLE(4)=8HLEV/RT3
ITITLE(5)=8HD/S/T=1
ITITLE(6)=8H
ITITLE(7)=8H
ITITLE(8)=8H
ITITLE(9)=8HJOB0194
ITITLE(10)=8HDELANEY
ITITLE(11)=8H W. F.
ITITLE(12)=8HKAL.MON1
LABEL=4HAVRD
CALL PLOT(NUMB,XRAD1,VMAG2,0,0,LABEL,ITITLE,3,0,1,0,0,2,2, 5,6,
1 0, LAST)
LABEL=4HAVAZ
CALL PLOT(NUMB,XRAD1,VPHI2,0,0,LABEL,ITITLE,3,0,2,0,0,2,2, 9,6,
1 0, LAST)
LABEL=4HAVEL
CALL PLOT(NUMB,XRAD1,AZ2 ,0,0,LABEL,ITITLE,3,0,1,0,0,2,2, 9,6,
1 0, LAST)
815 PRINT 667
667 FORMAT(/,30X, 5HVMAG2)
PRINT 668,(VMAG2(J), J=1,15)
668 FORMAT(/,1X,15F7.4)
PRINT 669

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669 FORMAT(/,30X,5HVPH12)
      PRINT 668,(VPH12(J),J=1,15)
      PRINT 670
670 FORMAT(/,30X,3HAZ2)
      PRINT 668,(AZ2(J),J=1,15)
      RETURN
      END
```

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SUBROUTINE ABFILT
DIMENSION S(10),VT(10),RANGE(10),TARGRNG(10),PD(10),
1,XTITLE(12),HD(10),VEL(10),ALT(10),PITCH(10),XT(10),
2,ZT(10),AZT(10),C(10,10),S(10),ELTI(10),XRAD(10),YRAC(10),ZRAD(10),
3,ELRAD(10),AZRAD(10),BOXMIN(10),BOXMAX(10),ELTEST(10),IAZI(10),
4,PRDRNG(10),PELRAD(10),PAZRAD(10),RADRNG(10),XTI(200),YTI(200),
5,XRAD1(200),YRAD1(200),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
6,(10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
7),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),RI(20),R2(20),
8,R3(20),RA(20),AZ1(20),AZ2(20),AZ3(20),AZ4(20)
COMMON RANGE,TARGRNG,PDET,PD,IR,RANDOM,NUMIF,DEV,
1,RANERR,RADRNG,HD,VEL,ALI,PITCH,XT,YI,NI,JA,I,I,TEST,
2,AZT,ELI,AZ,BOXMAX,BOXMIN,ELTEST,TEST,AZRAD1,
3,RADRNG1,ELRAD1,AZRAD,NUM1,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
4,FLAG,NUMIRK,NUM1,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
5,XRAD,YRAD,ZRAD,CONT,PRADRNG,PELRAD,XTI,YTI,XRAD1,YRAD1,INDEX,IN
6,DE,IAT,PXRAD,PYRAD,PZRAD,DOTX,DOTZ,DOTY,NR,HDFIX,PITFIX,VELFIX
7,ALPHA,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4
DO 20 L=1,NUMTRK
DO 21 IC=1,10
IF(C(IC,L)) 21,21,22
21 CONTINUE
N=10
XRAD(N)=PXRAD(L)
YRAD(N)=PYRAD(L)
ZRAD(N)=PZRAD(L)
GO TO 23
22 N=IC
XRAD(K)=(RADRNG(K))*COSF(ELRAD(K)/57.295777)*
1,SINF(AZRAD(K)/57.295777)
YRAD(K)=(RADRNG(K))*COSF(ELRAD(K)/57.295777)*
1,COSF(AZRAD(K)/57.295777)
ZRAD(K)=(RADRNG(K))*SINF(ELRAD(K)/57.295777)
23 DO 1 JJ=1,3
IF(JJ-1) 3,2,3

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2 OISE = XRADIN )
  PRED = PXRAD(L)
  DOTT = DOTX(L)
  GO TO 6
3 IF( JJ-2) 4,5,4
5 OISE=YRADIN)
  PRED = PYRAD(L)
  DOTT = DOTY(L)
  GO TO 6
4 OISE = ZRAD (N )
  PRED = PZRAD(L)
  DOTT = DOTZ(L)
6 SMOOTH = PRED + ALPHA * ( OISE - PRED)
  DOTT = DOTT + (BETA/T)* ( OISE-PRED)
  PRED = SMOOTH + I*DOTT
  IF( JJ-1) 8,7,8
7 PXRAD(L) = PRED
  XRAD(N ) = SMOOTH
  DOTX(L) = DOTT
  GO TO 1
8 IF( JJ-2) 9,96,9
96 PYRAD(L) = PRED
  YRAD(N ) = SMOOTH
  DOTY(L) = DOTT
  GO TO 1
9 PZRAD(L) = PRED
  ZRAD(N ) = SMOOTH
  DOTZ(L) = DOTT
1 CONTINUE
537 IF(ABSF(PXRAD(L))-0.001) 533,534,534
533 PXRAD(L) = 0.001
534 AZI = ATANF(PYRAD(L) / PXRAD(L) ) * RADDEG
530 PAZRAD(L) = 270.0 - AZI
  GO TO 532
531 PAZRAD(L) = 90.0 - AZI

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532 PELRAD(L ) = ATANF(PZRAD(IL )/SORTF((PARAD(L ))**2+
1(PYRAD(IL ))**2))*RADDEG
PRADRNG(L ) = SORTF((PXRAD(L ))**2 +(PYRAD(L ))**2+(PZRAD(L )
1 **2)
PRINT 201,PRADRNG(L ),PAZRAD (L ), PELRAD(L )
201 FORMAT(/,10X,10HPADRNG = ,F10.4,5X,9HPAZRAD = ,F10.4,5X,
1 9HPELRAD = ,F10.4)
20 CONTINUE
515 RETURN
END

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13. ABSTRACT

A model of a TWS radar is developed that provides a realistic computer simulation for comparing various radar tracking methods.

Prediction accuracy of a simplified alpha-beta tracker is compared to that of an adaptive filter. In addition, the effect on radar tracking of a variable gate size correlation technique is investigated.

DD FORM 1473

