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THESIS

SIMULATION OF A TRACK-WHILE-SCAN RADAR

by

William Frederick Delaney

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SIMULATION OF A TRACK-WHILE-SCAN RADAR

by

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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
June 1967

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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 ± 45° 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 T W S 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 = 600 n.m./hr.
(2) Attack profile shown in fig.
(3) Target weapon release point ≤ 10 n.m. max.
(4) Offensive weapon = missile (mach 3).
(5) Missile requires a high data rate for command guidance.
(6) Antenna height (h_a) = 50 ft.

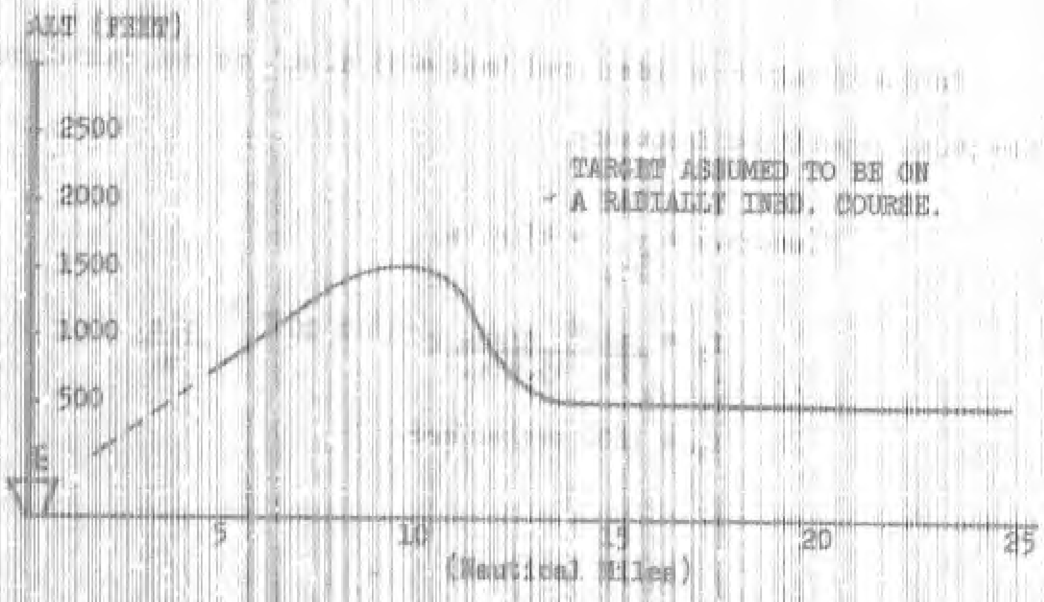


Fig. 1 ATTACK PROFILE

Desiring a 10 second sector scan in which to fire and control the defensive missle, 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.

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

h_t = height of target A/C.

given : h_a = 50 ft.

$r \cong 41$ miles $h_t = 500$ ft.

$r \cong 54$ miles $h_t = 1000$ ft.

Having obtained an idealized Rmax = 45 n. m., we can calculate the pulse repetition frequency.

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

$$f_r = \frac{3 \times 10^8 \text{ m/sec}}{2 \times 45 \text{ n.m.}} \times 5.4 \times 10^{-4} \frac{\text{n.m.}}{\text{m.}}$$

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

Assuming a fan shaped antenna beam (1° azimuth 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 mode 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 profile and realizing the advantages of short revisit rates a compromise value of 54.5° 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.

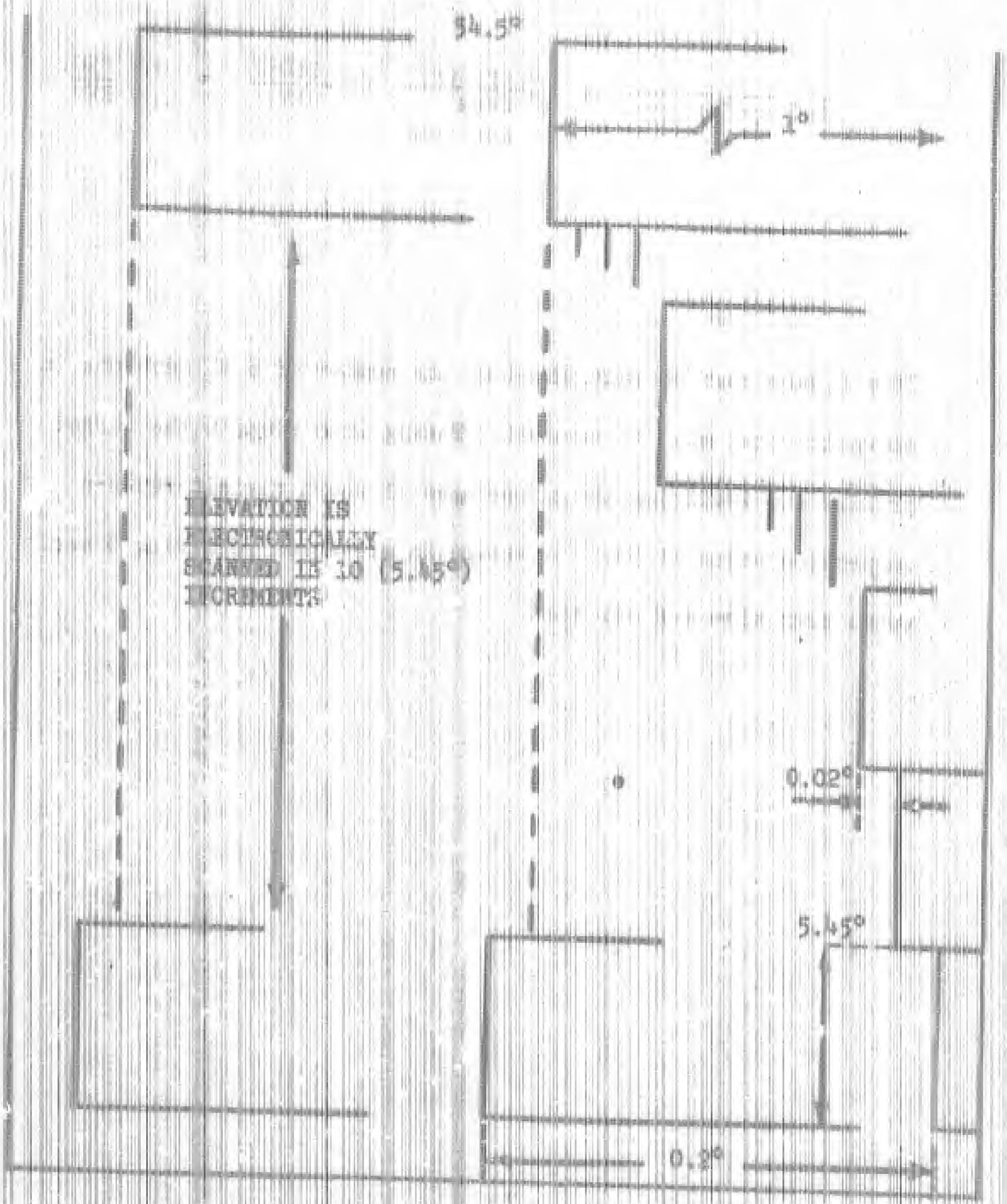


FIG. 2. SIMULATED ANTENNA MOTION -- MODE 1

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° x 2° 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 ± 45° AZ. by 60° EL. sector we have 45 x 30 ≅ 1350 (2° x 2°) 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.

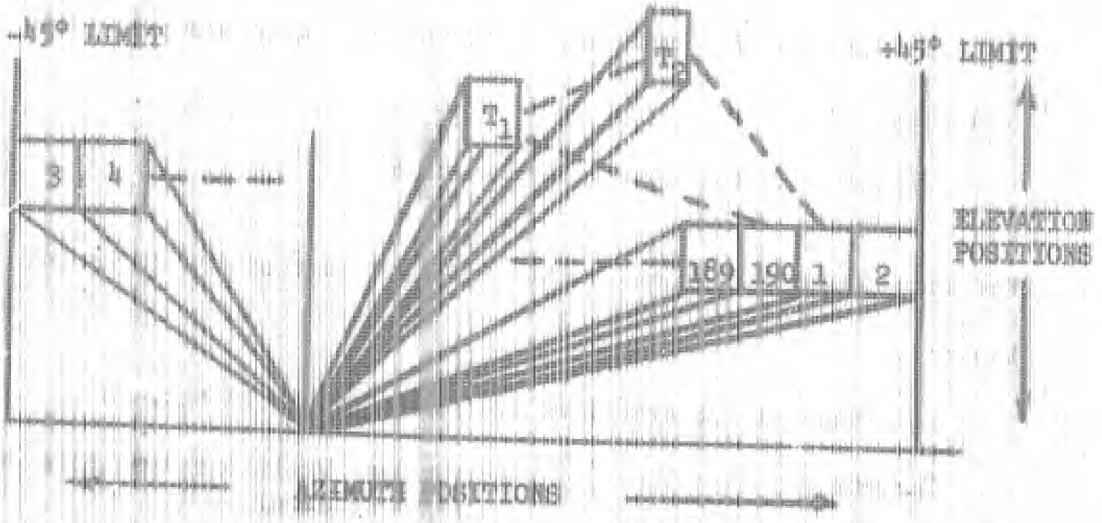


Fig. 3. BEAM SCANNING SEQUENCE FOR 2 TARGETS ENGAGED. MODE 2.

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, subroutine CORRAS was devised. Current radar observations are stored in the matrices RADRNG, AZRAD, ELRAD, While predicted values from the tracker are stored similiarly. 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 C(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 ± X n.m., azimuth and elevation angles must be within ± 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 = 2.0 * SQRTF [P(1,1)] n.m.

Azimuth gate = 1.0 * SQRTF [P(3,3)] n.m.

Elevation gate = 2.5 * SQRTF [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:

$$\Lambda_{sn} = \Lambda_{pn} + \alpha(\tilde{\Lambda}_n - \Lambda_{pn})$$

The prediction equations:

$$\dot{\Lambda}_n = \dot{\Lambda}_{n-1} + \frac{\beta}{T}(\tilde{\Lambda}_n - \Lambda_{pn})$$

$$\Lambda_{pn+1} = \Lambda_{sn} + \dot{\Lambda}_n * T$$

Where: Λ_{sn} = Smooth value of X,Y or Z for the n^{th} scan.

Λ_{pn} = Predicted value of X,Y or Z for the n^{th} scan.

$\tilde{\Lambda}_n$ = Noisy observation of X,Y or Z for the n^{th} scan.

$\dot{\Lambda}_n$ = Smooth prediction of X,Y or Z component of velocity for the n^{th} scan.

Where: $\hat{X}_{n+1}$ = Predicted X,Y or Z coordinate for the n + 1 scan.

T = Time between looks which is essentially constant.

T = 1 second for sector scan.

T = 6 seconds for full scan.

α = The smoothing parameter.

$\beta = \frac{\alpha^2}{2-\alpha}$ 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, ie., less than 3°/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 determining 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 extreme 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 pursuing this somewhat uncertain investigation, 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 equations 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 with automatic gate size reduction if we succeed.

The Kalman Filter Equations as given in (4):

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

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

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

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

$$P_{n+1/n} = \phi P_{n/n} \phi^T + Q$$

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

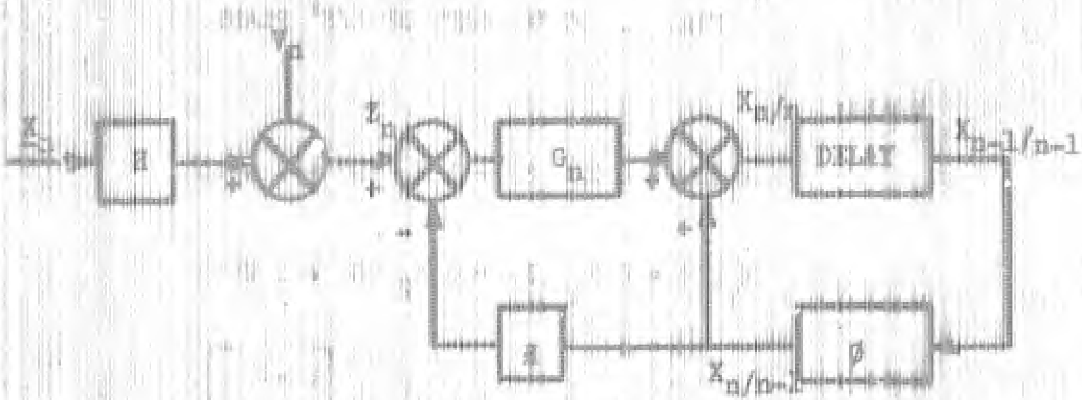


Fig. 4. BLOCK DIAGRAM OF FILTER EQUATIONS.

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:

$$A = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \Rightarrow \quad \underline{[SI-A]} = \begin{bmatrix} S & -1 \\ 0 & 1/S \end{bmatrix}$$

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

$$[SI-A]^{-1} = \frac{\begin{bmatrix} S & 0 \\ 1 & S \end{bmatrix}^T}{\Delta} = \frac{\begin{bmatrix} S & 1 \\ 0 & S \end{bmatrix}}{\Delta} = \begin{bmatrix} 1/S & 1/S^2 \\ 0 & 1/S \end{bmatrix}$$

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.

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

R = The covariance of the measurement noise is by definition $= E\,[\underline{V}\,\underline{V}^t]$

In this case the standard deviation of the measurement ors in Range, azimuth and elevation are known to have the following values.

Range = 0.3 n.m.

Az = 0.5 deg.

El = 0.5 deg.

hence:

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

$\underline{X}$ n/n-1 represents the predicted states of a radar target. To initialize the filter for a particular target, that is specify $\underline{X}$ 1/0, the following method is used.

$$\underline{X}\ 1/0 = \begin{bmatrix} \text{Radar Range} \\ \dot{R} = -0.166 \\ \\ \text{Radar Azimuth} \\ \dot{AZ} = 0.0 \\ \\ \text{Radar Elevation} \\ \dot{El} = 0.0 \end{bmatrix}$$

This method assumes the target is closing the radar radially ($\dot{AZ} = 0.0$) at a low altitude ($\dot{El} \cong 0.0$) with a velocity of approximately 600 n.m. /hr.

P n/n-1 represents the amount of uncertainty in the predicted values of target states X n/n - 1.

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

where: $\underline{X}$ is the true state.

$\hat{\underline{X}}$ is the predicted value.

To initialize the filter we must provide.

$P_{1/0}$ Given $\hat{X}_{1/0}$ defined previously and R the covariance of the measurement 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 mi./hr. we can assume the remaining diagonal elements of P which represent $\overline{V_R^2}$, $\overline{V_{Az}^2}$, $\overline{V_{EL}^2}$ will be small. Actual values were determined empirically and as a result the initial covariance of error matrix is determined.

$$P = \begin{bmatrix} 0.09 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.0278 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2.5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.25 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.25 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.00109 \end{bmatrix}$$

It should be noted here that $P_{1/0}(3,3) = 2.5$ 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.) $\cong \pm$ 0.027 n.m./sec.

$Q \triangleq E\,[\underline{W}\,\underline{W}^t]$ 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.

Taking 1/2 (1g) $\cong$ $.0027\ \frac{\text{n.m.}}{\text{sec}^2}$ x 1 sec.

implies that $Q(2,2) = (.0027)\ (.0027) \cong .00001$

Estimation of Q(3,3)

Assume the aircraft can make a (12° / second) max. turn.

Taking 1/2 (12°/sec) = 6°/sec. and using fig. 6

We have:

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

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

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.

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

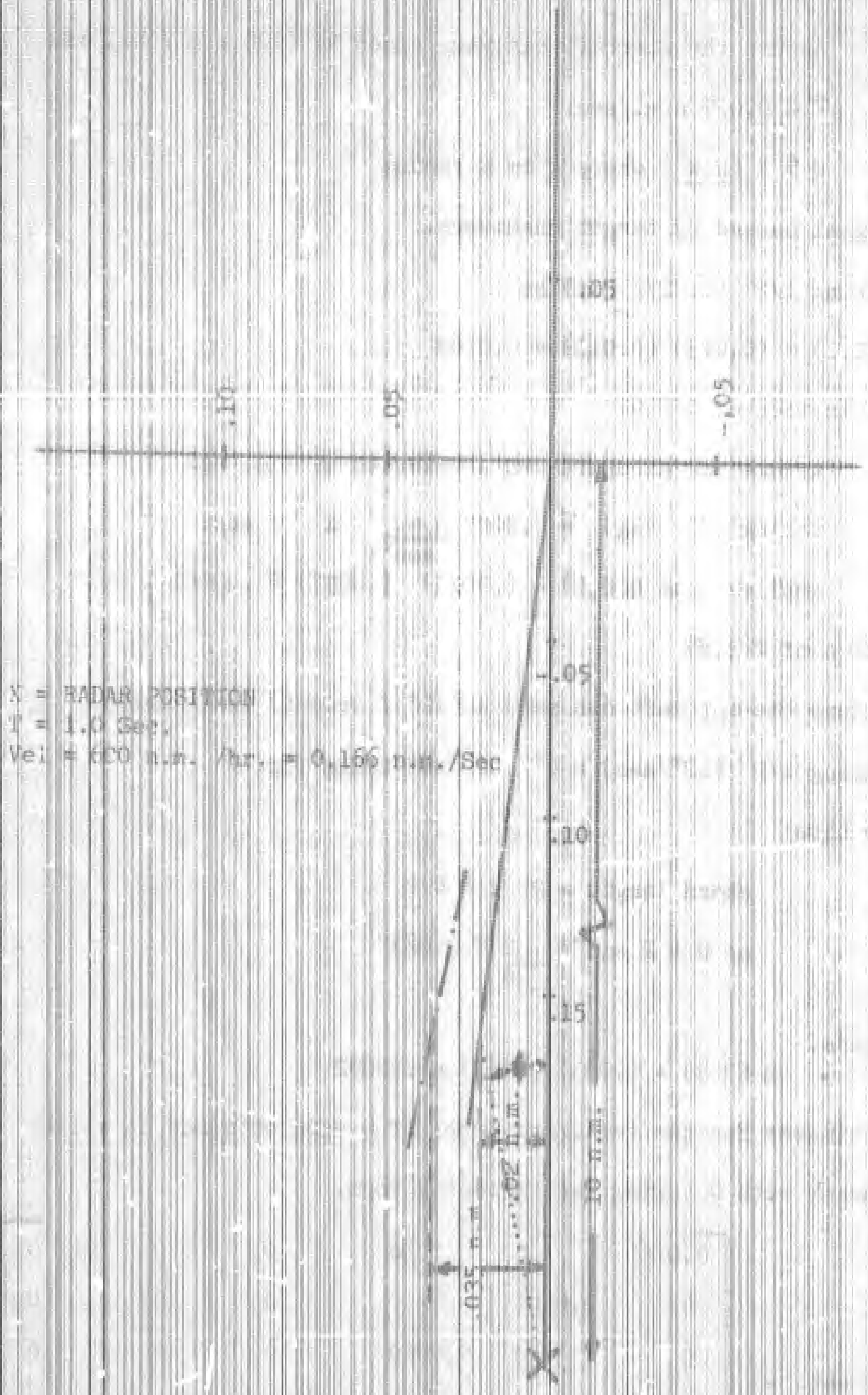


Fig. 6. CHANGE IN RADAR AZIMUTH DUE TO A TURNING TARGET.

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. turns with constant speed targets:

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

The Q_8 matrix values where 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 averages 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 track. 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 firmness 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 P 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.

BIBLIOGRAPHY

1. Povejsil, D. J. Raven, R. S. and Waterman, P. Airborne Radar, D. Van Nostrand Company, Inc. New York 1961.

2. Skolnik, M. I. Introduction to Radar Systems, McGraw-Hill Book Company Inc. New York 1962.

3. Dinneen, G. P. and Reed, I. S. An Analysis of Signal Detection and Location by Digital Methods IRE Transactions March 1956.

4. Benedict, T. R. and Bordner, G. W. Synthesis of an Optimal Set of Radar Track- While- Scan Smoothing Equations. IRE transactions on Automatic Control July 1962.

5. Lee, R. C. K. Optimal Estimation, Identification, and Control Research Monograph No. 28 The M. I. T. Press, Cambridge, Mass. 1964.

6. Briens, A. M. and Delaney, J. F. Multifunction Phased- Array Radar, P70, Raytheon Company, Bedford, Mass. 28 March 1966.

7. Titus, H. A. EE473 Class notes USNPGS Monterey, Calif. April - May 1967.

APPENDIX D

GRAPHICAL OUTPUT

Graph Page

Interpretation and constraints

(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°/sec.

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

(c) Each graph represents the results in range (R), azimuth (X), and elevation (Δ) 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.
Δ	predicted position target two.

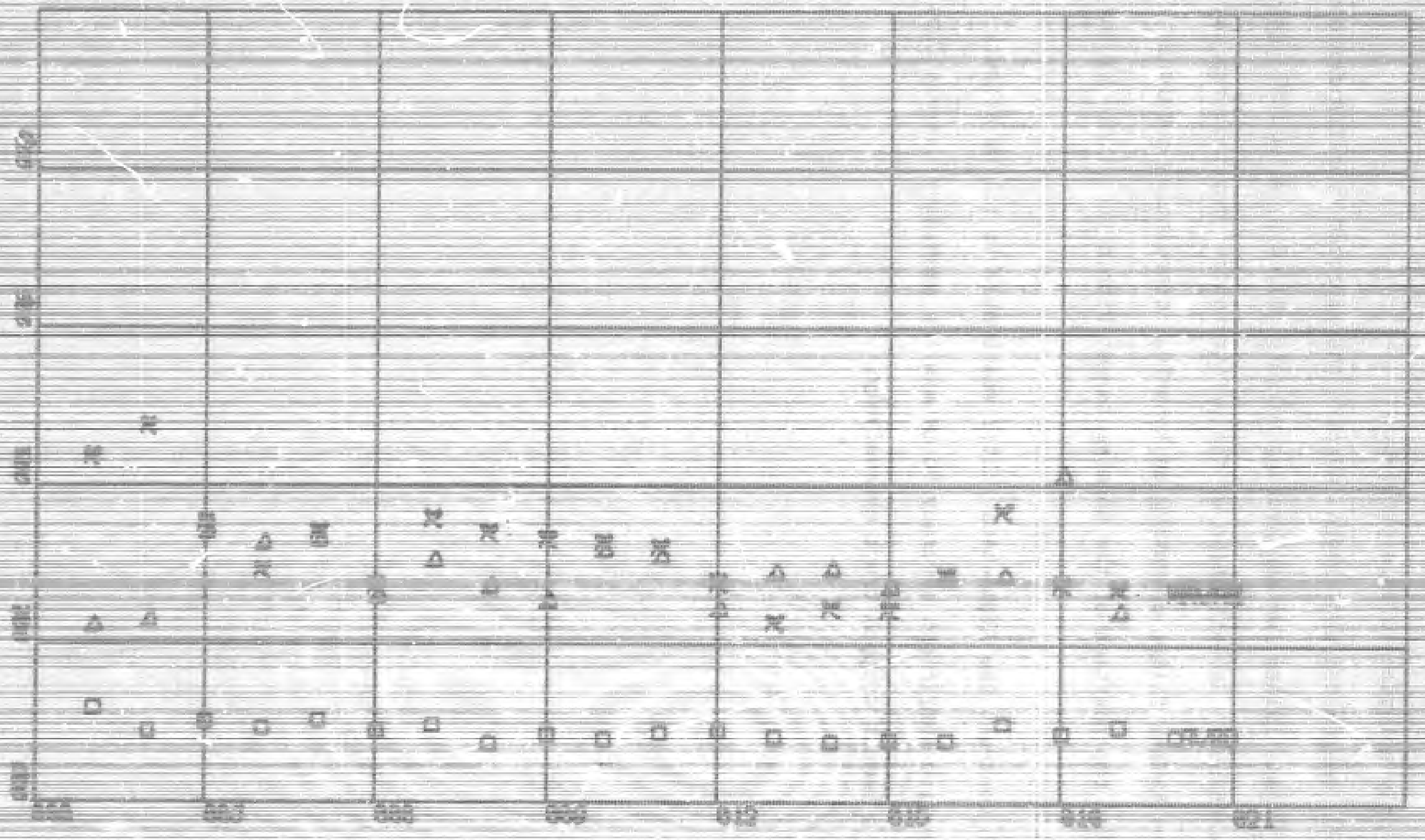
(2) Graphs nine and ten represent filtering ability for "look alike" targets. i.e. similar range, elevation, and azimuth.

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 8 sec.) has little or no effect. (see graphs 13 and 14).

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

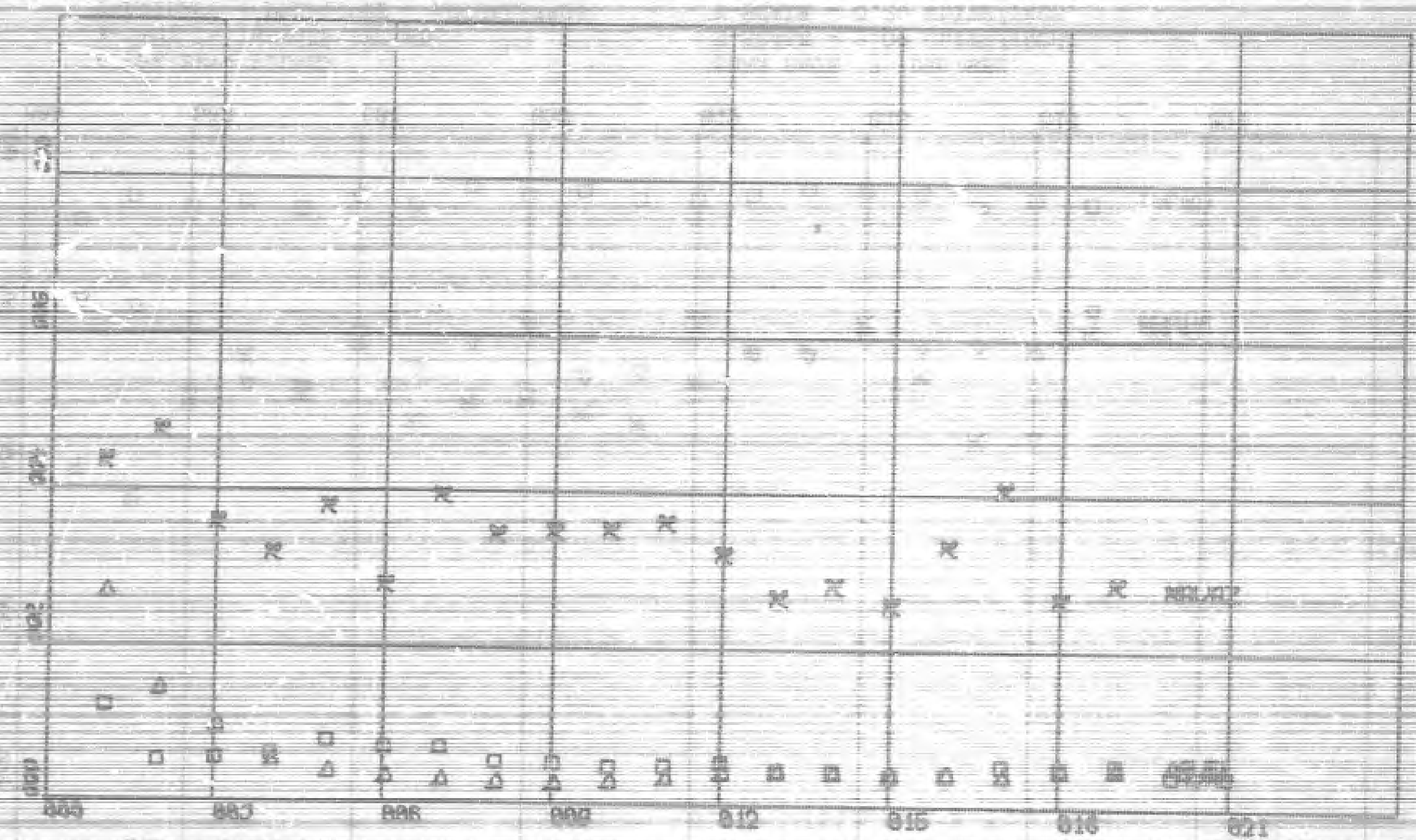
(3) Graphs ten and eleven indicate the improved tracking response of the Kalman filter for maneuvering targets, aided by a variable gate size technique. Investigation of the printed output for this run shows that the Kalman filter operating on spherical coordinates consistently predicted the position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



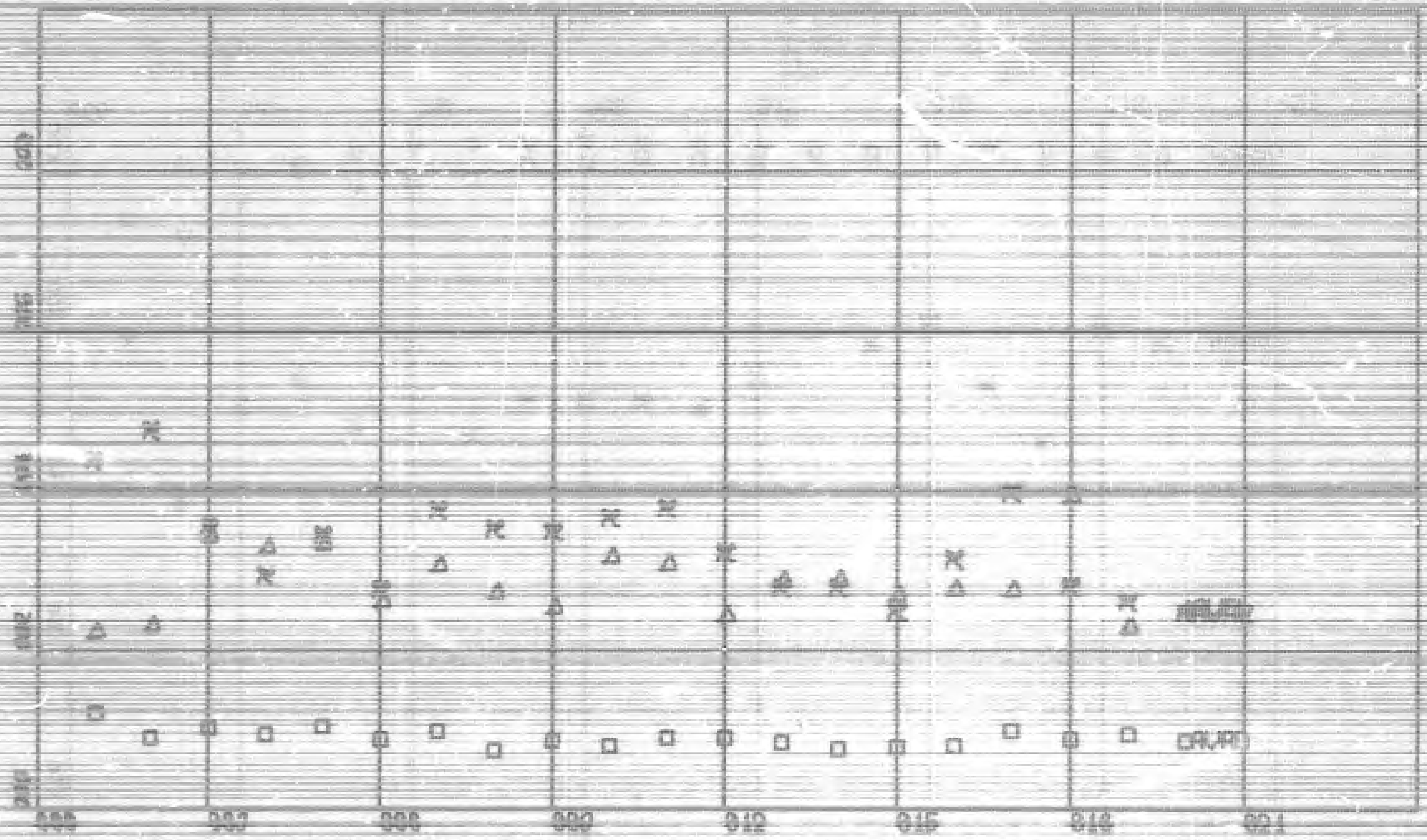
ALPHA-BETA FILTER
X-TIME IN INTEGER SECONDS
Y-AVERAGE ((PREDICTED - ACTUAL)**2)

TURN RATE 0   DEG/SEC.
X-SCALE - 3.00 UNITS/INCH.
Y-SCALE - 0.20 UNITS/INCH.



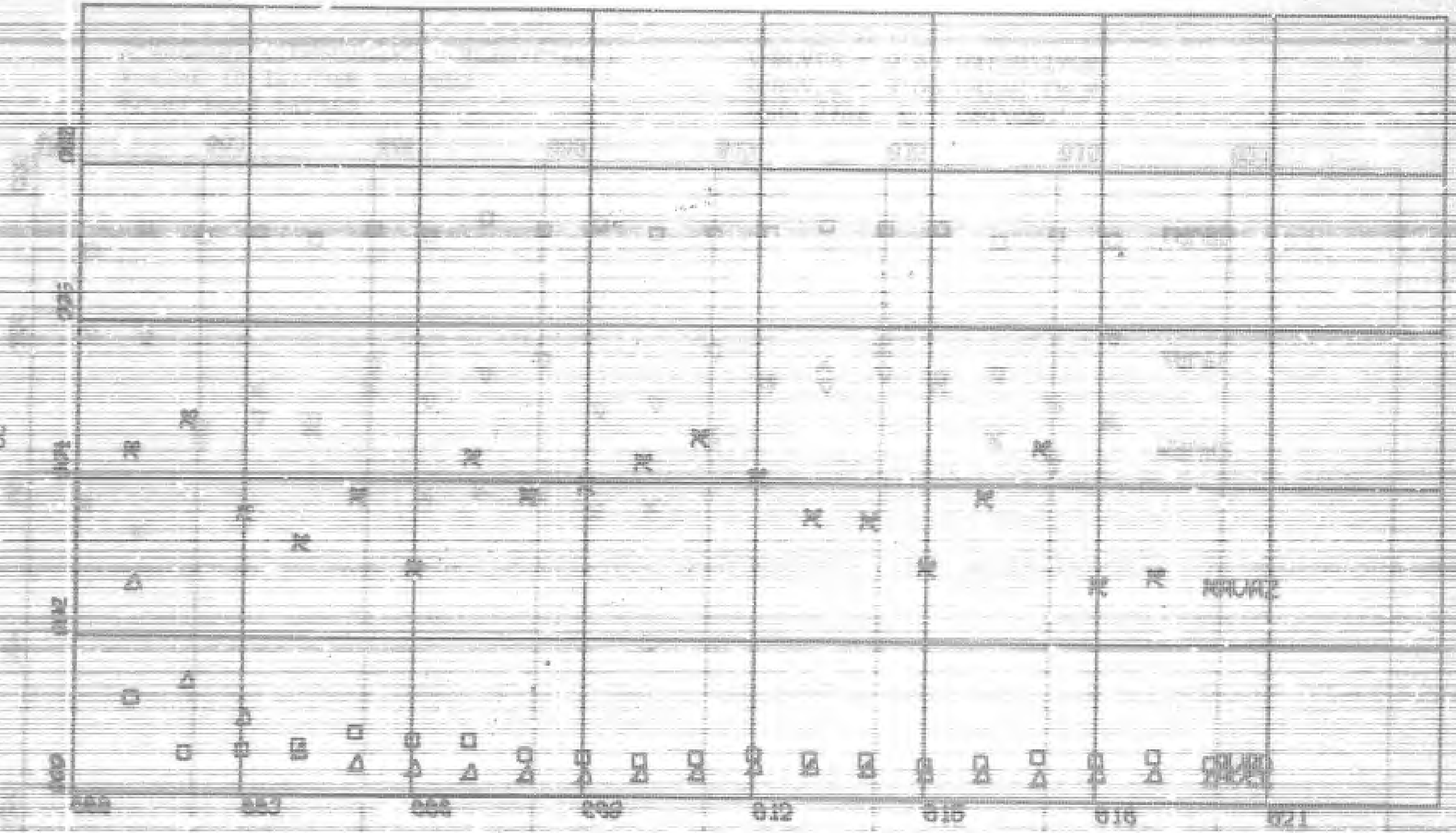
KALMAN FILTER
X - TIME IN INTEGER SECONDS
Y - AVG.((PREDICTED - ACTUAL)**2)

TURN RATE 0   DEG/SEC.
X-SCALE = 3.00 UNITS/INCH.
Y-SCALE = 0.20 UNITS/INCH.



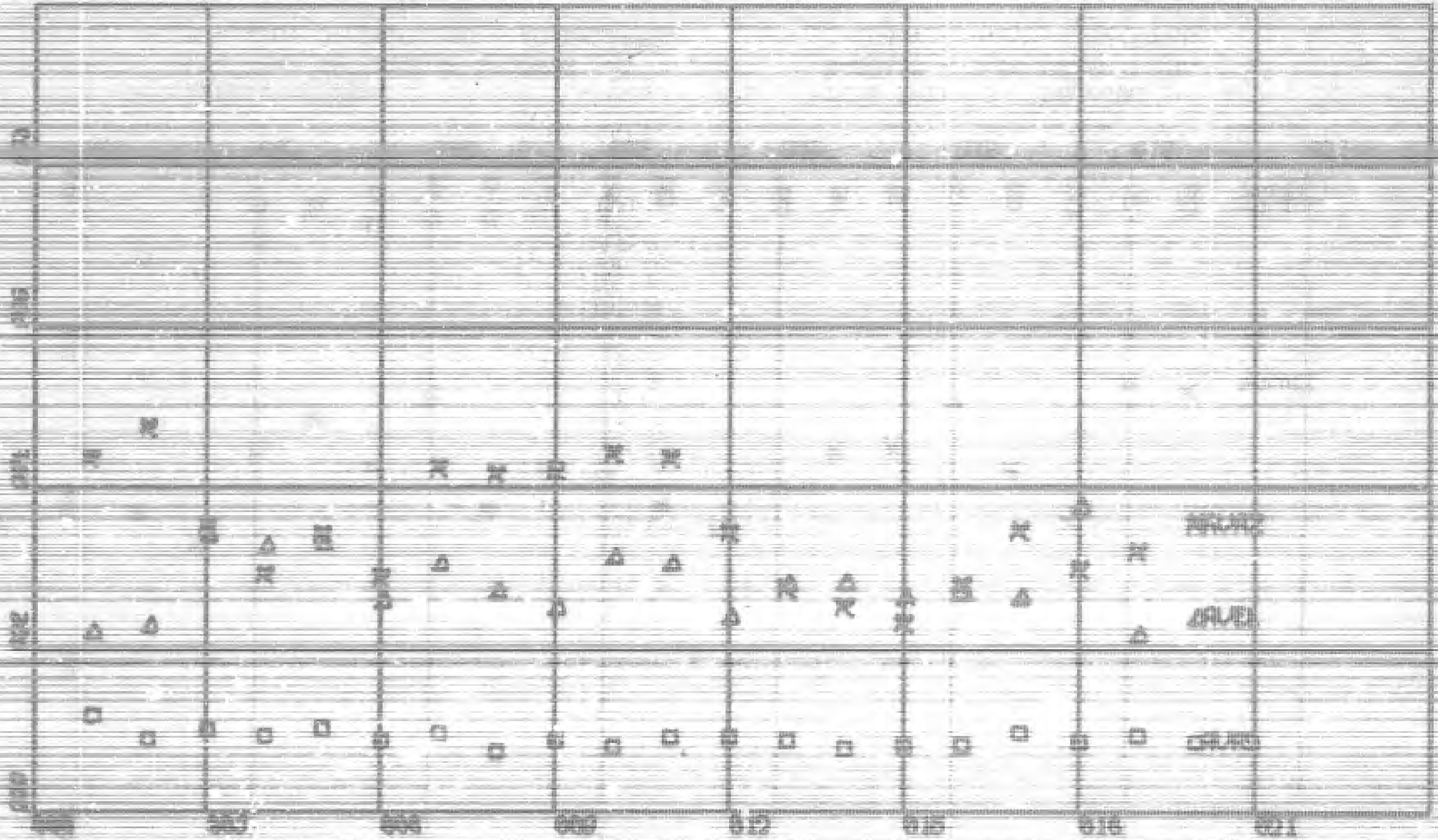
ALPHA-BETA FILTER
X-TIME IN INTEGER SECONDS
Y-AVERAGE ((PREDICTED - ACTUAL)**2)

TURN RATE 3 DEG/SEC.
X-SCALE - 3.00 UNITS/INCH.
Y-SCALE - 0.20 UNITS/INCH.



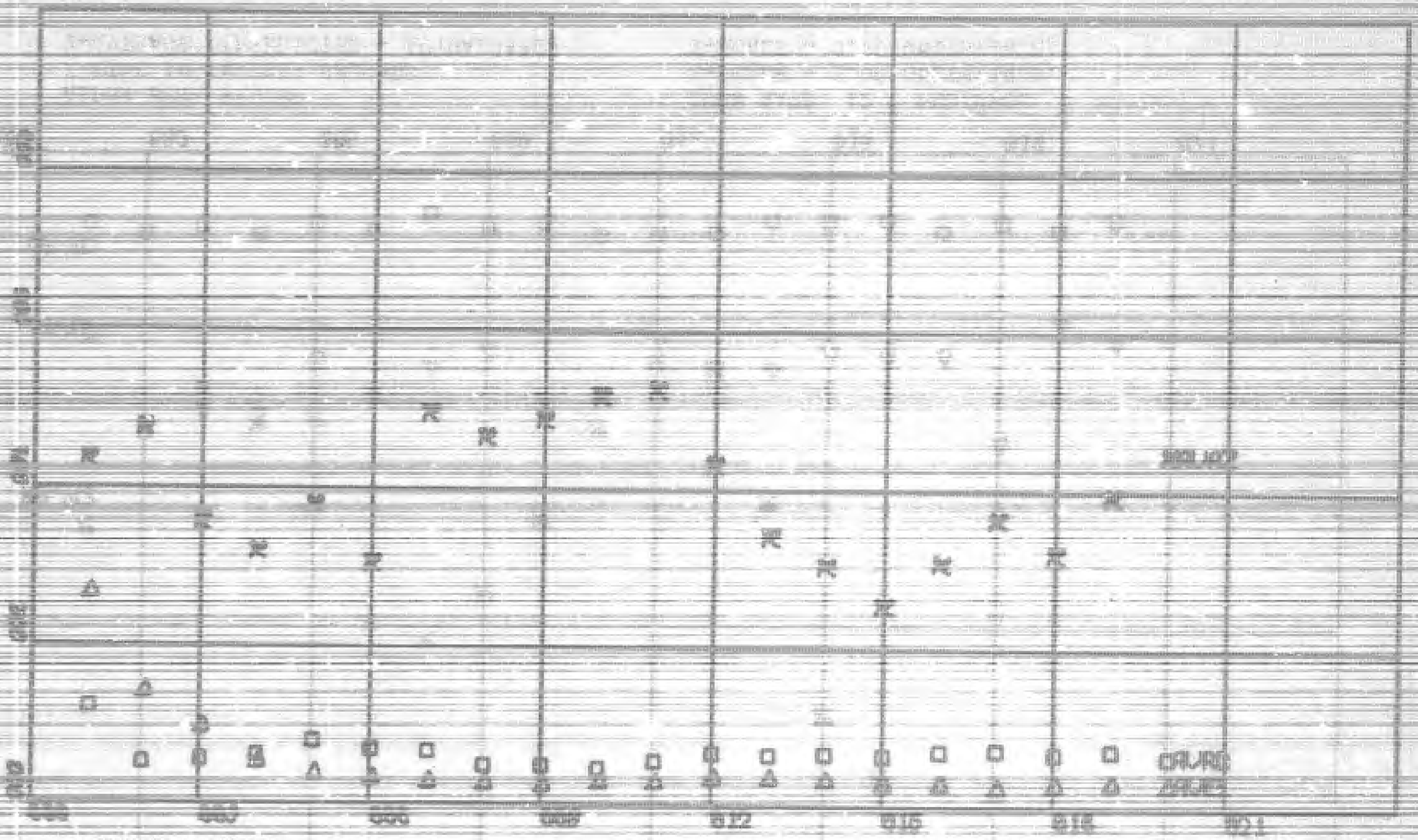
KALMAN FILTER
X - TIME IN INTEGER SECONDS
Y - AVG. ((PREDICTED - ACTUAL)**2)

TURN RATE 3 DEG/SEC.
X-SCALE - 3.00 UNITS/INCH.
Y-SCALE - 0.20 UNITS/INCH.



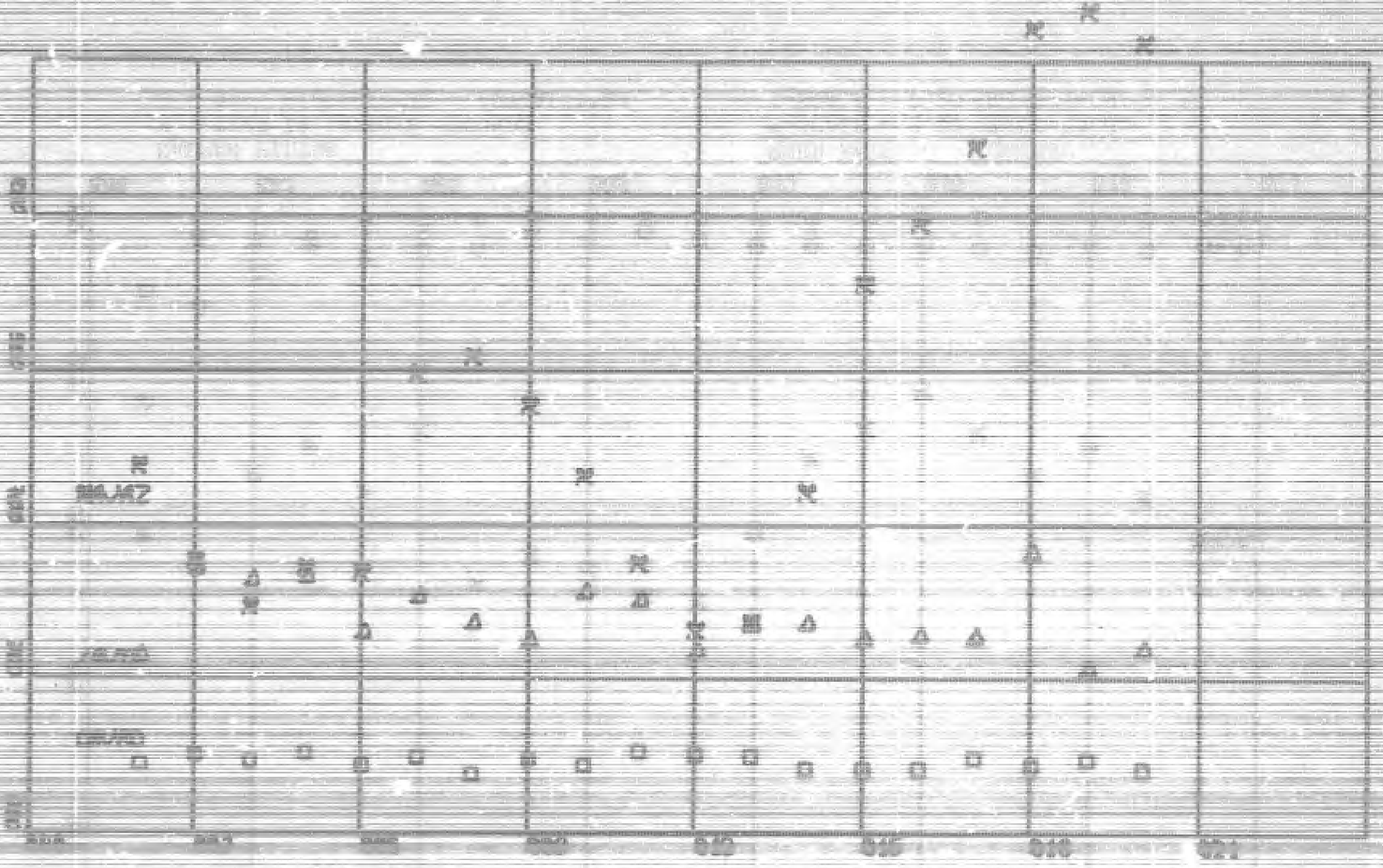
ALPHA-BETA FILTER
X-TIME IN INTEGER SECONDS
Y-AVERAGE ((PREDICTED - ACTUAL)**2)

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



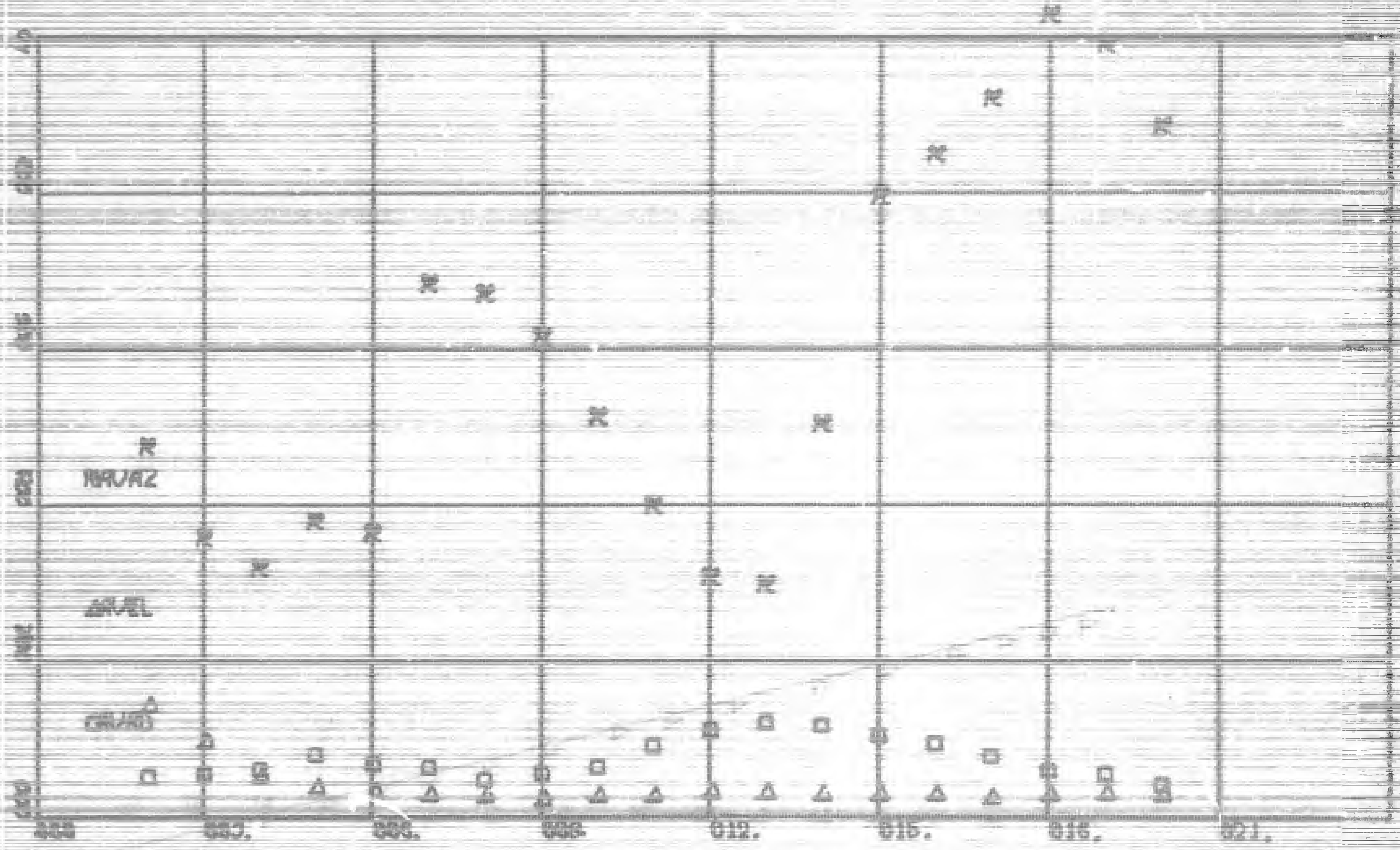
KALMAN FILTER
X - TIME IN INTEGER SECONDS
Y - AVG. ((PREDICTED - ACTUAL)**2)

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



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)

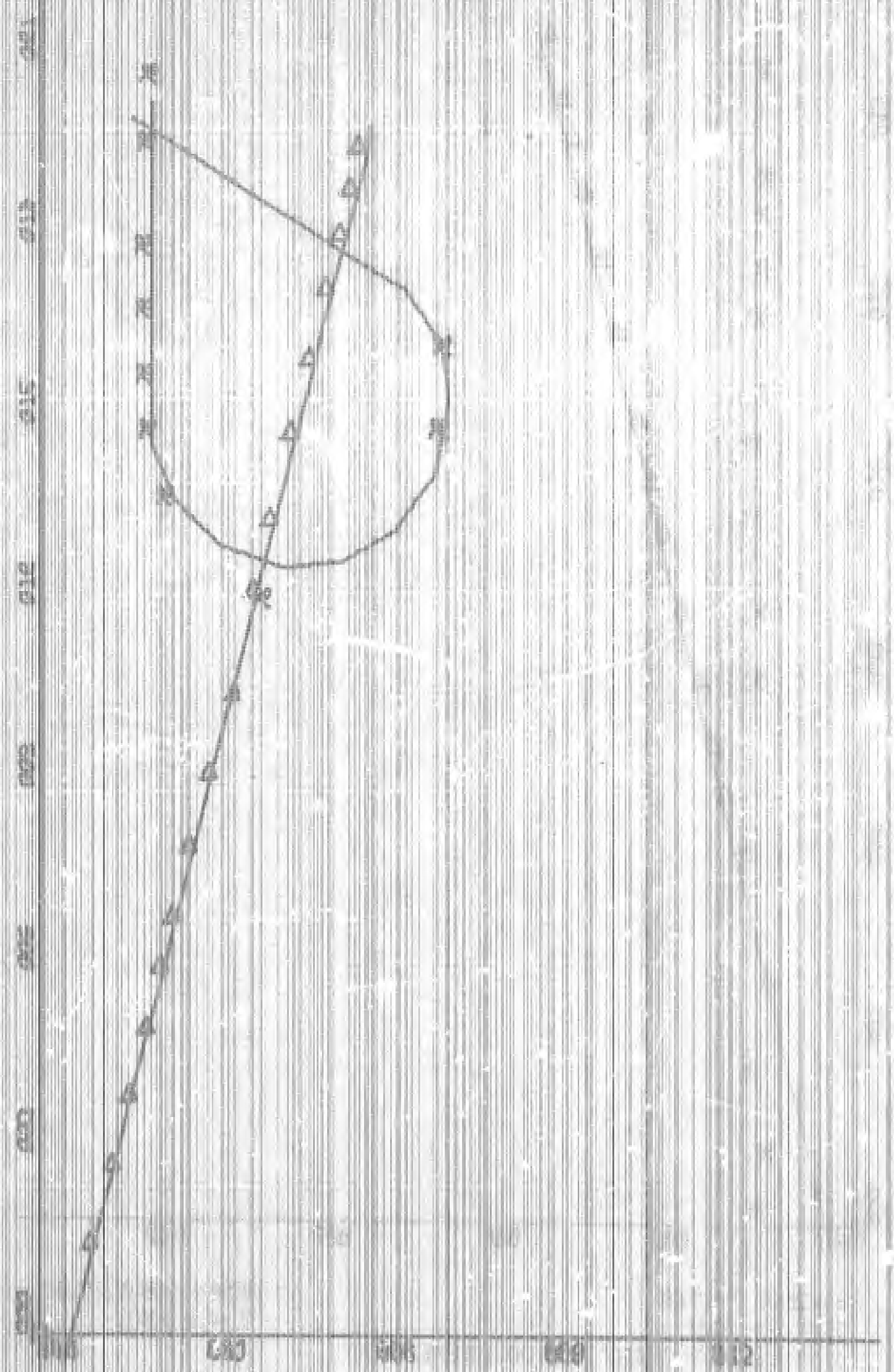
TURN RATE 12 DEG/SEC.
X-SCALE = 3.00 UNITS/INCH.
Y-SCALE = 0.20 UNITS/INCH.

ALPHA-BETA FILTER
X = Y = 3.4.
X SCALE = Y SCALE = 3.[illegible] UNITS/INCH

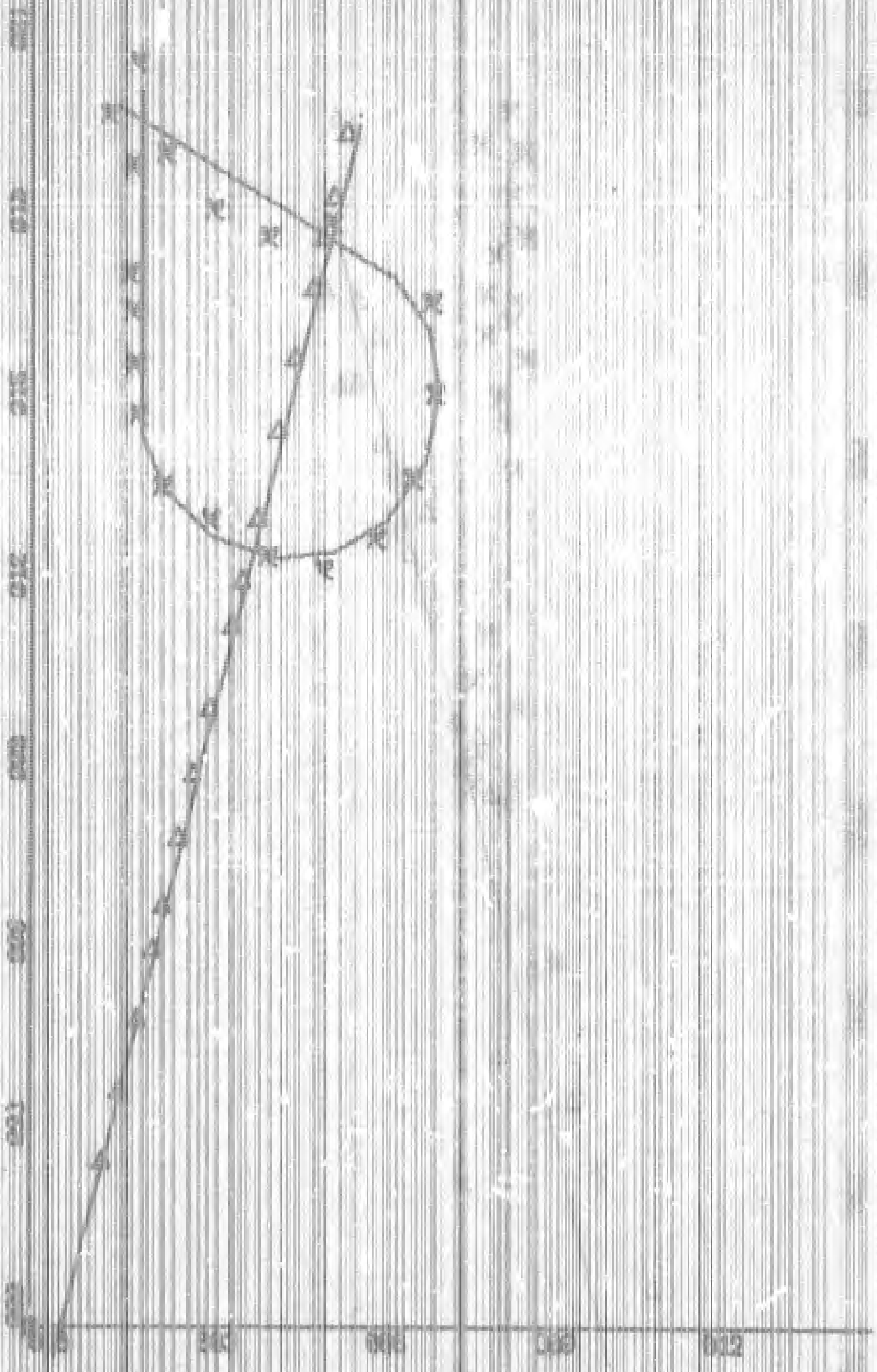
NON MANEUVERING
T = 8 SEC.

KALMAN FILTER
X = Y = N.M.
X SCALE = Y SCALE = 3.00 UNITS/INCH

NON MANEUVERING
T = 5 SEC



ALPHA-BETA FILTER [illegible] DEG/SEC
X = Y = N.M.
X SCALE = Y SCALE = 3.00 UNITS/INCH.



KALMAN FILTER 5 DEG/SEC

X + Y = N.M.

X SCALE = Y SCALE = 3.00 UNITS/INCH.

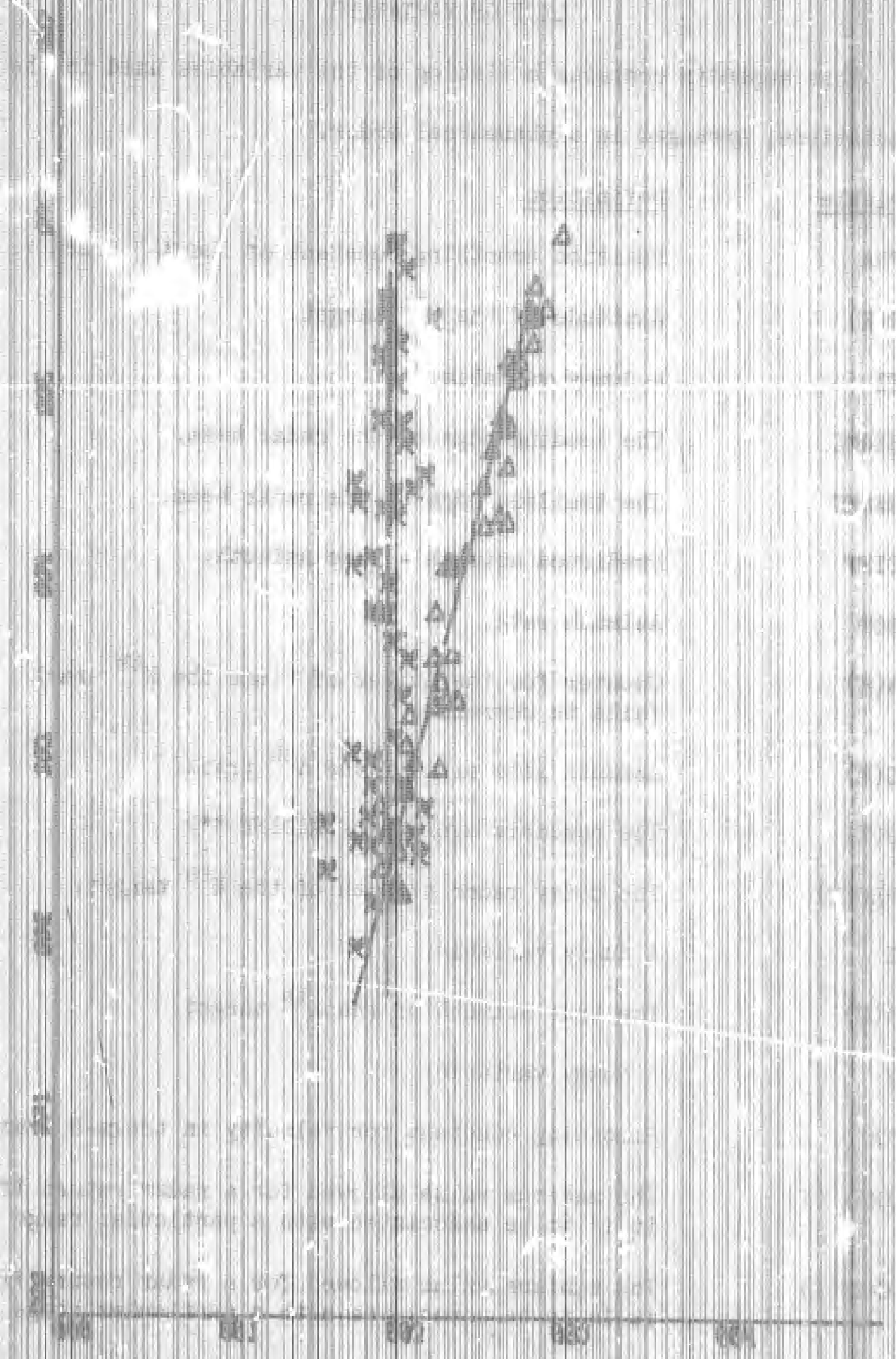
ALPHA-BETA FILTER

X = Y = N.M.

X SCALE = Y SCALE = 1.00 UNITS/INCH

NON MANEUVERING

T = 1 SEC.



KALMAN FILTER
X = Y = N.M.
X SCALE = Y SCALE = 1.00 UNITS/INCH

NON 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.

Variable	Definition
ALPHA	Position smoothing constant of the α-β tracker.
ALT(K)	Altitude of the K^{th} target.
ALTR	A dummy variable.
AZBEAML	The leading edge of the radar beam.
AZBEAMT	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 α-β tracker
BOXMAX (I)	The maximum value allowed for a radar return if it is to be associated with a particular range box.
BOXMIN(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.
CONT(K)	Azimuth of the leading edge of the radar beam on initial detection of the K^{th} target.
DELTA	Normalized velocity vector.

Variable	Definition
DOTT	A dummy variable.
DOTX	The predicted velocity components of the Kth target as given by the α-β tracker.
DOTY	
DOTZ	
ELBEAMB	Bottom extemity of the radar beam.
ELBEAMT	Top extemity 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 Kth 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 Kth aircraft in degrees.
HPNT	A dummy variable.
HT(I,J)	The transpose of the observability matrix.
IA	Range box index.
IAT(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 occured.
IAZREF	Reference azimuth of sector scan.

Variable	Definition
II	Elevation beam position indicator.
IRDE(I)	SEE IRDEX (I)
IRDEX (I)	IRDEX in conjunction with IRDE determine when a track fails, two consecutive times, to correlate thus initiating drop track procedure.
ITEL	The fixed point form of TEL.
ITEL1	A dummy variable.
ITEMP	The fixed point form of TEMP.
ITEMP1	A dummy variable.
KC(I)	A flag used to initialize the Kalman filter for a particular observation.
KER	Flag to indicate an improper matrix inverse operation.
LIMB	Lower limit of the sector scan.
LIML	Port limit of the sector scan.
LIMR	Starboard limit of the sector scan.
LIMU	Upper limit of the sector scan.
NR	The number of runs.
NDT	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.
NUMS	Sector scan counter.
NUM1	Dummy variables.
NUM2	
NUM3	
NUMSCAN	The number of 120 degree scans of the radar.
NUMTRK	Number of current active tracks.

Variable	Definition
PZEM	A dummy variable for the noisy radar observations (Range, Azimuth or Elevation.)
P(I,J)	The covariance of error matrix.
PAZRAD	The predicted radar azimuth of the target.
PAT	A dummy variable.
PD(I)	A discrete value of probability from the probability of detection table.
PDET	Probability of dection.
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 attitude of the Kth target in degrees.
PITCH1	A dummy variable.
P1····9(I,J)	Storage for P matrix associated with each track.
PRADRNG	Predicted radar range of a target.
PRED	A dummy variable used in the Alpha-Beta tracker for the predicted value of range, azimuth or elevation.
PXRAD	Predicted X,Y,Z, components of target position.
PYRAD	
PZRAD	
Q(I,J)	Matrix representing target maneuver capability.
Q1(I,J)	Q may be set equal to Q1 or Q8 as required by the appropriate scan time.
Q8(I,J)	
R(I,J)	Covariance matrix of the observation noise.

Variable	Definition
RADDEG	Constant used to convert radians to degrees.
RADIFF	Predicted range - true range.
RANDOM	Uniformly distributed random number.
RANERR	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 Kth 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	
TARGRNG	True value of target range as given by the target generator.
TEL	Temporary sector scan beam reference.
TEST	
TESTT	
TNT	
THETA	Value of target heading in radians with reference to the positive X-axis.
VEL(K)	Speed of the Kth target in n.m./hr.
VMAG2(I)	Ensemble average of radiff.

Variable	Definition
VHB	Fixed point form of HB.
VPHI2(I)	Ensemble average of azdiff.
XP(I,J)	Predicted state vector.
XPI	A dummy variable.
XRAD(K)	X coordinate of the K^{th} target as given by the radar.
XRAD1(K)	Stored radar track quantity for graphical output.
XRAD2(K)	⋮
XS	Smooth state vector.
XT(K)	The true X coordinate of the K^{th} target
XT1(K)	Stored target track quantity for graphical output.
XT2(K)	⋮
YRAD(K)	Radar Y coordinate of the K^{th} target.
YRAD1(K)	Stored radar track quantity for graphical output.
YRAD2(K)	⋮
YT(K)	The true Y coordinate of the K^{th} target.
YT1(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.
ZT(K)	The true Z coordinate of the K^{th} target.

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

1. ADD
2. PRINTT
3. PROD
4. READD
5. RECIP
6. TRANS

APPENDIX III

LOGIC FLOW DIAGRAMS

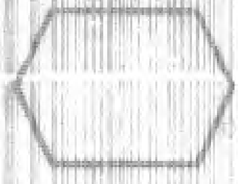
This Appendix contains a series of Logic Flow diagrams as listed below.

MAIN PROGRAM
SUBROUTINE RANGER
SUBROUTINE SCAN 360
SUBROUTINE DETECT
SUBROUTINE MOVAVE
SUBROUTINE CORRASS
SUBROUTINE ASSOC
SUBROUTINE ABFILT
SUBROUTINE KALFILT
SUBROUTINE SETUP
SUBROUTINE TWS
SUBROUTINE MONTE

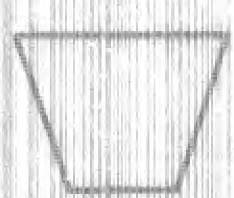
FLOW CHART SYMBOLS

A connector or terminal.

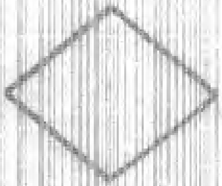
An offpage connector.



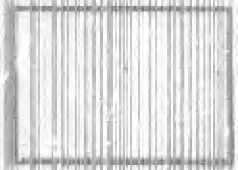
A predefined process or module/subroutine. A more detailed flow chart of this subroutine is also included.



Input/output other than display.

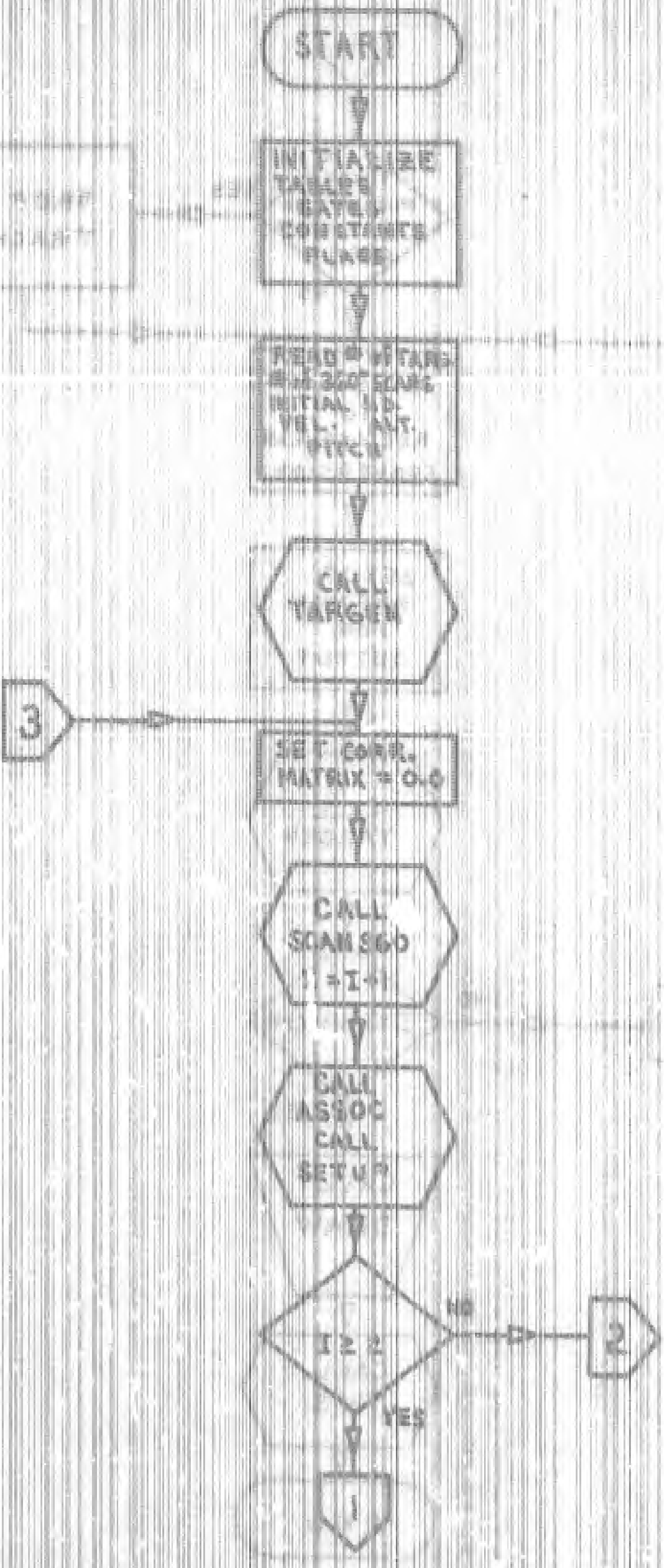


Decision.

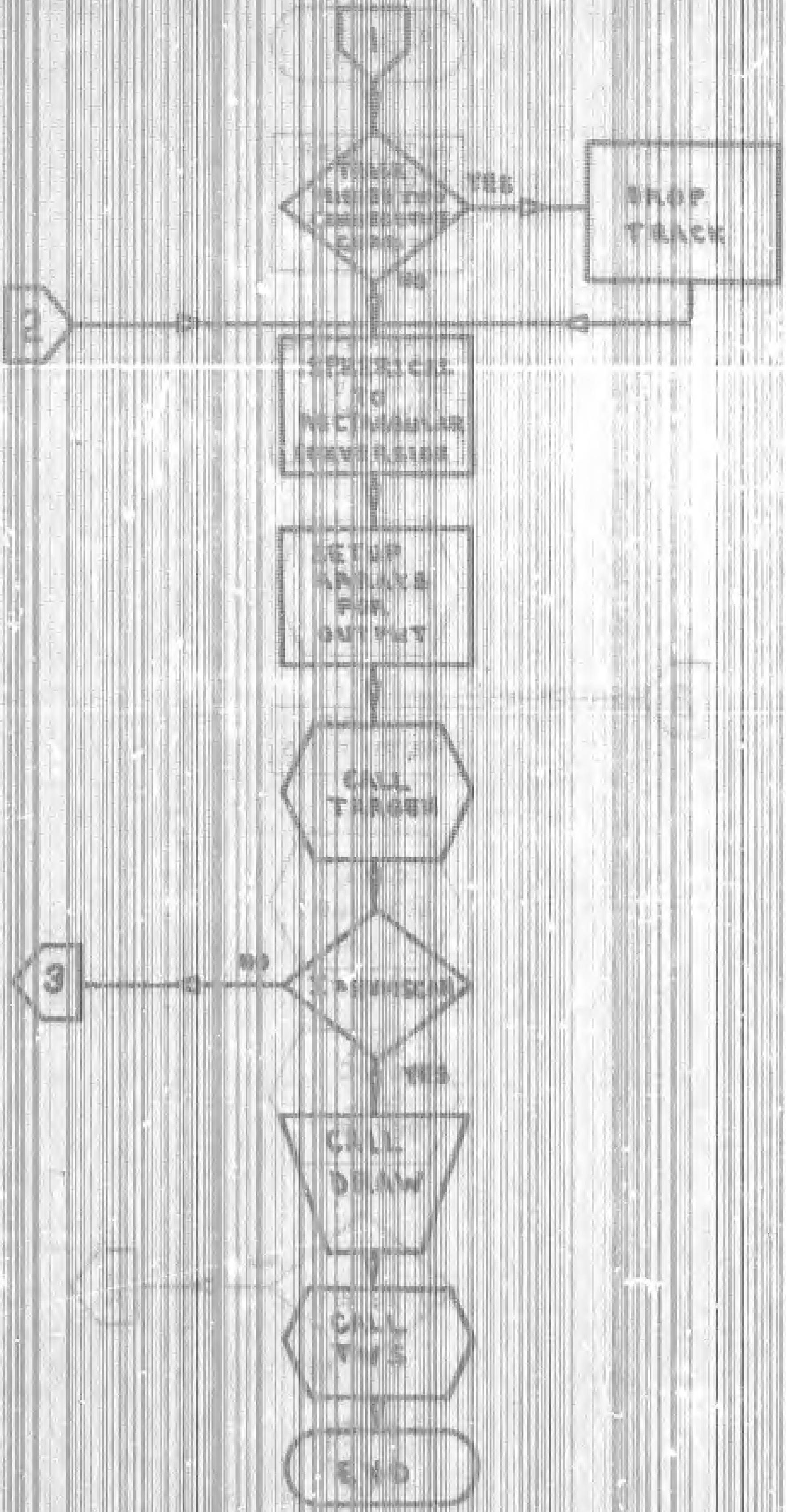


Processing, annotation.

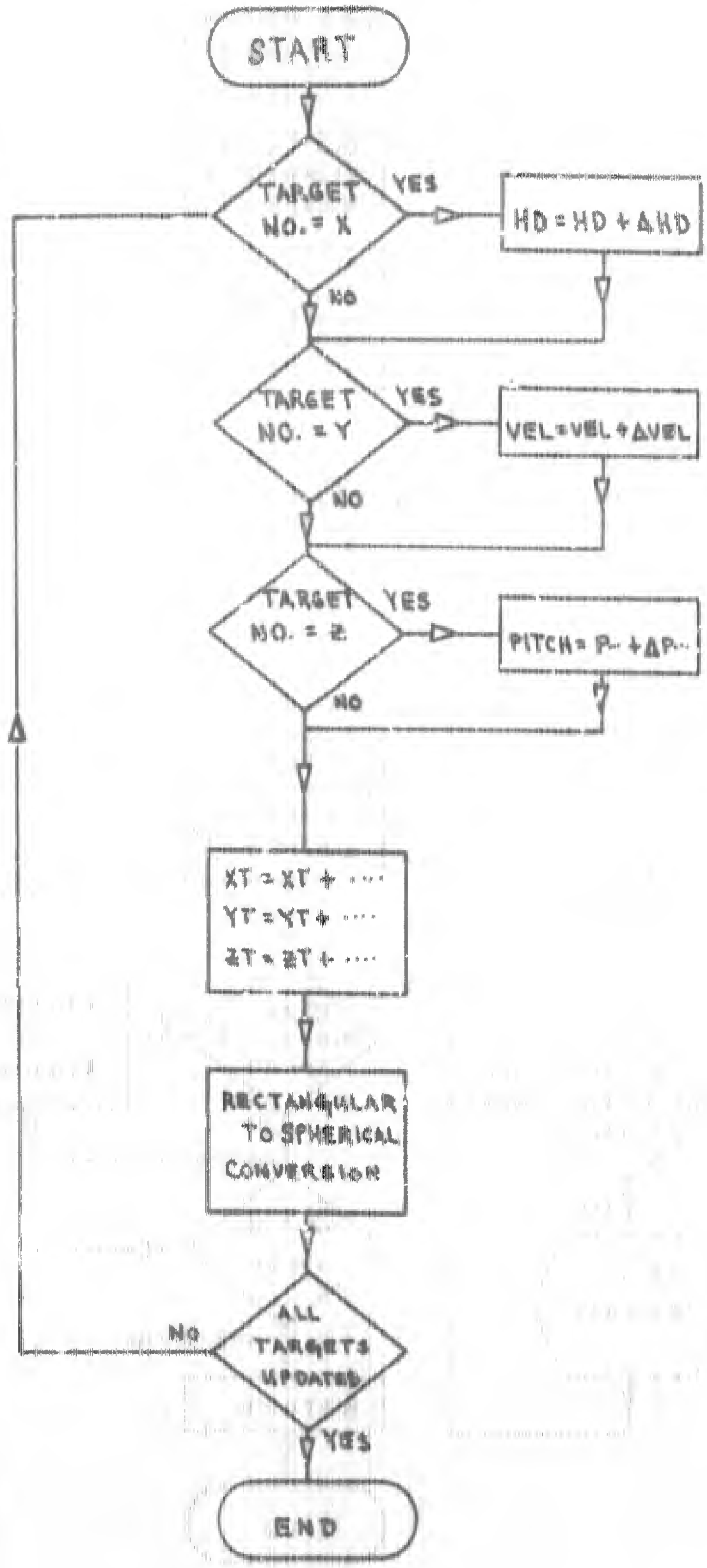
MAIN PROGRAM



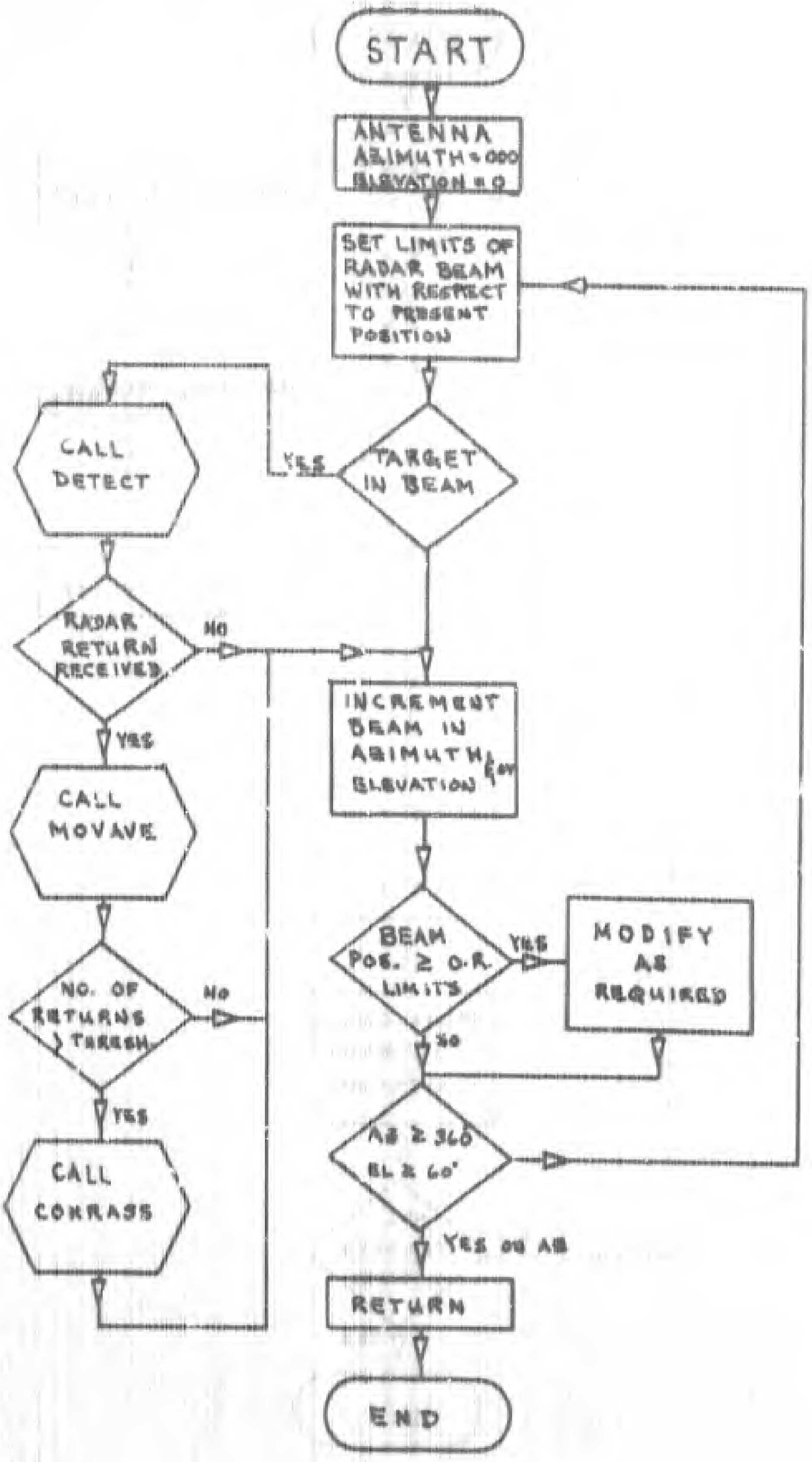
MAIN PROGRAM



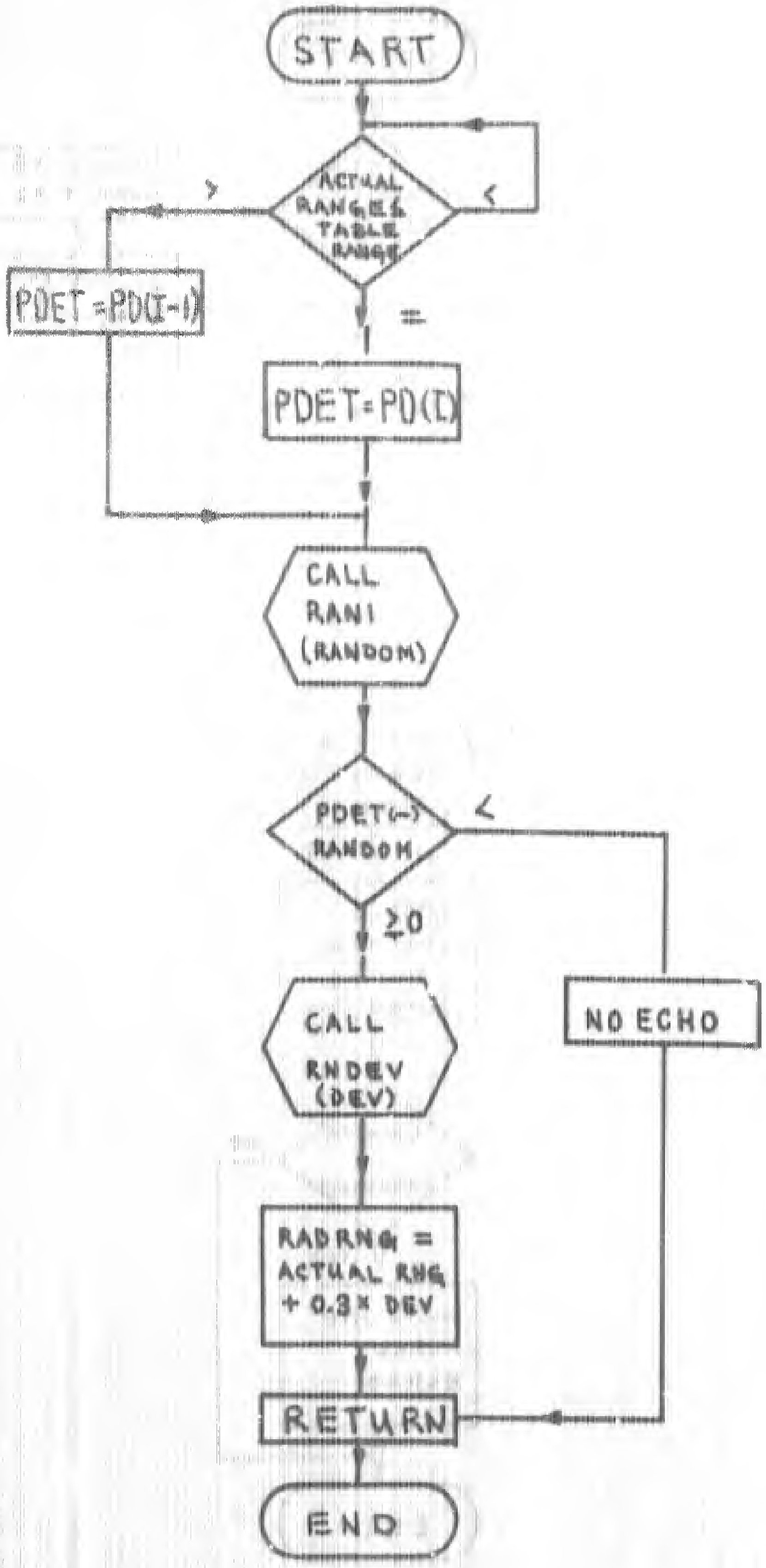
TARGEN


START
TARGET NO. = X
YES
HD = HD + ΔHD
NO
TARGET NO. = Y
YES
VEL = VEL + ΔVEL
NO
TARGET NO. = Z
YES
PITCH = P·· + ΔP··
NO
XT = XT + ····
YT = YT + ····
ZT = ZT + ····
RECTANGULAR TO SPHERICAL CONVERSION
ALL TARGETS UPDATED
NO
YES
END

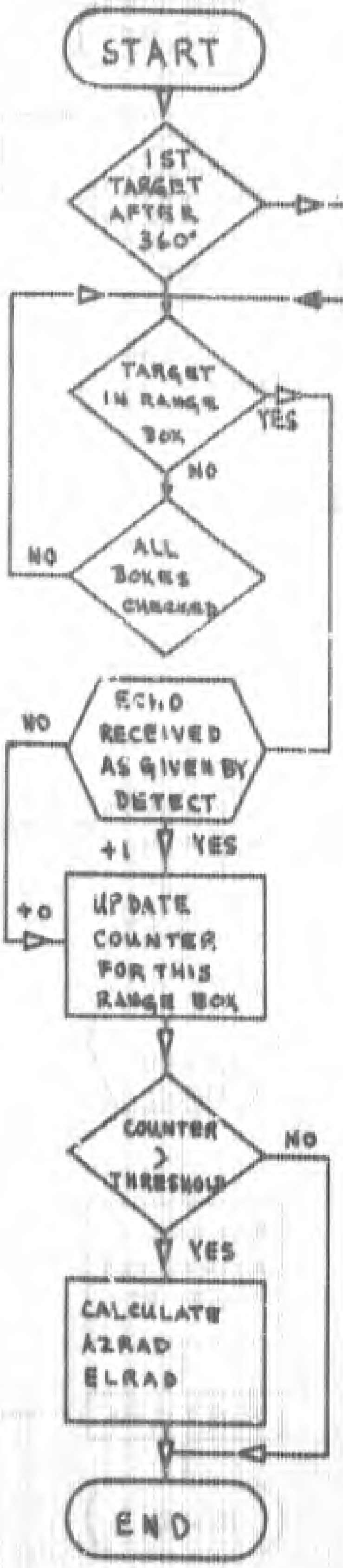
SCAN360


START
ANTENNA AZIMUTH = 000 ELEVATION = 0
SET LIMITS OF RADAR BEAM WITH RESPECT TO PRESENT POSITION
TARGET IN BEAM
YES
CALL DETECT
RADAR RETURN RECEIVED
NO
YES
CALL MOVAVE
NO. OF RETURNS > THRESH
NO
YES
CALL COMPASS
INCREMENT BEAM IN AZIMUTH &/or ELEVATION
BEAM POS. ≥ O.R. LIMITS
YES
MODIFY AZ REQUIRED
NO
AZ ≥ 360 EL ≥ 60°
YES ON AZ
RETURN
END

DETECT

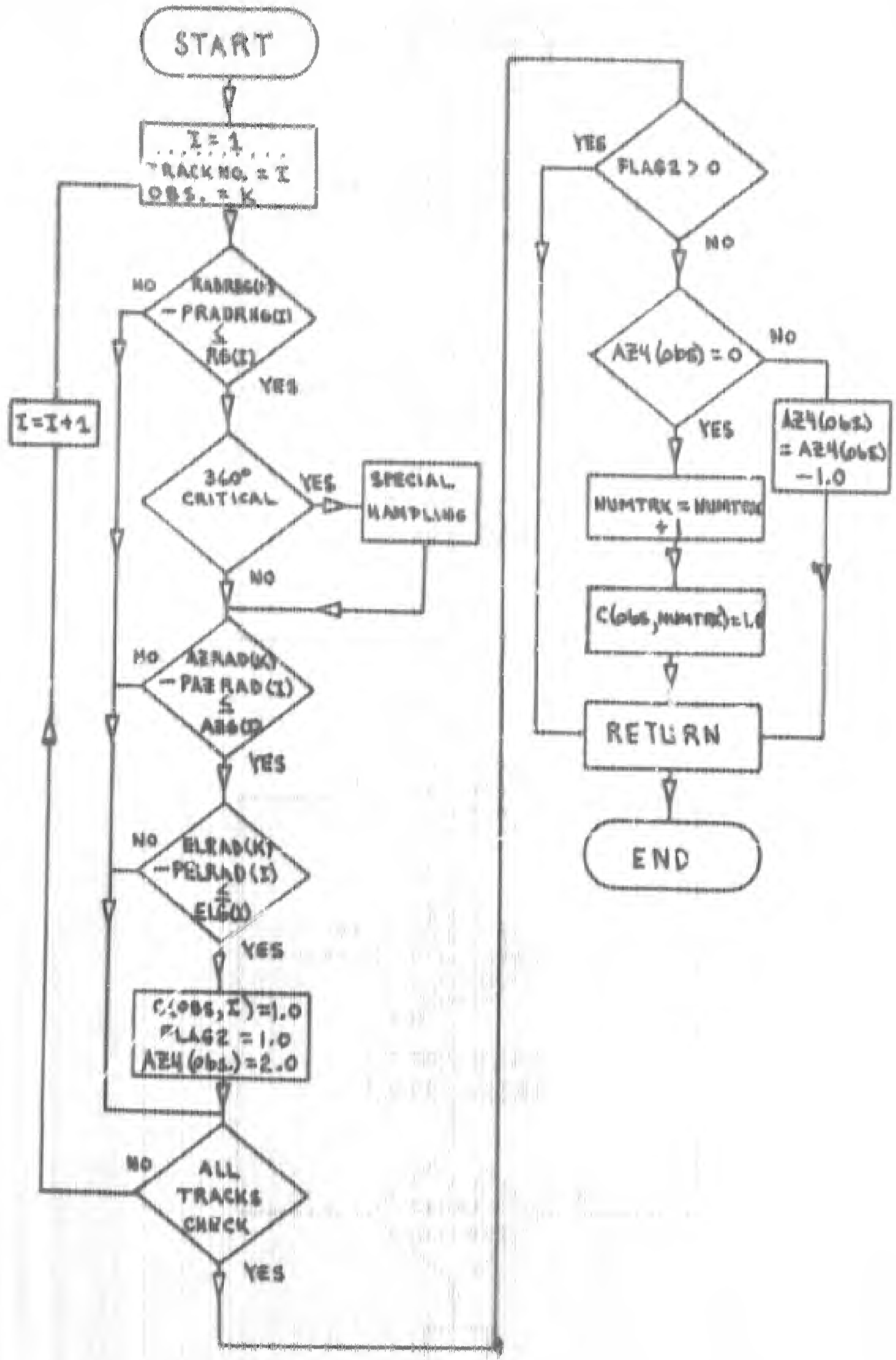

START
ACTUAL RANGE & TABLE RANGE
>
<
=
PDET=PD(I-1)
PDET=PD(I)
CALL RANI (RANDOM)
PDET(-) RANDOM
<
≥0
CALL RNDEV (DEV)
NO ECHO
RADRNG = ACTUAL RNG + 0.3× DEV
RETURN
END

MOVAVE

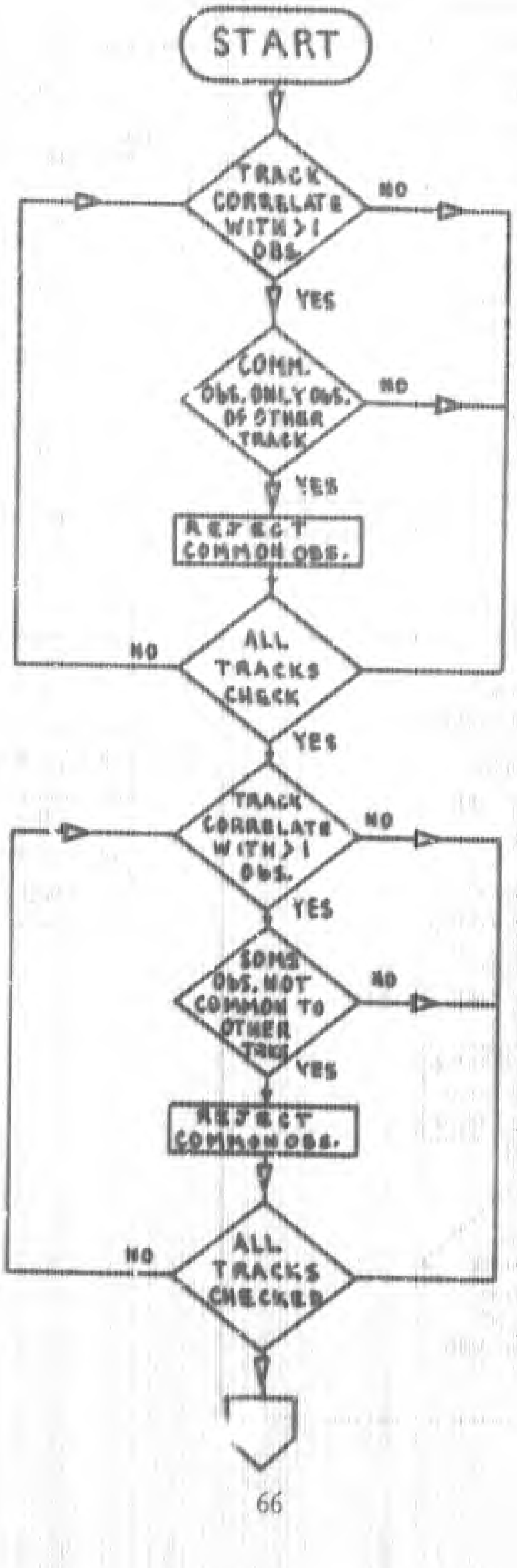


START
1ST TARGET AFTER 360°
INITIALIZE COUNTERS
ESTABLISH RANGE BOX LIMITS
TARGET IN RANGE BOX
YES
NO
ALL BOXES CHECKED
NO
ECHO RECEIVED AS GIVEN BY DETECT
NO
+1
YES
+0
UPDATE COUNTER FOR THIS RANGE BOX
COUNTER > THRESHOLD
NO
YES
CALCULATE AZRAD ELRAD
END

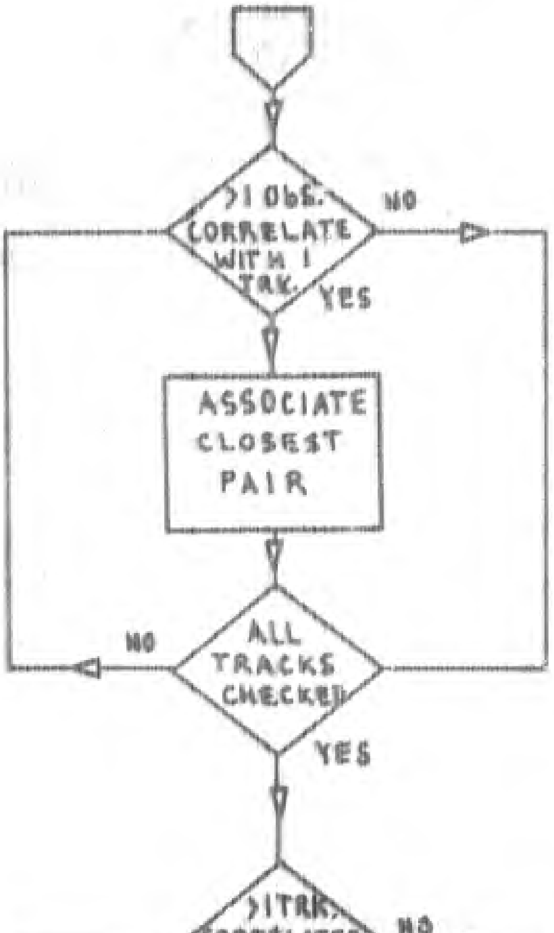
CORRASS


START
I = 1
TRACK NO. = I
OBS. = K
NO
RADRNG(K)
− PRADRNG(I)
≤
RG(I)
YES
I=I+1
360°
CRITICAL
YES
SPECIAL
HANDLING
NO
NO
AZRAD(K)
− PAZRAD(I)
≤
AZG(I)
YES
NO
ELRAD(K)
− PELRAD(I)
≤
ELG(I)
YES
C(OBS,I)=1.0
FLAG2 = 1.0
AZ4(obs.)=2.0
NO
ALL
TRACKS
CHECK
YES
YES
FLAG2 > 0
NO
AZ4(obs) = 0
NO
YES
AZ4(obs)
= AZ4(obs)
−1.0
NUMTRK = NUMTR
+
C(obs,NUMTRK)=1.
RETURN
END

ASSOC

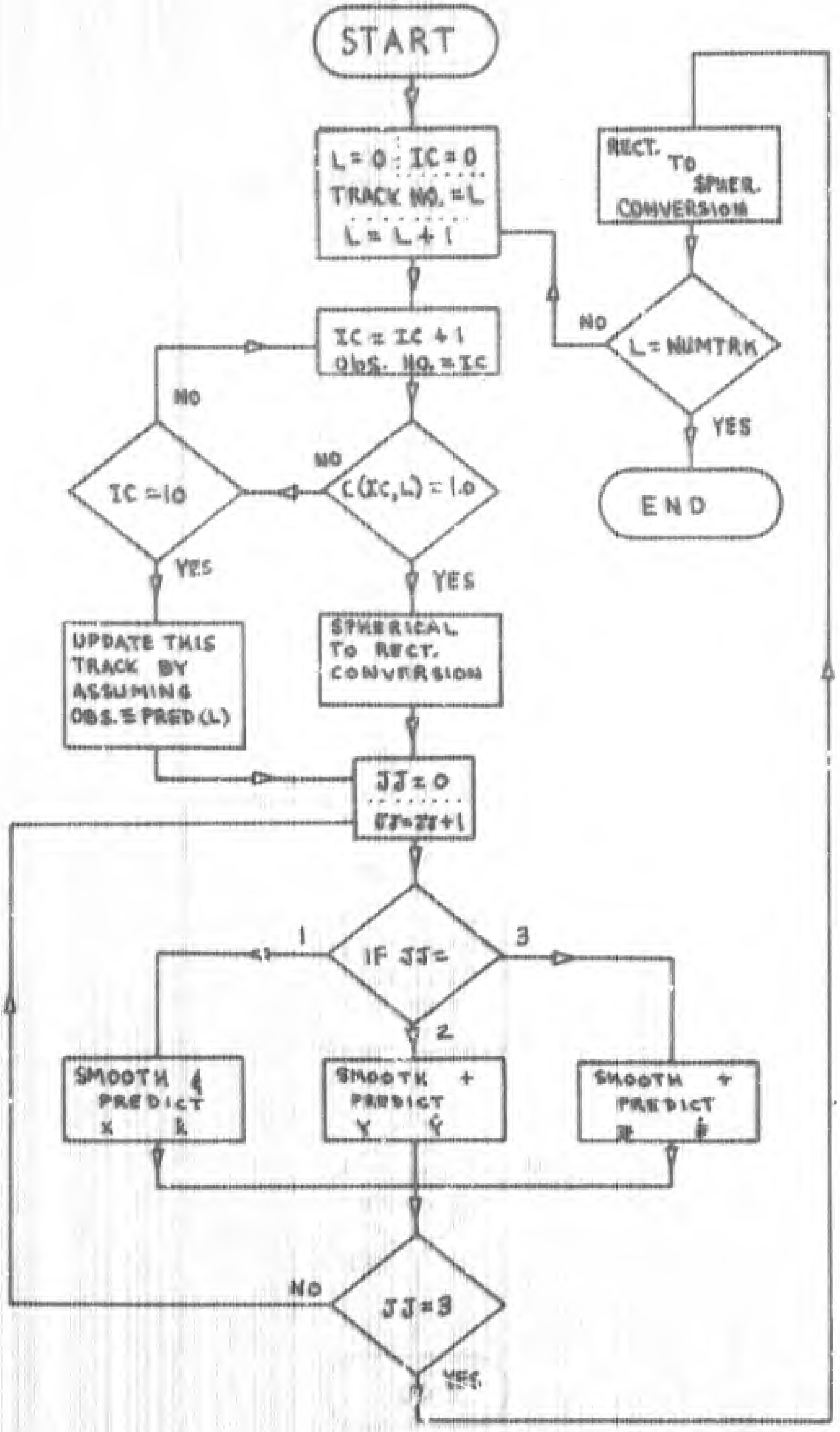

START
TRACK CORRELATE WITH >1 OBS.
NO
YES
COMM. OBS. ONLY OBS. OF OTHER TRACK
NO
YES
REJECT COMMON OBS.
ALL TRACKS CHECK
NO
YES
TRACK CORRELATE WITH >1 OBS.
NO
YES
SOME OBS. NOT COMMON TO OTHER TRK
NO
YES
REJECT COMMON OBS.
ALL TRACKS CHECKED
NO

ASSOC (CONT)

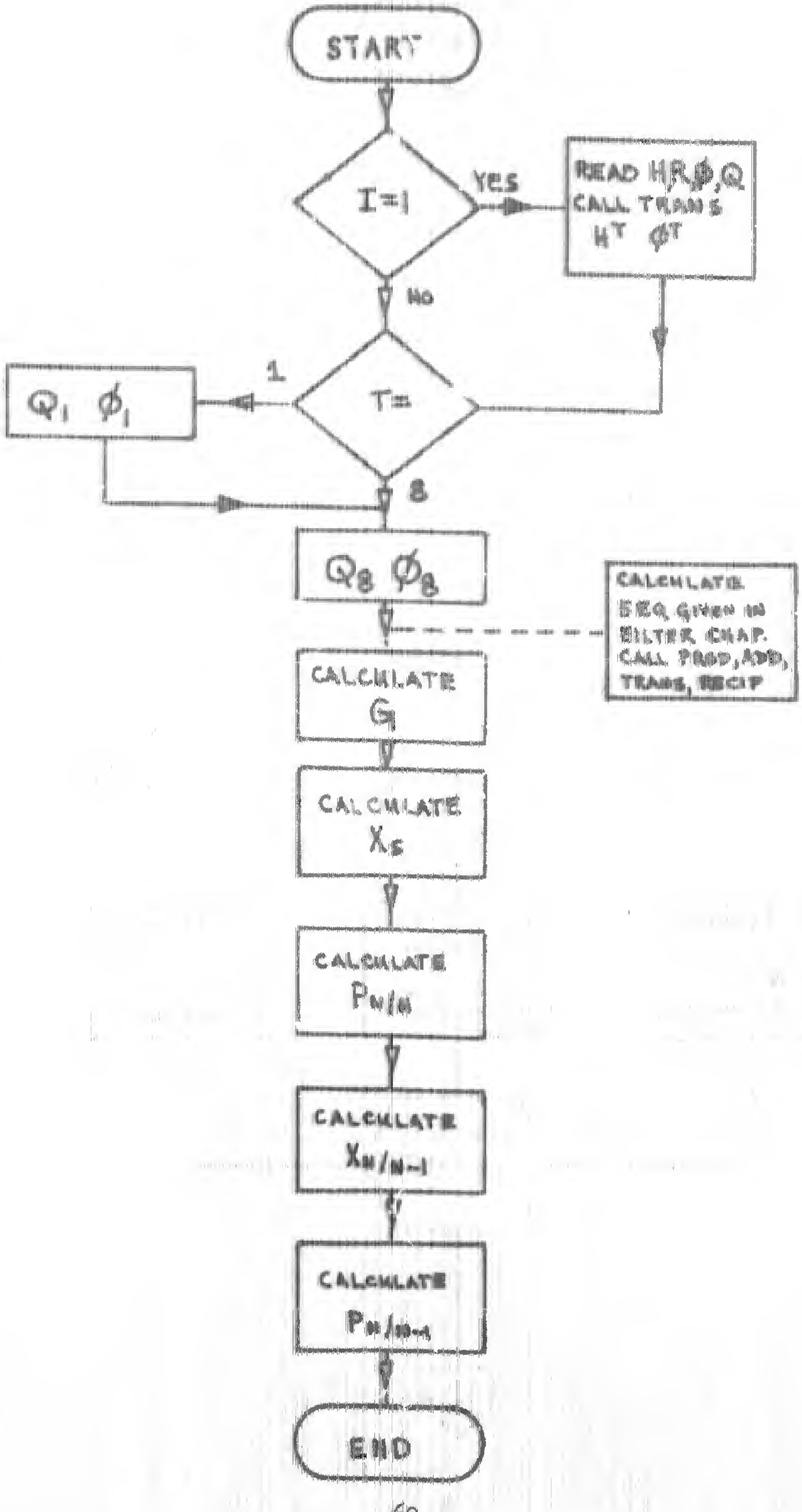


>1 Obs. CORRELATE WITH 1 TRK.
NO
YES
ASSOCIATE CLOSEST PAIR
ALL TRACKS CHECKED
NO
YES
>1 TRK. CORRELATES WITH 1 Obs.
NO
YES
ASSOCIATE CLOSEST PAIR
ALL Obs. CHECKED
NO
YES
END

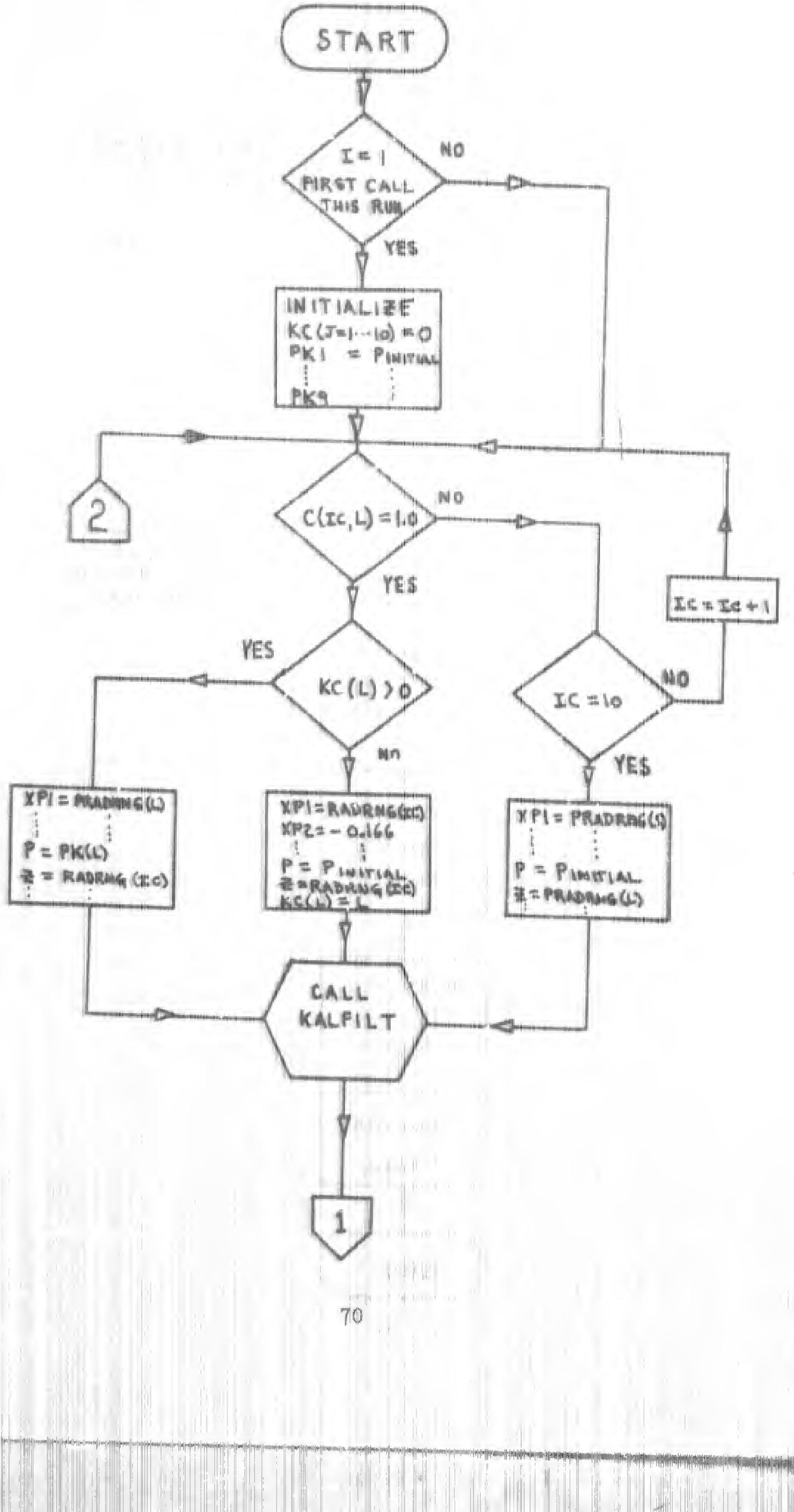
ABFILT


START
L = 0 ; IC = 0
TRACK NO. = L
L = L + 1
IC = IC + 1
Obs. NO. = IC
NO
C(IC,L) = 1.0
NO
IC = 10
YES
YES
UPDATE THIS TRACK BY ASSUMING OBS. = PRED(L)
SPHERICAL TO RECT. CONVERSION
JJ = 0
JJ = JJ + 1
IF JJ =
1
2
3
SMOOTH & PREDICT X $\dot{X}$
SMOOTH + PREDICT Y $\dot{Y}$
SMOOTH + PREDICT Z $\dot{Z}$
NO
JJ = 3
YES
RECT. TO SPHER. CONVERSION
NO
L = NUMTRK
YES
END

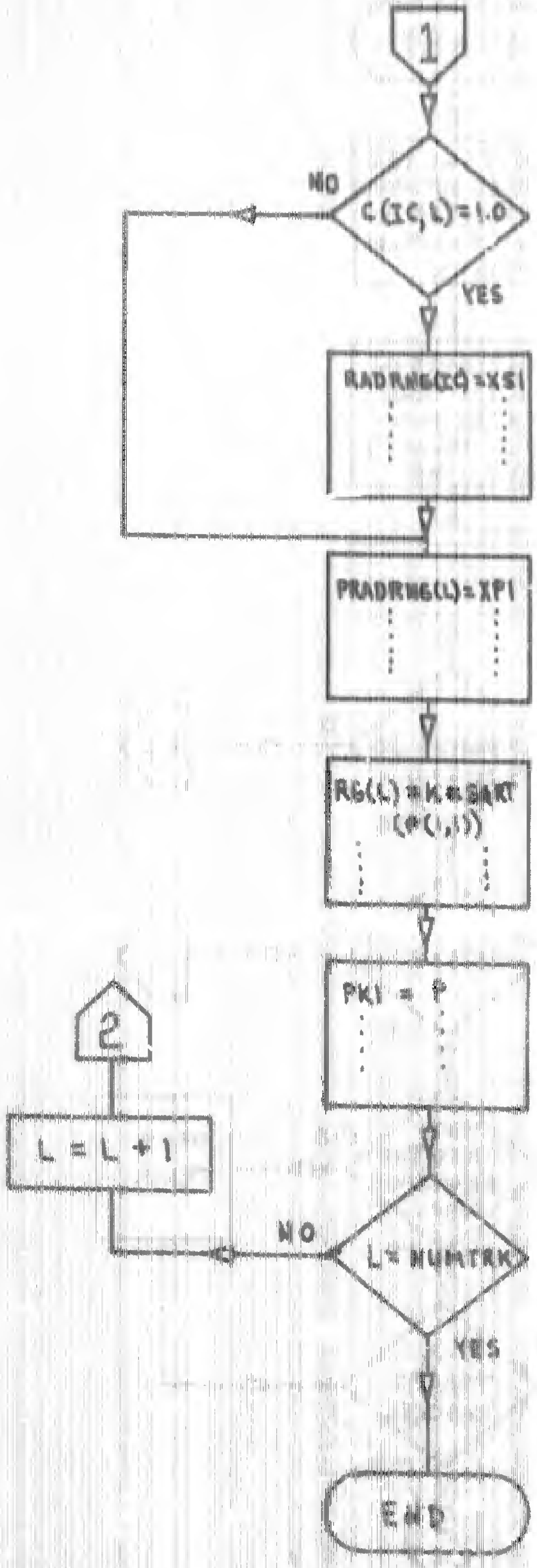
KALFILT


START
I=1
YES
READ H,R,ϕ,Q
CALL TRANS
H^T ϕ^T
NO
T=
1
Q_1 ϕ_1
8
Q_8 ϕ_8
CALCULATE EQ. GIVEN IN FILTER CHAP. CALL PROD, ADD, TRANS, RECIP
CALCULATE G_1
CALCULATE X_s
CALCULATE $P_{N/N}$
CALCULATE $X_{N/N-1}$
CALCULATE $P_{N/N-1}$
END

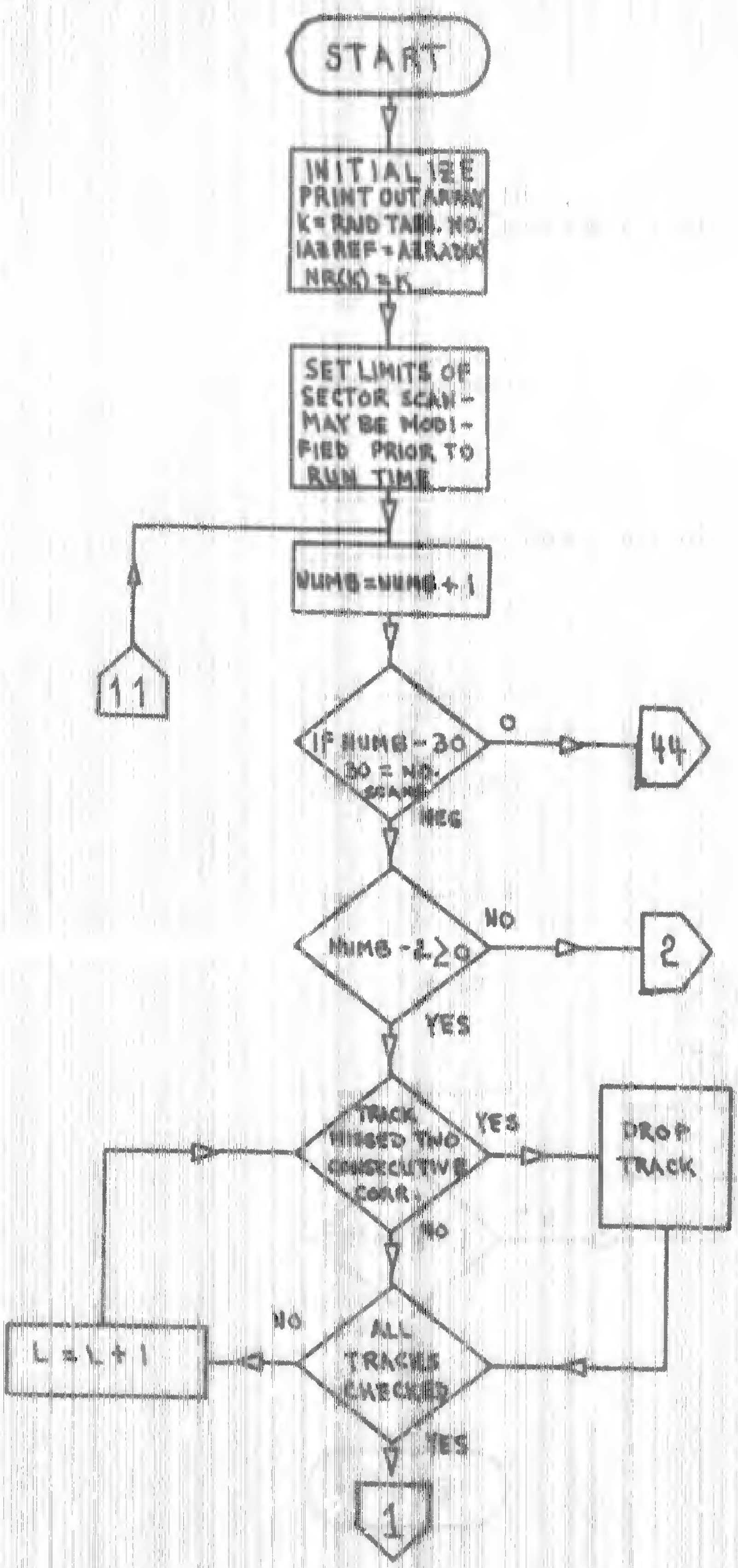
SETUP

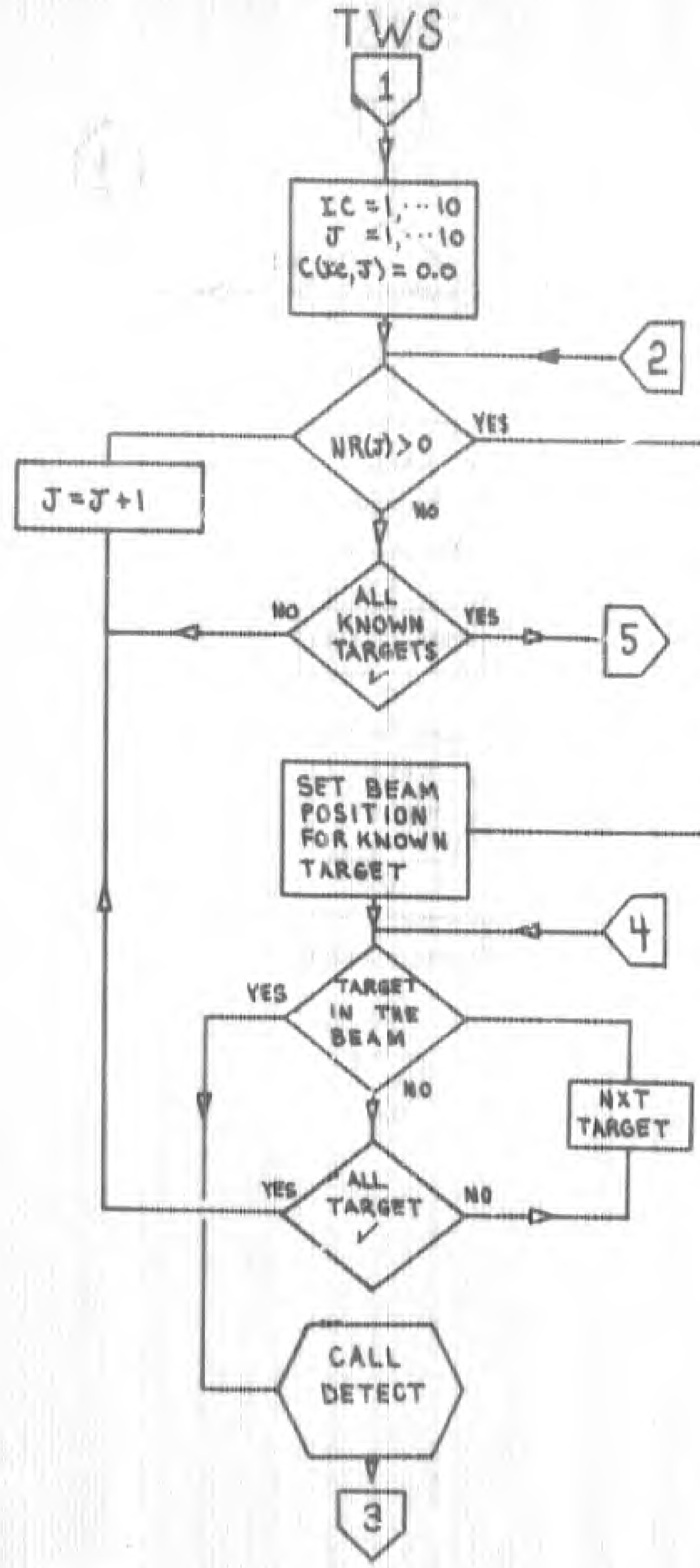

START
I = 1
FIRST CALL
THIS RUN
NO
YES
INITIALIZE
KC(J=1…10) = 0
PK1 = PINITIAL
PK9
2
C(IC,L) = 1.0
NO
YES
IC = IC + 1
YES
KC(L) > 0
NO
IC = 10
NO
YES
XP1 = PRADRNG(L)
P = PK(L)
Z = RADRNG (IC)
XP1 = RADRNG(IC)
XP2 = − 0.166
P = PINITIAL
Z = RADRNG(IC)
KC(L) = 1
XP1 = PRADRNG(1)
P = PINITIAL
Z = PRADRNG(L)
CALL
KALFILT
1

SETUP (CONT)

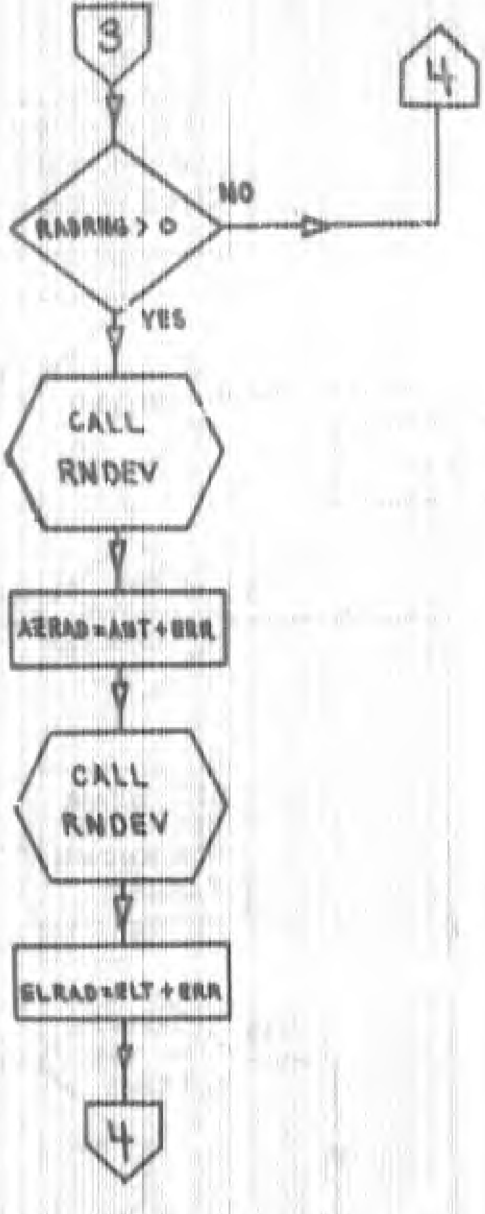

1
C(IC,L)=1.0
NO
YES
RADRNG(IC)=XS1
PRADRNG(L)=XP1
RG(L) = K*SQRT
(Φ(1,1))
PK1 = P
2
L = L + 1
NO
L = NUMTRK
YES
END

TWS

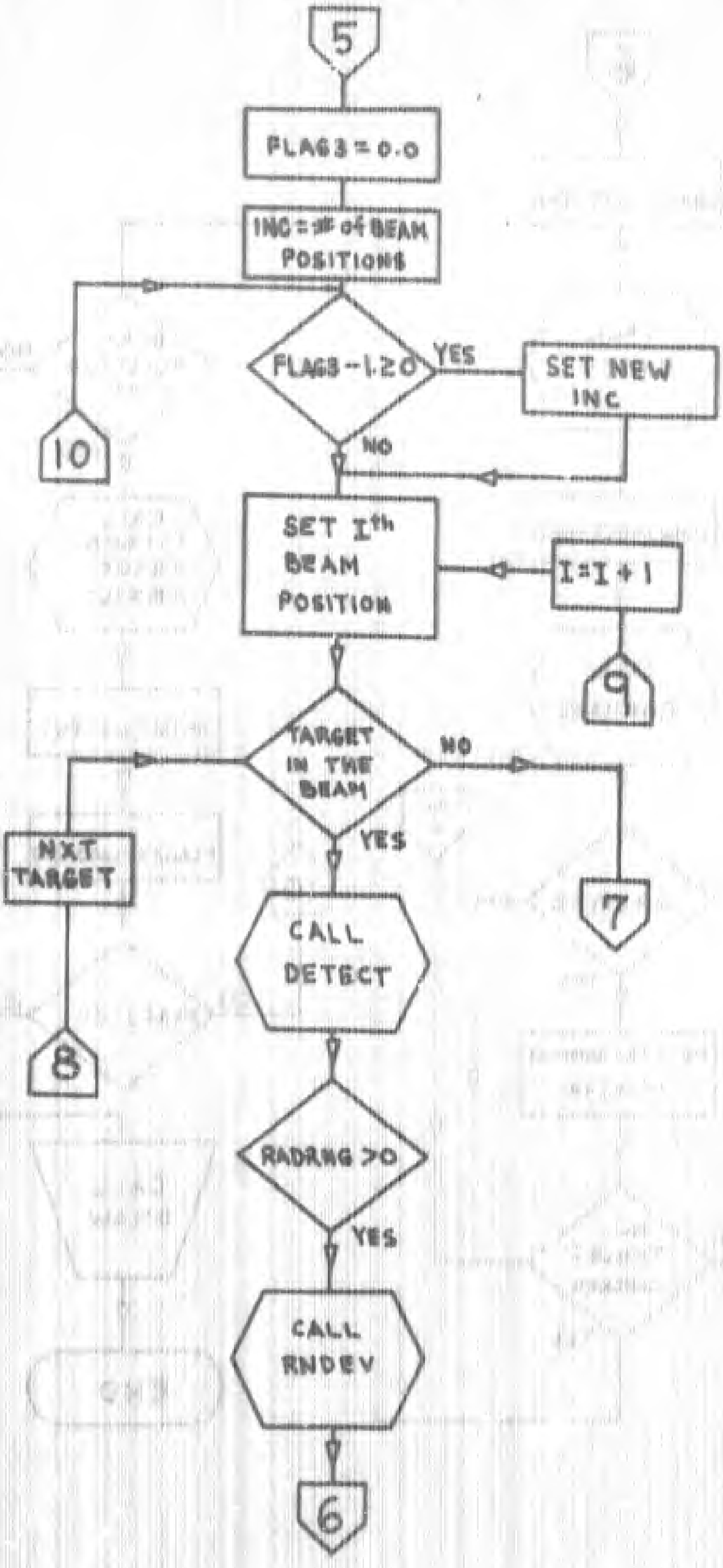

START
INITIALIZE
PRINT OUT ARRAY
K = RAD TAB. NO.
IABREF = ABRADK
NB(K) = K
SET LIMITS OF SECTOR SCAN - MAY BE MODIFIED PRIOR TO RUN TIME
NUMB = NUMB + 1
11
IF NUMB - 30
30 = NO. SCANS
0
44
NEG
NUMB - 2 ≥ 0
NO
2
YES
TRACK MISSED TWO CONSECUTIVE CORR.
YES
DROP TRACK
NO
ALL TRACKS CHECKED
NO
L = L + 1
YES
1


TWS
1
IC = 1, ··· 10
J = 1, ··· 10
C(IC,J) = 0.0
2
NR(J) > 0
YES
NO
J = J + 1
NO
ALL KNOWN TARGETS ✓
YES
5
SET BEAM POSITION FOR KNOWN TARGET
4
YES
TARGET IN THE BEAM
NO
NXT TARGET
YES
ALL TARGET ✓
NO
CALL DETECT
3

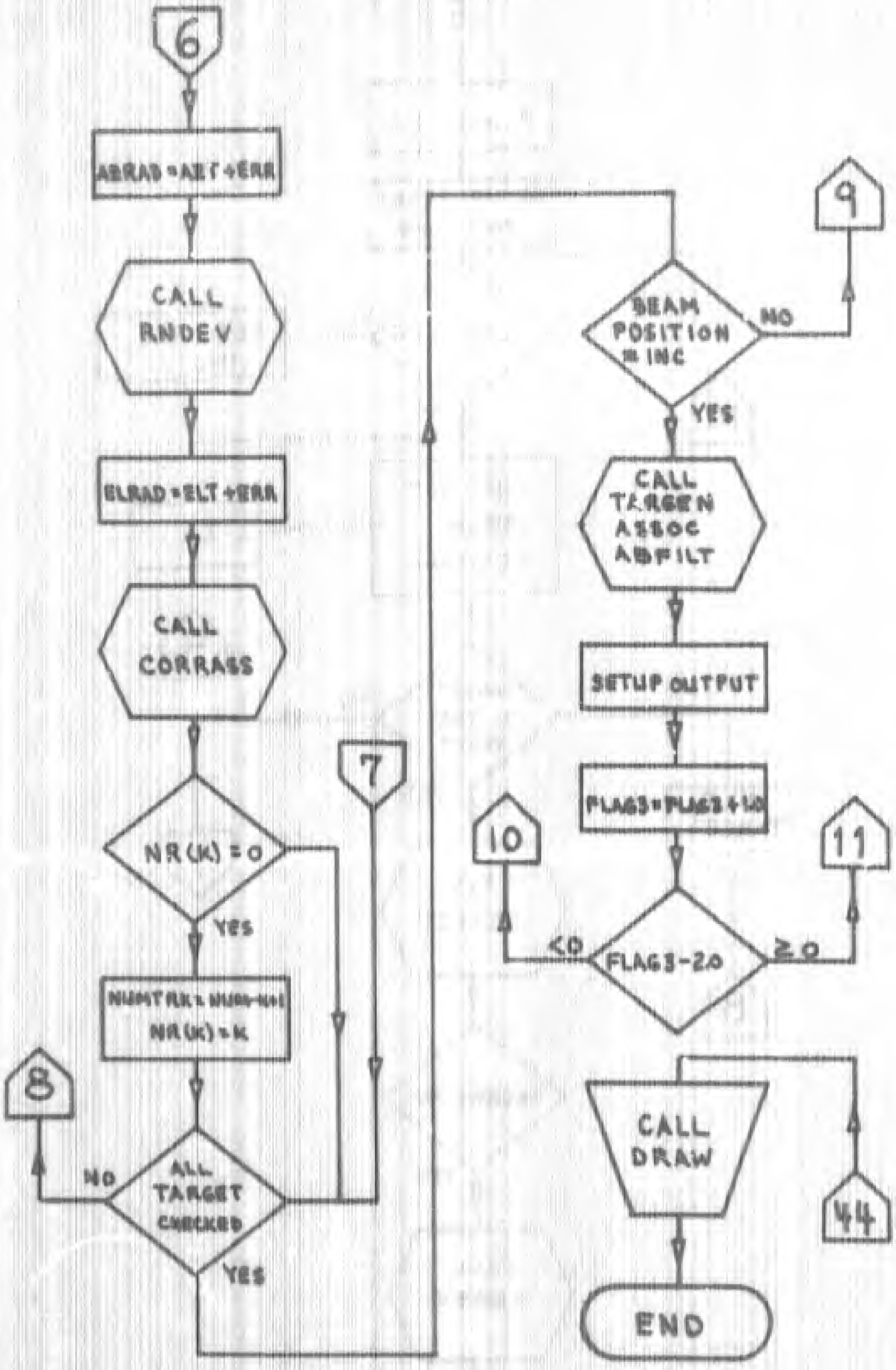
TWS


3
4
RADRNG > 0
NO
YES
CALL RNDEV
AZRAD = AZT + ERR
CALL RNDEV
ELRAD = ELT + ERR
4

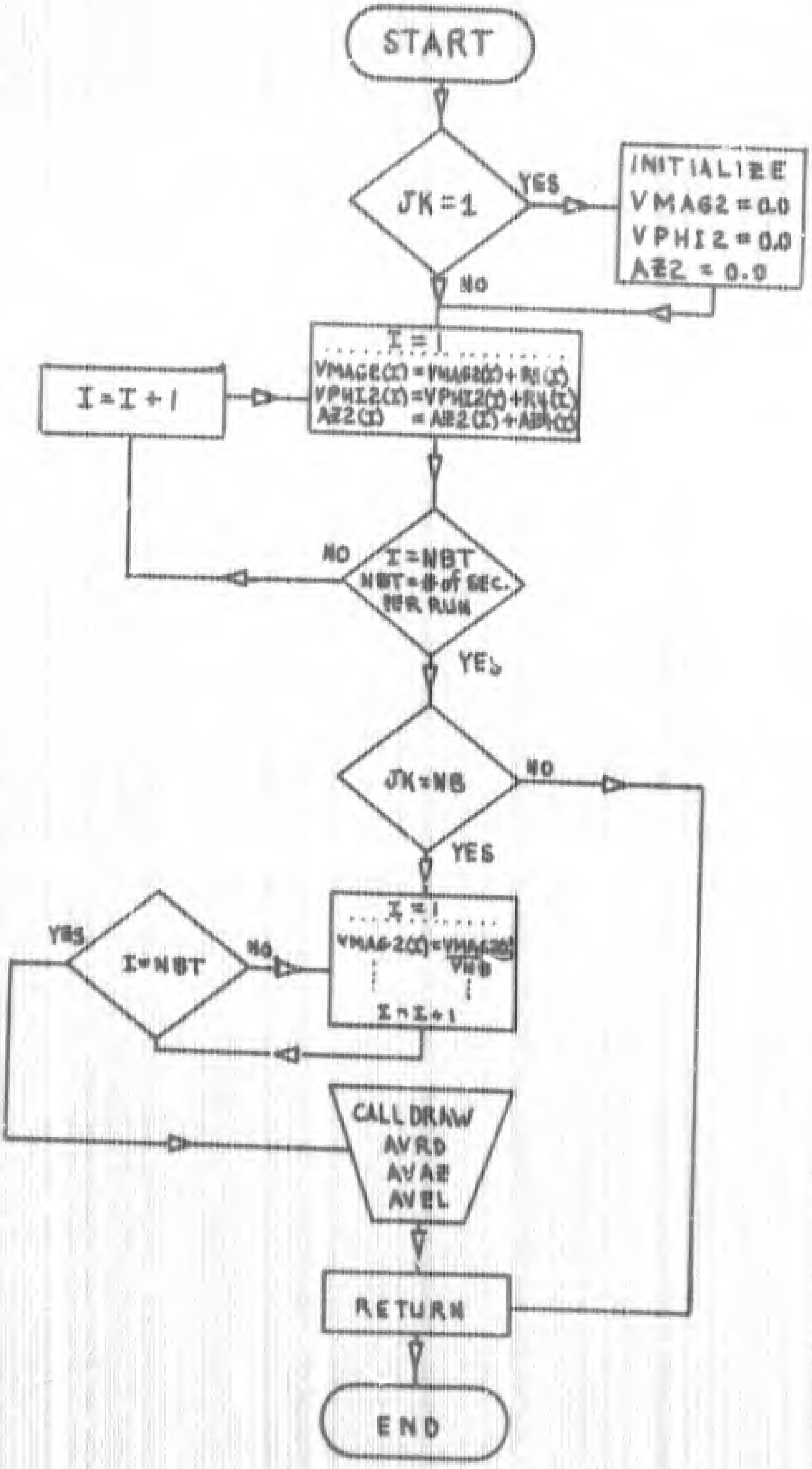
TWS


5
FLAG3 = 0.0
INC = # of BEAM POSITIONS
FLAG3 - 1. ≥ 0
YES
SET NEW INC
NO
10
SET Ith BEAM POSITION
I = I + 1
9
TARGET IN THE BEAM
NO
YES
NXT TARGET
7
CALL DETECT
8
RADRNG > 0
YES
CALL RNDEV
6

TWS


6
ABRAD=AZT+ERR
CALL RNDEV
ELRAD=ELT+ERR
CALL CORRASS
NR(K)=0
YES
7
NUMTRK=NUMTRK+1
NR(K)=K
8
NO
ALL TARGET CHECKED
YES
9
BEAM POSITION = INC
NO
YES
CALL TARGEN ASSOC ABFILT
SETUP OUTPUT
FLAG3=FLAG3+1.0
10
11
<0
FLAG3-2.0
≥0
CALL DRAW
44
END

MONTE


START
JK = 1
YES
INITIALIZE
VMAG2 = 0.0
VPHI2 = 0.0
AZ2 = 0.0
NO
I = 1
VMAG2(I) = VMAG2(I) + R1(I)
VPHI2(I) = VPHI2(I) + R4(I)
AZ2(I) = AZ2(I) + A[illegible](I)
I = I + 1
NO
I = NBT
NBT = # of SEC. PER RUN
YES
JK = NB
NO
YES
I = 1
VMAG2(I) = VMAG2(I) / NB
I = I + 1
YES
I = NBT
NO
CALL DRAW
AVRD
AVAZ
AVEL
RETURN
END

APPENDIX IV

PROGRAM LISTING

```
      PROGRAM KA2TVGS
      DIMENSION           RANGE(10),TARGRNG( 10   ),PD(10),
     1ITITLE(12),HD(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),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)
     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),XP1(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,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
     2 AZT    ,    ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TF  T,AZRAD1,
     3RADRNG1,ELRAD1, 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,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
C
C
C        KALMAN FILTER IN POLAR COORDINATES
C HEADING = DEGREES    VELOCITY = N.M./ HR.  ALTITUDE = FEET
C
C
C
C        FORMAT STATEMENTS
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)
  105 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,  I10    )
  120 FORMAT(  F10.4)
  122 FORMAT(/, I5,1X,6F10.4,I5)
  123 FORMAT(/,4X,3H K ,3X, 8H RADRNG ,2X,6H AZRAD, 4X, 6H ELRAD, 4X,
     15H XRAD, 5X, 5H YRAD, 5X, 5H ZRAD, 5X, 4H  I )
  161 FORMAT(/,10X,5HLL = ,I2,5X,6HXT1 = ,F10.4,5X, 4HYT1 = , F10.4 )
  162 FORMAT(/,10X, 5HLL = ,I2,5X,8HXRAD1 = ,F10.4,5X, 9HYRAD1 = ,F10.4)
  191 FORMAT(/,5X,5H K = ,I2, 5X, 7H AZT = ,F10.4,5X,7H ELT =  ,F10.4,
     15H XT = ,F10.4, 5HYT = , F10.4 ,5X,10HTARGRNG = ,F10.4)
C
C
C          CONSTANTS AND FLAGS
C
      RADDEG = 57.2957795131
      NUNIF = 12207003125.
      IR=71625307
      READ 106,(PD(J),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 ITITLE(J) = 8H
      DO 53 J=1,10
      INDE(J)=0
   53 INDEX(J)=0
      T=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(I-(INDE(J) +1)) 156,154,156
  156 INDEX(J) =1
      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)
      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)) *
     1SINF(AZRAD(K   ) / 57.29577)
      YRAD(K   )=(RADRNG(K   )*COSF(ELRAD(K   )/57.29577)) *
     1COSF(AZRAD(K   )/ 57.29577)
      LL= I
      IF(K-1)200,200,201
  200 XT1(LL)= XT(K)
      YT1(LL)= YT(K)
      IF(I-1) 57,57,58
   57 XRAD1(LL)=XRAD(K)
      YRAD1(LL)=YRAD(K)
      GO TO 56
   58 CC= .0
      DO 51 J=1,10
   51 CC=CC+C(K,J)
```

```
      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-1) 557,557,558
  557 XRAD2(LL)=XRAD(K)
      YRAD2(LL)=YRAD(K)
      GO TO 56
  558 CC= .0
      DO 551 J=1,10
  551 CC=CC+C(K,J)
        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
      PRINT122, K,RADRNG(K   ),AZRAD(K   ), ELRAD(K   ),XRAD(K   ), YRAD(K
     1), 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
```

```
 ITITLE(7)=8H DELANEY
 ITITLE(8)=8H W.F.
 ITITLE(9)=8HKALMAN
 ITITLE(10)=8HJOB0194
 ITITLE(11)=8H
 ITITLE(12)=8H
 LABEL=4H
 CALL DRAW(LL,XT1,YT1,1,0,LABEL,ITITLE, 3., 3.,0,0,2,2,5, 8,0,LAST)
 CALL DRAW(LL,XT2,YT2,2,0,LABEL,ITITLE, 3., 3.,0,0,2,2,5, 8,0,LAST)
 CALL DRAW(LL,XRAD2,YRAD2,2,5,LABEL,ITITLE, 3.,3.,0,3,2,2,6,10,0,
1EAST)
 CALL DRAW(LL,XRAD1,YRAD1,3,1,LABEL,ITITLE, 3.,3.,0,3,2,2,6,10,0,
1LAST)
 CALL TWS
 END
 SUBROUTINE SCAN360
 DIMENSION         RANGE(10),TARGRNG( 10   ),PD(10),
1ITITLE(12),HD(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),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        RANGE,TARGRNG,PDET,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,
3RADRNG1,ELRAD1, 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,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
 GO= .0
```

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

```
10 IF(I1-11) 11,8,8
 9 GO =0.0
   RETURN
   END
   SUBROUTINE DETECT
   DIMENSION          RANGE(10),TARGRNG( 10    ),PD(10),
  1ITITLE(12),HD(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),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         RANGE,TARGRNG,PDET,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,
  3RADRNG1,ELRAD1, 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,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 RANI(IR, RANDOM)
      IF(PDET - RANDOM )7,6,6
    6 CALL RNDEV(NUNIF,DEV)
      RANERR = (DEV*0.3)
      RADRNG(K  )=TARGRNG(K  )+RANERR
      PRINT 412, K, RADRNG(K  )
  412 FORMAT(/,10X,4HK = ,I2, 9HRADRNG = , F10.4,
     1 20HA GOOD RADAR TARGET )
      GO TO 8
    7 RADRNG(K  )=0.0
  411 FORMAT(/,10X,13HTARGET NO. = , I2, 7H A MISS )
      PRINT 411,K
    8 RETURN
      END
      SUBROUTINE MOVAVE
      DIMENSION          RANGE(10),TARGRNG( 10   ),FD(10),
     1ITITLE(12),HD(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),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          RANGE,TARGRNG,PDET,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,
     3RADRNG1,ELRAD1, 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,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=TARGRNG(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 = NUM3
      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
   15 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
      TESTT=TESTT +1.0
      PRINT 18,AZRAD(N  ), ELRAD(N  ), ELERR
   18 FORMAT(/,10X,13HGO TO CORRASS ,8HAZRAD = ,F10.4, 10X, 8HELRAD = ,
     1 F1 .4,10X,8HELERR = , F10.4)
   14 RETURN
      END
      SUBROUTINE CORRASS
      DIMENSION           RANGE(10),TARGRNG( 10    ),PD(10),
     1ITITLE(12),HD(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),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          RANGE,TARGRNG,PDET,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,AZRADI,
     3RADRNG1,ELRAD1, 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,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
      N = NUM3
      FLAG2=0.0
  505 DO 18 K = 1, NUMTRK
      PRINT 203,RG(K),AZG(K),ELG(K)
```

```
203 FORMAT(//,30X,5HRG = ,F10.6,5X,6HAZG = ,F10.6,5X, 6HELG = ,F10.6)
      IF(ABSF(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(ABSF(AZY-PAZRAD(K))-AZG(K)) 16,16,18
304 IF(ABSF(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(ABSF(PAZY-AZRAD(N)) -AZG(K)) 16,16,18
 16 IF(ABSF(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. ,I2,2X, 23HDID NOT CORRELATE WITH ,I2,
   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
    RC(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),
```

```
      1ITITLE(12),HD(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),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        RANGE,TARGRNG,PDET,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,
      3RADRNG1,ELRAD1, 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,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
  121 DO 19 J= 1,10
      SUM1=0
      DO 25 IC=1,10
   25 SUM1=C(IC,J)+SUM1
      IF(SUM1-1.)19,19,26
   26 DO 119 IC=1,10
      IF(C(IC,J)-1.)19,20,19
   20 JP1=J+1
      DO 21 JP2=JP1,10
      IF(C(IC,JP2)-1.)21,22,21
   22 IP1=1
      SUM2=0
      DO 23 IP1=1,10
   23 SUM2=C(IP1,JP2)+SUM2
      IF(SUM2-1.)21,24,21
   24 C(IC,J)=0
   21 CONTINUE
  119 CONTINUE
```

```
 19 CONTINUE
    DO 31 J=1,10
    SUM3=0
    DO 32 IC=1,10
 32 SUM3=C(IC,J)+SUM3
    IF(SUM3-1.)31,31,33
 33 DO 131 IC=1,10
    IF(C(IC,J))131,31,36
 36 SUM4=0
    JP3=J+1
    DO 35 JP4=JP3,10
 35 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
 39 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
 42 SUM6=SUM6+C(IC,J)
    IF(SUM6-1.)41,41,43
 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=IA,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
   49 C(IC,J)=0
      C(NB,J)=1
   41 CONTINUE
      DO 51 IC=1,10
      SUM7=0
      DO 52 J=1,10
   52 SUM7=SUM7+C(IC,J)
      IF(SUM7-1.)51,51,53
   53 DO 54 J=1,10
      S(J)=.210
      IF(C(IC,J))54,54,555
  555 S(J) = PRADRNG(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
   59 C(IC,J)=0
      C(IC,NC) = 1
   51 CONTINUE
      PRINT 63
   63 FORMAT(/10X,24H      CORRELATION MATRIX)
```

```
   PRINT 60,((C(IC,J),J=1,10),IC=1,10)
60 FORMAT(//10X,10F10.3)
   END
    SUBROUTINE TARGEN
   DIMENSION           RANGE(10),TARGRNG( 10   ),PD(10),
  1ITITLE(12),HD(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),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         RANGE,TARGRNG,PDET,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,
  3RADRNG1,ELRAD1, 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,YPAD1,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
   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
   GO TO 8
```

```
11 AZT(K      ) = 270.0 -AZ1
 8 TARGRNG(K      ) = SQRTF((XT(K       ))**2 +(YT(K       ))**2+
  1(ZT(K))**2)
  ELT(K      ) = ATANF(ZT(K       )/SQRTF((XT(K       ))**2
 1 +(YT(K       ))**2)) *RADDEG
  ALT(K)=6076.1*ZT(K)
 1 CONTINUE
  RETURN
  END
  SUBROUTINE SETUP
  DIMENSION           RANGE(10),TARGRNG( 10    ),PD(10),
  1TITLE(12),HD(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),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)
  DIMENSION HPHT(6,6),X(6,6),VNI(6,6),Z(6,6),PHT(6,6),
  1PHIT(6,6), P1(6,5  ),H(6,6),HT(6,6),PHI(6,6),R(6,6),Q(6,6),P(6,6),
  2XS(6,6),XP(6,6),XP1(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),
  1MC(10),PK1(6,6),PK2(6,6),PX3(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, EV,
  1 RANERR, RADRNG,HD,VEL,ALT,PITCH,XT,YT,NT,JA,T,I,TEST,
  2 AZT    ,   ELT, IAZ, BOXMAX,BOXMIN,ELTEST,TESTT,AZRAD1,
  3RADRNG1,ELRAD1, AZRAD ,C,S,DOTT,ZT,PAZRAD,ELBEAMT
  4,FLAG, NUMTRK, NUM1 ,NUM2,NUM3,AZBEAMT,RADDEG,ELRAD
  5, XRAD,YRAD,ZRAD,CONT,PRAURNG,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
  IF(I-1) 425,425,61
```

```
425 DO 104 J=1,10
104 KC(J)= 0
    DO 488 L=1,6
    DO 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) = P(L,M)
 61 DO 777 L=1,NUMTRK
 23 NUM2 = T
    DO 21 IC= 1,10
    IF(C(IC,L)) 21,21,22
 21 CONTINUE
    XP(1,1)= PRADRNG(L)
    XP(2,1)= RDOT(L)
    XP(3,1)= PAZRAD(L)
    XP(4,1)= AZDOT(L)
    XP(5,1)= PELRAD(L)
    XP(6,1)= ELDOT(L)
    DO 296 M=1,6
    DO 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)
```

```
      GO TO 267
   22 LT=L
      IF(KC(LT)) 264,264,265
  264 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)=RADRNG(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)= RDOT(L)
      XP(3,1)= PAZRAD(L)
      XP(4,1)= AZDOT(L)
      XP(5,1)= PELRAD(L)
      XP(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,JJ)=PK1(J,JJ)
```

```
      GO TO 267
  269 DO 272 J=1,6
      DO 272 JJ=1,6
  272 P(J,JJ)= PK2(J,JJ)
      GO 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 DC 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 KALFILT(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)
263 RDOT(L) = XP(2,1)
    AZDOT(L) = XP(4,1)
    ELDOT(L) = XP(6,1)
    PRADRNG(L)=XP(1,1)
    PAZRAD(L)= XP(3,1)
    PELRAD(L) =XP(5,1)
    RG(L) = 2.0 * SQRTF(P(1,1))
    AZG(L) = 1.0 * SQRTF(P(3,3))
     ELG(L) = 2.5* SQRTF(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 4I4 JJ=1,6
414 PK5(J,JJ)= P(J,JJ)
```

```
    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            RANGE(10),TARGRNG( 10    ),PD(10),
   1ITITLE(12),HD(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),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)
   9,XT2(30),YT2(30),XRAD2(30),YRAD2(3 )
    DIMENSIONXS(6,6),XP(6,6),P(6,6),KC(10)
    COMMON          RANGE,TARGRNG,PDET,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,
   3RADRNG1,ELRAD1, 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,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
      ITITLE(1)=8HSECT SCA
      ITITLE(2)=8HN MANEUV
      ITITLE(3)=8HING TARG
      ITITLE(4)=8H0 DEG/SE
      ITITLE(5)=8HC
      ITITLE(6)=8HKALMAN
      ITITLE(7)=8H DELANEY
      ITITLE(8)=8H W.F.
      ITITLE(9)=8H
      ITITLE(10)=8HJOB0I94
      ITITLE(11)=8HTEST RUN
      ITITLE(12)=8H 2
      IXX = 20
      I= 1
      T=  .5
       DO 105 LL=1,200
      XT1(LL)=0.0
      YT1(LL)=0.0
       XRAD1(LL)=0.0
      YRAD1(LL)=0.0
  105 CONTINUE
      LL=
      LB=
      NUMB=0
      NUMTAR=1
      K=NUM3
      NR(K)=K
      IAZREF=AZRAD(K)
      PRINT 60,NT,K,IAZREF
   60 FORMAT(/,10X,3HNT=,I2,5X,2HK=,I2,5X,7HIAZREF=,I4)
      LIML=IAZREF-44
```

```
      IF(LIML) 2,4,4
    2 LIML=360+LIML
    4 LIMR=IAZREF +44
      IF(LIMR-360) 6,6,5
    5 LIMR=LIMR-360
    6 LIMB =1
      LIMT=29
      ITEL1=LIMB
      ITEMP1 = LIML
   28 NUMB=NUMB+1
       IF( NUMB - 30 ) 43,43,44
   43 PRINT 111, NUMB
  111 FORMAT(/,10X,7HNUMB = , I2)
       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-(INDE(J) +1)) 156,154,156
  156 INDEX(J) =1
      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  ,I2)
       NUMTRK =NUMTRK -1
```

```
  150 CONTINUE
      DO 55 IC=1,10
      DO 55 J= 1,10
   55 C(IC,J)=0.0
  160 DO 19 J=1,NT
      PRINT 61,J,NR(J)
   61 FORMAT(/,10X,2HJ=,I2,6HNR(J)=,I2 )
      IF( NR(J)) 19,19,23
   23 ITEL=ELRAD(NR(J))
      TEL=ITEL
      ITEMP = AZRAD(NR(J))
      TEMP=ITEMP
      IF(TEL) 75,70,75
   75 IF( (ELRAD(NR(J)) -TEL) -0.5000) 77,70,70
   70 TEL =TEL+1.0
   77 IF(TEL-29.0) 71,71,76
   76 TEL=TEL- 1.0
   71 IF((AZRAD(NR(J))-TEMP)-0.5000) 73,72,72
   72 TEMP =TEMP+1.0
   73 PRINT 74, TEL,ELRAD(NR(J)),TEMP,AZRAD(NR(J))
   74 FORMAT( /,10X,7H TEL = ,F10.4,5X,7HELRAD= ,F10.4, 5X,
     1 7HTEMP = ,F10.4,5X,8HAZRAD = ,F10.4)
C
C         THIS SECTION LOOKS AT KNOWN TARGETS
C
      DO 18 K=1,NT
      IF(ABSF(  TEL  - ELT(K))- 1.0) 16,16,18
   16 IF( AZT(K) -1.0) 92,92,94
   92 IF( 359.0 -TEMP) 93,93,94
   93 AZTT=AZT(K) + 360.0
      IF( ABSF(TEMP -AZTT) -1.0) 17,18,18
   94 IF(ABSF(  TEMP - AZT(K ) ) -1.0) 17,18,18
   17 NUM3=K
      PRINT 62,TEL,ELT(K),TEMP,AZT(K),K
   62 FORMAT(/,10X,4HTEL=,F10.4,5X,9H ELT(K)=,F10.4,5X,5HTEMP=,F10.4,5X,
     17HAZT(K)=,F10.4,5X,2HK=,I2)
```

```
      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 , I2,5X, 9HRADRNG = ,F10.4,5X,8HAZRAD = ,
     1F10.4, 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 KNOWM 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=IYEL1
      TEMP=ITEMP1
   37 DO 26 K=1,NT
      IF(ABSF(TEL  - ELT(K))-1.0) 25,25,26
   25 IF(ABSF( TEMP -AZT(K)) -1.0) 45,26,26
   45 NUM3=K
      CALL DETECT
      IF(RADRNG(K)) 26,26,34
   34 CALL RNDEV (NUNIF,DEV)
      AZRAD(K) = AZT(K) +DEV/100.
```

```
      CALL RNDEV (NUNIF,DEV)
      ELRAD(K) = ELT(K)+DEV/100.
      PRINT 20,K,RADRNG(K),AZRAD(K),ELRAD(K)
      CALL CORRASS
      IF( NR(K)) 106,106,26
  106 NUMTAR = NUMTAR +1
      NR(K)=K
   26 CONTINUE
      ITEMP1=ITEMP1+2
      IF(ITEMP1-360) 91,91,90
   90 ITEMP1=1
   91 IF( LIMR -90)82,83,83
   82 IF((ITEMP1 +90)-360) 83,80,80
   83 TEMP=ITEMP1
      IITEMP = TEMP
      IF( LIMR-IITEMP) 84,80,80
   84 ITEMP1=LIML
      ITEL1=ITEL1+2
      IF( ITEL1- 29) 80,80,85
   85 ITEL1=1
   80 CONTINUE
   36 CALL TARGEN
      CALL ASSOC
      CALL SETUP
      DO 56 K=1,NT
      XRAD(K   )=(RADRNG(K   )*COSF( ELRAD(K   )/57.29577)) *
     1SINF(AZRAD(K   ) / 57.29577)
      YRAD(K   )=(RADRNG(K   )*COSF(ELRAD(K   )/57.29577)) *
     1COSF(AZRAD(K   )/ 57.29577)
      LL = NUMB
      IF(K-1)200,200,201
  200 XT1(LL)= XT(K)
      YT1(LL)= YT(K)
   58 CC= .0
      DO 51 J=1,10
   51 CC=CC+C(K,J)
```

```
      IF(CC) 54,54,53
   53 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)
  558 CC= .0
      DO 551 J=1,10
  551 CC=CC+C(K,J)
       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 CONTINUE
      IF(LL - IXX) 301,300,301
  301 FLAG3=FLAG3+ 1.0
      FLAG3= FLAG3+1.0
      IF(FLAG3 -2.0) 102,28,28
  300 CALL DRAW(LL,XT1,YT1,1,0,LABEL,ITITLE, 1., 1.,0.0,2,2.5, 8.0,LAST)
      CALL DRAW(LL,XT2,YT2,2,0,LABEL,ITITLE, 1., 1.,0.0,2,2.5, 8.0,LAST)
      CALL DRAW(LL,XRAD2,YRAD2,2,5,LABEL,ITITLE, 1.,1.,0.3,2,2.6,10.0,
     1LAST)
      CALL DRAW(LL,XRAD1,YRAD1,3,1,LABEL,ITITLE, 3.,3.,0.3,2,2.6,10.0,
     1LAST)
      IXX = 21
      IF( NUMB - 21) 302,44,44
  302 NUMB= 0
      GO TO 301
   44 RETURN
      END
      SUBROUTINE KALFILT(Z,XS,XP,P,NUM1,NUM2)
```

```
      DIMENSION HPHT(6,6),X(6,6),VNI(6,6),Z(6,6),PHT(6,6),
     1PHIT(3,6), 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),XP1(6,6),T1(6,6),T2(6,6),Q1(6,6),Q8(6,6),PHI1(6,6)
     3,PHI8(6,6)
C
C THE FIRST SECTION OF KALFILT SETS UP THE INITIAL MATRICES REQUIRED
C IN THE RECURSION EQATIONS
C SECTION ONE IS EXECUTED IF NUM1=0
C         NUM3 = K OR TARGET NUMBER
C         NUM2 = T I.E. 1 OR β SEC. ACTS AS A FLAG TO PICK THE CORRESPONDING Q
C         AND PHI MATRIX
C
      IF(NUM1-1) 61,60,60
   61 PRINT 1
    1  FORMAT(//,40X,26H OBSERVABILITY OR H MATRIX )
      CALL READD(3,6,H)
      PRINT 2
    2 FORMAT(//,40X,19H H TRANSPOSE OR HT )
      CALL TRANS(H,3,6,HT)
      DO 3 I=1,6
    3 PRINT 4,(HT(I,J),J=1,3)
    4 FORMAT(/,3F13.5)
      PRINT 5
    5 FORMAT(//,20X,43HCOVARIANCE OF MEASUREMENT NOISE OR R MATRIX )
      CALL READD(3,3,R)
      PRINT 6
    6 FORMAT(//,40X,28HSTATE TRANSION OR PHI MATRIX )
      CALL READD(6,6,PHI1)
      PRINT 6
      CALL READD(6,6,PHI8)
      PRINT 7
    7 FORMAT(//,20X,39HCOVARIANCE OF PERTURBATIONS OR Q MATRIX )
      CALL READD(6,6,Q1)
      PRINT 7
      CALL READD(6,6,Q8)
C
```

```
C
   60 IF( NUM2 -1) 62,62,64
   62 DO 63 L=1,6
      DO 63 M=1,6
      Q(L,M)=Q1(L,M)
   63 PHI(L,M)=PHI1(L,M)
      GO TO 66
   64 DO 65 L=1,6
      DO 65 M= 1,6
      Q(L,M)=Q2(L,M)
   65 PHI(L,M)=PHI2(L,M)
   66 NUM1= 1
C
C Z IS THE OBSERVABILITY VECTOR TIMES X PLUS NOISE
C
C
C CALCULATE THE GAIN MATRIX G(N)
C
      CALL PROD(P,HT,6,6,3,PHT)
      CALL PROD(H,PHT,3,6,3,HPHT)
      CALL ADD(HPHT,R,3,3,HPHT)
      CALL RECIP(3,0.000001,HPHT,VNI,KER)
      IF(KER-2) 92,91,92
   91 PRINT 90, KER
   90 FORMAT(//,10X,6HKER = ,I2)
   92 CALL PROD(PHT,VNI,6,3,3,G)
C
C CALCULATE THE SMOOTH X VECTOR OR XS
C
      PRINT 100
  100 FORMAT(//,20X,2HXP)
      CALL PRINTT(6,1,XP)
      PRINT 101
  101 FORMAT(//,20X,1HZ)
      CALL PRINTT(3,1,Z)
      CALL PROD(H,XP, 3,6,1,XP1)
```

```
      DO 10 I=1,3
   10 XP1(I,1)= - XP1(I,1)
      CALL ADD(Z,XP1,3,1,Z)
      DO 31 I=1,6
      DO 31 J=1,6
   31 T1(I,J) =0.0
      CALL PROD(G,Z,6,3,1,T1)
      CALL ADD(XP,T1,6,1,XS)
      PRINT 102
  102 FORMAT(//,20X,2HXS)
       CALL PRINTT(6,1,XS)
C
C CALCULATE THE COVARIANCE OF THE ERROR MATRIX PNN
C
      CALL PROD(H,P,3,6,6,P1)
      DO 32 I=1,6
       DO 32 J= 1,6
   32 T2(I,J) = 0.0
      CALL PROD(G,P1,6,3,6,T2)
      DO 11 I=1,6
      DO 11 J=1,6
   11 T2(I,J)= - T2(I,J)
      CALL ADD(P,T2,6,6,P)
C
C CALCULATE THE PRIDICTED VALUE OF THE X VECTOR XN/N-1
C
      CALL PROD(PHI,XS,6,6,1,XP)
      PRINT 100
      CALL PRINTT(6,1,XP)
C
C CALCULATE THE PREDICTED COVARIANCE MATRIX OF ERROR PN/N-1
C
      CALL TRANS(PHI,6,6,PHIT)
      PRINT 14
   14 FORMAT(//,40X,20HPHI TRANSPOSE MATRIX )
      CALL PRINTT (6,6,PHIT)
```

```
      CALL PROD(P,PHIT,6,6,6,P1)
      DO 30 I=1,6
      DO 30 J=1,6
   30 T1(I,J) = 0.0
      CALL PROD(PHI,P1,6,6,6,T1)
      CALL ADD (T1,Q,6,6,P)
      PRINT 103
  103 FORMAT(//,20X,6HPN/N-1)
      CALL PRINTT(6,6,P)
   85 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=I,N )
      END
      SUBROUTINE PRINTT (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 D(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
      D(I,J)=0.0
      DO 151 K=1,M
```

```
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
    A(I,J)=B(I,J)
  1 X(I,J)=0.0
    DO 2 K=1,N
  2 X(K,K)=1.0
 10 DO 34 L=1,N
    KP=
    Z=0.0
    DO 12 K=L,N
    IF(Z-ABSF(A(K,L)))11,12,12
 11 Z=ABSF(A(K,L))
    KP = K
 12 CONTINUE
    IF(L-KP)13,20,20
 13 DO 14 J=L,N
    Z=A(L,J)
    A(L,J)=A(KP,J)
 14 A(KP,J)=Z
    DO 15 J=1,N
    Z=X(L,J)
    X(L,J)=X(KP,J)
 15 X(KP,J)=Z
 20 IF(ABSF(A(L,L))-EP)50,50,30
 30 IF(L-N)31,34,34
 31 LP1=L+1
```

```
      DO 36 K=LP1,N
      IF(A(K,L))32,36,32
   32 RATIO=A(K,L)/A(L,L)
      DO 33 J=LP1,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-N)41,43,43
   41 IIP1=II+1
      DO 42 K=IIP1,N
   42 S=S A(II,K)*X(K,J)
   43 X(II,J)=(X(II,J)-S)/A(II,II)
      KER=1
      RETURN
   50 KER=2
      RETURN
      END
       END
```

```
      PROGRAM KALMON1
      DIMENSION          RANGE(10),TARGRNG( 10    ),PD(10),
     1ITITLE(12),HD(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(100),YT1(100),
     5XRAD1(100),YRAD1(100),INDEX(10),INDE(10),CONT(10),IAT(10),PXRAD
     6(10),PYRAD(10),PZRAD(10),DOTX(10),DOTZ(10),DOTY(10),NR(10),HDFIX(
     710),PITFIX(10),VELFIX(10),RG(10),AZG(10),ELG(10),R1(40),R2(40),
     8R3(40),R4(40),AZ1(40),AZ2(40),AZ3(40),AZ4(40),VMAG1(40),VMAG2(40),
     9VMAG3(40),VMAG4(40),VPHI1(40),VPHI2(40),VPHI3(40),VPHI4(40)
      DIMENSION A(6,6),B(6,6),D(6,6),X(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),
     2 X5(6,6),XP(6,6),XX(6,6),VNI(6,6),Z(6,6),PHT(6,6),HPHT(6,6),XP1(
     3 6,6),T1(6,6),T2(6,6)
      COMMON         RANGE,TARGRNG,PDET,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,
     3RADRNG1,ELRAD1, 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,DOTX,DOTZ,DOTY,NR,HDFIX,PITFIX,VELFIX
     7 ,ALPHA ,BETA,RG,AZG,ELG,R1,R2,R3,R4,AZ1,AZ2,AZ3,AZ4,VMAG1,VMAG2,
     8VMAG3,VMAG4,VPHI1,VPHI2,VPHI3,VPHI4
  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)
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
```

```
C  NB = THE NUMBER OF RUNS
C   NBT = NUMBER OF DISCRETE TIMES
      NB=100
      NBT=20
      T=1.0
      NT =1
C
C
      ITITLE(1)=8HHD160/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)=8HKALMONI
      RADDEG= 57.2957795131
      NUNIF = 12207003125.
      DO 714 K=1,NT
      READ 100, HD(K), VEL(K), ALT(K), PITCH(K)
       ZT(K)= ALT(K)/ 6076.1
  714 READ 102, XT(K   ),YT(K   )
      HEAD=HD(1)
      VELOC= VEL(1)
      ALTIT= ALT(1)
      PIT= PITCH(1)
      ZIT= ZT(1)
      XPOS= XT(1)
      YPOS= YT(1)
      NUM2=0
      DO 804 JK=1,NB
      HD(1)= HEAD
```

```
      VEL(1)= VELOC
      ALT(1)= ALTIT
       PITCH(1)= PIT
      ZT(1)= ZTT
      XT(1)= XPOS
      YT(1)= YPOS
      CALL TARGEN
  721 DO 708 I=1,NBT
       K=1
      XRADI(I)= I
      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=ABSF(XP(1,1) )-ABSF(TARGRNG(K))
      AZDIFF= ABSF(XP(3,1) )-ABSF(AZT(K))
      IF(AZDIFF-10.0) 165,165,166
  165 IF(10.0-AZDIFF ) 166,265,265
  166 AZDIFF=ABSF(360.0- AZDIFF)
  265 ELDIFF=ABSF(XP(5,1))- ABSF(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)
```

```
      AZ3(NUMB)=(XS(1,1)*COSF(XS(5,1)/RADDEG))*COSF(XS(3,1)/RADDEG)
      R2(NUMB)=XT(K)
       R3(NUMB)= YT(K)
  708 CONTINUE
      NUM2=1
      PRINT 671, JK
  671 FORMAT(//,20X,4HJK= ,I2)
      PRINT 667
  667 FORMAT(//,30X,9HRADIFF**2)
      PRINT668,(R1(J), J=1,15)
  668 FORMAT(/,1X,15F7.4)
      PRINT 669
  669 FORMAT(//,30X,9HAZDIFF**2)
      PRINT 668,(R4(J), J=1,15)
      PRINT 670
  670 FORMAT(//,30X,9HELDIFF**2)
      PRINT 668,(AZ4(J),J=1,15)
      CALL MONTE (NB,NBT, JK,R1,R4,AZ4,NUMB)
      IF(JK-NB) 804,999,804
  999 LABEL=4HACTU
      CALL PLOT(NUMB,R2,R3,0,0,LABEL,ITITLE,2.,2.,5,5,2,2,10,10,0,LAST)
      LABEL=4HSMTH
      CALL PLOT(NUMB,AZ2,AZ3,0,0,LABEL,ITITLE,2.,2.,5,5,2,2,10,10,0,LAST
     1 )
  804 CONTINUE
      END
      SUBROUTINE MONTE (NB,NBT,JK,R1,R4,AZ4,NUMB)
      DIMENSION R1(40),R4(40),AZ4(40),VMAG2(40),VPHI2(40),XRAD1(100)
     1,ITITLE(12),AZ2(40)
      IF( JK-1) 811,811,812
  811 DO 813 LL=1,NBT
      VMAG2(LL)=0.0
      VPHI2(LL)=0.0
  813 AZ2(LL)=0.0
  812 DO 806 L=1,NBT
       VMAG2(L)=VMAG2(L)+R1(L)
```

```
      VPHI2(L)= VPHI2(L) +R4(L)
      AZ2(L)= AZ2(L) +AZ4(L)
  806 CONTINUE
      IF(JK-NB  )815,814,815
  814 DO 810 L=1,NBT
      XRAD1(L)=L
      VNB=NB
      VMAG2(L)= VMAG2(L)/VNB
      VPHI2(L)= VPHI2(L)/VNB
  810 AZ2(L)=AZ2(L) /VNB
      ITITLE(1)=8HHD160/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)=8HKALMON1
      LABEL=4HAVRD
      CALL PLOT(NUMB,XRAD1,VMAG2,0,0,LABEL,ITITLE,3.,0.1,0,0,2,2, 9.6,
     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
```

```
669 FORMAT(//,30X,5HVPHI2)
    PRINT 668,(VPHI2(J),J=1,15)
    PRINT 670
670 FORMAT(//,30X,3HAZ2)
    PRINT 668,(AZ2(J),J=1,15)
    RETURN
    END
```

```
      SUBROUTINE ABFILT
      DIMENSION              RANGE(10),TARGRNG( 10    ),PD(10),
     1ITITLE(12),HD(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),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)
      COMMON          RANGE,TARGRNG,PDET,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,
     3RADRNG1,ELRAD1, 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,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
      K= IC
      XRAD(K   )=(RADRNG(K   )*COSF( ELRAD(K    )/57.29577)) *
     1SINF(AZRAD(K   ) / 57.29577)
      YRAD(K   )=(RADRNG(K   )*COSF(ELRAD(K    )/57.29577)) *
     1COSF(AZRAD(K   )/ 57.29577)
      ZRAD(K   )=RADRNG(K   )*SINF( ELRAD(K    )/57.29577)
   23 DO 1 JJ=1,3
      IF(JJ-1) 3,2,3
```

```
    2 OISE = XRAD(N  )
      PRED = PXRAD(L)
      DOTT = DOTX(L)
      GO TO 6
    3 IF( JJ- 2) 4,5,4
    5 OISE=YRAD(N)
       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 + T*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 AZ1 =ATANF(PYRAD(L  )/PXRAD(L  ))*RADDEG
      IF(PXRAD(L  )) 530,531,531
  530 PAZRAD(L  ) = 270.0-AZ1
      GO TO 532
  531 PAZRAD(L  ) = 90.0 -AZ1
```

```
532 PELRAD(L  ) = ATANF(PZRAD(L  )/SQRTF((PXRAD(L  ))**2+
   1(PYRAD(L  ))**2))*RADDEG
    PRADRNG(L  ) =SQRTF((PXRAD(L  ))**2 +(PYRAD(L  ))**2+(PZRAD(L  ))
   1 **2)
    PRINT 201,PRADRNG(L  ),PAZRAD (L  ), PELRAD(L  )
201 FORMAT(/,10X,10HPRADRNG = ,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.

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