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# Adaptive tracking of maneuvering targets

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# NAVAL POSTGRADUATE SCHOOL

ADAPTIVE TRACKING OF

MANEUVERING TARGETS

by

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15 April 1968

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ABSTRACT:

The requirements of a track-while-scan radar data processing scheme are stated from the point of view of the evader in a pursuit-evasion game. The rules of the game, determined in part by the nature of the pursuer's weapons, are such that the evader must be able to discriminate reliably between straight-line and maneuvering pursuer motion. A suggested method for such discrimination is tested by simulation. The method employs bias-sensitive maneuver detection and gain-adaptive discrete Kalman filtering. Also tested is a smoothing scheme for establishing long-term trends in a pursuer's maneuvering track. The outcome of both tests indicate that the suggested processing methods may be useful in the formulation of fire control policies for destruction of maneuvering targets.

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## Introduction

Consider a pursuit-evasion problem where the pursuer is a high-speed, highly maneuverable object and the evader is slower and less maneuverable. Both pursuer and evader possess weapons capable of destroying their respective adversary. For purposes of illustration, we shall assign the role of pursuer to a PT-type boat, and that of evader to a ship the size of a destroyer or larger. Both are presumed to possess radar for purposes of relative position location.

This paper concentrates upon the tracking methods employed by the evader, whose tactical decisions will be conditioned in larger measure upon hopefully reliable estimates of the pursuer's current and near-future intent. A significant measure of this intent is the nature of the pursuer's present motion, i. e., is he maneuvering or is he proceeding in a straight line? The significance of maneuver information lies in the fact that the pursuer, for purposes of proper gyro alignment, must proceed in a straight line for a given time interval just prior to launching a torpedo. Given a tracking scheme with reliable maneuver detection, the evader may thwart the pursuer's attempted launch by firing projectiles in such a manner as to destroy the pursuer or at least force him to maneuver and thus abort the launch.

## The evader's track-while-scan/maneuver detection requirements

We shall assign two conditions of motion to the pursuer; he is either maneuvering or moving in a straight line. The maneuver detector will at any given time, then, fall into one of the following four possibilities:

| | Detector says: | Pursuer is: |
|---|---|---|
| A | straight | straight |
| B | maneuvering | maneuvering |
| C | straight | maneuvering |
| D | maneuvering | straight |

Of these possibilities, A and B are obviously to be desired. Of the two error conditions C and D, D is by far the more dangerous because it allows the pursuer to carry out a weapon launch without the harassment of the specific anti-launch tactics that would otherwise be carried out by the evader. Error condition C, on the other hand, is an error in the conservative direction, and may result at worst in wasted ammunition. Minimization of D-type errors is therefore stated as a requirement.

For purposes of further discussion, two descriptors are now defined. The descriptor "short-term" shall apply to estimates and predictions of pursuer position and velocity no more than one sample interval ahead of the current time. The descriptor "long-term" shall apply to estimates and predictions of the same quantities many samples ahead of the current time, where "many" is understood to be related to the flight time of ballistic projectiles fired by the evader.

Common sense tells us that it would be foolish to attempt a classical fire-control solution (i. e., one in which the target is assumed to proceed from a known position with constant speed and heading) when the pursuer is maneuvering. This is not to say that the evader should, under these conditions, refrain from firing shells; it does say that he needs long-term prediction capability of a markedly different nature than that which would be obtained by simple extension of short-term predictions. Long-term prediction under maneuvering conditions will require considerable smoothing of data from the immediate and extended past, to the end that gross trends in the pursuer's track are established. Once obtained, such trends can form the basis for patterns of fire covering areas of ocean in which it is most probable that the pursuer will be after shell flight time has elapsed.

The requirement for short-term tracking is two-fold. The maneuver sensor will base its decisions on the difference between the pursuer's radar returns for a series of observations and the corresponding short-term predicted positions for that series. Secondly, the short-term tracker must be such that after tracking a non-maneuvering target for a given length of time, its velocity estimates must converge to such an accuracy as to allow extension to long-term position prediction for the gun fire control solution.

Fig. 1 summarizes, in block diagram form, the various functions to be accomplished in the track-while-scan processing described above. The following sections will describe the details of a particular processing scheme that was simulated and tested on the digital computer.

## A suggested track-while-scan processor

The gross features of the suggested processor are given as follows:

Short-term tracker -- a Kalman filter (sequential estimator) with provision for backsliding in the gain schedule consistent with maneuver information.

Long-term tracker -- a least-squares fit of a straight line, constant velocity track to at least 40 seconds worth of immediate past data

Maneuver sensor -- an indication is given that a maneuver <u>may</u> be in progress if

a) two consecutive differences between predicted and radar x or y locations exceed a gate of given size

and b) both differences are of the same sign.

(Detailed descriptions of the processing are included in the following section on simulation).

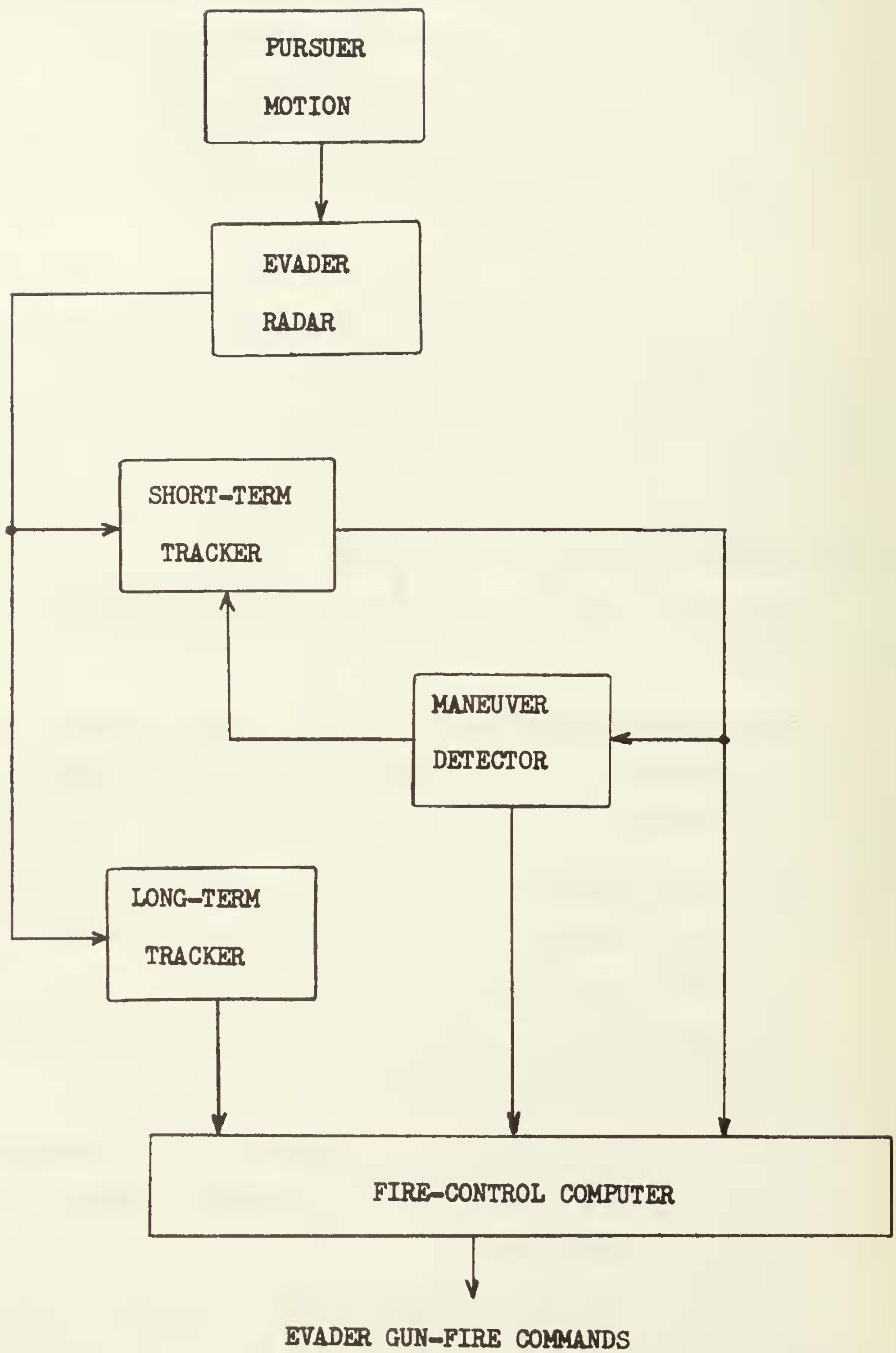



Fig. 1 Block diagram of evader's track-while-scan processing

A simulation for evaluation of track-while-scan processing

A digital computer simulation program was written to investigate and evaluate the processing methods outlined above.

Pursuer Tracks

Two standard pursuer tracks were used in the evaluation. Both tracks were initiated at a range of 15,000 yards and an azimuth of 45°. The pursuer maintains a speed of 30 knots in both tracks. In track A, the pursuer proceeds toward the evader (at the origin and stationary) in straight-line motion for the entire 80 second track history. In track B, the pursuer starts out as in Track A, but commences a zig-zag maneuver at 20 seconds. The zig-zag continues for 40 seconds, whereupon the track resumes straight line motion to 80 seconds total time. A and B are shown, with broken axes, in Figure 2.

Evader's Radar

The evader's radar is assumed to have a one-second data rate. Radar measurement errors are assumed to be gaussion, zero-mean, white sequences with standard deviations of 4 yards in range and 2 milliradians in azimuth. The evader's digital processor is assumed to accept noisy range information with 10-yard quantization levels, and noisy azimuth information with 13-bit encoder accuracy. These quantizations are included in the simulation.

Short-term Tracker

The short-term tracker is basically a standard Kalman filter based on a second-order, pure inertia target dynamics description in uncoupled x,y coordinates. In pre-computing the filter gain schedule, the cartesian measurement error covariance matrix was made diagonal and constant indicating that we assume the (x,y) measurement errors to be additive and independent.

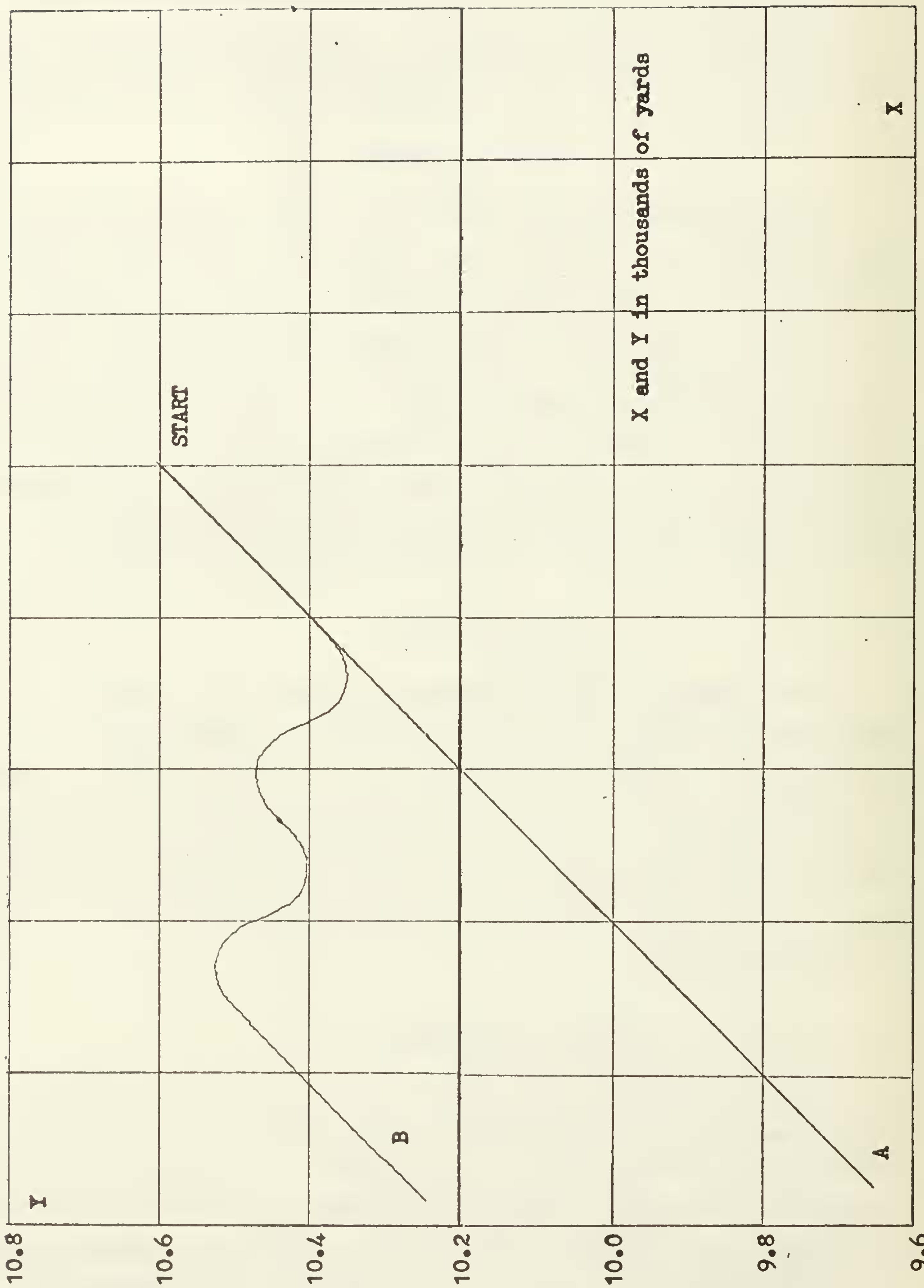



Fig. 2 Standard straight-line and zig-zag pursuer courses

This is, of course, not the case, since coordinate transformation from polar $(r,\theta)$ to cartesian $(x,y)$ involves the polar errors multiplicitavely and nonlinearly in the cartesian errors. Furthermore, cartesian error components are space dependent, so that $\sigma x$ and $\sigma y$ are non-constant. To fully account for all these effects of the coordinate transformation upon cartesian measurement error components would require on-line computation of the error covariance and of filter gain values, at considerable cost in computation time. Filter performance with a gain schedule based on constant and independent cartesian error statistics has proved quite satisfactory; the results are felt to justify the assumptions. At worst, if a given tracking situation should result in a large spread of pursuer-evader relative range, two or more complete gain schedules could be stored and used for the appropriate range levels.

The filter prediction-correction equations are identical for both x and y, and are as follows:

Prediction
$$\hat{x}_{k|k-1} = \hat{x}_{k-1|k-1} + \hat{\dot{x}}_{k-1|k-1} \cdot T \qquad (1)$$

$$\hat{\dot{x}}_{k|k-1} = \hat{\dot{x}}_{k-1|k-1} \qquad (2)$$

Correction
$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + g1_k \cdot \left(z_k - \hat{x}_{k|k-1}\right) \qquad (3)$$

$$\hat{\dot{x}}_{k|k} = \hat{\dot{x}}_{k|k-1} + g2_k \left(z_k - \hat{x}_{k|k-1}\right) \qquad (4)$$

where $z_k$ is the radar observation in x or y.

The gain schedule $(g1,g2)_k$ and the equations and constants used in its calculation are given in Appendix A. It should be noted here that a null random excitation covariance was used in the calculation of the gain schedule. This places the necessity of following pursuer acceleration with the maneuver detector, and allows the short-term filter to do a more accurate job of estimation when the pursuer is moving in straight-line motion. One consequence of using a null excitation covariance is the convergence of filter gains to zero value. To allow the actual schedule to so converge, without truncation, would be unwise because long-term drift tendencies in a nominally straight pursuer track could lead to highly undesirable diverging biases in the estimation. The use of a drift detector has been suggested and is certainly feasible. The present study, however, does not include drift detection.

Built into the short-term tracker is a backsliding feature which causes a re-processing of the most recent three pieces of radar information. The rationale for backslide processing is this; the maneuver detector indicates positively when it senses a sizable estimation bias building up over two consecutive observations. The ultimate effect of that bias, and the time required to recover from it once it is recognized, can be reduced by going back to where the bias most likely started accumulating, namely two sample intervals back.
If the radar data collected two samples back is then given more credence in the re-processing, the effect will be to reduce the bias. This increase in the weighting of back radar data can be accomplished by going back to a very early point in the gain schedule, where respective gains are associated with relatively infirm tracks. In maneuvering situation, the track becomes degraded.

Let us be explicit about the nature of the re-processing. Let us say that we have just received the $k^{th}$ radar observation, we have compared it with the conditional estimate or prediction of what the observation should have been, and we have decided on the basis of this and the previous comparison that a maneuver is in progress. The following equations are solved, in the order given.

$$\hat{x}_{k-2|k-2} = \hat{x}_{k-2|k-3} + g1_n \cdot \left(xR_{k-2} - \hat{x}_{k-2|k-3}\right)$$

$$\hat{\dot{x}}_{k-2|k-2} = \hat{\dot{x}}_{k-2|k-3} + g2_n \cdot \left(xR_{k-2} - \hat{x}_{k-2|k-3}\right)$$

$$\hat{x}_{k-1|k-2} = \hat{x}_{k-2|k-2} + \hat{\dot{x}}_{k-2|k-2} \cdot T$$

$$\hat{\dot{x}}_{k-1|k-2} = \hat{\dot{x}}_{k-2|k-2}$$

$$\hat{x}_{k-1|k-1} = \hat{x}_{k-1|k-2} + g1_{n+1} \left(xR_{k-1} - \hat{x}_{k-1|k-2}\right)$$

$$\hat{\dot{x}}_{k-1|k-1} = \hat{\dot{x}}_{k-1|k-2} + g2_{n+1} \left(xR_{k-1} - \hat{x}_{k-1|k-2}\right)$$

$$\hat{x}_{k|k-1} = \hat{x}_{k-1|k-1} + \hat{\dot{x}}_{k-1|k-1} \cdot T \tag{5}$$

$$\hat{\dot{x}}_{k|k-1} = \hat{\dot{x}}_{k-1|k-1}$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + g1_{n+2} \left(xR_k - \hat{x}_{k|k-1}\right)$$

$$\hat{\dot{x}}_{k|k} = \hat{\dot{x}}_{k|k-1} + g2_{n+2} \left(xR_k - \hat{x}_{k|k-1}\right)$$

This set of equations differs from the basic prediction correction set (1) through (4) in the gain index. In equations (5), we note that the re-processing starts with a gain schedule index of n, where $n \leq k-2$. It was found by trial and error in the simulation that $n = 1$ was the most satisfactory starting point in the gain schedule for re-processing. After the execution of equations (5), routine processing continues, with the gain schedule index proceeding to n+3, n+4, etc., until a maneuver indication is once again received.

## The Maneuver Detector

On the basis of a 100-member ensemble, raw radar cartesian errors for the standard tracks of Figure 2 were found to be 20 yards standard deviation in both x and y. By trial in the simulation, a maneuver detector gate of ± 40 yards was found to be most satisfactory. This is equivalent to ± 2σ on the raw radar. The detector was made to give a re-process/backslide command when, for two consecutive observations, the predicted and observed cartesian positions differed by more than 40 yards, with the differences of the same sign. In equation form,

$$\begin{aligned} &\text{if} \quad \left|\left(z_k - \hat{x}_{k|k-1}\right)\right| \geq 40 \\ &\text{and} \quad \left|\left(z_{k+1} - \hat{x}_{k+1|k}\right)\right| \geq 40 \end{aligned} \qquad (6)$$

and both differences have the same sign, then a maneuver indication is given.

## Non-Maneuvering Test

This test consisted of processing an ensemble of 100 runs of standard pursuer track A of Fig. 2, i. e., straight-line, constant velocity motion. Each run differed from the others in the measurement noise sequence used in the generation of simulated radar observations. The test was conducted to determine two things; 1) how often would the maneuver detector give a positive (in this case, false) indication, and 2) what sort of runs errors in position and velocity could be expected from the short-term tracker operating on an extended straight-line tracks. The first result was obtained simply by establishing a counter to count the number of re-processing commands generated by the detector. This result was 53 commands. Expressed as a percentage of the total number of observations processed, which was 100x80 = 8000, the detector gave false indications on 0.665% of the observations. This percentage could be reduced even further by requiring two or more consecutive re-process commands to occur before the track is interpreted as maneuvering. This does not suggest that the indicated re-processing be suppressed, but that several re-process commands in sequence be required before stating that the pursuer is maneuvering.

Figures 3 and 4 are plots of the ensemble rms error in x and $\dot{x}$, respectively, for estimates produced by the short-term tracker. Embedded in these plots are the effects of the 0.665% false maneuver indications as discussed above, i. e., re-processing was done where indicated. The steady state values of these rms errors are approximately 6 yards and 1 yard per second, respectively. Similar plots were obtained for the y coordinate.

## Maneuvering Test

This test consisted of processing an ensemble of 100 runs of standard pursuer track B of Figure 2, i. e., a combination of straight and zig-zag motion at constant speed. As in the non-maneuvering test, each run differed from all others in the measurement noise sequence used in the generation of simulated radar observations. The test was conducted to determine the effectiveness of the short-term tracker/maneuver detector against a maneuvering pursuer, and to observe the trend-estimating capability of the long-term, least-squares tracker.

Figure 5 is a plot of the standard maneuvering track upon which are superimposed vertical bars whose lengths are proportioned to the number of times, in the ensemble of 100, that re-processing was dictated by the maneuver sensor at that particular point in the true track. It may be noted that the maneuver sensor quite rapidly re-establishes a non-maneuver

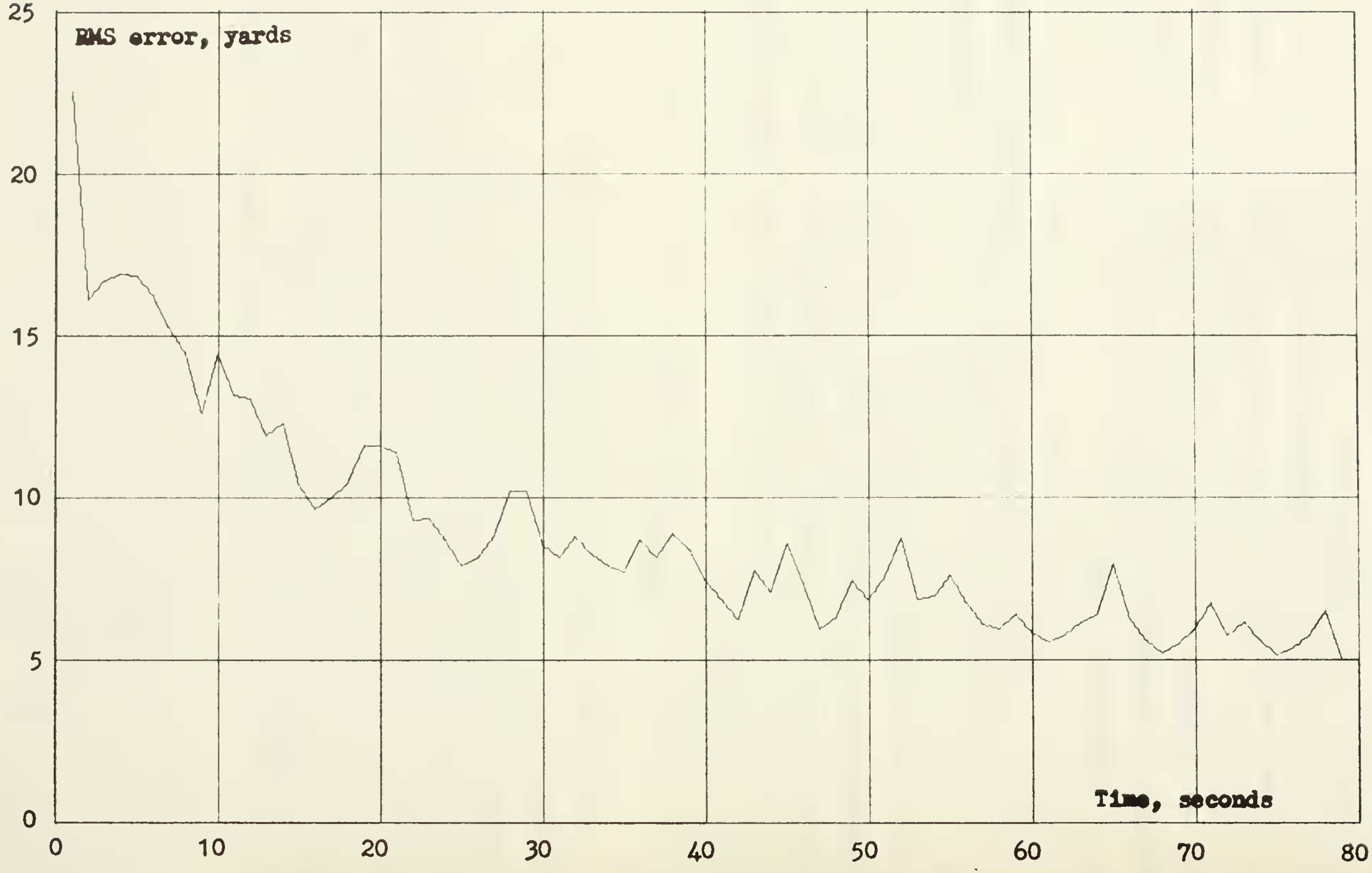



Fig. 3 RMS error in estimation of X for an ensemble of tracks(A)

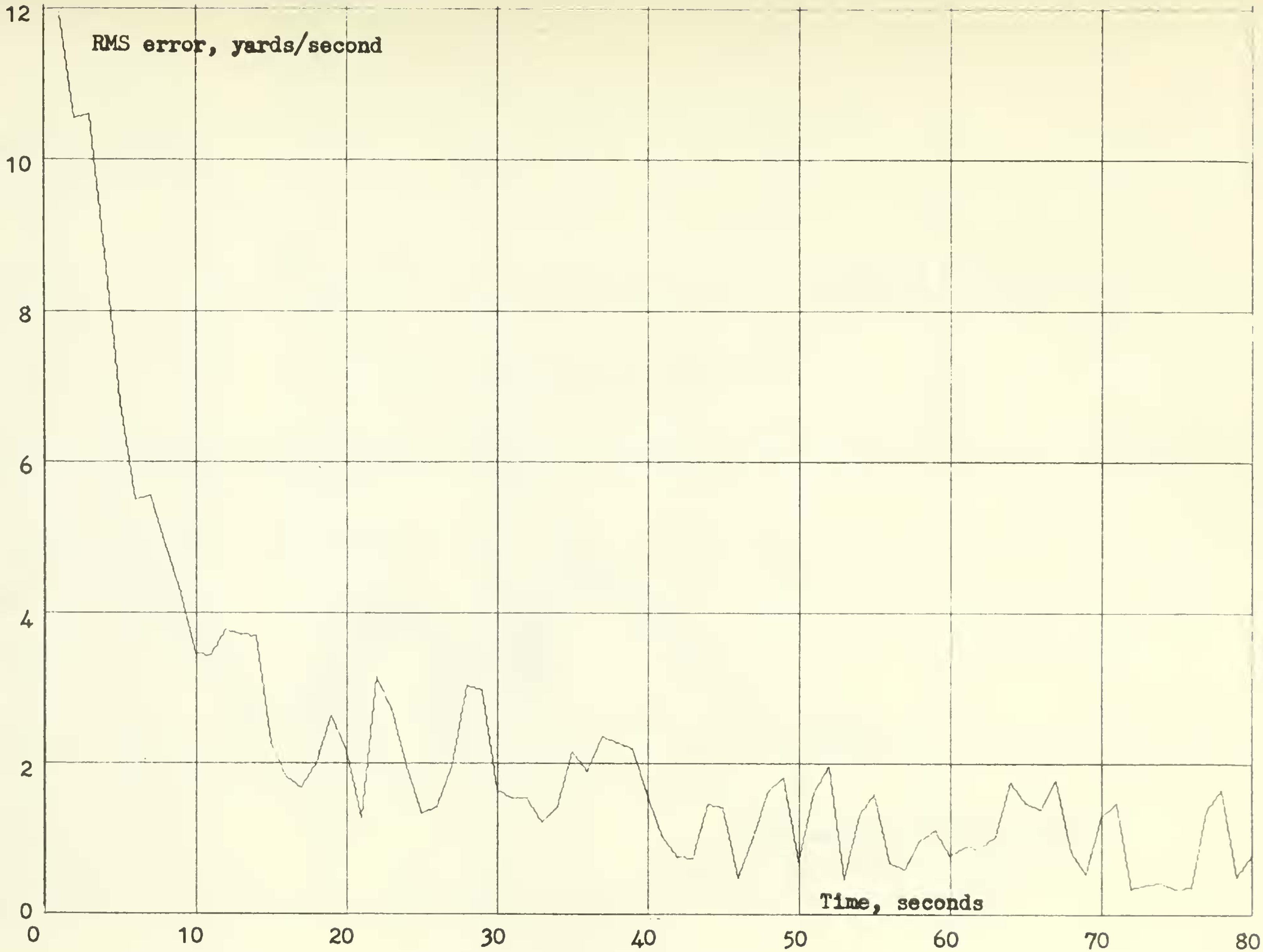



Fig. 4 RMS error in estimation of $\dot{X}$ for an ensemble of tracks A

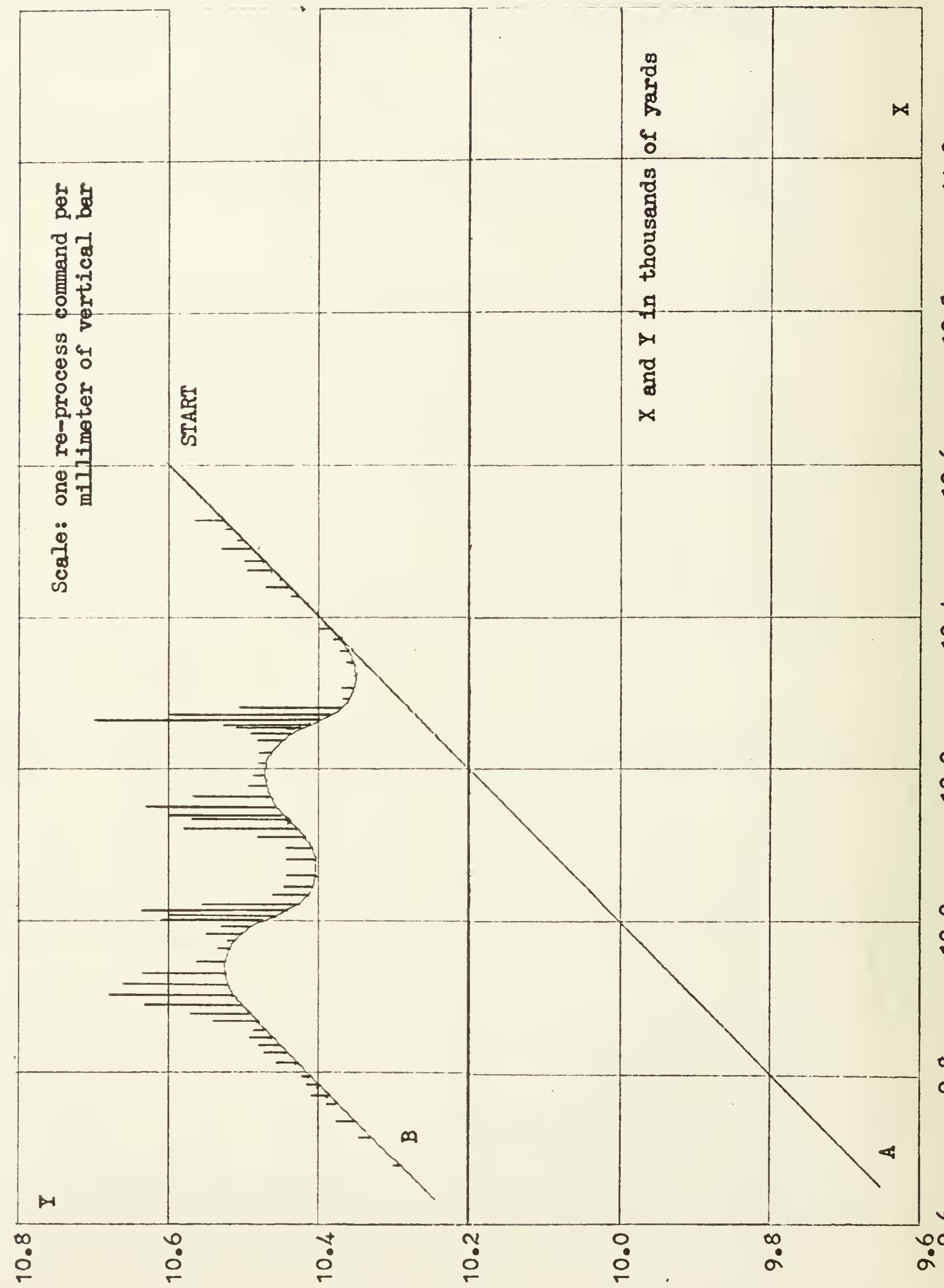



Fig. 5 Re-process command history for track B, ensemble of 100 trials

indication after 60 seconds, during the tail-end straight portion of track B.

Figure 6 and 7 are plots of the ensemble rms error in x and $\dot{x}$, respectively, for estimates produced by the short-term tracker. These plots display quite vividly the effect of the maneuver on the short-term tracking; for the first twenty seconds, they are identical to Figures 3 and 4. The zig-zag portion of the track extends over the time interval from twenty to sixty seconds, during which time the rms error in position rises to a level somewhat below that of the raw radar data. After the track resumes straight-line motion at sixty seconds, the error levels in both position and velocity resume their downward trend toward the values achieved in the steady-state of Figures 3 and 4. Had the short-term tracker not been adaptive to maneuvers in the sense of gain schedule backsliding, the true and filtered tracks would have diverged.

It is obvious from Figure 7 that velocity estimation suffers considerable inaccuracy during the maneuver portion of the track. This degradation is acceptable, since these maneuvering velocity estimates are not to be used in establishing long-term position predictions for fire control purposes. Such fire would be futile in the light of the evader's knowledge that the pursuer is maneuvering. Only when the pursuer is known not to be maneuvering are the short-term tracker's velocity estimates used for fire control position prediction.

## The Long-Term Tracker

During those periods in which the pursuer is maneuvering, the evader may wish to lay down a pattern of fire based not upon point-by-point predictions of pursuer position, but upon areas or zones through which it is highly likely that the pursuer, over a given time interval, will pass. The location of these zones may in some measure be aided by determining

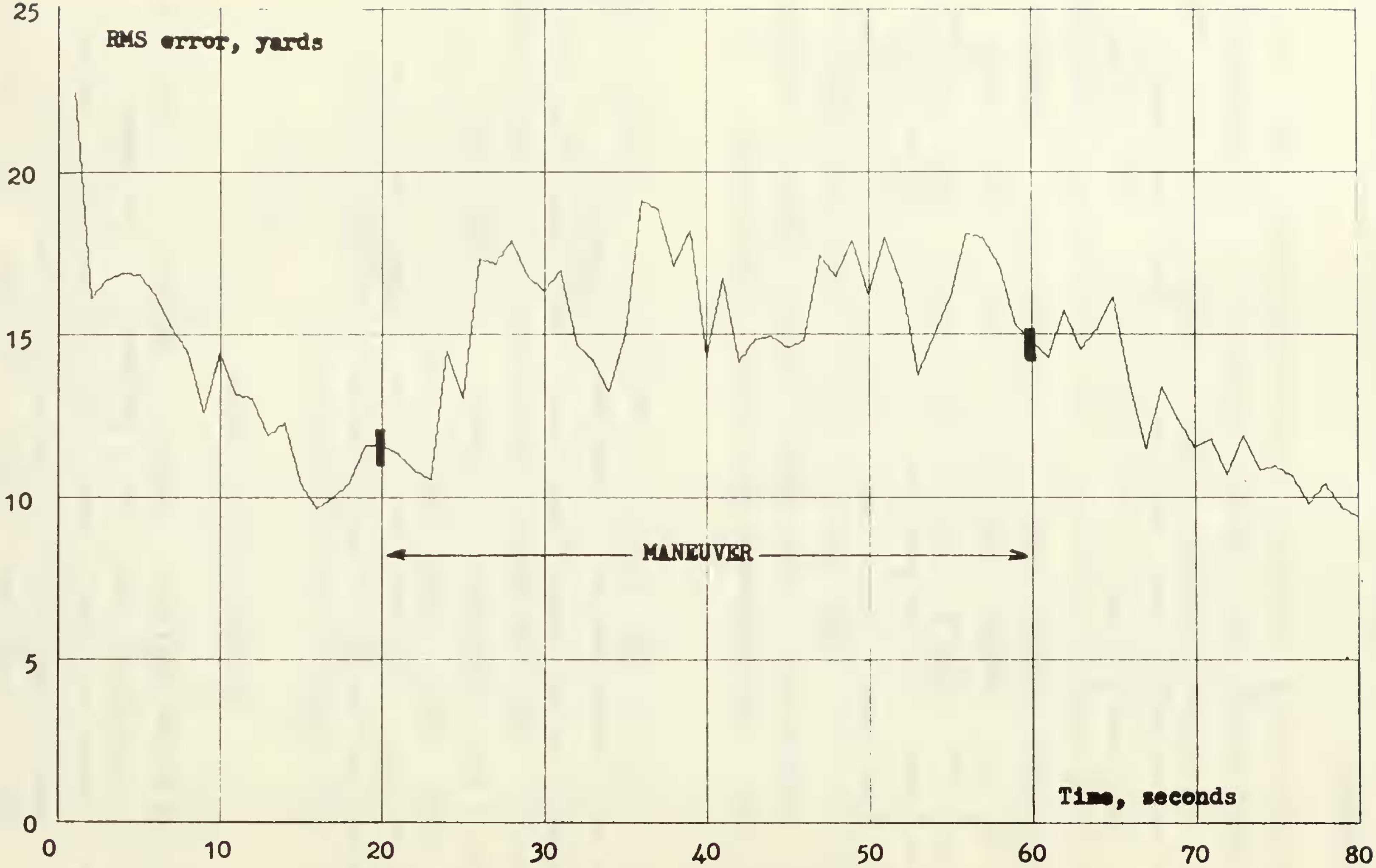



Fig. 6 RMS error in estimation of X for an ensemble of tracks B

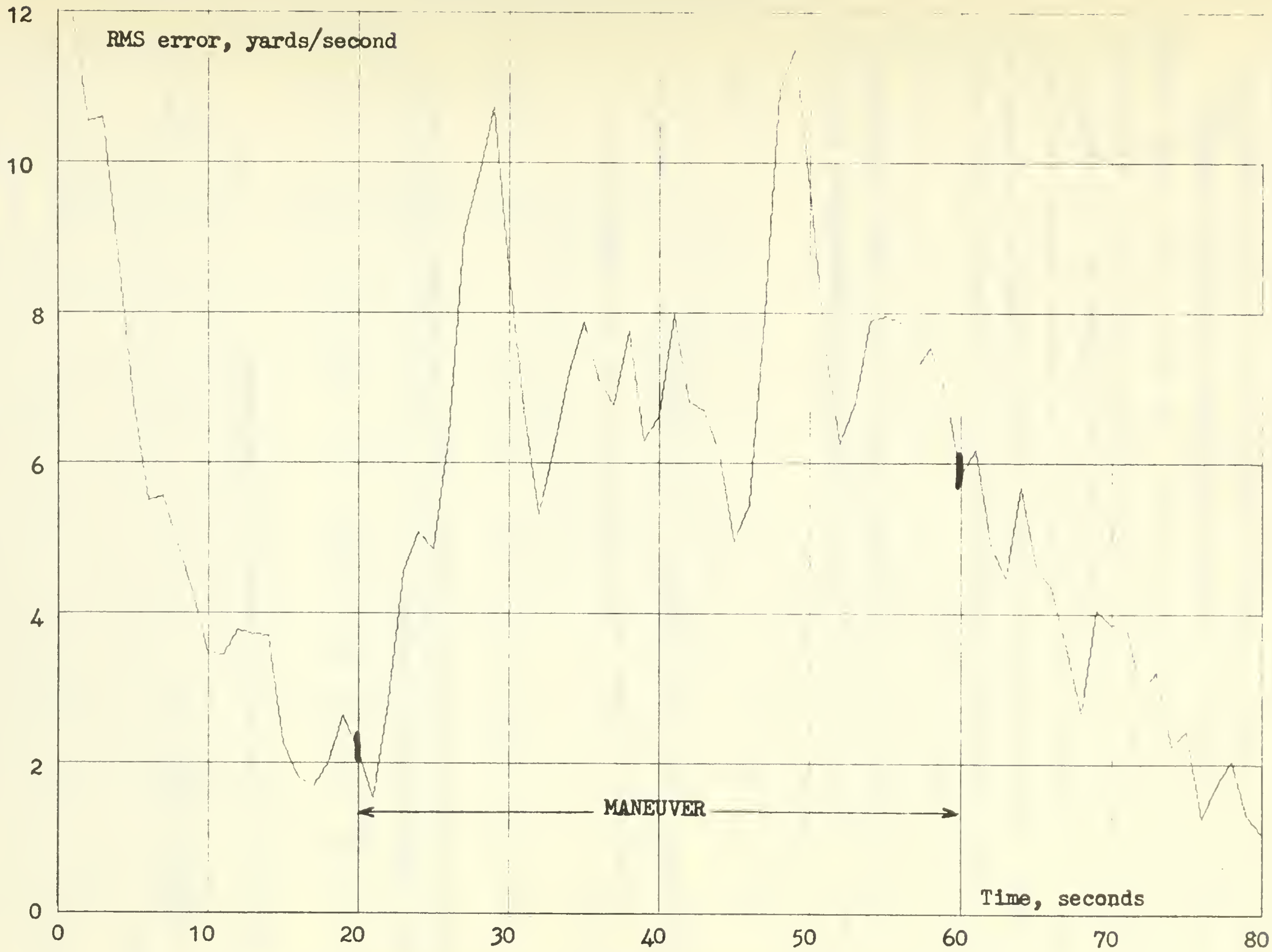



Fig. 7 RMS error in estimation of $\dot{X}$ for an ensemble of tracks B

long-term trends in the pursuer's motion. The feasibility of processing radar data so as to provide this trend information was tested by applying least squares curve fitting techniques to the same ensemble of maneuvering tracks described above. The processing was done as follows. As soon as the first fourty radar observations were taken and stored, a straight line, constant velocity, least squares track was fitted to the observations. Thereafter, as a new radar observation became available, the most remote data were dropped, thereby keeping the observation list of size fourty and effecting a sliding fit over the last fourty pieces of data.

The processing algorithm for such a fit is very straightforward. Straight line pursuer motion may be described (for the x cartesian coordinate) as

$$x(t) = x(0) + v_x \cdot t \tag{7}$$

If we devote the raw cartesian observations at $t = t_i$ as $x_i$, the difference between the observation and the fitted line will be

$$c_i = x_i - x(t_i) = x_i - x(0) - v_x \cdot t_i \tag{8}$$

If we sum the squares of all such differences over our list of fourty observations, we have

$$C = \sum_{i=1}^{40} c_i^2 = \sum_{i=1}^{40} \left(x_i - x(0) - v_x \cdot t_i\right)^2 \tag{9}$$

To minimize this sum of squared differences,

$$\frac{\partial \epsilon}{\partial x(0)} = \frac{\partial c}{\partial v_x} = 0 \tag{10}$$

Satisfaction of equation (10) yields

$$\sum_{i=1}^{40} x(0) + \sum_{i=1}^{40} v_x \cdot t_i = \sum_{i=1}^{40} x_i \qquad (11)$$

$$\sum_{i=1}^{40} x(0) \cdot t_i + \sum_{i=1}^{40} v_x \cdot t_i^2 = \sum_{i=1}^{40} x_i \cdot t_i$$

For purposes of convenience, the time reference is selected so that $t_1 = -39$ seconds and $t_{40} = 0$ seconds, with the result that x(0) is the least squares estimate of position "now", i.e.,at the most recent end of the forty-observation list. The resulting solution for present position and velocity is

$$x(0) = \frac{20,540 \sum_{i=1}^{40} x_i + 780 \sum_{i=1}^{40} x_i \cdot t_i}{213,200} \qquad (12)$$

$$v_x = \frac{40 \sum_{i=1}^{40} x_i \cdot t_i + 780 \sum_{i=1}^{40} x_i}{213,200}$$

The least squares positions and velocities obtained through equations twelve were averaged over the ensemble for times 41 through 80 seconds. The x and y velocities are plotted in Figures 8 and 9, respectively.

Figure 10 is another copy of the standard maneuvering track (B) upon which are superimposed several representative position and velocity estimates from the long-term tracker. The origin of each arrow is placed at the least-squares position for that point in time. The line from that point to the true track indicates where the pursuer actually is at this time. The head of the arrow rests upon that point at which the track would be in twenty seconds, based upon least-squares velocity for position

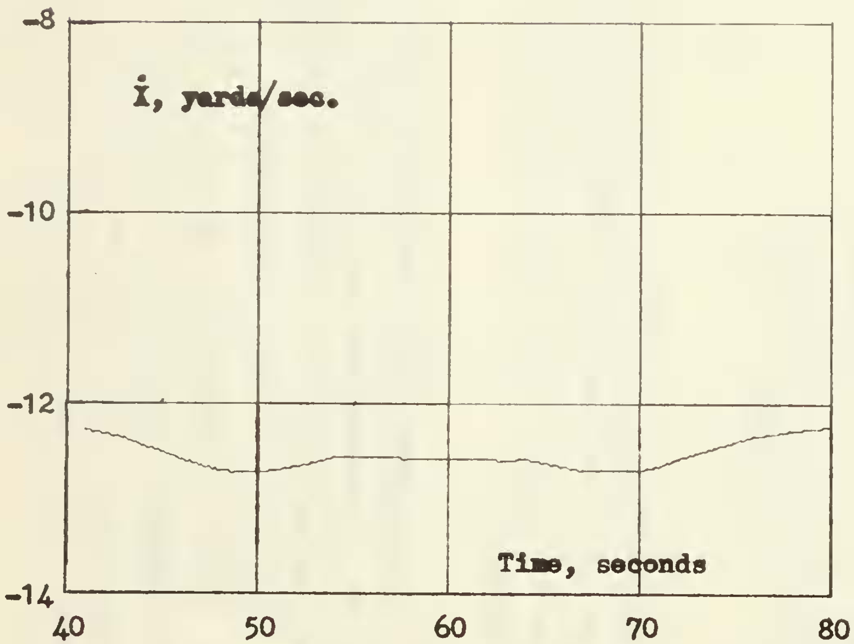



Fig. 8 Mean $\dot{X}$ from sliding least-squares fit, for ensemble of tracks B

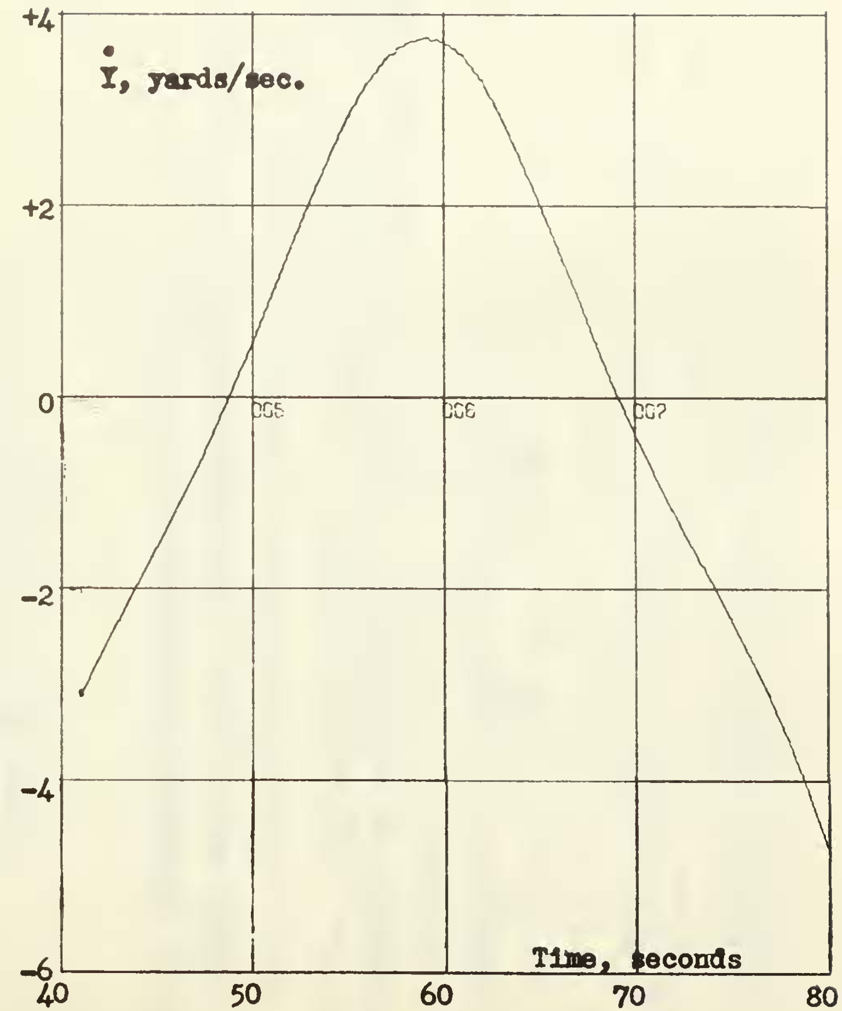



Fig. 9 Mean $\dot{Y}$ from sliding least-squares fit, for ensemble of tracks B

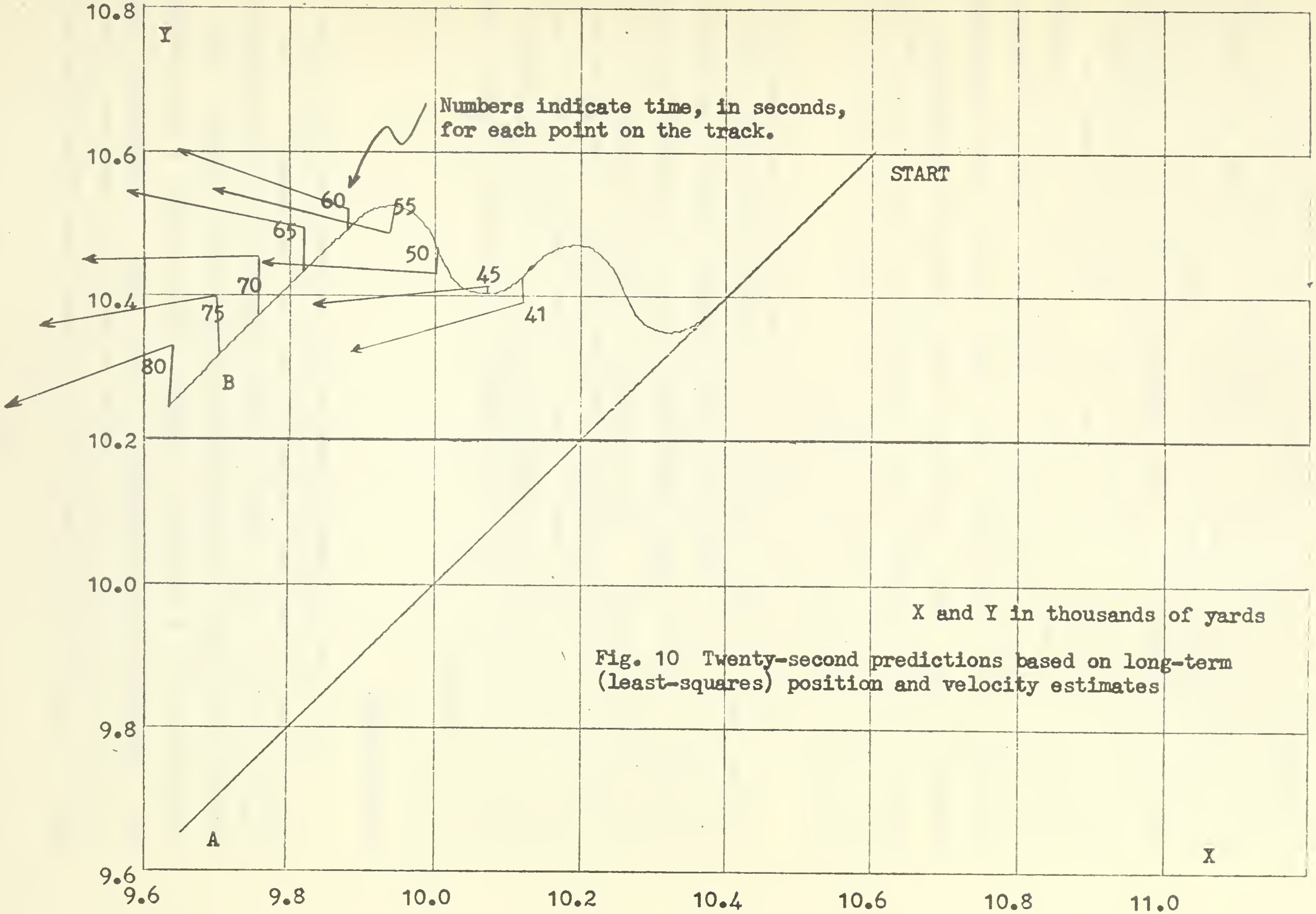



Fig. 10 Twenty-second predictions based on long-term (least-squares) position and velocity estimates

prediction. The results shown in Figure 10 may be interpreted as follows. The first output of the long-term tracker, at time 41 seconds, shows the considerable influence of the initial straight-line portion of the track. As time progresses beyond 41 seconds and much of the straight-line data is dropped off the stale end of the observation list, the long-term predictions begin to align most favorably with the directional trend of the track's zig-zag section. This alignment is especially evident in the time interval from 55 to 65 seconds. For times beyond 65 seconds, the long-term tracker is producing obviously poor predictions, but these are of little importance because by this time, the short-term tracker and maneuver detector have indicated that the pursuer is once again moving with straight-line motion, with full tracking responsibility shifted to the short-term tracker.

It should be noted that the structure of the long-term tracker used in this study is by no means suggested as the "only way to go". There is nothing sacred about a straight-line fit; higher-order polynomial curve fitting may provide even better results. Nor is fourty seconds duration for the observation list necessarily the best figure. The point we hope to have illustrated is that in the context of this particular set of tactical circumstances, for reasons discussed above, it may be highly advantageous to run two parallel radar data processors.

## Conclusions

In a pursuit-evasion game where pursuer straight-line motion constitutes the greatest threat to the evader, it is essential that the evader have the capability of discriminating between straight-line and maneuvering pursuer motion. The combination of a maneuver detector and a Kalman filter whose gain schedule is made adaptive with respect to detected maneuvers has been shown to be effective both for maneuver tracking and for meeting relatively high accuracy specifications for steady-state tracking of straight-line motion.

It has been shown, also, that parallel processing of the evader's radar returns by least squares curve fitting may be quite helpful in establishing long-term trends of the maneuvering phases of the track. These trends might conceivably be used in forming a pattern of fire against a maneuvering target.

## Appendix A

The recursive Kalman filter equations from which the gain schedule was computed are given as follows. The equations apply to x and y axis estimation alike.

$$G_k = \begin{bmatrix} g1_k \\ g2_k \end{bmatrix} = P_{k|k-1} H^T \left[ H P_{k|k-1} H^T + R \right]^{-1} \tag{A-1}$$

$$P_{k|k} = (I - G_k H) P_{k|k-1}$$

$$P_{k+1|k} = \Phi P \Phi^T + Q$$

where the transition matrix $\Phi$ is given by

$$\Phi = \begin{bmatrix} 1 & T \\ 0 & 1 \end{bmatrix} \tag{A-2}$$

the measurement matrix H by

$$H = \begin{bmatrix} 1 & 0 \end{bmatrix} \tag{A-3}$$

and the excitation covariance matrix Q by

$$Q = \begin{bmatrix} 0 \end{bmatrix} \tag{A-4}$$

The measurement error covariance was chosen as

$$R = \begin{bmatrix} 400 \end{bmatrix} \tag{A-5}$$

on the basis of experimental mean square values of quantized radar position minus true position.

The recursive computations were started with the following initial condition.

$$P_{1|0} = \begin{bmatrix} 25(10^6) & 0 \\ 0 & 300 \end{bmatrix} \qquad (A-6)$$

The initial filter state vector for each member of the ensemble was given the value

$$\begin{bmatrix} x \\ \dot{x} \end{bmatrix}_{1|0} = \begin{bmatrix} 0.0 \\ 0.0 \end{bmatrix} \qquad (A-7)$$

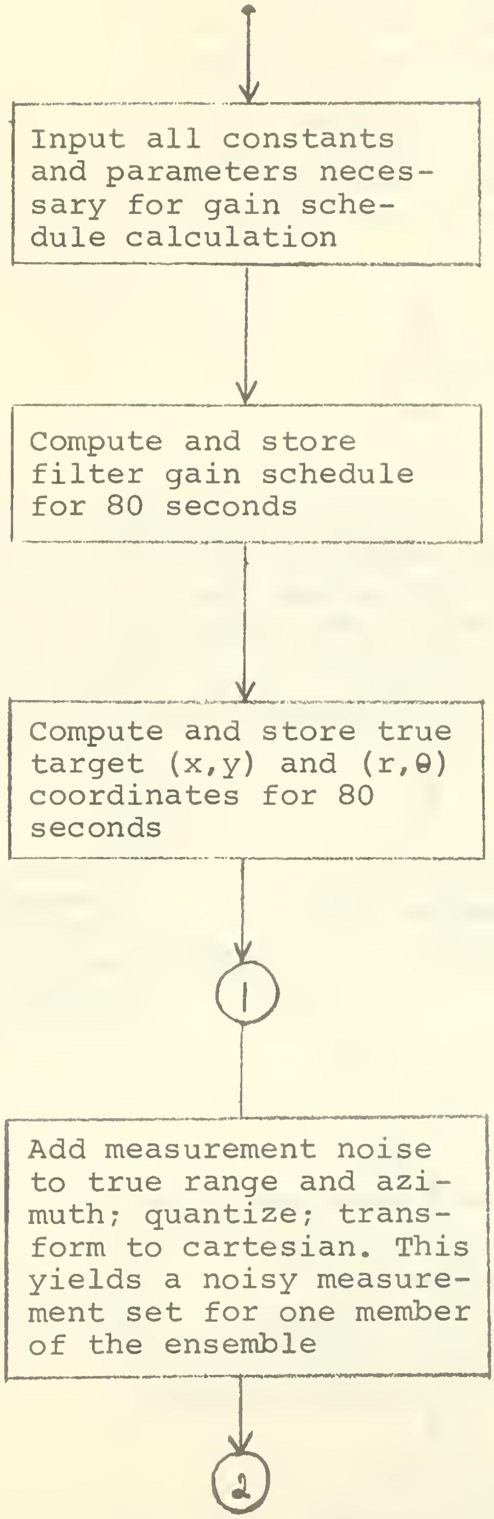
The first fifteen seconds of the gain schedule, as computed from equations (A-1) through (A-6), is shown in Table A-1.

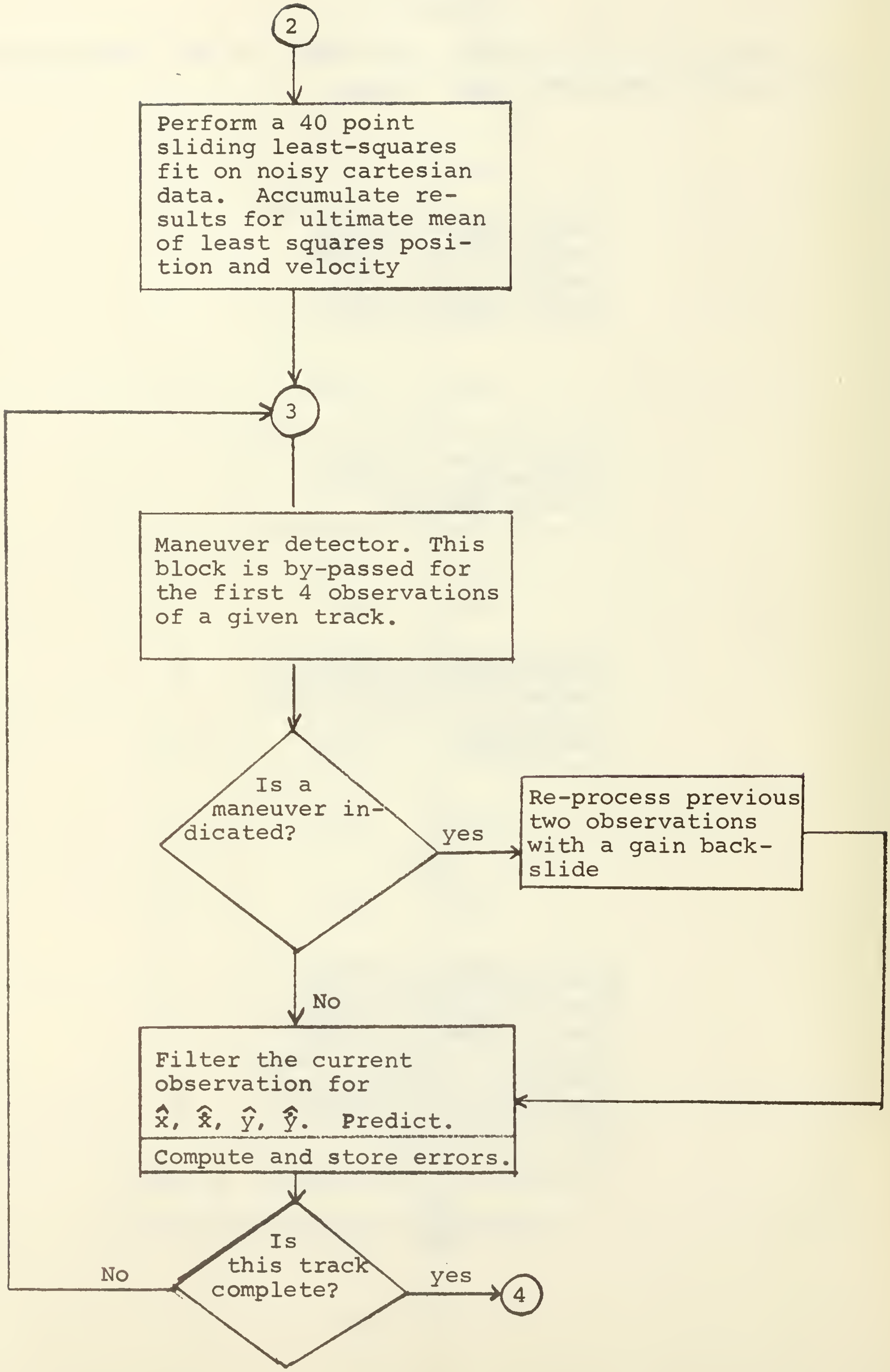
| k | g1 | g2 |
|---|---|---|
| 1 | 0.99 | 0.00 |
| 2 | 0.64 | 0.27 |
| 3 | 0.63 | 0.30 |
| 4 | 0.60 | 0.24 |
| 5 | 0.55 | 0.18 |
| 6 | 0.49 | 0.13 |
| 7 | 0.45 | 0.10 |
| 8 | 0.41 | 0.08 |
| 9 | 0.37 | 0.07 |
| 10 | 0.34 | 0.05 |
| 11 | 0.31 | 0.05 |
| 12 | 0.29 | 0.04 |
| 13 | 0.27 | 0.03 |
| 14 | 0.25 | 0.03 |
| 15 | 0.24 | 0.02 |

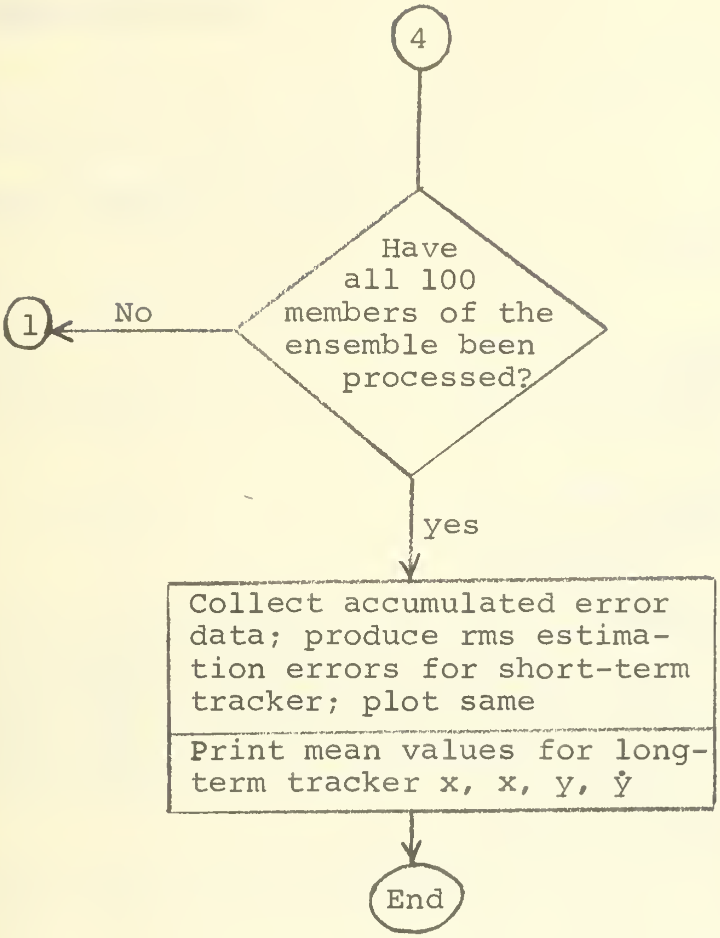
Table A-1 The first fifteen seconds of the short-term tracker gain schedule

## Appendix B

Figure B-1 is an overall flow chart for the tracking simulation program employed in the study.




2
Perform a 40 point sliding least-squares fit on noisy cartesian data. Accumulate results for ultimate mean of least squares position and velocity
3
Maneuver detector. This block is by-passed for the first 4 observations of a given track.
Is a maneuver indicated?
yes
Re-process previous two observations with a gain back-slide
No
Filter the current observation for $\hat{x}$, $\hat{\dot{x}}$, $\hat{y}$, $\hat{\dot{y}}$. Predict.
Compute and store errors.
Is this track complete?
No
yes
4


4
Have all 100 members of the ensemble been processed?
No
1
yes
Collect accumulated error data; produce rms estimation errors for short-term tracker; plot same
Print mean values for long-term tracker x, x, y, ẏ
End

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13 ABSTRACT

The requirements of a track-while-scan radar data processing scheme are stated from the point of view of the evader in a pursuit-evasion game. The rules of the game, determined in part by the nature of the pursuer's weapons, are such that the evader must be able to discriminate reliably between straight-line and maneuvering pursuer motion. A suggested method for such discrimination is tested by simulation. The method employs bias-sensitive maneuver detection and gain-adaptive discrete Kalman filtering. Also tested is a smoothing scheme for establishing long-term trends in a pursuer's maneuvering track. The outcome of both tests indicate that the suggested processing methods may be useful in the formulation of fire control policies for destruction of maneuvering targets.

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| Track-while-scan | | | | | | |
| Data processing | | | | | | |