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Report R-82

A THIRD REPORT ON THE EXPERIMENTS WITH THE PROGRAMS FOR THE SIMULATION OF LARGE SCALE AUTOMATA ON A DIGITAL COMPUTER

Prepared by

P. G. Braunfeld
L. D. Fosdick
J. N. Snyder

CONTROL SYSTEMS LABORATORY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS
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The authors are deeply indebted to Misses Betty Ricks and Marcia Leuchter, who assisted in the almost overwhelming task of data reduction and in the preparation of parameter tapes for the Illiac.

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THIRD REPORT ON SIMULATION STUDIES

1. Introduction

This is the third report on the experiments with a simulated fleet air surveillance and control system. A complete description of this system is presented in the CSL report R-35 by A. Nordsieck. The description of the simulation of this system is presented in the CSL report R-58 by J. N. Snyder. Two previous reports on experiments with the simulated system are R-59 by L. Fosdick, J. Lawson and J. N. Snyder, and R-67 by L. Fosdick and J. N. Snyder. The present report describes further experiments with special reference to the problem of tracking in the presence of radar errors of varying magnitude.

We will review briefly the general properties of the fleet air surveillance and control system described in R-35. It consists of from 5 to 25 shipborne search radars which survey and collect reports from an area of up to 512 x 512 miles square. Ideally these reports are sent, in digital form, via a radio link to a central sorting and tracking computer. The sorting and tracking computer, given the name TASC, has a capacity of 1024 tracks on a magnetic drum which, rotating at 100 rev/sec, is capable of accepting 100 target reports per second, sorting them against the existing tracks on the drum, associating them with and correcting the tracks on the drum, and extrapolating these tracks during the intervals between reports. In the absence of effective radio communication each ship possessing such a computer can carry out the above process using the reports from its own radars. Identity and status information on the tracks is stored on the magnetic drum by humans operating a keyset. The stored track information is made available to the "users", either human or machine, via a clear picture data link, transmitting track data at a 20 ms rate; that is, one track (position, velocity, identity and status) every 20 ms.

A system as complex as this one is not easily studied by analytical methods. Though one might attempt to study various parts of it in this manner, which in many cases is still exceedingly difficult, the study of the system as a whole defies such methods. Hopefully, in the future when these systems are better understood and the requisite mathematical techniques are made available, such an approach will be possible. Thus, for the present anyway, we are forced to bypass the analytic approach, and must rely on more direct methods for studying the system.

A method which is becoming increasingly popular in such problems where the actual construction of the system is costly in time and money, and where the analytic approach fails, is that of simulation. The aircraft industry has been using simulation with high-speed computers for testing the flight characteristics of newly designed aircraft. Physicists have recently been employing this method in the design of new ultra-high energy particle accelerators. And in a problem similar to the one at hand, Lincoln Laboratories at MIT have been employing a high speed computer to simulate various aspects of the SAGE system. The application of high-speed general purpose computers to the simulation problem is especially useful because of the relative ease with which changes may be made in the system under simulation; such changes do not require changes in hardware, as they would in an analogue computer, but only a change in the "program".

The simulation method has been applied to the study of the air surveillance system described above. To simulate the system a program was written by J. N. Snyder of CSL for use with the Illiac (the University of Illinois' high-speed general purpose digital computer). This program logically represents a 1/5-scale model of the system; thus, it represents a system consisting of from 1 to 5 radars, handling up to 20 target reports per second, in a surveillance area of 256 x 256 miles. It simulates the entire system including the generation of simulated radar reports from simulated aircraft flying any one of a variety of possible courses, and the generation of noise or false target reports. The program is described in detail in the report mentioned above, R-58.

The simulation program does not operate in real time: in particular, it runs slower by a factor of about 30; thus, to simulate one hour of real time operation takes about 30 hours of computation time on the

Illiac. This factor varies slightly depending on the details of the problem being simulated. This great slow-down factor is at first sight discouraging because simulation of the many possible modes of operation of the system is prohibited. Instead, one must concentrate on a few things of special interest and try to gain some information about them. However, it may be that this is a blessing in disguise for it is difficult even now to digest and understand the tremendous mass of data that is accumulated in these studies.

The course to follow in this simulation study is certainly ill-defined. Because of the obvious time limitation one cannot hope to run through all possible parametric configurations in a search to find the "best" one. In fact the meaning of "best" is far from clear. The course we have adopted, which seems both reasonable and practical, is to select a limited number of problems for study which appear particularly important. Or, to put it in another way, we apply the simulation program to a small set of problems, the handling of which might be used as a reasonable estimate of the practicability of the system being simulated. In selecting system parameters to be applied to the various problems, one is guided heavily by intuition developed from experience in working with the simulated system. Of course, there are a number of situations in which computations can be made which will serve as a useful guide in the choice of system parameters, but intuition gained from experience is relied on heavily in the absence of suitable analytic methods.

The problems we have studied and are continuing to study are listed below:

1. Tracking performance on a target executing a 90° turn at various speeds and accelerations.

2. Tracking performance on two targets flying courses which intersect at various angles.

3. The effect of noise on this tracking performance.

4. The effect of radar errors (i.e. errors in reported position) on tracking performance.

5. Lifetimes of noise tracks and their population density.

6. Susceptibility of the system to break-down resulting from saturation.

7. Automatic initiation.

A wealth of data has been accumulated from these studies, much of which has been presented in R-59 and R-67, and will be summarized in Section 3 of this report.

2. Review of the System Parameters and the Method of Data Reduction.

The system under simulation contains a variety of parameters. It will be worthwhile to review briefly their significance and the notation that has been adopted.

The basic arithmetic operations performed by the TASC are very simple and few in number, but highly repetitious. These operations are sorting, smoothing, and up-to-dating. (The simplicity of these operations, their repetitious nature, and the peculiar requirements imposed by the sorting problem, led us to adopt a special purpose drum computer as the computing element rather than a general purpose computer with a random access memory. This viewpoint is at variance with that adopted in the design of the SAGE system which employs a high-speed general purpose computer with a random access memory.)

The sorting operation consists in comparing a radar report having rectangular coordinates* ξ, η with the existing tracks, having rectangular coordinates x_i, y_i, to determine which one of the tracked objects is represented by this radar report. The decision is based on the following computation: form $|\xi - x_i|$ and $|\eta - y_i|$ and require that

$$|\xi - x_i| \leq \epsilon \ \underline{\text{and}} \ |\eta - y_i| \leq \epsilon. \quad (1)$$

The parameter ϵ is known as the sorting parameter. When condition (1) is satisfied it is said that the radar report (ξ, η) is associated with the track (x_i, y_i). Thus, the necessary condition for an association is that the radar report fall within a square bin of dimensions $2\epsilon \times 2\epsilon$

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* We will talk here only about two dimensions since the simulation program is designed to track in two dimensions only. It must be remembered, however, that the actual system is designed to track in three dimensions when height information is provided.

centered about the track. The association is made with the first track found to satisfy condition (1) in the sequential testing of the existing tracks on the drum. The consequences of taking the first track that satisfies condition (1) rather than the closest track, if two or more tracks satisfy this condition, have been examined and were found to have an insignificant effect on the general tracking quality. If the radar report does not associate with any of the existing tracks, then a new track with coordinates $x = \xi$, $y = \eta$ is automatically put into an empty track location on the drum; this is a step in the process of automatic track initiation. The sorting parameter is not a constant, but depends on two other variables f, called firmness, and t, the time since the last association. It is intuitively obvious why a variable ϵ is desirable. Firstly, the sorting bin should be as small as possible to reduce the probability of an erroneous association. Secondly, the bin should be sufficiently large to account for the error in the track coordinates, possible accelerations of the aircraft, and errors in the radar report. Since it is natural to expect the tracking error to diminish as reports continue to associate with a track, yielding a more accurate estimate of the true position of the object through the smoothing operation described below, the bin size should be decreased accordingly. Conversely, in the absence of associations the uncertainty of the true track position increases and the sorting bin should grow correspondingly. Details of the dependence of ϵ on f and t will be described later.

An auxiliary sorting bin is sometimes provided to define a region in the neighborhood of a track wherein automatic initiation is suppressed. Specifically, we set a parameter E, a constant, and specify the condition that any report falling outside of the ϵ-bin but in a square bin 2E x 2E centered about the track will not be permitted to automatically initiate a track. This process we commonly refer to as double-bin sorting (DBS). It was found in our tracking studies that radar reports will occasionally initiate false tracks near an already existing track. This is a result of an usually larger error in the radar report itself or a large position error in the track or a combination of these two events. It was also found that these spurious tracks very frequently "rob" the already existing track of its reports and thereby cause its death. This effect is especially important when large radar errors are present, and since the DBS feature appears to be a simple and easy remedy to this problem it has been included in most of the experiments that have been run where radar errors were simulated.

The smoothing operation, which is the second basic arithmetic operation, is an averaging process on the radar data associating with a track introduced to smooth out errors in the radar data. There is a fundamental limitation on the smoothing process imposed by the logic of the TASC, namely, that it must be an iterative process which does not refer <u>explicitly</u> to any radar data other than that currently received and found to associate with the $i^{\underline{th}}$ track. Storage space for past radar reports associating with the track is not provided, and would indeed be very space-consuming and result in logical complexity. It is not clear that a smoothing scheme which makes explicit reference to the sequence of past radar reports, or a portion of that sequence, would have a sufficiently good effect on the quality of the tracking to outweigh the obvious advantage of simplicity and economy of space characteristic to the scheme employed by the TASC. This smoothing scheme is described by the relations

$$\begin{aligned} x_i &\longrightarrow x_i + \alpha\,(\xi - x_i), \\ y_i &\longrightarrow y_i + \alpha\,(\eta - y_i), \\ u_i &\longrightarrow u_i + \frac{\beta}{t}\,(\xi - x_i), \\ v_i &\longrightarrow v_i + \frac{\beta}{t}\,(\eta - y_i), \end{aligned} \tag{2}$$

where the arrow indicates that the quantity on the left is replaced by the quantity on the right, u_i is the x-component of velocity and v_i is the y-component of velocity, α and β are called the smoothing parameters, ξ, η are again the position coordinates of the radar report found to associate with the track with position coordinates x_i, y_i, and t is the time since the last radar report associated with the $i^{\underline{th}}$ track. The interpretation of these relations is simple. In smoothing the position coordinate it is seen that the radar coordinate is combined linearly with the track coordinate, weighting the two quantities by α and $1 - \alpha$, respectively. Clearly α is a number in the range $0 \leq \alpha \leq 1$; for small α the track coordinate is weighted most heavily and for large α the radar coordinate is weighted most heavily. The smoothing parameter β describes the weight given the apparent velocity error $\frac{\xi - x_i}{t}$ or $\frac{\eta - y_i}{t}$. The range of β is $0 \leq \beta \leq 1$. For small β the apparent velocity error is given a low weight and for large β it is given a high weight. In practice, β and t are combined and we consider the quantity $\frac{\beta}{t}$ as the velocity smoothing parameter. Like ϵ, α and β are not constant but are again functions of f and t. The arguments for a variable α and β follow those given earlier for ϵ.

The third basic arithmetic operation is that of up-to-dating. A fundamental design requirement of the TASC is that every track must have its position up-to-date to within one second at all times. (This requirement was later altered slightly to make 1 1/2 seconds, rather than 1 second, the basic time quantization interval. The simulation program uses 1 second, so here we will still regard 1 second as the basic interval). The up-to-dating process is described by the following relations:

$$\begin{aligned} x_i &\rightarrow x_i + u_i \\ y_i &\rightarrow y_i + v_i \end{aligned} \qquad (3)$$

where the units on u_i and v_i are mi/sec. This operation is performed on each track once every second, thus satisfying the requirement described above. In addition to the position, two other quantities are continually brought up-to-date, namely f and t. Since t is merely the time in seconds elapsed since the previous association, 1 is simply added to it each second until another association occurs, at which time t is reset to zero.

The quantity f, called the firmness, may be interpreted as a measure of the reliability of the track coordinates, or the general track quality. This can be understood by following the operations on this quantity as the history of the track unfolds. When a track is initiated, f is given the value $\underline{f_o}$, after which f will be decreased by an amount $\underline{f_d}$ every $\underline{t_s}$ seconds. Whenever this track associates with a radar report, f is increased by an amount $\underline{f_i}$, and, subsequently, f will be decreased by $\underline{f_d}$ every $\underline{t_s}$ seconds until the next association occurs, and so forth. f is an integer and has a maximum value $\underline{f_m}$ and $f \leq \underline{f_m}$, always. f has a minimum value of -1* and whenever this value is reached the track is assumed "dead" or "scratched"; accordingly, drum locations containing tracks with f = -1 are considered as empty and may be used for the initiation of new tracks. (Later developments in the system provide for the holding of tracks with f = -1, if desired. This feature is not included in the simulation program as it is not particularly relevant to our problem of studying the general system performance.) Thus it is seen that tracks are automatically scratched by the system when the firmness drops below a certain value. Provision of this automatic scratching feature is a clear necessity in a system which provides automatic initiation; otherwise, the track storage locations would quickly become saturated with useless information arising mostly from noise or false radar reports.

Although f and t appear to be related in the sense that large t will generally imply a small f and vice versa, there is an important distinction. The firmness refers to the accumulated history of the track whereas t refers only to the interval since the last association.

We have now reviewed the three basic arithmetic operations performed by the TASC and reproduced exactly by the simulation program. They involve three parameters ϵ, α and β, known as the sorting and smoothing parameters. Several other parameters have been defined in this discussion and have been underlined above. These are called preset parameters.

We will now discuss the remaining preset parameters which are more closely related to other parts of the surveillance system than to the TASC itself.

A set of four preset parameters is used to characterize each of the simulated radars in the system. They are denoted by $\underline{X_i}$, $\underline{Y_i}$, $\underline{\omega_i}$ and $\underline{R_i}$ (i = 1, 2 ···5) representing the rectangular coordinates of the radar

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* The firmness as it is used by the simulation program and as we describe it here differs by one from that used in R-35: f (simulation) + 1 = f (R-35).

in miles, the angular velocity of the antenna (in units of 1/128 of a circle per sec.), and the range of the radar in miles, respectively.

A report from one of these radars consists of the rectangular coordinates ξ, η of the simulated object, quantized to mile units and referred to a universal coordinate system, and a quantity $\underline{\sigma}$ denoting the strength of this report; σ is a random variable having integral values in the range $0 \leq \sigma \leq 7$. The quantization of ξ and η is provided by truncating the true position coordinates of the object at the one mile digit as illustrated in Figure 1. Truncation will result in reporting the object at the lower left corner of the quantization box in which it is located.

In addition to the truncation error, which is strictly a necessary result of the digital nature of the radar reports, there are other errors that may be expected to be present in the real system. These arise from the non-zero beam width of the radar and the characteristics of the data processing devices used to detect the presence and center of a target from the echoes of the individual pulses. The simulation of this collection of errors has been provided in the simulation program. The scheme for this simulation is to add random numbers Δx and Δy to the true position of the object; after this addition the result $(x + \Delta x, y + \Delta y)$ is truncated to form the simulated report (ξ, η). The random numbers Δx, Δy are uniformly distributed in the interval $-a \leq \Delta x \leq a$, $-a \leq \Delta y \leq a$ where $\underline{a}$, the "radar error", is a preset parameter. This simulation is crude but fair in that it probably pictures the true situation as somewhat worse than it really is.

Each radar has a buffer storage facility associated with it. The purpose of this buffer storage is to hold the radar reports until consulted by the TASC, at which time the contents of the buffer store is ingested and processed by the TASC. Consultation of the buffer stores proceeds in a round-robin fashion. A preset parameter $\underline{Q_i}$ specifies the number of buffer store locations (one location per radar report) for the $i^{\underline{th}}$ radar. A total of 40 such locations are provided in the program and these may be divided among the radars as desired.

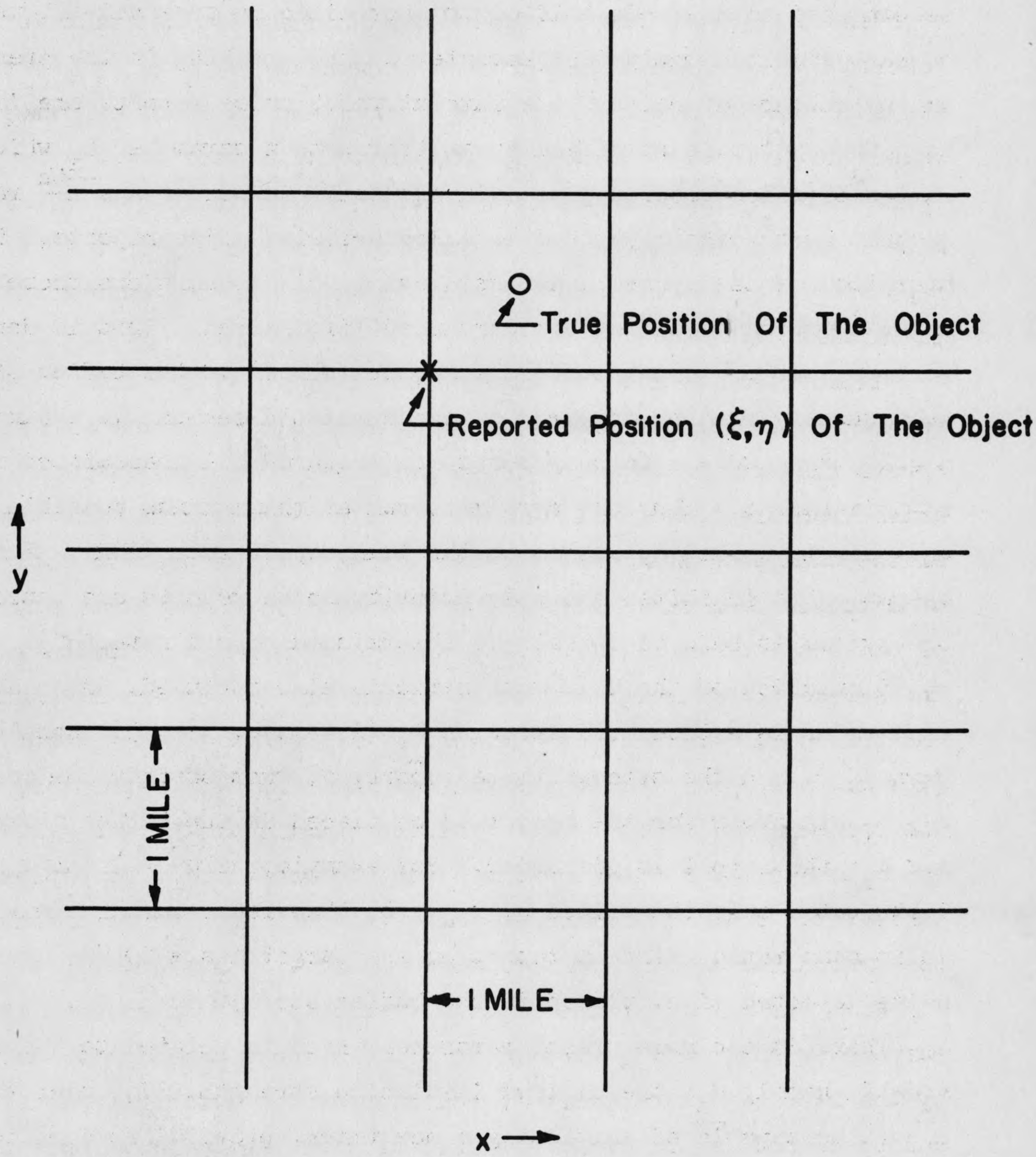

FIG. I ILLUSTRATION OF THE EFFECT OF THE I MILE QUANTIZATION ON THE REPORTED POSITION OF THE OBJECT.

Noise is simulated by generating random numbers ξ, η uniformly distributed over a certain interval in the two coordinates. In most cases the interval is specified by $0 \leq \xi \leq 128$, $0 \leq \eta \leq 256$; thus noise is confined to the left half of the surveillance area and allows one to compare simultaneously the character of the tracking in the presence and in the absence of noise. The rate at which noise reports are introduced into the system is specified by another preset parameter $\underline{N_i}$ which is the number of noise reports placed in the buffer store of the $\underline{i^{th}}$ radar every second; such noise reports are called priority noise reports. To test operation of the system under saturating noise conditions there is another means by which noise may be introduced, if desired. This is done as follows: If the total number of reports placed in the buffer stores, and subsequently read by the TASC in one simulated second, is a number $n < 20$, then $20 - n$ noise reports are prepared and transmitted to the TASC in this second. Thus the system is run at the maximum possible data rate, and this is called operation at the full report rate (FRR). When this operation is inhibited and only priority noise reports are introduced, the system is said to operate at the reduced report rate (R^3).

Simulation of the blip scan ratio is also included. Associated with each radar is a threshold strength $\underline{\sigma_i}$ $(i = 1, 2, \cdots, 5)$, another preset parameter, and the strength of a report, σ, must satisfy the conditions $\sigma \geqslant \sigma_i$, in order for the report to be placed in the buffer store. If $\sigma < \sigma_i$, the report is discarded. For example, if $\sigma_1 = 4$ and σ is uniformly distributed over the values 0, 2, 4, 6, then radar number 1 has a 50 % "blip scan ratio" since a report on any target has a 50 % chance of being detected (i.e. placed in the buffer store).

There is one more preset parameter which is related to the TASC itself, namely $\underline{\sigma_o}$, the minimum initiation strength. In order that a report be capable of initiating a new track, provided it does not associate with an already existing track, the condition $\sigma \geqslant \sigma_o$ must be satisfied.

This completes the list of preset parameters. Another set of parameters used by the simulation program is used to characterize the orbit preparer--that portion of the program simulating the motion of the objects under surveillance.

Two of the available orbit preparers have been used almost exclusively, namely the fishook and scissors orbit preparers. The fishook orbit preparer generates the orbits for up to 100 "planes"; each plane moves initially along a straight line with x-, y-components of velocity $\underline{v_{1x}}$ and $\underline{v_{1y}}$ for $\underline{t_1}$ seconds; then the plane moves along the arc of a circle of radius $\underline{R}$ at $\underline{w}$ radians per second for $\underline{t_2} - \underline{t_1}$ seconds; then the plane again moves along a straight line path with x-, y-components of velocity $\underline{v_{2x}}$, $\underline{v_{2y}}$. The orbit of any plane is identical to that for any other plane except for a linear coordinate translation. Normally the planes are uniformly distributed over the surveillance area with a 25 mile separation between neighbors. A sample pattern is shown in Figure 2. In this figure, as in Figure 3, the planes are numbered according to the sexadecimal number system.* Circles indicate the radar cover. The scissors orbit preparer also generates the orbits for up to 100 planes; here each plane flies only a straight line path; the even and odd numbered planes are paired with the courses of each even-odd pair intersecting; the odd plane flies with x-, y-component of velocity v_{1x}, v_{1y} and the even plane with v_{2x}, v_{2y}. The pairs are uniformly distributed over the area as shown in Figure 3.

The association-print form of output has been used to gather the raw data from the simulation experiments. Data is recorded (i.e. output onto punched tape) only at the times at which a track associates with a report. When the association occurs, the following data is recorded:

1. Identification number of the report associating with the track - indicating the object represented by this report, or indicating that it is a noise report.
2. Identification number of the track.
3. The Illiac storage location of the track.
4. The x and y coordinates of the track.
5. The x and y coordinates of the track relative to the true position of the object.
6. The x and y velocity components of the track.

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* 10, 11, 12, 13, 14, 15 are represented by K, S, N, J, F, L, respectively.

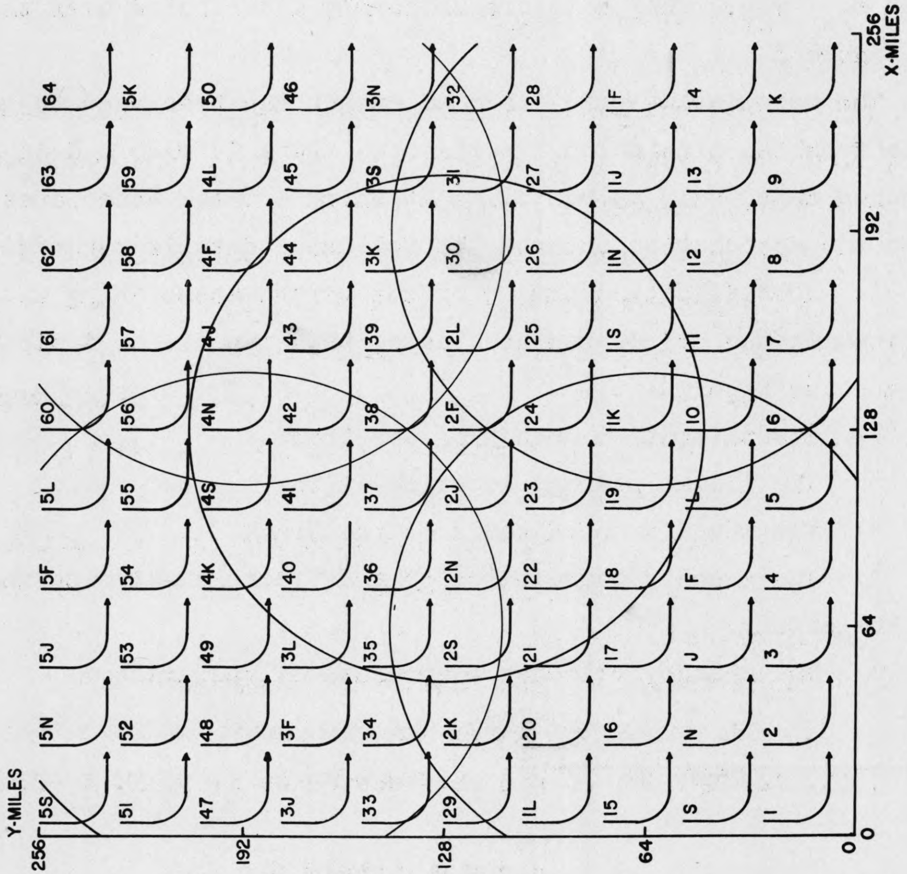

FIGURE 2. A SAMPLE FISHHOOK PATTERN

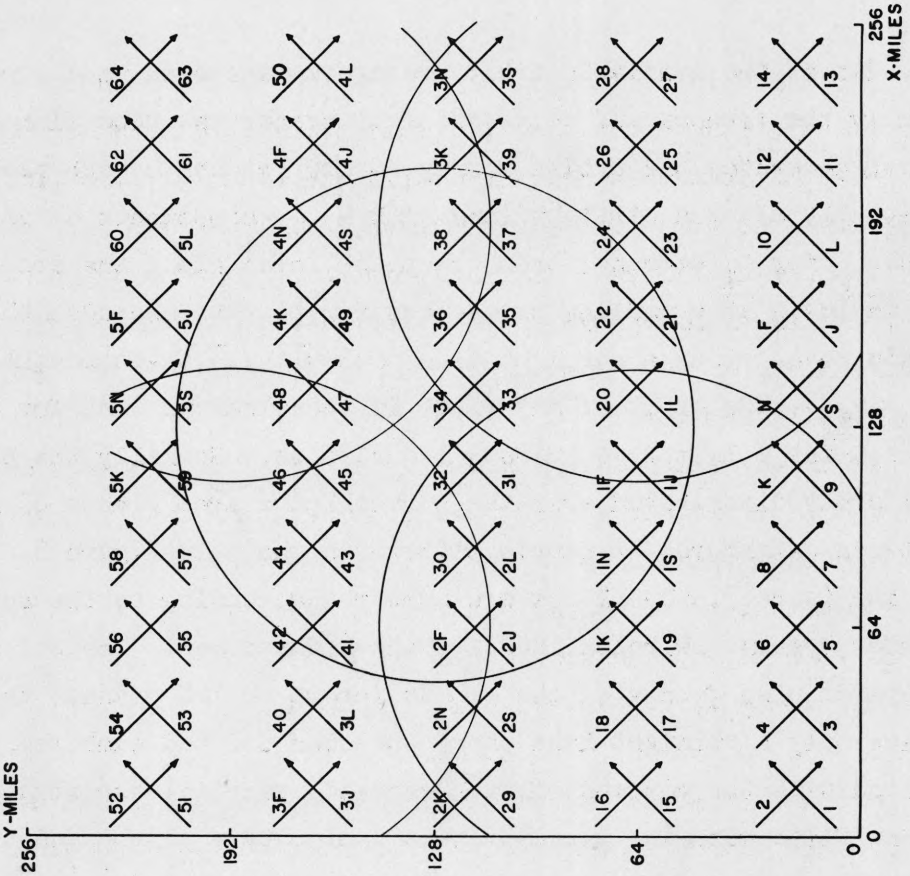

FIGURE 3. A SAMPLE SCISSORS PATTERN

7. The track firmness.

8. The time since the last association for this track.

9. The total elapsed time since the start of the simulation experiment.

This raw data is collected and reduced with the aid of various data processing routines. It should be pointed out that only items 4, 6, 7 and 8 are available to the TASC, the other data is saved and recorded only to assist in the data reduction. Some of the schemes for data reduction will now be reviewed.

To assess the ability of the system to track objects flying in the fishook or scissors pattern a classification scheme has been set up for each of these cases.

For a target executing a turn the tracking of the turn will be labeled A, B, C, D or E according to the following rules.

The tracking of the turn is type A if:

1. A track is initiated at $t \leq T_o$.
2. No secondary tracks are initiated in the interval $T_o < t \leq T_1$.
3. There is at least one correct association with this track in the interval $T_2 < t \leq T_3$.

The tracking of the turn is type B if:

1. A track, called the primary track, is initiated at $t \leq T_o$.
2. At least one other track, called a secondary track, is initiated in the interval $T_o < t \leq T_1$.
3. There is at least one correct association with the primary track in the interval $T_2 < t \leq T_3$.

The tracking of the turn is type C if:

1. A track, called the primary track, is initiated at $t \leq T_o$.
2. At least one secondary track is initiated in the interval $T_o < t \leq T_1$.
3. There is no correct association with the primary track in the interval $T_2 < t \leq T_3$.

The tracking of the turn is type D if:

1. A track is initiated in the interval $t \leq T_o$.
2. No secondary tracks are initiated in the interval $T_o < t \leq T_1$.
3. There is no correct association in the interval $T_2 < t \leq T_3$.

The tracking of the turn is type E if:

1. A track is initiated at $t > T_1$ but not at $t \leq T_1$.

The time T_o is chosen such that the plane begins the turn at T_o or slightly after, T_2 is just a short time after completion of the turn, T_1 is equal to or slightly greater than T_2, T_3 is the time of the end of the experiment. (Usually about 1-2 minutes after completion of the turn).

It is seen that three rules are used to determine the classification of the tracking. The first rule is to establish whether or not there is a track at all before the turn begins. The second rule is to determine whether or not there is a splitting of the track into more than one track during the turn and in the interval immediately following the turn when transient effects may still be operating. The third rule determines whether or not the track which was being carried on the plane before the start of the turn is still associating with reports from the plane after completion of the turn.

For two planes flying on intersecting courses, a similar scheme of classification is used. The tracking of the intersection is labeled A, B, C, D, E, or F according to the following rules.

The tracking of the intersection is type A if:

1. Tracks are initiated on both planes at $t \leq T_o$.
2. There is at least one correct association with each of these tracks at $T_1 \leq t \leq T_2$.

The tracking of the intersection is type B if:

1. A track is initiated on only one plane at $t \leq T_o$.
2. There is at least one correct association with this track at $T_1 \leq t \leq T_2$.

The tracking of the intersection is type C if:

1. A track is initiated on only one plane at $t \leq T_o$.
2. There is no correct association with this track at $T_1 \leq t \leq T_2$.

The tracking of the intersection is type D if:

1. Tracks on both planes are initiated at $t \leq T_o$.
2. There is a correct association with only one of these tracks at $T_1 \leq t \leq T_2$.

The tracking of the intersection is type E if:

1. Tracks are initiated on both planes at $t \leq T_o$.
2. There is no correct association with either of the tracks at $T_1 \leq t \leq T_2$.

The tracking of the intersection is type F if:

1. No tracks are initiated on either plane at $t \leq T_o$.

The time T_o is chosen such that there is negligible probability of confusing reports from the two intersecting planes when $t < T_o$ (usually the planes are about 10 miles apart at time T_o). The time T_1 is a time after completion of the intersection and chosen such that there is again negligible probability of confusing reports from the two planes. The time T_2 is chosen such that the interval $T_1 \leq t \leq T_2$ includes about 5 scan times, thus insuring good probability of a correct association in this interval if the track has the proper coordinates.

Categories A, D, and E describe the tracking of the intersection of two planes on which there are well established tracks before the intersection. Categories B and C describe the tracking of one plane which intersects with another plane not being tracked just before the intersection. Categories B, C, and F contain all situations in which there has been some difficulty in track initiation.

These classification rules have been chosen because they seem to describe in a simple manner important characteristics of the tracking performance and can be easily applied. They represent an attempt to describe, in a clearly defined fashion, the quality of tracking.

Two methods have been adopted to characterize the nature of noise tracks. One of these is simply to prepare histograms of the distribution of the observed lifetimes of noise tracks under various conditions. The other is to compute and tabulate the average number of noise tracks at various firmness levels under different conditions. The latter computation provides a means for estimating the number of noise tracks to be expected on the clear picture displays.

The "goodness" of the system as it concerns automatic initiation is studied by examining the average time interval between the first appearance of a target in radar cover and the first association of a report from this object with the track corresponding to it. Track stutter, or tentative initiation and subsequent scratching of the track shortly thereafter, is another factor of importance in assessing automatic initiation.

Several other schemes for reducing the data have been employed and discussed in earlier reports.

3. Past Experiments with the Simulation Program

In this section we will briefly review some of the results of past experiments with the simulation program, which have already been reported in detail in R-59 and R-67.

The ability of the system to track an object executing a 90° change in heading (i.e., a fishook) has been examined for a variety of conditions. For the purposes of the present review we will describe the outcome of the tracking of an object executing a 90° change in heading in terms of the probability of successfully tracking the object through this maneuver. Tracking is called successful if it can be classified as type A or type B, according to the rules laid down in Section 2. Tracking will be called good, poor, or bad according as the probability of success is greater than or equal to 90 %, between 75 % and 90 %, or less than 75 %, respectively. Tables 1, 2, 3 and 4 present results on tracking of objects flying the fishook pattern at 450 mph. Each table presents results for different accelerations, in units of $g = 32$ ft/sec^2, and different types of cover, the blip scan ratio being indicated as B/S; in multiple cover, which is essentially double cover, there is a combination of 50 % and 75 % blip scan ratios. The different tables refer to different noise densities and different antenna scan times; Tables 1 and 2 refer to scan times of 12 seconds and noise densities (expressed as number of noise reports per second in a 128 mile x 256 mile area) of zero and approximately 10, respectively; Tables 3 and 4 refer to scan times of 10 seconds and noise densities of zero and approximately 10, respectively. In all cases the radar error, given by the preset parameter a, was zero. Of course, the quantization error indicated in Figure 1 was present. All of these results are for the sorting and smoothing parameters known as SS-5 (see the appendix for a listing of these parameters).

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	bad	good	good
1/2g	poor	good	good
1g	bad	good	good
4g	bad	poor	good

Table 1: Tracking of fishooks for 450 mph objects with various accelerations in different types of cover with zero noise density, zero radar error, and a 12 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	bad	bad	good
1/2g	bad	bad	good
1g	bad	bad	poor
4g	bad	bad	poor

Table 2: Tracking of fishooks for 450 mph objects with various accelerations in different types of cover with noise density of about 10, zero radar error, and a 12 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	good	good	good
1g	poor	good	good
4g	poor	good	good

Table 3: Tracking of fishooks for 450 mph objects with various accelerations in different types of cover with zero noise density, zero radar error, and a 10 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	bad	bad	good
1g	bad	poor	good
4g	bad	poor	poor

Table 4: Tracking of fishhooks for 450 mph objects with various accelerations in different types of cover with noise density of about 10, zero radar error, and a 10 second scan time.

The following general observations can be made about these results:

1. A single radar with a 50 °/o blip scan ratio will not yield good tracking in any case.
2. A single radar with a 75 °/o blip scan ratio will yield good tracking if the noise density is nearly zero (probably zero, one, or two) and the acceleration is held a little below 4g (probably 2g or less).
3. In multiple cover the tracking is always good if the noise density is nearly zero. For high noise densities, of the order of 10, there is poor tracking for accelerations of 1g and above.
4. Reduction of the scan time from 12 seconds to 10 seconds improves the tracking slightly. (Other experiments indicate that optimum results can be achieved with a scan time of about 8 seconds).

In Section 4 of this report the results of similar experiments, but with the radar error, a, unequal to zero, will be discussed.

A noise density of 10 is higher than expected under normal conditions of operation for the real system; noise densities of 5 or less are more realistic. The high noise density situation has been investigated simply because of our interest in examining the behavior of the system under "worst" conditions. Although these worst conditions should be relatively rare it is clearly important to know how the system will react to them. It is encouraging to see that the system does not break down under these conditions of high noise density, and, in fact, continues to operate well under conditions of multiple cover.

The detailed character of some typical tracks is shown in Figures 4, 5 and 6, where track history plots for 1/4g, 1g, and 4g turns at a speed of 450 mph are shown. In each figure the true course of the aircraft is shown in an x, y coordinate system with the time of arrival at points along the course marked in seconds. The squares of the grid are 1 mi x 1 mi. Each track is indicated by a light line composed of straight line segments joining the points of association, indicated by · , or ⊙ ; if the former symbol appears it indicates that the track associated with a report from the "plane"; if the latter symbol appears it indicates that the track associated with a noise report. At each association the time, in seconds, is recorded.

Inspection of Figure 4 for the 1/4g turn shows the maximum position error of the track to be slightly greater than 2 miles. There is good recovery to the true course after completion of the turn with the track being on course about 30 seconds after completion of this maneuver. The sharp changes in heading of the track during the turn indicate the fluctuations that arise in the track velocity. Averaging the results for a number of these 1/4g, 450 mph turns it has been found that the RMS velocity error during the turn is about 100 mph.

In Figure 5, showing the track history plot for a 1g, 450 mph turn it is seen that the maximum position error is slightly greater than 3 miles. The track is on the correct course about 45 seconds after completion of the maneuver. Averaging the results for a number of 1g, 450 mph turns, it has been found that in the initial stages of the turn the RMS velocity error becomes as large as 300 mph; it is quickly reduced (about 30 seconds) to about 100 mph, and subsequent decrease is relatively slow.

In Figure 6, showing the track history plot for a 4g, 450 mph turn, it is seen that the maximum position error is again slightly greater than 3 miles. Recovery to the correct course after completion of the maneuver is slow; note, however, that here the data rate is less than for the 1g turn. (Analysis of velocity errors for the 4g turn has not been made.) Notice also that the noise association at t = 138 seconds is particularly fortunate in that it did not throw the track wildly off course.

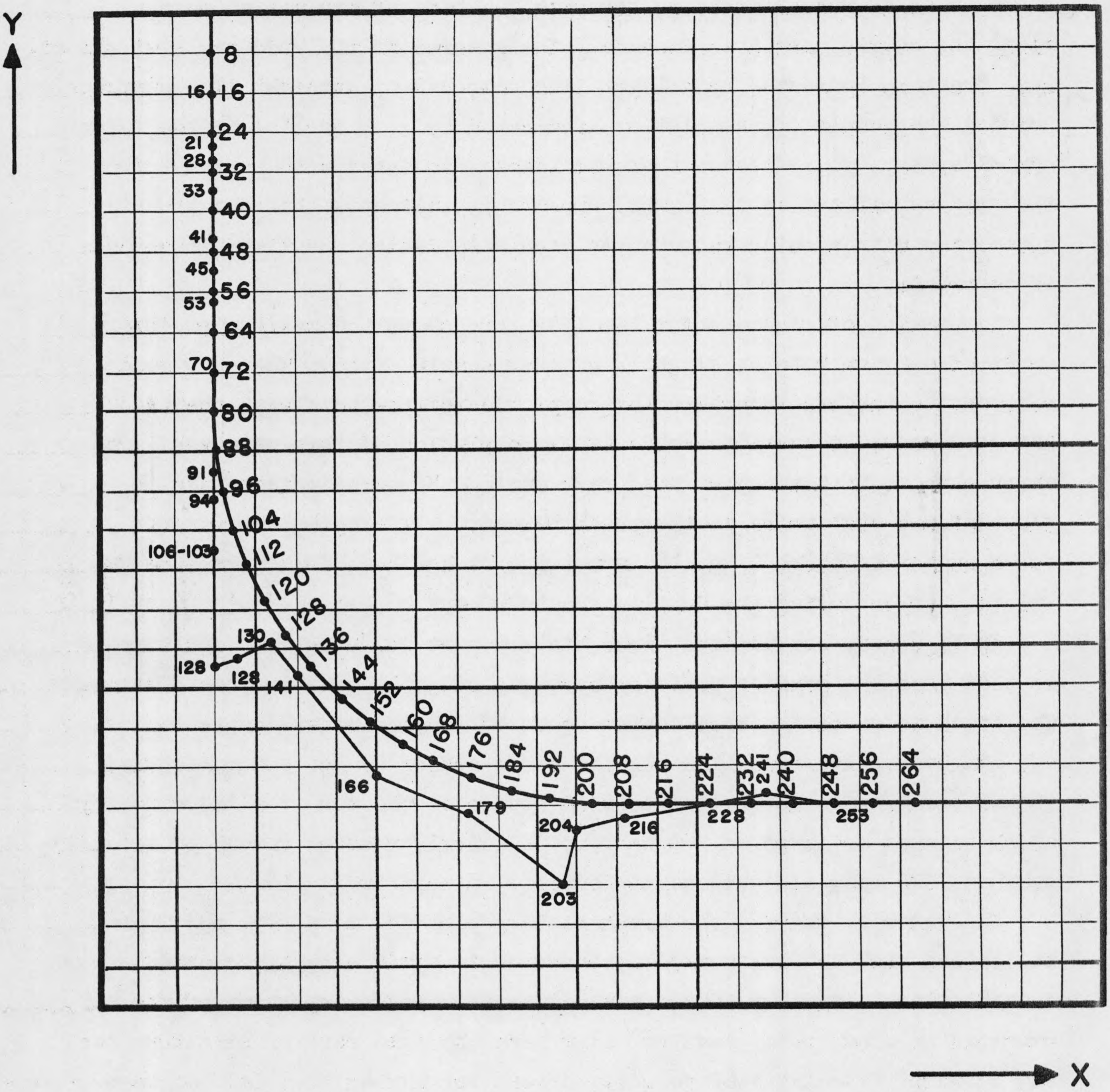

FIG. 4 TRACK HISTORY PLOT OF A ¼ g, 450 mph FISHOOK.

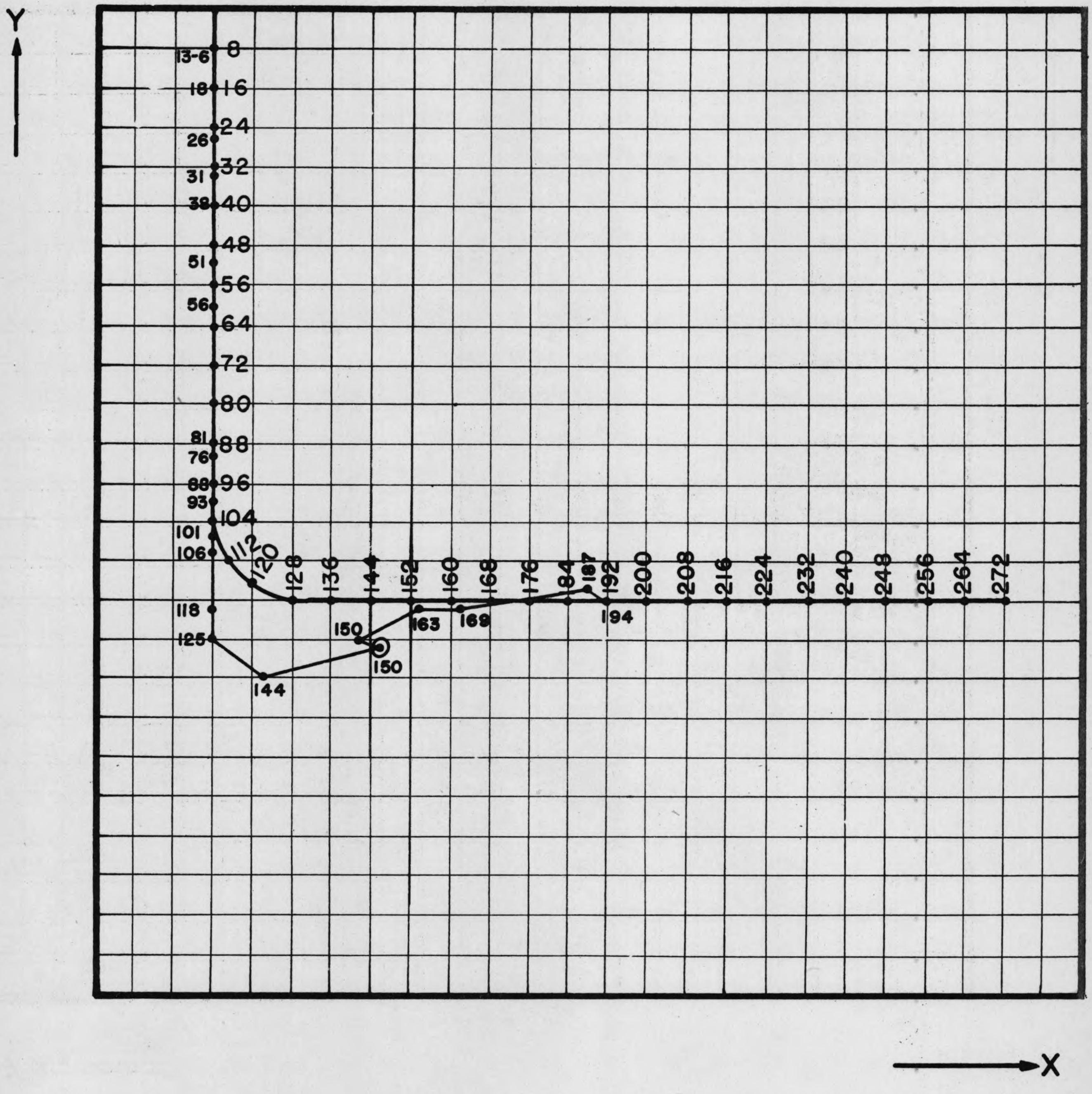

FIG. 5 TRACK HISTORY PLOT OF A lg, 450 mph FISHOOK.

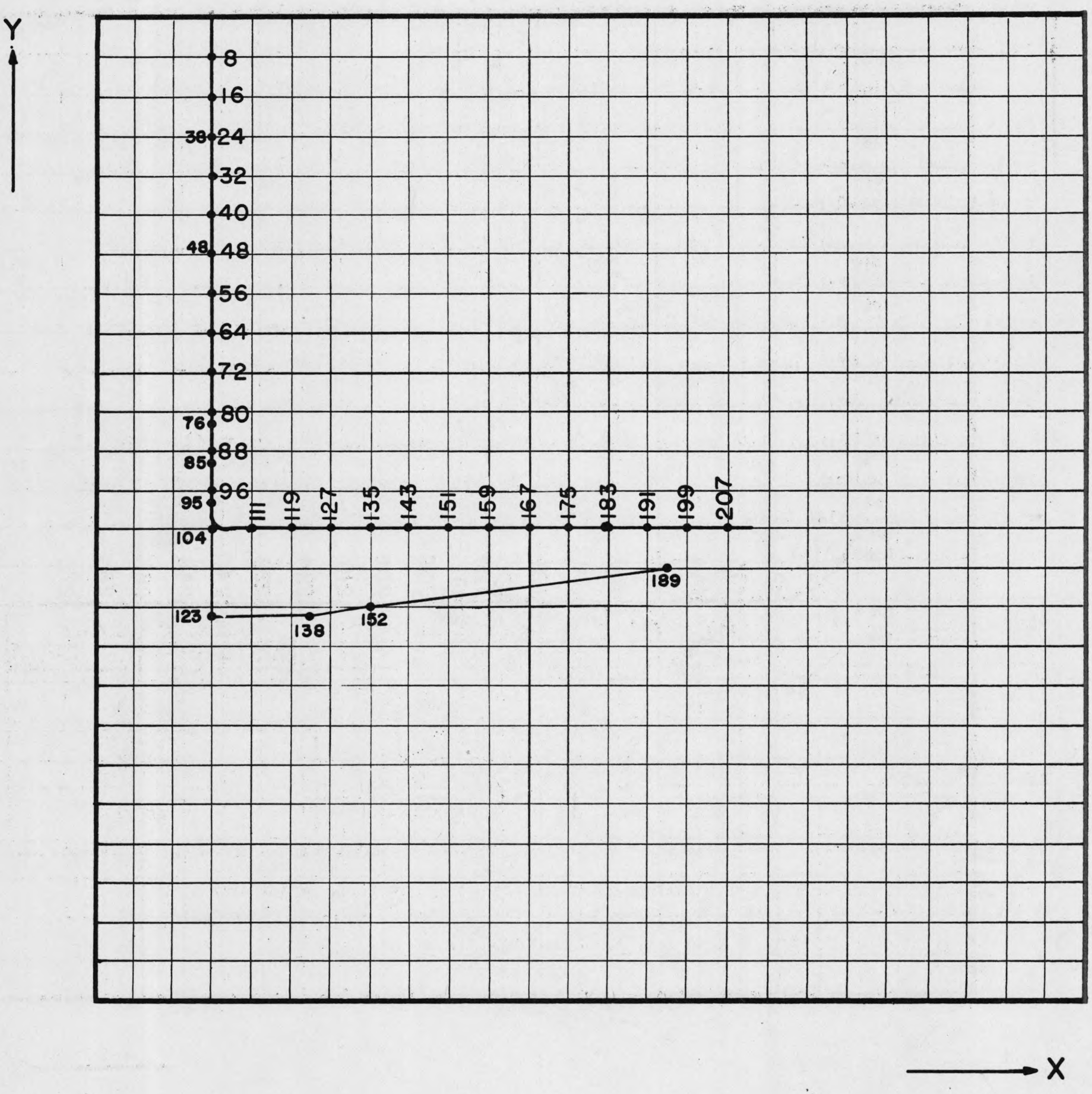

FIG. 6 TRACK HISTORY PLOT OF A 4g, 450 mph FISHOOK.

TASC was designed to handle objects having speeds up to 600 mph. This upper limit is not a fundamental logical one but exists primarily because of the number of bits allotted to velocity information. Fishook experiments with objects moving in the neighborhood of this limiting speed have been run and are reviewed below.

The results for a series of fishooks with 562 mph (5/32 mi/sec) planes executing 1/4g, 1g and 4g turns are presented in Tables 5 and 6. The scheme of presentation is the same as that adopted for Tables 1-4. Table 5 refers to results obtained for zero noise density, zero radar error and a 10 second scan time. Table 6 refers to results obtained for a noise density of about 10, zero radar error, and a 10 second scan time. It is seen from Table 5 that these speedier planes can be successfully tracked in very low noise densities and multiple cover. Table 6 shows the results to be generally bad for a noise density of 10.

In Tables 7 and 8 the results for similar experiments with 675 mph objects are shown. The results are clear--the system cannot track objects with this speed through turns under any of the conditions.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	bad	poor	good
1g	good	poor	good
4g	bad	poor	good

Table 5: Tracking of fishooks for 562 mph objects with various accelerations in different types of cover with zero noise density, zero radar error, and a 10 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1/4g	bad	bad	poor
1g	bad	bad	good
4g	bad	bad	bad

Table 6: Tracking of fishooks for 562 mph objects with various accelerations in different types of cover with a noise density of about 10, zero radar error, and a 10 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1g	bad	bad	bad
4g	bad	bad	bad

Table 7: Tracking of fishooks for 675 mph objects with different accelerations and different types of cover with zero noise density, zero radar error, and a 10 second scan time.

Acceleration	Single Cover (B/S = 50 °/o)	Single Cover (B/S = 75 °/o)	Multiple Cover (B/S = 50 °/o, 75 °/o)
1g	bad	bad	bad
4g	bad	bad	bad

Table 8: Tracking of fishooks for 675 mph objects with different accelerations and different types of cover with noise density about 10, zero radar error, and a 10 second scan time.

Although most of our attention has been focused on experiments of the fishhook type, a number of scissors experiments have also been run. Many of the problems connected with the tracking of a pair of objects through an intersection of their flight paths could be removed if height information and some velocity information were available with the radar reports. Inclusion of this data would increase the dimension of the space in which the sorting is done and thereby reduce the probability of making an erroneous association. Since it is felt that the poor quality of the scissors tracking can be properly improved only by these means, no particular attempt has been made to find a set of system parameters (within the present framework of the system) which yield good tracking for scissors.

To review the results of the scissors experiments we we will describe the outcome of the tracking of a pair of planes with flight paths that intersect at an angle θ in terms of the probability of successfully tracking the pair through this maneuver. Tracking is called successful if it can be classified as type A according to the rules laid down in Section 2. Tracking will be called <u>good</u>, <u>poor</u>, or <u>bad</u>, according as the probability of success is greater than 90 °/o, between 90 °/o and 75 °/o, and less than 75 °/o, respectively. Tables 9 and 10 summarize the results of scissors experiments with 450 mph objects. Table 9 contains results for three types of cover, three angles of intersection ($\theta = 60^\circ, 90^\circ, 120^\circ$), zero noise density, zero radar error, and a 12 second scan time. Table 10 is similar to Table 9 but refers to results obtained with a noise density of about 10 for $\theta = 60^\circ$ and 120° and a noise density of 5 for $\theta = 90^\circ$.

The results for 90° scissors in Table 9 appear somewhat anomolous. This is due to the fact that for the 90° scissors experiments we ran the system at a considerably lower data input rate than for the 60° and 120° scissors experiments, where the system was operated under maximum data rate conditions. Statistics for scissors experiments are not as good as they are for fishhooks but it seems clear from the data collected thus far, and summarized in these two tables, that tracking of scissors is very unsatisfactory. It is worth noting that the sorting and smoothing parameters used for the results reported in Tables 1, 2, 3 and 4 are the

θ	Single Cover (B/S = 50 %)	Single Cover (B/S = 75 %)	Multiple Cover (B/S = 50 %, 75 %)
60°	bad (statistics poor)	bad	bad
90°	bad	good	good
120°	bad	bad	poor

Table 9: Tracking of scissors for 450 mph objects with different angles of intersection, in different types of cover with zero noise density, zero radar error, and a 12 second scan time.

θ	Single Cover (B/S = 50 %)	Single Cover (B/S = 75 %)	Multiple Cover (B/S = 50 %, 75 %)
60°	bad	bad	bad
90°	bad	bad	poor
120°	bad	bad	bad

Table 10: Tracking of scissors for 450 mph objects with different angles of intersection, in different types of cover with noise density of 10 for $\theta = 60^\circ$, 120° and 5 for $\theta = 90^\circ$, zero radar error, and a 12 second scan time.

same as those used in the above scissors experiments. Other sorting and smoothing parameters have been found which yield better results for scissors experiments but they give poor results for fishooks.

The lifetimes of noise tracks and their population density have been studied and reported in the two earlier reports on the simulation experiments. Typical results are presented below.

With a noise density of 10 and 100 planes in the surveillance area the average lifetime of a noise track in the TASC was found to be about 100 seconds. The average lifetime on a clear picture display when the display threshold (f_o)

is equal to 4 is about 46 seconds. The system parameters applying to these figures are about the same as those used in obtaining the results shown in Tables 1 and 2. With these same system parameters and noise density it was found that there would be about 20.3 noise tracks, on the average, appearing on a clear picture display when $f_o = 4$. When $f_o = 5$, there are on the average only 9.7 noise tracks appearing. When the noise density is reduced to 5, everything else remaining the same, the noise track life time is effected only very slightly but the density of noise tracks is greatly reduced; for $f_o = 4$ only 2.3 noise tracks on the average will appear, and for $f_o = 5$ only 0.9 appear.

Saturation of the system by forcing it to run at the full report rate does not appear to significantly reduce the performance quality. Only in the case of automatic initiation does a little trouble arise. When the system is saturated new spaces are continually being cleared on the TASC drum to permit initiation of new tracks. The locations that are cleared correspond to those tracks with lowest firmness, which are tracks in the process of dying or newly initiated tracks. The increased probability of prematurely scratching newly initiated tracks when the drum is saturated causes initiation difficulties in single cover but usually not in multiple cover.

A measure of the alertness of the system is provided by a number we call the first association time delay. This is the average time between appearance of a target in radar cover and the time that a report first associates with a track on the object. For a noise density of 5 and a 12 second scan time, typical results are 40 seconds in single cover and about 20 seconds in multiple cover. The difference between single cover with B/S = 50 $^{o}/_{o}$ and B/S = 75 $^{o}/_{o}$ is very little. When B/S = 50 $^{o}/_{o}$, however, it is sometimes likely that a track will make a couple of starts and get scratched before it finally starts and builds up a high firmness and a reasonably correct velocity. This effect is known as initiation stuttering. As noted above, initiation stuttering is particularly apparent when saturation conditions are present.

4. Recent Experiments with the Simulation Program

Since the completion of the last report on the simulation program, R-67, many more experiments have been run, and it is the purpose of this section to describe these experiments and the results that have been obtained. In this period 134 simulation experiments were run, representing some 400 hours of Illiac computation time. Since our normal allotment of Illiac time is about 65 hours a month, these experiments have been run over a period of about 6 months. It is interesting to note that these experiments represent about 1500 plane-hours of real time operation, at a cost of only about $14.50 per plane-hour; it should be remembered in this connection that real time experiments amounting to 1500 hours of useful experimental time would actually involve a much longer operating time because of equipment failures, etc.

For the most part, the experiments to be reported on here involve simulation of radar errors according to the method described in Section 2. Three values for the radar error preset parameter a have been used: a = 1/4 mi, 1 mi , and 2 mi. Fixed target experiments, fishhook experiments and scissors experiments have all been run with radar errors present.

a. Fixed Target Experiments

Six experiments are described in this section: Exps. I_{123}, I_{124}, I_{125}, I_{132}, I_{133}, and I_{134}. They are called fixed target experiments because all planes had zero velocity. Presumably it should be easier to track a fixed target than any other kind of target. In fact, a fixed target should be even easier to track than one moving at constant velocity because truncation of the radar reports makes such targets appear to move discontinuously in jumps of one mile. When radar errors were introduced it seemed logical to test the system in this simple situation before proceeding to the more difficult problem of tracking maneuvering targets.

The 100 planes were arranged on the points of a square lattice covering the 256 mi x 256 mi surveillance area. Separation of each lattice point from its nearest neighbors was 25 mi -- thus, reports from neighboring targets could not possibly be confused. Five radars with 80 mi ranges and scan times of 10 seconds were distributed over the area so that there were regions of single cover and regions of multiple cover; 66 planes were in single cover and 34 planes were in multiple cover. The preset parameter describing the threshold strength, σ_1, of each radar was set to provide a 75 % blip scan ratio. Noise reports were allowed to fall randomly over the entire 256 mi x 256 mi area and the noise density, or rate of generation of noise reports, was varied from experiment to experiment. In all six experiments the radar error preset parameter was set to give 1/4 mi. radar errors. Since the planes were located at the grid points for which the coordinates were integers (in mile units), this radar error has the identical effect as any larger radar error up to 1 mi because of truncation. In Exps. I_{123}-I_{125} the system was run at the full report rate (FRR) with total priority noise levels of 10, 15 and 5, respectively. In Exps. I_{132}-I_{134} the system was run at the reduced report rate (R^3) with total priority noise levels of 5, 1, and 3. In all experiments smoothing and sorting parameters SS-5 were used. Each experiment was run for a period of time equivalent to 10 minutes of real time operation. A detailed description of all of the parameter settings for these experiments is presented in the appendix.

The problem of primary interest here concerns the ability of the system to hold on to a track. (Loss of a track, even though subsequent initiation is automatic, is highly undesirable because of the re-identification problem.) A primary cause of loss of a track is association of the track with a noise report. The effect of these noise perturbations on the tracking is illustrated in Table 11. In this table we list, for each experiment, and for the two types of radar cover, the total number of such noise perturbations which did not result in loss of the track and the number which did result in loss of the track. The following rules were used to obtain this data:

(1) A noise association with a track was counted as such if and only if the two preceding associations of the track were right associations (i.e., associations with reports from the plane represented by the track).

(2) A track is counted as lost subsequent to a noise association if and only if it has no more right associations at all before being scratched or if at least one of the next two associations is with a noise report.

Rule 1 requires the noise perturbation to be on a track that is at least fairly well-established, with good position accuracy. Thus, just-born tracks, which associate with a noise report were not counted. Rule 2 defines loss of a track. There are two ways in which a track might be considered as lost. First, it may be scratched from the drum and cease to exist at all, or, second, it might wander away from the position of the object it represents but continue to exist by associations with noise reports. For purposes of data processing, it is easy to count events of the first type. In the second situation it is not quite so simple; however, examination of a number of events has shown that whenever a track has two or more associations with noise reports out of a sequence of three successive associations, it is almost certain that there will be no further right associations with the track. Since such events are also easily counted in data processing, and almost invariably lead to loss of the track, we have formulated Rule 2 in the above form.

For the first three experiments the noise rate was practically the same and equal to about 10 noise reports entering the system per second; this is a consequence of running at the full report rate. Differences resulting from the different priority noise levels are of secondary importance; in effect, the radars have slightly lower blip scan ratios in the higher priority noise experiments because of saturation of the buffer stores. It will be noted that the results for these first three experiments are very nearly the same. We note from this table that for the first three experiments the probability of losing a track subsequent to a noise association changes very little, if at all, in going from single cover to multiple cover - this probability being roughly 1/3. Noting that there were 66 planes in single cover and 34 in multiple cover, we see that nearly half the tracks are lost in a 10 minute period in each type of cover for these three, full report rate experiments.

The results are better for the three reduced report rate experiments. Remember that here the noise rate is given entirely by the priority noise; thus, in Exp. I_{132} there are just 5 noise reports per second entering the system, etc. In going from single cover to multiple cover the probability of losing a track subsequent to a noise association is decreased by 1/2 to 1/3.

Also, the percentage of plane tracks lost is considerably reduced. For I_{134} just 14 tracks on 66 planes in single cover are lost in 10 minutes, or the probability of losing a track is about 21 °/o in 10 minutes; in multiple cover this probability is about 6 °/o.

We have talked so far only about tracks which are lost as a result of noise perturbations. Some tracks will be occasionally lost even without noise perturbations, due to lack of data and errors in the data. Table 12 lists the number of tracks lost (i.e. scratched) which never associated with noise reports at all.

Although the figures in Table 12 are somewhat scattered, there are no clear trends and it appears that on the average there are between 5 and 6 lost tracks for each experiment. Furthermore, it seems from this data that the probability of losing one of these tracks on a fixed target does not depend very strongly on the type of cover; only for I_{133} is there a large variation.

It appears that the frequency at which tracks on fixed targets are lost under conditions of high noise density (the full report rate experiments) is too high to be considered acceptable. In Exp. I_{123}, where a total of 56 tracks on 100 planes were lost in 10 minutes, there is an average of 5 tracks (5 °/o) being lost every minute. Under these conditions humans would be kept very busy re-identifying the lost tracks when they are reinitiated. Looked at another way, if the probability of losing a track in a 10 minute period is 50 °/o, then the probability of losing either the bogey track or the friendly track, while vectoring a friend on an intercept mission (which may take of the order of 10 minutes) is much too great.

In the low noise density situation represented by Exps. I_{133} and I_{134}, where the noise densities are 1 and 3, respectively, the percentage of tracks lost is considerably less. In Exp. I_{133}, there is on the average about 1 track (1 °/o) lost per minute. Here the rate at which reidentification personnel would have to work becomes a more reasonable value. Also the probability of losing a track on the bogey or the friend during an intercept computation is reduced to 10 °/o - 20 °/o. This is still higher than desirable but not out of reason. One should

	1 Radar (B/S = 75 °/o)		2 or 3 Radars (B/S = 75 °/o)	
Identification	Noise assn and not lost	Noise assn and lost	Noise assn and not lost	Noise assn and lost
I_{123} PN = 10, FRR, SS-5	52	34	26	16
I_{124} PN = 15, FRR, SS-5	60	33	28	14
I_{125} PN = 5, FRR, SS-5	59	44	24	13
I_{132} PN = 5, R^3, SS-5	27	18	20	6
I_{133} PN = 1, R^3, SS-5	8	3	6	0
I_{134} PN = 3, R^3, SS-5	16	14	8	2

Table 11: Effect of noise associations with tracks on fixed targets.

Identification	1 Radar (B/S = 75 °/o) No Noise Assn. and Lost	2 or 3 Radars (B/S = 75 °/o) No Noise Assn. and Lost
I_{123} PN = 10, FRR, SS-5	4	2
I_{124} PN = 15, FRR, SS-5	2	3
I_{125} PN = 5, FRR, SS-5	3	0
I_{132} PN = 5, R^3, SS-5	1	4
I_{133} PN = 1, R^3, SS-5	9	0
I_{134} PN = 3, R^3, SS-5	3	2

Table 12: Number of fixed target tracks lost not due to noise associations.

bear in mind that with low noise densities it will be possible to provide bigger sorting bins and thereby further reduce the probability of track loss. Second, for Exp. I_{133}, there were no tracks lost at all in multiple cover, so one can probably expect good performance of the system, at least under these conditions. Finally, even for Exp. I_{134} where the noise density is a little higher (PN = 3), the number of tracks lost in multiple cover is still small.

b. Fishook Experiments

To examine the ability of the system to track a maneuvering aircraft when radar errors are present, a number of experiments have been run using the fishook orbit preparer and different values of the radar error (preset parameter a). The effect of double bin sorting has also been examined; experiments were run with E = 0 mi. (i.e. no DBS), E = 4 mi. and E = 8 mi. Several sets of sorting and smoothing parameters were tested since it was found that the parameters SS-5, used previously in the zero radar error experiments, were not too satisfactory when radar errors were present. A complete list of the system parameters used in each experiment is presented in the Appendix.

Experiments I_{126}-I_{131} are a set of six fishook experiments, all with 1/4 mile radar errors, no double bin sorting, and sorting and smoothing parameters SS-5. Experiments I_{126}-I_{128} were run at the full report rate, representing a noise density of about 10 noise reports per second. Experiments I_{129}-I_{131} were run at the reduced report rate, and have a noise density of nearly 10 due to a high priority noise level. Noise was always confined to the left half of the surveillance area, $x < 128$ mi. Each plane executed a 90° change in heading at a speed of 450 mph. The acceleration in the turn varied from experiment to experiment; values of 1/4g, 1g and 4g were used. Five radars were arranged in the area to provide regions of single cover and multiple cover. Two radars had blip scan ratios of 50 °/o and three had blip scan ratios of 75 °/o. They all had ranges of 80 miles and a scan time of 10 seconds.

In Table 13 we present the results of the track classification on these six experiments. The number of tracks in each class (A, B, C, D or E) for each kind of radar cover, in the noisy region $x < 128$ mi and the non-noisy region $x \geq 128$ mi is listed for every experiment. In the left-most column of the table the identification number of the experiment is given and below it are written the acceleration of the turn (1/4g, 1g or 4g), the report rate (FRR or R^3), and the identification number of the sorting and smoothing parameters (in this case always SS-5). In the right-most column a Y or N indicates that the figures in the corresponding row refer to tracks in the noisy region, or non-noisy region, respectively.

The figures in Table 13 indicate very poor tracking in all cases of single cover with a 50 $^o/_o$ blip scan ratio radar. In single cover with B/S = 75 $^o/_o$ the tracking appears to be good in the non-noisy region for 1/4g turns, and for 1g and 4g turns in the case of Exps. I_{127}, and I_{131}. In the reduced report rate experiments the higher acceleration turns do not appear to be very well tracked. In the noisy region with single cover, B/S = 75 $^o/_o$, tracking appears to be poor.

Perhaps the most striking feature exhibited by these numbers is the relatively high proportion of type C tracks in multiple cover in the reduced report rate experiments. Because of the somewhat lower noise density in these experiments one might expect better tracking than in the full report rate experiments. This phenomena is explained as follows. In the full report rate experiments the track scratcher operates very frequently due to saturation of the TASC drum; thus newly initiated tracks have little chance for survival. Now a plane report will occasionally fall outside the sorting bin (due to maneuver of the target, error in the radar report, or error in the track position) and cause the initiation of a new track. This newly created track then competes with the old track for associations with subsequent reports on the target; this process can cause death of the old track when the new track wins this competition -- the result is then a C type track. However the frequent operation of the track scratcher in the FRR experiments inhibits this process by quickly killing off the new-born tracks, but in the R^3 experiment, where the track scratcher did not operate so frequently, this process has a higher probability of occurring - hence the higher probability of type C tracks in the R^3 experiments. When double bin sorting is used this pehnomena should not appear, and later we will indeed see that this is true.

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 Radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{126}	4	1	10	2	2	13	1	3	0	1	19	3	0	0	0	Y
1/4g, FRR, SS-5	10	0	1	2	1	14	0	0	0	1	12	0	0	0	0	N
I_{127}	9	0	5	3	2	12	2	2	0	2	18	3	1	0	0	Y
1g, FRR, SS-5	7	0	1	5	1	14	0	0	C	1	12	0	0	0	0	N
I_{128}	5	1	7	4	2	8	2	5	1	1	18	2	1	1	0	Y
4g, FRR, SS-5	7	0	2	2	2	9	2	1	0	3	9	1	2	0	0	N
I_{129}	9	1	4	4	1	9	2	3	3	1	16	2	4	0	0	Y
1/4g, R^3, SS-5	9	0	2	1	2	14	0	0	0	1	11	1	0	0	0	N
I_{130}	5	1	5	6	2	14	1	2	1	0	14	2	5	1	0	Y
1g, R^3, SS-5	10	0	3	0	1	10	2	2	0	1	10	2	0	0	0	N
I_{131}	7	0	6	3	3	9	0	8	1	0	10	5	7	0	0	Y
4g, R^3, SS-5	10	0	1	2	1	11	1	2	0	1	9	1	2	0	0	N

Table 13: Track classification of fishook experiments with 1/4 mile radar errors and no double bin sorting.

The non-noisy region of multiple cover appears to yield good tracking for 1/4g and 1g turns, but tracking of the 4g turns is not quite so good. In the noisy region of multiple cover tracking appears to be good for the 1/4g and 1g turns (with FRR) but not quite so good for the 4g turns.

A sequence of twelve experiments, similar to the ones just described except for the inclusion of double bin sorting with E = 4 mi., were run; they are Exps. I_{159}-I_{170}. The first group of six experiments (I_{159}-I_{164}) is identical to the second group (I_{165}-I_{170}) except for the use of a different entry into the random number sequence. Thus, I_{159} and I_{165} are identical, but statistically independent, experiments, etc. Results of the track classification for these experiments are presented in Table 14.

In single cover with B/S = 50 °/o tracking is completely unacceptable in all cases in the noisy region; in the non-noisy region the tracking is improved considerably and in many cases is very good. An indication of the statistical fluctuations that can be expected is given by comparing I_{159} with I_{165}, I_{160} with I_{166}, etc. Note especially I_{167} which has a

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 Radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{159}	5	0	6	2	2	8	1	5	4	0	19	2	1	0	0	Y
1/4g, FRR, SS-5	11	0	0	0	3	10	0	0	0	0	12	0	0	0	0	N
I_{160}	9	0	1	4	1	10	1	3	2	2	21	0	1	0	0	Y
1g, FRR, SS-5	10	0	1	0	3	10	0	0	0	0	12	0	0	0	0	N
I_{161}	7	0	2	4	1	11	0	2	3	2	19	2	1	0	0	Y
4g, FRR, SS-5	11	0	1	0	2	9	0	1	0	0	11	1	0	0	0	N
I_{162}	3	0	10	1	1	12	1	2	2	1	20	1	1	0	0	Y
1/4g, R^3, SS-5	10	0	0	2	2	10	0	0	0	0	12	0	0	0	0	N
I_{163}	4	0	4	6	1	13	1	2	1	1	20	1	1	0	0	Y
1g, R^3, SS-5	13	0	0	0	1	10	0	0	0	0	12	0	0	0	0	N
I_{164}	7	0	2	3	3	12	3	0	1	2	21	0	0	0	1	Y
4g, R^3, SS-5	9	0	0	3	2	8	0	1	1	0	12	0	0	0	0	N
I_{165}	4	0	5	2	4	12	0	4	2	0	15	4	3	0	0	Y
1/4g, FRR, SS-5	11	0	1	1	1	9	0	0	0	1	12	0	0	0	0	N
I_{166}	4	0	2	5	4	10	1	3	3	1	18	0	3	1	0	Y
1g, FRR, SS-5	13	0	0	1	0	8	0	2	0	0	12	0	0	0	0	N
I_{167}	7	0	2	4	2	6	3	3	6	0	19	0	3	0	0	Y
4g, FRR, SS-5	10	0	2	2	0	7	0	2	1	0	11	1	0	0	0	N
I_{168}	6	0	4	3	2	14	1	2	1	0	17	2	3	0	0	Y
1/4g, R^3, SS-5	9	0	1	0	4	10	0	0	0	0	12	0	0	0	0	N
I_{169}	8	0	5	2	0	12	2	1	2	1	20	1	1	0	0	Y
1g, R^3,SS-5	11	0	1	0	2	10	0	0	0	0	12	0	0	0	0	N
I_{170}	6	0	7	2	0	13	0	3	1	1	19	2	1	0	0	Y
4g, R^3, SS-5	11	0	1	0	2	10	0	0	0	0	12	0	0	0	0	N

Table 14: Track classification of fishook experiments with 1/4 mile radar errors and double bin (E = 4 mile) sorting.

total of 4 lost planes in single cover, B/S = 50 °/o, non-noisy region, as compared with I_{161} which has only 1 lost plane.

In single cover with B/S = 75 °/o tracking is poor in the noisy region in all cases. In the non-noisy region the tracking is much improved and is, in fact, only slightly better than for the 50 °/o blip scan ratio. Notice again the fluctuations between the statistically independent, but otherwise identical, experiments.

The tracking is much improved in multiple cover. Notice especially that not a single track in the non-noisy region was lost in all twelve experiments. In the noisy region there appear about two lost tracks, on the average, out of twenty-two. One peculiarity of the data is that in every case the second one of each pair of statistically independent experiments has at least as many lost tracks as the first, and frequently more lost tracks. We have no found any error which might have caused this; probably it is just coincidence.

It was mentioned earlier that without DBS, there is a tendency to have a larger number of type C tracks in an R^3 experiment than in a FRR experiment. This was noticeable in the multiple cover data of Table 13. As we expected, the data in Table 14, which all refer to experiments with DBS, do not show this difference between FRR and R^3 experiments.

Again comparing the data in Table 13 with the data in Table 14 we note that in every case the tracking in the DBS experiments is always at least as good, if not better, than for the experiments without DBS in the non-noisy region; this is especially noticeable in single cover with B/S = 50 °/o. In the noisy region, in single cover, there does not appear to be any evidence that DBS has made a significant effect on the tracking.

Another group of six experiments, I_{182}-I_{187}, were run with DBS and E = 8 mi. Except for the larger value of E this group is identical to the group I_{159}-I_{164}, which we have just discussed. Classification of tracks for these experiments is shown in Table 15.

Comparison of the data in Table 15 with that in Table 14 does not show any significant differences in the quality of tracking, though there is some tendency for a larger proportion of type E tracks, for the E = 8 mi group of experiments. This is not surprising. Recall that type E tracks are those which do not get initiated before a certain

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 Radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{182}	3	1	5	4	2	6	0	3	7	2	17	2	1	1	1	Y
1/4g, FRR, SS-5	10	0	0	0	4	10	0	0	0	0	12	0	0	0	0	N
I_{183}	6	0	5	3	1	9	1	2	3	3	20	1	0	1	0	Y
1g, FRR, SS-5	10	0	0	1	3	10	0	0	0	0	12	0	0	0	0	N
I_{184}	6	0	2	5	1	10	1	1	4	2	21	0	0	1	0	Y
4g, FRR, SS-5	11	0	0	1	2	9	0	1	0	0	12	0	0	0	0	N
I_{185}	3	1	4	4	3	10	1	1	2	4	21	1	0	0	0	Y
1/4g, R^3, SS-5	10	0	0	2	2	10	0	0	0	0	12	0	0	0	0	N
I_{186}	4	0	3	6	2	13	0	0	2	3	22	0	0	0	0	Y
1g,R^3, SS-5	13	0	0	0	1	10	0	0	0	0	12	0	0	0	0	N
I_{187}	6	0	3	4	2	13	1	0	1	2	20	2	0	0	0	Y
4g,R^3, SS-5	10	0	0	2	2	8	0	0	2	0	12	0	0	0	0	N

Table 15: Track classification of fishook experiments with 1/4 mile radar errors and double bin (E = 8 mile) sorting.

time, (i.e. T_0) and with a larger region in which automatic track initiation is inhibited (i.e. in the E = 8 mile experiments) it is natural to expect a larger proportion of type E tracks. Although the larger double bin has no significant effect when just 1/4 mile radar errors are present it can be expected to be more effective when larger radar errors are present.

We now consider a group of fishook experiments in which there were 1 mile radar errors (a = 1 mile), and double bin sorting with E = 8 mi was used. A portion of this group, I_{217}-I_{228}, is identical to the group I_{154}-I_{170}, with the following exceptions:

(a) the radar error is 1 mile (a = 1 mile),

(b) the double bin is 8 miles (E = 8 mile),

(c) the priority noise has been reduced to a total of 5 ($N_1=N_2=N_3=N_4=N_5=1$),

(d) smoothing and sorting parameters SS-6 were used.

The priority noise was reduced to obtain data referring to a more uniform spread of noise densities. In the earlier experiments the priority noise was so high that the noise density even at R^3 was nearly 10 and thus differed but little from the noise density at FRR. The new smoothing and sorting parameters were introduced in an attempt to more properly take into account the increased uncertainty in the radar data which result from $a = 1$ mile. The new smoothing and sorting parameters, SS-6, differ from the old ones, SS-5, only by a constant added to ϵ, the sorting bin parameter: $\epsilon_{SS-6} = \epsilon_{SS-5} + 1.5$, $\alpha_{SS-6} = \alpha_{SS-5}$, $\beta/t_{SS-6} = \beta/t_{SS-5}$.

The second portion of the present group of experiments consists of Exps. I_{244}-I_{246}. These three experiments are identical to I_{217}-I_{219} except that the old smoothing and sorting parameters, SS-5, were used instead of SS-6.

Classification of the tracks for the experiments of this group is presented in Table 16. For the set of experiments using SS-6 we note that tracking in single cover with B/S = 50 °/o is generally bad in the noisy region. Tracking is improved in the non-noisy region, with B/S = 50 °/o but certainly cannot be considered as generally "good". In single cover with B/S = 75 °/o the tracking is still bad in the noisy region, differing but little from the B/S = 50 °/o case. In the non-noisy region with B/S = 75 °/o the tracking is improved considerably; in fact, there is a total of just 3 lost tracks out of 120 tracks in the 12 experiments. In multiple cover tracking is poor in the noisy region for FRR but with R^3 only 10 °/o or less of the tracks are lost. In the non-noisy region of multiple cover tracking is very good with just 2 tracks lost out of a total of 144 for the 12 experiments. Notice that for the non-noisy region the results in single cover with B/S = 75 °/o differ but little from those in multiple cover.

Compare now the set of experiments I_{217}-I_{219} (using SS-6) with the set I_{244}-I_{246} (using SS-5). In single cover with B/S = 50 °/o the results are comparable, and bad, for both sets. In single cover with B/S = 75 °/o, tracking is poor in the noisy region for both sets; in the non-noisy region the tracking appears to be the same for 1/4g and 1g turns but perhaps slightly worse for 4g turns in the SS-5 experiments (however this difference might still be accounted for by statistical fluctuations). In multiple cover tracking is fair to poor in both sets in the noisy region; in the non-noisy region tracking is good for both sets with 1/4g and 1g turns (no planes lost) but appears to be worse for the SS-5 set with 4g turns.

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 Radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{217}	3	0	3	5	4	9	0	4	2	3	14	6	1	1	0	Y
1/4g, FRR, SS-6	12	0	0	1	1	10	0	0	0	0	12	0	0	0	0	N
I_{218}	4	0	3	4	4	8	0	3	4	3	17	1	2	2	0	Y
1g, FRR, SS-6	10	0	0	3	1	10	0	0	0	0	12	0	0	0	0	N
I_{219}	2	0	2	6	5	11	1	0	3	3	15	4	3	0	0	Y
4g, FRR, SS-6	11	0	0	1	1	9	0	0	1	0	12	0	0	0	0	N
I_{220}	4	0	3	3	5	11	1	2	1	3	20	0	2	0	0	Y
1/4g, R^3, SS-6	10	0	0	3	1	10	0	0	0	0	11	0	0	1	0	N
I_{221}	6	0	1	5	3	14	0	1	1	2	20	0	2	0	0	Y
1g, R^3, SS-6	14	0	0	0	0	10	0	0	0	0	11	0	0	1	0	N
I_{222}	10	0	1	1	3	12	0	2	2	2	21	1	0	0	0	Y
4g, R^3, SS-6	13	0	0	1	0	9	0	0	1	0	12	0	0	0	0	N
I_{223}	4	0	5	5	1	8	0	7	2	1	14	1	6	1	0	Y
1/4g, FRR, SS-6	11	0	0	1	2	9	0	0	1	0	11	1	0	0	0	N
I_{224}	7	0	4	3	1	7	0	2	8	1	18	1	3	0	0	Y
1g, FRR, SS-6	12	0	0	1	1	10	0	0	0	0	12	0	0	0	0	N
I_{225}	8	0	2	5	0	14	0	1	1	2	18	3	0	1	0	Y
4g, FRR, SS-6	12	0	0	1	1	10	0	0	0	0	12	0	0	0	0	N
I_{226}	6	0	2	4	3	11	0	2	2	3	19	1	1	1	0	Y
1/4g, R^3, SS-6	12	0	1	1	0	10	0	0	0	0	12	0	0	0	0	N
I_{227}	9	0	3	1	2	13	0	1	3	1	20	1	0	1	0	Y
1g, R^3, SS-6	10	0	0	3	1	10	0	0	0	0	12	0	0	0	0	N
I_{228}	8	1	1	3	2	12	0	1	4	1	21	1	0	0	0	Y
4g, R^3, SS-6	11	0	0	2	1	10	0	0	0	0	12	0	0	0	0	N
I_{244}	3	0	2	5	5	9	0	6	2	1	16	1	1	4	0	Y
1/4g, FRR, SS-5	9	0	1	3	1	9	0	0	1	0	12	0	0	0	0	N
I_{245}	4	0	0	5	6	12	1	1	4	0	18	1	2	1	0	Y
1g, FRR, SS-5	11	0	0	3	0	10	0	0	0	0	12	0	0	0	0	N
I_{246}	3	0	4	5	3	13	0	1	3	1	15	3	1	3	0	Y
4g, FRR, SS-5	5	0	2	4	2	7	0	0	3	0	9	0	3	0	0	N

Table 16: Track classification of fishook experiments with 1 mile radar errors and double bin (E = 8 mile) sorting.

It appears that both parameter sets SS-5 and SS-6 give comparable results for 1/4g and 1g turns. However, for 4g turns parameters SS-6 consistently yield better results.

Comparison of the data in Table 15, referring to fishooks with 1/4 mile radar errors and parameters SS-5, and the data in Table 16, referring to fishooks with 1 mile radar errors and parameters SS-6, we find the following: tracking is comparable and poor for single radar cover; in multiple cover, in the noisy region with FRR, the tracking appears to be a little worse for the 1 mile radar error case; in multiple cover in the non-noisy region there is no apparent difference between the two sets of results.

We now consider a group of 15 fishook experiments, I_{229}-I_{243}, having 2 mile radar errors and double bin sorting with E = 8 mi. The first set of six experiments in this group, I_{229}-I_{234}, use smoothing and sorting parameters SS-6 and are identical to the set I_{217}-I_{222} except for the difference in the size of the radar error. A second set of experiments in this group, I_{235}-I_{237}, use new smoothing and sorting parameters, SS-7,* but are otherwise identical to I_{229}-I_{231}. A third set of experiments, I_{238}-I_{240}, are identical to the set I_{229}-I_{231}, except for the entry into the random number sequence; thus, they are identical, but statistically independent. Similarly, the fourth set of experiments, I_{241}-I_{243}, is identical to, but statistically independent of, the set I_{235}-I_{237}. Classification of the tracks for the experiments in this group is presented in Table 17.

Consider first the set of experiments in which smoothing and sorting parameters SS-6 were used: I_{224}-I_{234}, I_{238}-I_{240}. In single cover with B/S = 50 %, the tracking is generally poor or bad. In single cover with B/S = 75 %, tracking is bad in the noisy region; in the non-noisy region the tracking is good in most cases but there are indications that it is marginal (notice Exp. I_{233}, which has strikingly many lost tracks in this region in comparison with other members of this set). In multiple cover tracking is poor in the noisy region, but good in the non-noisy region with only 5 out of 108 tracks lost in all nine experiments.

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* Parameters SS-7 are related to SS-5 as follows: $\epsilon_{SS-7} = \epsilon_{SS-5} + 1$, $\alpha_{SS-7} = \alpha_{SS-5}$, $\beta/t_{SS-7} = \beta/t_{SS-5}$.

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{229}	2	3	3	3	4	4	2	5	5	2	9	1	8	3	1	Y
1/4g, FRR, SS-6	7	0	0	1	6	9	0	1	0	0	11	1	0	0	0	N
I_{230}	4	0	1	6	4	4	1	4	6	3	11	4	6	1	0	Y
1g, FRR, SS-6	3	0	0	7	4	10	0	0	0	0	10	1	0	1	0	N
I_{231}	4	1	2	6	2	4	1	3	7	3	12	3	7	0	0	Y
4g, FRR, SS-6	10	0	0	1	3	8	0	1	1	0	11	1	0	0	0	N
I_{232}	3	0	2	7	3	4	1	6	4	3	17	3	0	1	1	Y
1/4g, R^3, SS-6	6	0	1	3	4	10	0	0	0	0	12	0	0	0	0	N
I_{233}	8	0	0	5	2	6	0	5	5	2	16	0	5	0	1	Y
1g, R^3, SS-6	4	0	0	5	5	4	0	3	2	1	11	0	0	1	0	N
I_{234}	3	0	2	9	1	7	0	3	7	1	15	1	4	1	1	Y
4g, R^3, SS-6	5	0	1	3	5	9	0	0	1	0	12	0	0	0	0	N
I_{235}	3	0	5	4	3	2	1	7	5	3	4	5	10	3	0	Y
1/4g, FRR, SS-7	7	0	1	1	5	8	1	0	1	0	3	8	0	1	0	N
I_{236}	3	0	5	5	2	7	0	4	5	2	9	1	9	1	2	Y
1g, FRR, SS-7	3	0	1	6	4	8	0	0	2	0	10	0	1	1	0	N
I_{237}	1	0	2	10	2	5	0	3	7	3	9	1	7	4	1	Y
4g, FRR, SS-7	9	0	1	1	3	7	0	0	3	0	9	1	0	2	0	N
I_{238}	3	1	4	4	3	4	0	6	4	4	14	3	3	2	0	Y
1/4g, FRR, SS-6	5	0	1	3	5	6	0	0	0	4	9	1	0	2	0	N
I_{239}	3	0	1	8	3	5	0	5	4	4	13	5	2	2	0	Y
1g, FRR, SS-6	8	0	1	1	4	6	0	1	1	2	11	0	1	0	0	N
I_{240}	7	0	5	2	1	5	0	2	8	3	13	2	2	5	0	Y
4g, FRR, SS-6	7	0	0	3	4	4	0	0	4	2	11	1	0	0	0	N
I_{241}	1	0	3	5	6	3	0	6	5	4	8	2	8	2	2	Y
1/4g, FRR, SS-7	3	0	3	3	5	4	0	1	1	4	8	1	2	1	0	N
I_{242}	2	0	3	7	2	5	1	3	6	3	11	2	3	5	1	Y
1g, FRR, SS-7	5	0	3	2	4	7	1	0	0	2	10	0	2	0	0	N
I_{243}	4	0	4	4	3	2	2	3	7	4	14	1	2	5	0	Y
4g, FRR, SS-7	4	0	1	6	3	5	0	1	2	2	10	1	0	1	0	N

Table 17: Track classification of fishook experiments with 2 mile radar errors and double bin (E = 8 mile) sorting.

Now consider the experiments using smoothing and sorting parameters SS-7. Again, in single cover with B/S = 50 °/o the tracking is generally bad. In single cover with B/S = 75 °/o the tracking is bad in the noisy region; in the non-noisy region the tracking is only fair. Tracking in multiple cover in the noisy region is bad, and in the non-noisy region we could just call it fair (11 tracks lost out of 72 in six experiments).

Comparison of the results for parameters SS-6 and parameters SS-7 indicates that parameters SS-6 generally yield a smaller percentage of lost tracks; differences are especially apparent in the non-noisy regions.

Comparison of the results for 1 mile radar errors with those for 2 mile radar errors using parameters SS-6 show clear evidence of deterioration in the tracking quality with the larger radar errors, which is especially noticeable in the noisy region under multiple cover. However, there is one exception, namely in multiple cover in the non-noisy region where there does not appear to be any effect on the percentage of lost tracks.

Another group of experiments were run using 2 mile radar errors and double bin sorting with E = 8 mi, namely I_{247}-I_{252}, I_{254}-I_{259}. The first set of experiments, I_{247}-I_{252}, use the old smoothing and sorting parameters SS-5 but are otherwise identical to experiments I_{229}-I_{234} of Table 17. In the second set of experiments I_{254} and I_{255} are 1/4g fishhooks run at FRR and R^3, like I_{247} and I_{250}, but they use different smoothing and sorting parameters -- SS-8. Experiments I_{256} and I_{257} are 1g fishhooks run at FRR and R^3, like I_{248} and I_{251}, but they use the smoothing and sorting parameters SS-8. Finally, experiments I_{258} and I_{259} are 1g fishhooks, just like I_{256} and I_{257}, but they use still a different set of smoothing and sorting parameters, SS-9.

Smoothing and sorting parameters SS-8 are related to smoothing and sorting parameters SS-5 as follows:

$$\alpha_{SS-8} = \alpha_{SS-5} - 0.249,$$

$$\beta/t_{SS-8} = \beta/t_{SS-8} - 0.01,$$

$$\epsilon_{SS-8} = \epsilon_{SS-5}.$$

Thus, α and β are reduced and ϵ is unchanged. The other set of smoothing and sorting parameters, SS-9, is related to the parameters SS-5 as follows:

$$\alpha_{SS-9} = \alpha_{SS-5} - 0.249,$$
$$\beta/t_{SS-9} = \beta/t_{SS-5} - 0.02,$$
$$\epsilon_{SS-9} = \epsilon_{SS-5} \quad .$$

Thus, α is the same as for SS-8 and β/t is still smaller, and ϵ remains unchanged. Reductions of α and β/t correspond to reducing the weight given to the radar data in the smoothing process. This is the natural direction to alter these parameters when the radar error increase, because of the resultant decrease in the accuracy of the data. With parameters SS-6 and SS-7 we learned what could be achieved by altering ϵ only. With these two newer sets, SS-8 and SS-9, we sought the effect of varying just α and β/t, and keeping ϵ fixed.

Classification of the tracks for the experiments in this group is presented in Table 18. Consider first the set of experiments I_{247}-I_{252} which use the old set of smoothing and sorting parameters, SS-5. It is evident that these parameters are not capable of giving good tracking with these large radar errors. Even with the best conditions, namely, multiple cover in the non-noisy region, tracking is poor.

Consider next the set of four experiments in which smoothing and sorting parameters SS-8 are used: Exps. I_{254}-I_{257}. Let us compare the results obtained here with those obtained in corresponding experiments using parameters SS-6, which have given the best results so far. In single cover, both for B/S = 50 °/o and B/S = 75 °/o the results of these two sets of experiments do not show any significant differences. In multiple cover at the full report rate there appears to be a slight tendency toward fewer lost tracks in the experiments using parameters SS-8; however the difference is small and since tracking for these cases is poor anyway it is not especially significant. In multiple cover in the reduced report rate experiments the parameters SS-6 seem to give significantly better results than the parameters SS-8.

Finally, we compare the results obtained in the two experiments using sorting and smoothing parameters SS-9 with the corresponding ones using

Identification	1 Radar (B/S = 50 °/o)					1 Radar (B/S = 75 °/o)					2 or 3 Radars (B/S = 50 °/o, 75 °/o)					
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	Noise
I_{247}	0	1	0	7	7	3	1	4	7	3	4	1	10	6	1	Y
1/4g, FRR, SS-5	4	1	1	3	5	5	1	2	2	0	4	2	3	2	1	N
I_{248}	0	1	3	4	5	6	1	3	4	4	7	3	7	4	1	Y
1g, FRR, SS-5	1	0	0	8	5	4	0	2	3	1	6	1	3	2	0	N
I_{249}	1	0	0	7	7	5	1	3	5	4	4	4	7	5	2	Y
4g, FRR, SS-5	4	0	2	3	5	3	0	1	5	1	7	0	3	2	0	N
I_{250}	1	0	4	6	4	4	0	6	4	4	7	3	8	1	3	Y
1/4g, R^3, SS-5	2	0	2	6	4	3	0	5	1	1	6	2	1	2	1	N
I_{251}	5	0	0	7	3	6	0	4	7	1	7	1	7	4	3	Y
1g, R^3, SS-5	3	0	0	5	6	5	0	3	1	1	5	0	2	3	2	N
I_{252}	4	0	2	6	3	7	0	2	7	2	7	3	3	5	4	Y
4g, R^3, SS-5	3	0	2	3	6	4	0	3	2	1	8	1	1	2	0	N
I_{254}	3	0	6	3	3	7	2	2	5	2	7	6	7	2	0	Y
1/4g, FRR, SS-8	6	0	2	1	5	7	3	0	0	0	5	5	1	1	0	N
I_{255}	5	0	4	5	1	5	1	7	3	2	13	2	5	1	1	Y
1/4g, R^3, SS-8	6	0	1	3	4	7	0	1	0	2	12	0	0	0	0	N
I_{256}	2	0	5	6	2	4	2	2	9	1	13	3	5	1	0	Y
1g, FRR, SS-8	4	0	0	6	4	9	0	0	1	0	10	1	1	0	0	N
I_{257}	10	0	1	4	0	5	0	4	9	0	10	3	6	3	0	Y
1g, R^3, SS-8	5	0	0	5	4	5	0	0	3	2	6	3	1	2	0	N
I_{258}	2	0	3	9	1	10	0	3	4	1	9	6	3	4	0	Y
1g, FRR, SS-9	4	0	0	5	5	9	0	0	1	0	9	1	0	2	0	N
I_{259}	8	0	0	6	1	6	0	4	8	0	12	4	3	3	0	Y
1g, R^3, SS-9	6	0	0	4	4	4	0	1	3	2	10	0	0	2	0	N

Table 18: Track classification of fishook experiments with 2 mile radar errors and double bin (E = 8 mile) sorting.

parameters SS-6. In single cover the results appear to be about the same, with the exception of I_{258} for B/S = 75 °/o where the tracking is considerably better than for the corresponding experiments using parameters SS-6 -- I_{230} and I_{239}. In multiple cover the results again appear to be about the same for the two sets.

Only a few sets of experiments have been run with the newer parameters SS-8 and SS-9, because of lack of time. The scanty results that we do have indicate that worthwhile results might be achieved by using a still different set of parameters having an α and β/t given by SS-9 and an ϵ given by SS-6.

A group of fishook experiments was run using different antenna scan times to investigate the effect of variations in the data rate. Experiments of this type had been run before but without radar error. In the present experiments 1/4 mile radar errors were included. Only one radar was used and it was placed at the center of the 256 mi x 256 mi surveillance area; this radar had a blip scan ratio of 75 °/o and a priority noise of 10. The experiments were run at the reduced report rate so the noise density was just 10. The planes flew a 1g fishook at 450 mph. In the set of experiments I_{171}-I_{174} the scan time, τ , had the values of 6 sec., 8 sec., 10 sec., and 12 1/2 sec., respectively. These four experiments were repeated with a different entry to the random number sequence--they are identified as I_{175}-I_{178}. Double bin sorting with E = 4 mile was used in these experiments. In another set of experiments, I_{196}-I_{199}, double bin sorting was omitted; otherwise these experiments were identical to the set I_{171}-I_{174}. Classification of the tracks for this group of experiments is presented in Table 19.

First we note that even at the shortest scan time a few tracks are lost in the noisy region. This is not surprising since the data rate here is slightly less than the average for multiple cover in the experiments just discussed and we noted there that some tracks were lost in the noisy region (cf. Exps. I_{160}, I_{163}, I_{166}, I_{169} in Table 9). In the non-noisy region it is interesting to note that no tracks are lost for τ = 8 sec or below while for τ = 10 sec and above, lost tracks appear. It was noted in an earlier report that an 8 second scan time was about optimum (in the absence of radar errors) and we notice here evidence for the same conclusion

Identification	1 Radar (B/S = $75\ ^{o}/_{o}$)					
	A	B	C	D	E	Noise
I_{171}	51	1	3	0	0	Y
DBS, τ = 6 sec.	36	0	0	0	0	N
I_{172}	43	1	6	3	1	Y
DBS, τ = 8 sec.	36	0	0	0	0	N
I_{173}	41	1	9	4	0	Y
DBS, τ = 10 sec.	13	0	3	0	2	N
I_{174}	32	0	15	4	4	Y
DBS, τ = 12 1/2 sec	34	0	0	1	1	N
I_{175}	46	3	6	0	0	Y
DBS, τ = 6 sec.	36	0	0	0	0	N
I_{176}	47	1	3	4	0	Y
DBS, τ = 8 sec.	36	0	0	0	0	N
I_{177}	40	3	6	5	1	Y
DBS, τ = 10 sec.	35	0	0	1	0	N
I_{178}	28	2	13	7	5	Y
DBS, τ = 12 1/2 sec	30	0	1	2	2	N
I_{196}	44	7	6	2	0	Y
No DBS, τ = 6 sec.	39	1	1	0	0	N
I_{197}	44	5	6	4	0	Y
No DBS, τ = 8 sec.	33	3	5	0	0	N
I_{198}	35	2	15	6	1	Y
No DBS, τ = 10 sec.	32	4	2	3	0	N
I_{199}	40	1	5	9	4	Y
No DBS, τ = 12 1/2 sec	35	0	1	0	5	N

Table 19: Track classification of fishook experiments with various antenna scan times.

in the non-noisy region. In the last set of experiments, where DBS is lacking, the number of lost tracks is increased considerably; even at $\tau = 6$ sec. there is a track lost in the non-noisy region.

This completes the list of fishook experiments that have been run. Presentation of the results, as we have just done, by listing the number of tracks of every class for each experiment is quite detailed and although it illustrates rather explicitly the character of the tracking in each situation it is somewhat bewildering because of the large mass of data. To help point up some of the important features of the results that have just been presented, we will now display them in a more condensed, but perhaps more easily understood, form.

This summary of results appears in Figures 7-24. In the first group, Figures 7-15, we display the results so as to show especially the effect of sorting bin size on the tracking. In the second group, Figures 16-24 we display the results to show particularly the effect of radar error on the tracking.

In Figure 7 the results for tracking 1/4g fishooks with 2 mile radar errors in the non-noisy region are displayed as a function of ϵ, the bin size; or, more precisely, as a function of the increments to ϵ for SS-5 (1.0 mile, and 1.5 mile) used to generate SS-7 and SS-6. The abscissa of this figure represents the bin size, labeled according to the corresponding sorting and smoothing parameters, and the ordinate gives the percentage of successful tracks; we define class A and class B tracks as successful. The results for FRR and R^3 have been combined for this presentation. We have somewhat arbitrarily divided the ordinate axis into intervals 100 °/o-95 °/o, 95 °/o-90 °/o, 90 °/o-80 °/o, 80 °/o-50 °/o, 50 °/o-0, and labelled them as excellent, good, fair, poor, and bad, respectively.* Results are shown for each of the three types of cover (good radar means B/S = 75 °/o, and poor radar means B/S = 50 °/o). In Figures 8 and 9 there is a similar presentation of results for 1g and 4g fishooks.

With one exception, namely the 1g turn in good radar cover, the percentage of successful tracks always appears to increase linearly with increasing ϵ.

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* Previous use of the words excellent, good, etc. does not necessarily comply with the present scheme of labels.

It is clear that parameters SS-6 give the best results and always yield good to excellent tracking in multiple cover. Both for multiple cover and for cover by one poor radar the slope of the curves are about the same for every case; in addition, the position of each curve does not change very much as the acceleration is changed. Thus it appears that the percentage of successful tracks is affected only slightly, if at all, by the acceleration in the turn. One expects differences in the tracking considered as a function of the acceleration to diminish with increasing radar errors, since accelerations imparted to the track by the errors tend to mask the true accelerations of the target. In the present case it appears that the radar errors are sufficiently large to obfuscate any changes that might result in the tracking quality due to different accelerations in the turn.

It is interesting to note that the ordinate of the curve for one poor radar at ϵ for SS-6 is always within 5 °/o of the ordinate of the curve for multiple cover at ϵ for SS-5. This result seems to imply that the loss in blip scan ratio in going from multiple cover to single cover by one poor radar, a loss of roughly 80 °/o, is just "balanced" by the increased data rate resulting from the large sorting bin for parameters SS-6.

In Figures 10-12 a similar presentation is made of the results in the noisy region for reduced report rate experiments. Data for parameters SS-7 is lacking and is therefore not shown in these figures; however, the position along the abscissa where this data would appear is indicated in brackets. In single cover the tracking is always poor or bad and generally changes little, if at all, with increasing ϵ. In multiple cover the tracking falls in the good or excellent region in only one instance--namely, the 1/4g turn with parameters SS-6. Comparison of these figures with Figures 7-9 for the no noise region indicates the deterioration in tracking quality caused by the noise.

In Figures 13-15 a similar presentation is made of the results in the noisy region for the full report rate experiments. In no case is the tracking even fair; in fact, the percentage of successful tracks never exceeds 75 °/o. Though the tracking is of generally poor quality, the

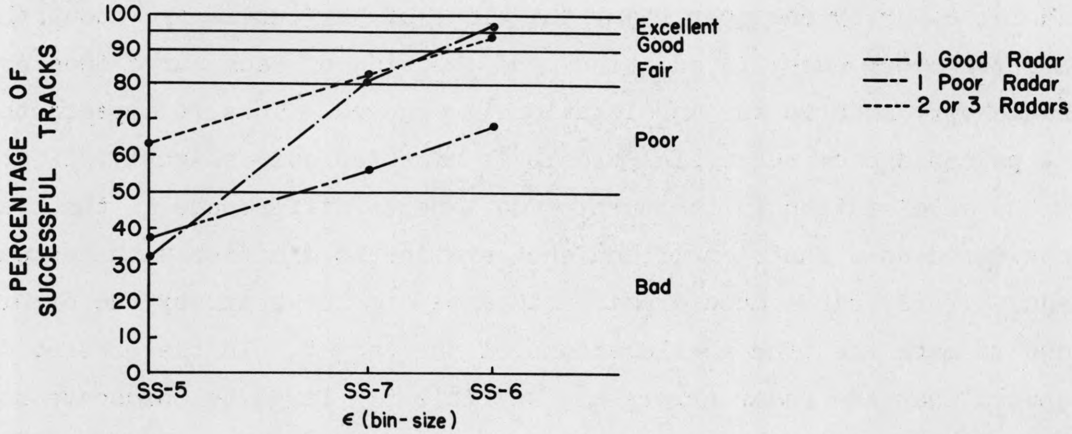

FIG. 7 TRACKING OF ¼g, 450mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7, WITH 2 MILE RADAR ERRORS AND NO NOISE.

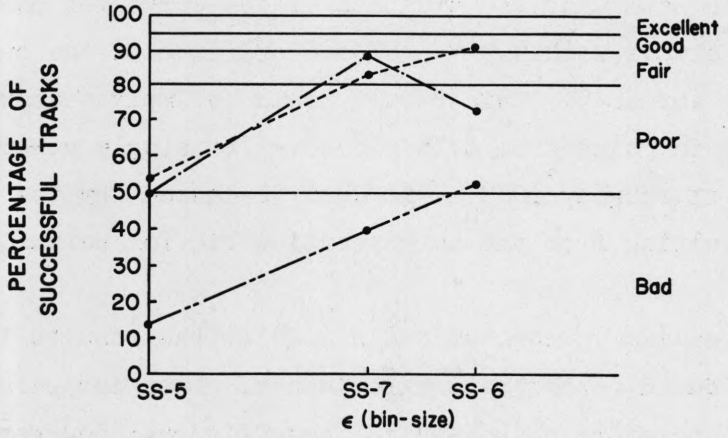

FIG. 8 TRACKING OF 1g, 450mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7, WITH 2 MILE RADAR ERRORS AND NO NOISE.

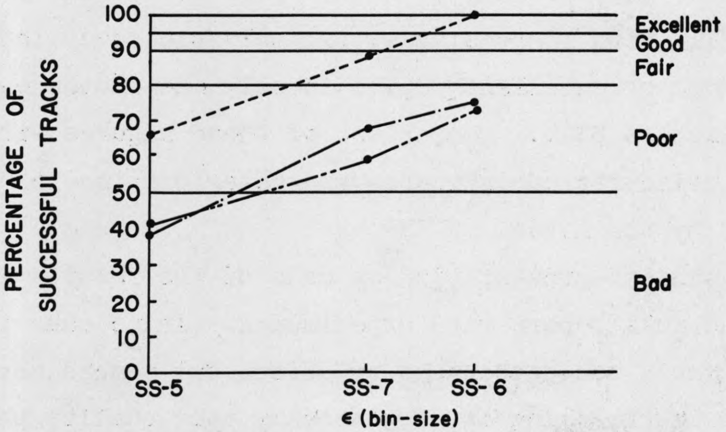

FIG. 9 TRACKING OF 4g, 450mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7, WITH 2 MILE RADAR ERRORS AND NO NOISE.

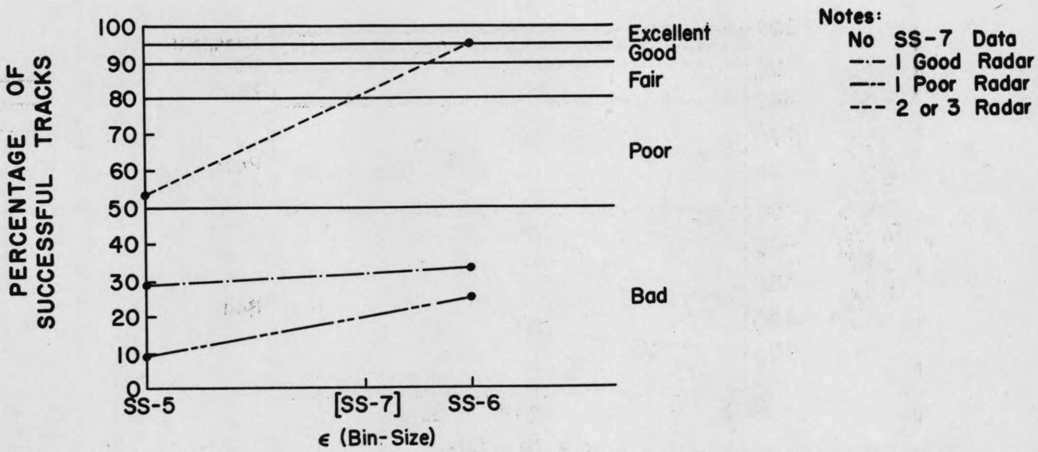

FIG. 10 TRACKING OF $\frac{1}{4}$g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, REDUCED REPORT RATE, IN THE NOISY REGION.

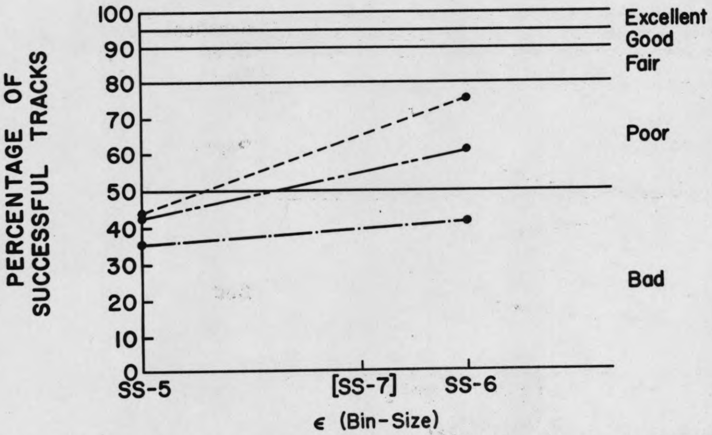

FIG. 11 TRACKING OF 1g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, REDUCED REPORT RATE, IN THE NOISY REGION.

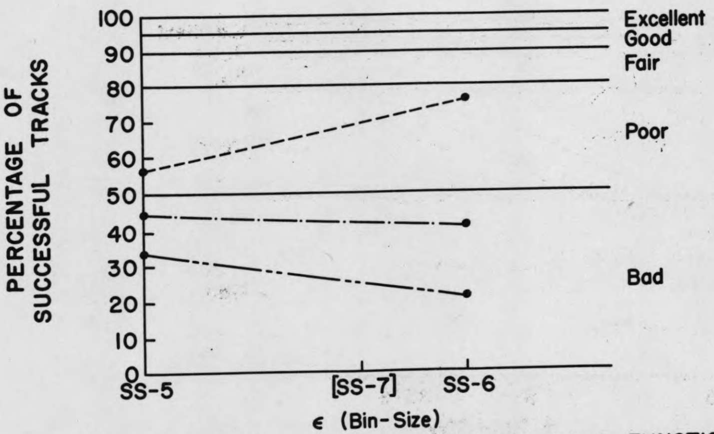

FIG. 12 TRACKING OF 4g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, REDUCED REPORT RATE, IN THE NOISY REGION.

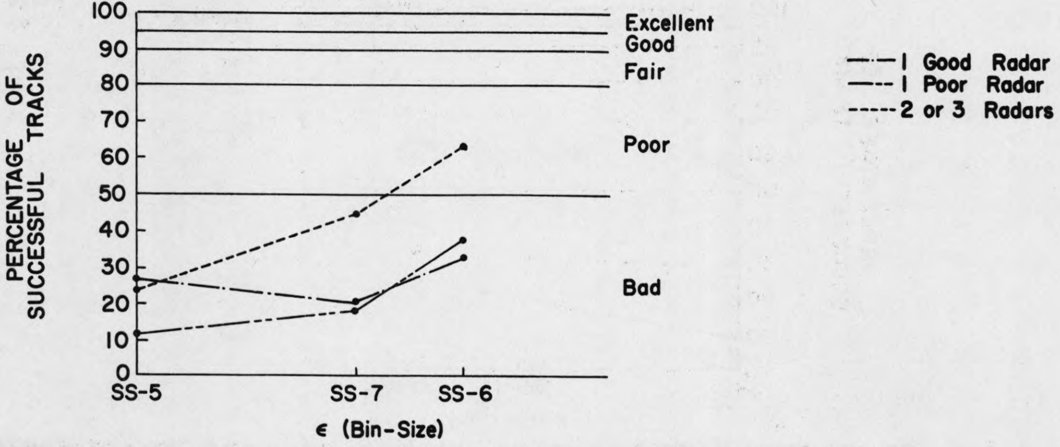

FIG. 13 TRACKING OF ¼g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, FULL REPORT RATE, IN NOISY REGION.

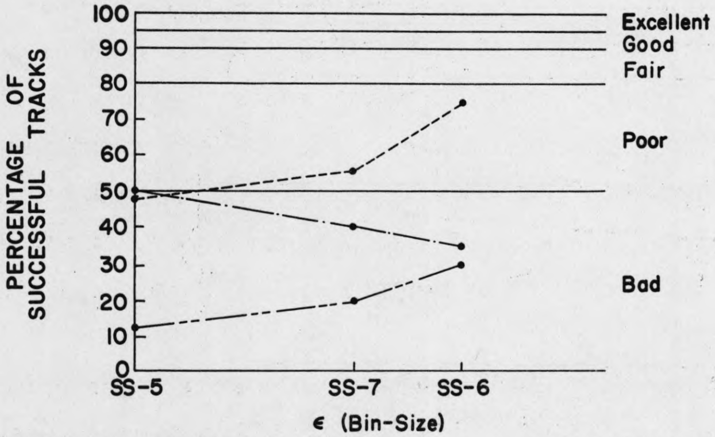

FIG. 14 TRACKING OF 1g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, FULL REPORT RATE, IN NOISY REGION.

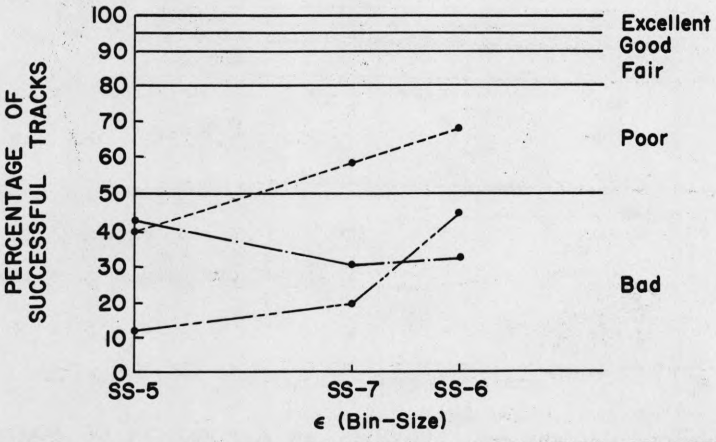

FIG. 15 TRACKING OF 4g, 450 mph, FISHOOKS AS A FUNCTION OF SORTING AND SMOOTHING PARAMETERS SS-5, SS-6, SS-7 WITH 2 MILE RADAR ERRORS, FULL REPORT RATE, IN NOISY REGION.

parameters SS-6 do represent some improvement over SS-5 and SS-7. It is not known whether a further improvement in tracking can be achieved by making the sorting bin still larger. Of course, continued increase in ϵ will not yield continued increase in tracking quality for two important reasons. First, the probability of a noise report falling inside the sorting bin increases (in fact, with ϵ^2) and second, noise reports falling inside, but near the edge, of a large ϵ induce large false accelerations in the tracks.

In Figure 16 the results for tracking 1/4g fishhooks in the non-noisy region are displayed as a function of radar error. The abscissa of this figure gives the radar error and the ordinate gives the percentage of successful tracks. The results for FRR and R^3 have been combined for this presentation. We have again arbitrarily labelled the regions 100 °/o-95 °/o, 95 °/o-90 °/o, 90 °/o-80 °/o, 80 °/o-50 °/o, and 50 °/o-0 °/o as excellent, good, fair, poor and bad, respectively. The results apply to the smoothing and sorting parameters which appear to be best for the corresponding radar error; identification of the "best" smoothing and sorting parameter is given just below the corresponding radar error along the abscissa. In Figures 17 and 18 there is a similar presentation of results for 1g and 4g fishhooks. Results are shown for each of the three types of cover.

The change in the tracking quality with increasing radar error is clearly illustrated in these figures. Only in multiple cover does the tracking remain good to excellent for all accelerations and all sizes of radar error. In single cover the quality of tracking drops off sharply with 2 mile radar errors for 1g and 4g turns.

Figures 19, 20 and 21 present similar data for the reduced report rate experiments and tracks in the noisy region. Results for 1/4 mile radar errors are not shown because in the reduced report rate experiments having this 1/4 mile radar error the priority noise was nearly 10 while in the experiments having 1 mile and 2 mile radar errors the priority noise was only 5; thus, direct comparison of the 1/4 mile radar error, R^3 results with these other results would not be too meaningful.

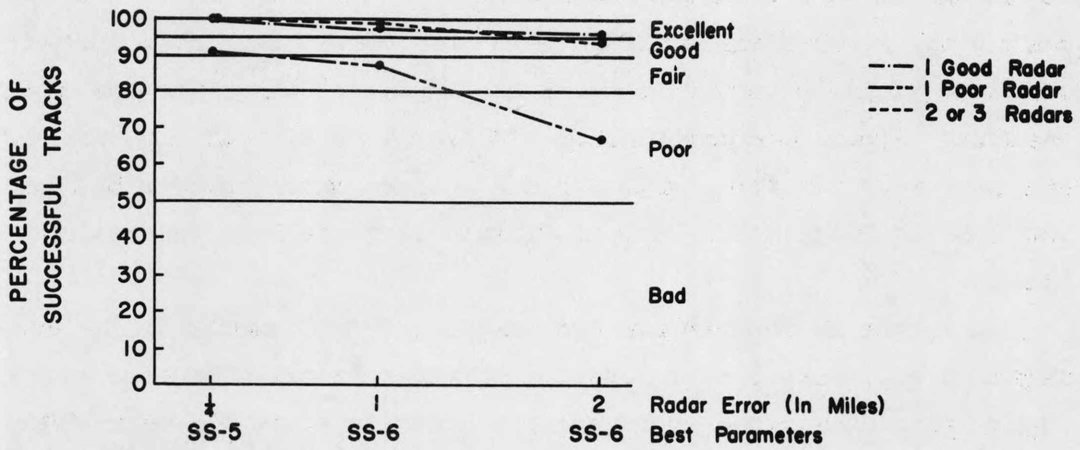

FIG. 16 TRACKING OF ¼g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR WITH NO NOISE.

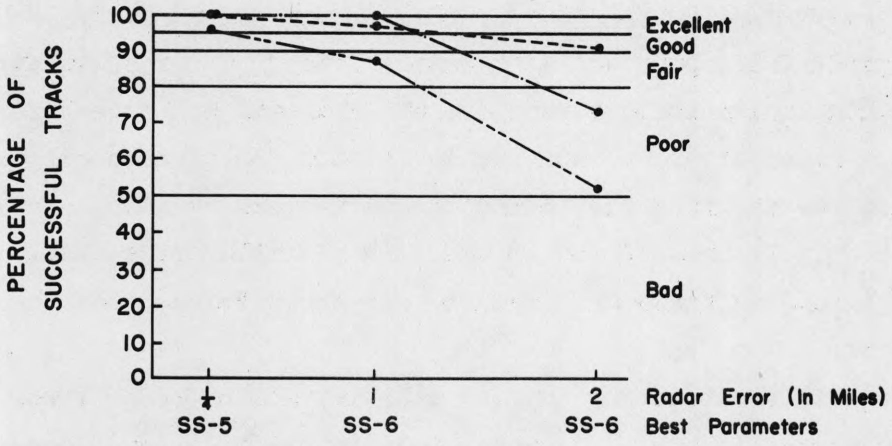

FIG. 17 TRACKING OF 1g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR WITH NO NOISE.

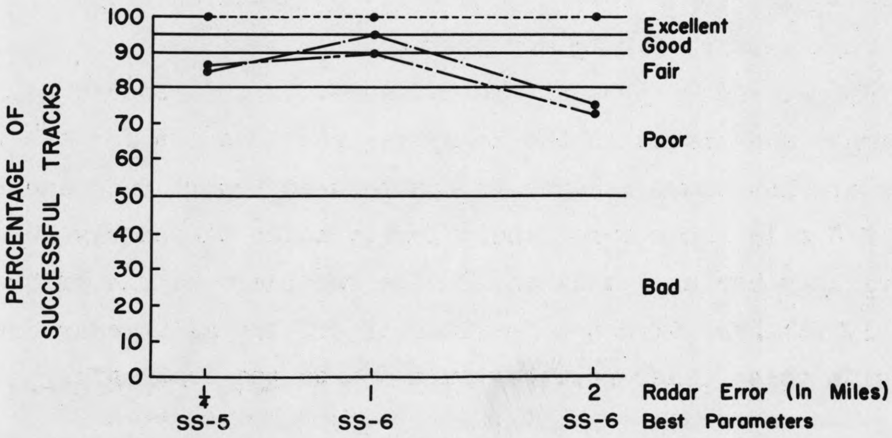

FIG. 18 TRACKING OF 4g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR WITH NO NOISE.

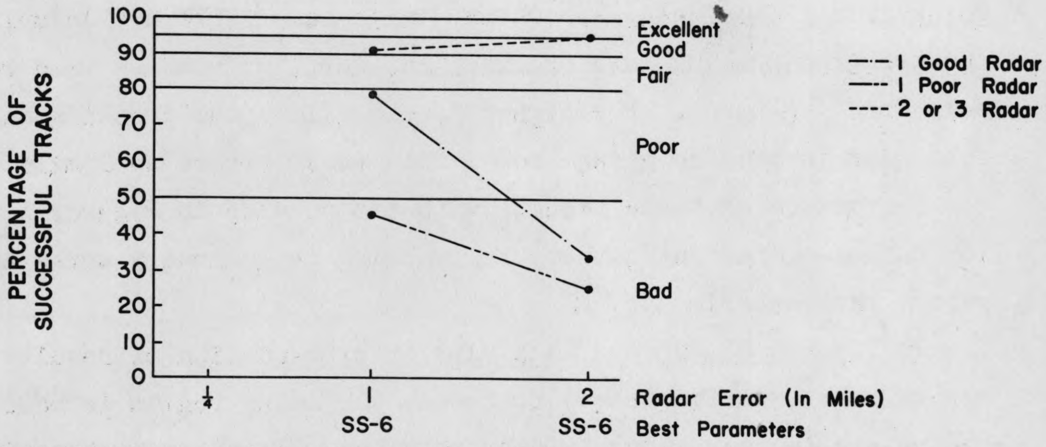

FIG. 19 TRACKING OF $\frac{1}{4}$g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH REDUCED REPORT RATE, AND IN THE NOISY REGION.

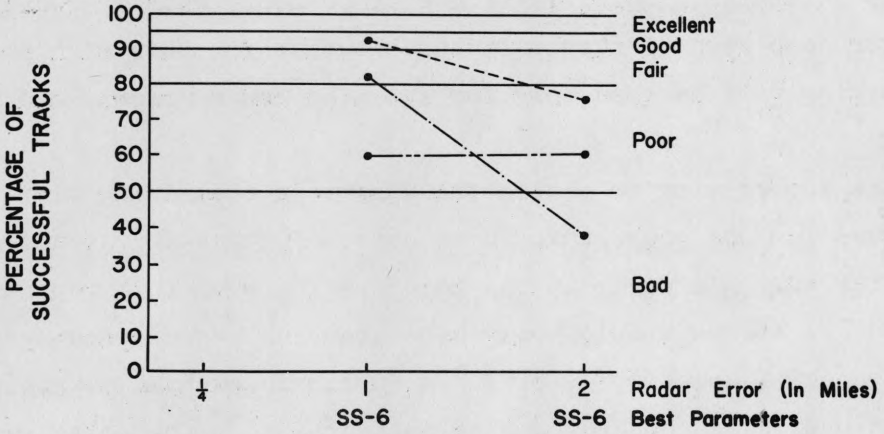

FIG. 20 TRACKING OF 1g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH REDUCED REPORT RATE, AND IN THE NOISY REGION.

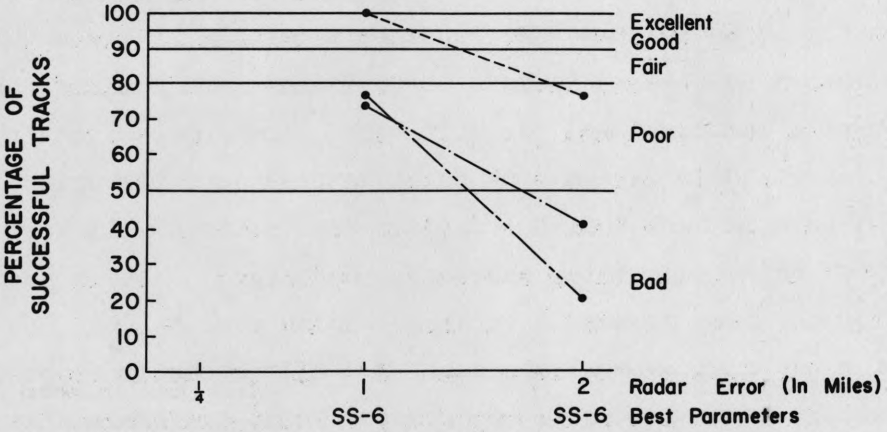

FIG. 21 TRACKING OF 4g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH REDUCED REPORT RATE, AND IN THE NOISY REGION.

In single cover, both for B/S = 75 $^{o}/_{o}$ and B/S = 50 $^{o}/_{o}$ the tracking is almost always poor or bad and usually becomes significantly worse in going from 1 mile radar errors to 2 mile radar errors. In multiple cover the tracking remains good or excellent for 1 mile and 2 mile radar errors only for 1/4g turns. For higher accelerations the tracking deteriorates from good to poor in going from 1 mile radar errors to 2 mile radar errors.

Comparison of these results with the results in Figures 16, 17 and 18, for no noise, indicates that the tracking is generally worse in the reduced report rate experiments.

In Figures 22, 23 and 24 a similar presentation of results for the full report rate experiments and tracks in the noisy region is made. Tracking by the single poor radar is uniformly bad. Tracking by the single good radar is nearly always poor or bad. In multiple cover there is a steady decrease in tracking quality (from good to poor) with increasing radar error for each type of turn. It appears that for this high noise density the tracking will be good only for 1/4 mile radar errors, and multiple cover.

It is interesting to notice that there is a striking similarity between the curves for the poor radar in no noise (Figures 16, 17 and 18) and the curves for multiple cover in the noisy region with full report rate (Figures 22, 23, 24). With only one exception, corresponding points show a difference of about 6 $^{o}/_{o}$ or 7 $^{o}/_{o}$, which is certainly within statistical fluctuations. This indicates that an increase in the noise rate may be balanced by an increase in the blip scan ratio, independent of the radar error and the acceleration in the turn. Another way to express this relationship is as follows: We consider a particular track which, on the average, has N noise associations per unit time and M plane associations (i.e. correct associations) per unit time. Now suppose that the noise rate is increased to give $N + \Delta N$ noise associations per unit time, then there exists a ΔM such that $M + \Delta$ plane associations will keep the probability of this track being successful unchanged. Let us now compute ΔN and ΔM for the case at hand. In the no noise case $N = 0$. The corresponding number for the full report rate case, $N + \Delta N$, is easily computed. The total noise rate is about 100 noise reports per scan, uniformly distributed over

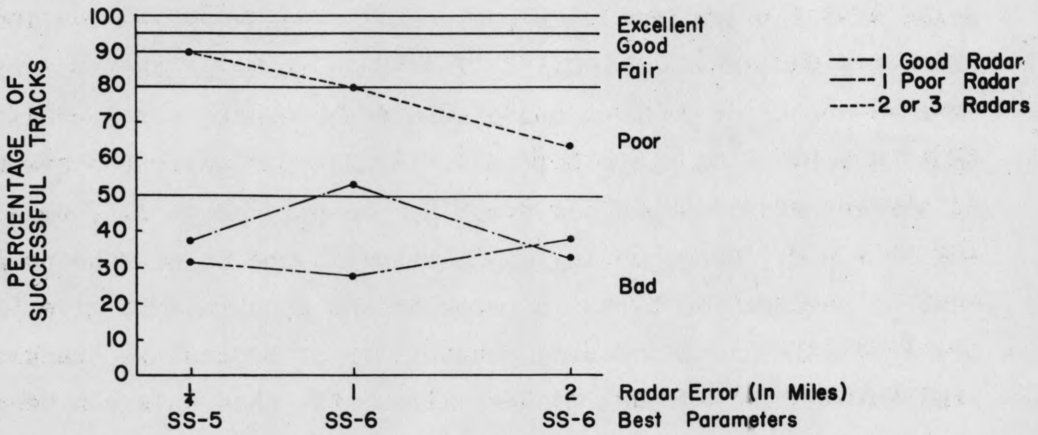

FIG. 22 TRACKING OF ¼ g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH FULL REPORT RATE, AND IN THE NOISY REGION.

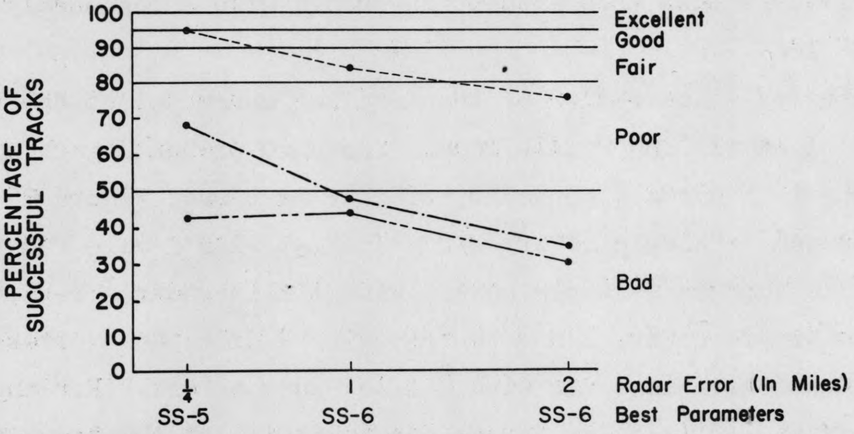

FIG. 23 TRACKING OF 1g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH FULL REPORT RATE, AND IN THE NOISY REGION.

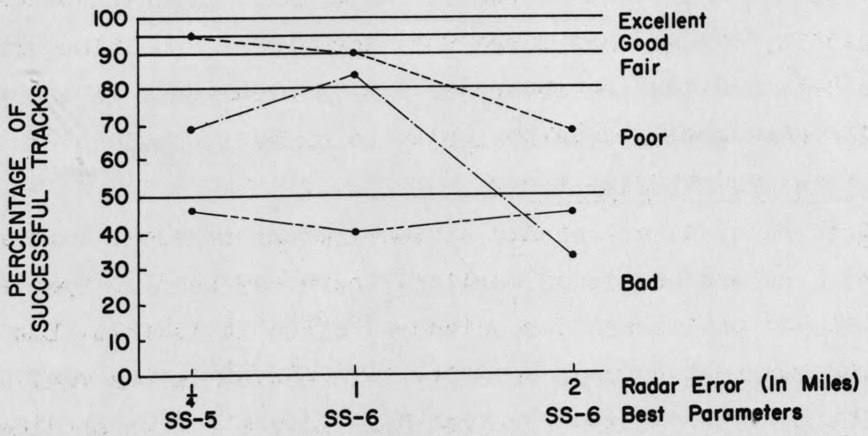

FIG. 24 TRACKING OF 4g, 450 mph, FISHOOKS AS A FUNCTION OF RADAR ERROR, WITH FULL REPORT RATE, AND IN THE NOISY REGION.

an area of 128 mi x 256 mi. If we estimate the average sorting bin size to be 49 sq. mi. (i.e. average $\epsilon = 3.5$ mi), then the average number of noise associations per track per scan is $\frac{49}{128 \times 256} \times 100 = 0.15$. Since $N = 0$ we have $\Delta N = 0.15$. In single cover of the poor radar the average number of correct associations per track per scan is about 0.5; thus, $M = 0.5$. On the other hand, in multiple cover the average number of correct associations per track per scan is about 1.3; thus, $M + \Delta M = 1.3$ and $\Delta M = 0.8$. Consequently, an increase in the noise rate to give $\Delta N = 0.15$ must be accompanied by an increase in the data rate to give $\Delta M = 0.8$ in order to maintain a constant probability of success in tracking, for the present example. If one assumes linearity, then this can be stated as a general result independent of N and M; that is, $\Delta M = 5.3 \, \Delta N$. For large variations in N and M the assumption of linearity may well be false, but for small variations this assumption should give a reasonably correct approximation.

As a brief illustration of the detailed character of the tracks in the presence of 1 mile and 2 mile radar errors, we present track history plots, like those in Figures 4, 5 and 6, of four 1g turns: Figure 25 shows a turn executed in single cover, B/S = 75 °/o, with 1 mile radar errors, Figure 26 a turn in multiple cover, with 1 mile radar errors, Figure 27 a turn in single cover, B/S = 75 °/o, with 2 mile radar errors, Figure 28 a turn in multiple cover with 2 mile radar errors. For the turns executed with 1 mile radar errors the deviation of the track from the true course is usually not greater than 2 miles. The appearance of the tracks with two mile radar errors is especially striking because of the large velocity changes and large position errors; position errors as large as 5 to 6 miles are observed. It is clear that in the presence of 2 mile radar errors track velocity is exceedingly inaccurate.

c. Scissors Experiments

In this section the results of some recent scissors experiments are presented. As was mentioned earlier, there has been no special effort made to find "best" parameters for scissors, since it is felt that providing height information and some velocity information is the real solution to this problem. The results reported here have all been obtained using parameters found to be "best" for fishooks.

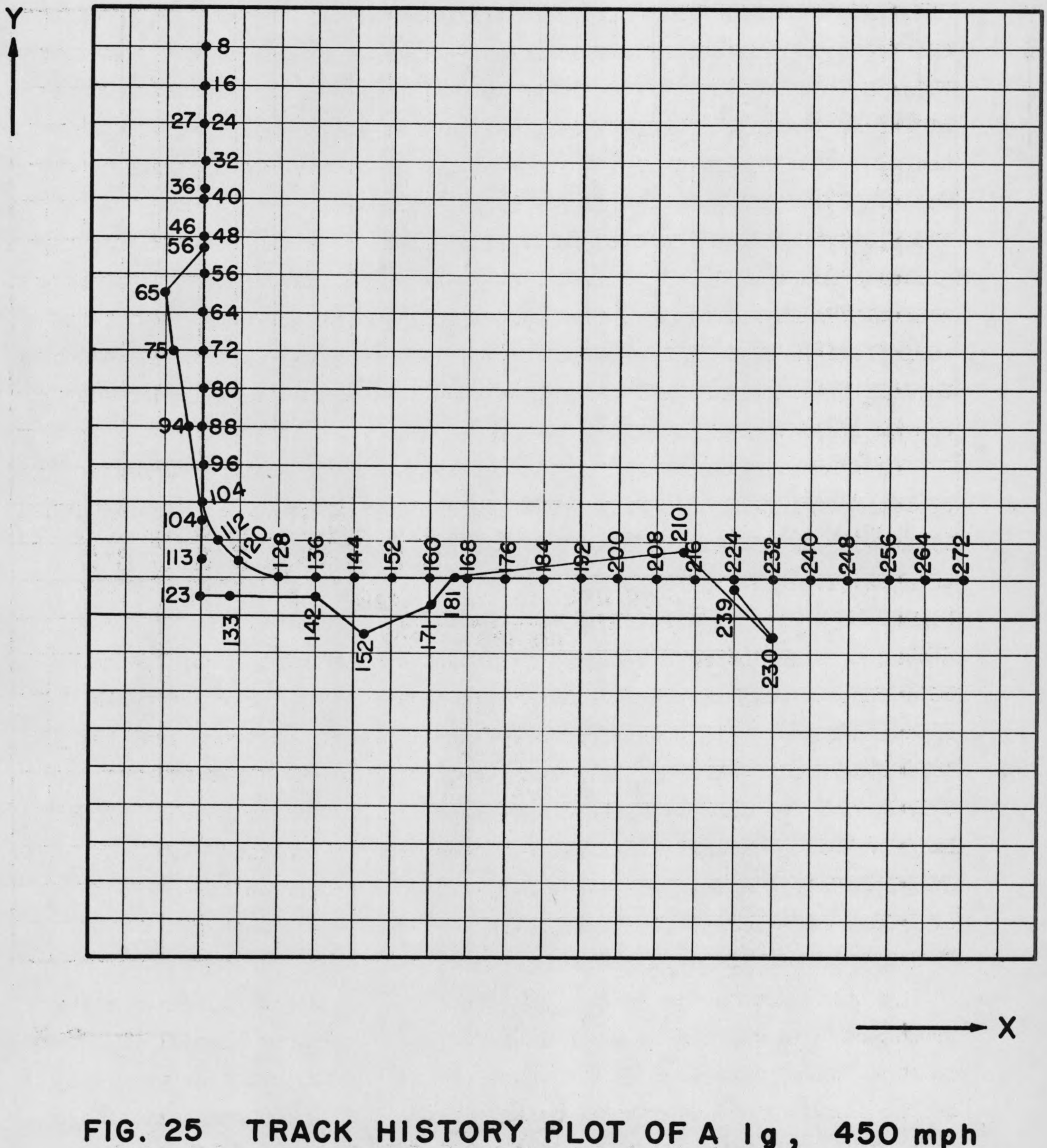

FIG. 25 TRACK HISTORY PLOT OF A 1g, 450 mph FISHOOK EXECUTED IN SINGLE COVER WITH 1 MILE RADAR ERRORS PRESENT.

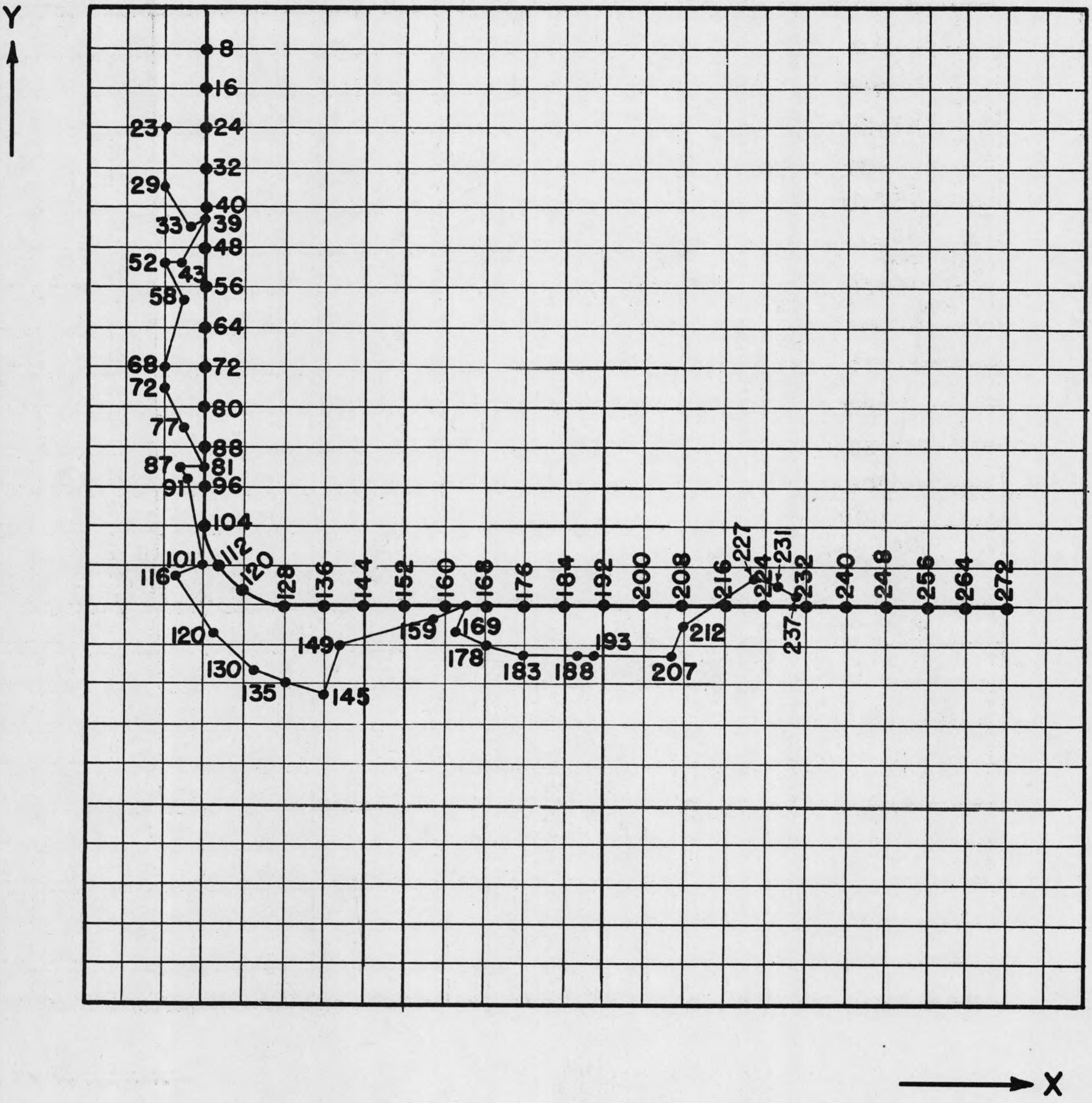

FIG. 26 TRACK HISTORY PLOT OF A 1g, 450 mph FISHOOK EXECUTED IN MULTIPLE COVER WITH 1 MILE RADAR ERRORS PRESENT.

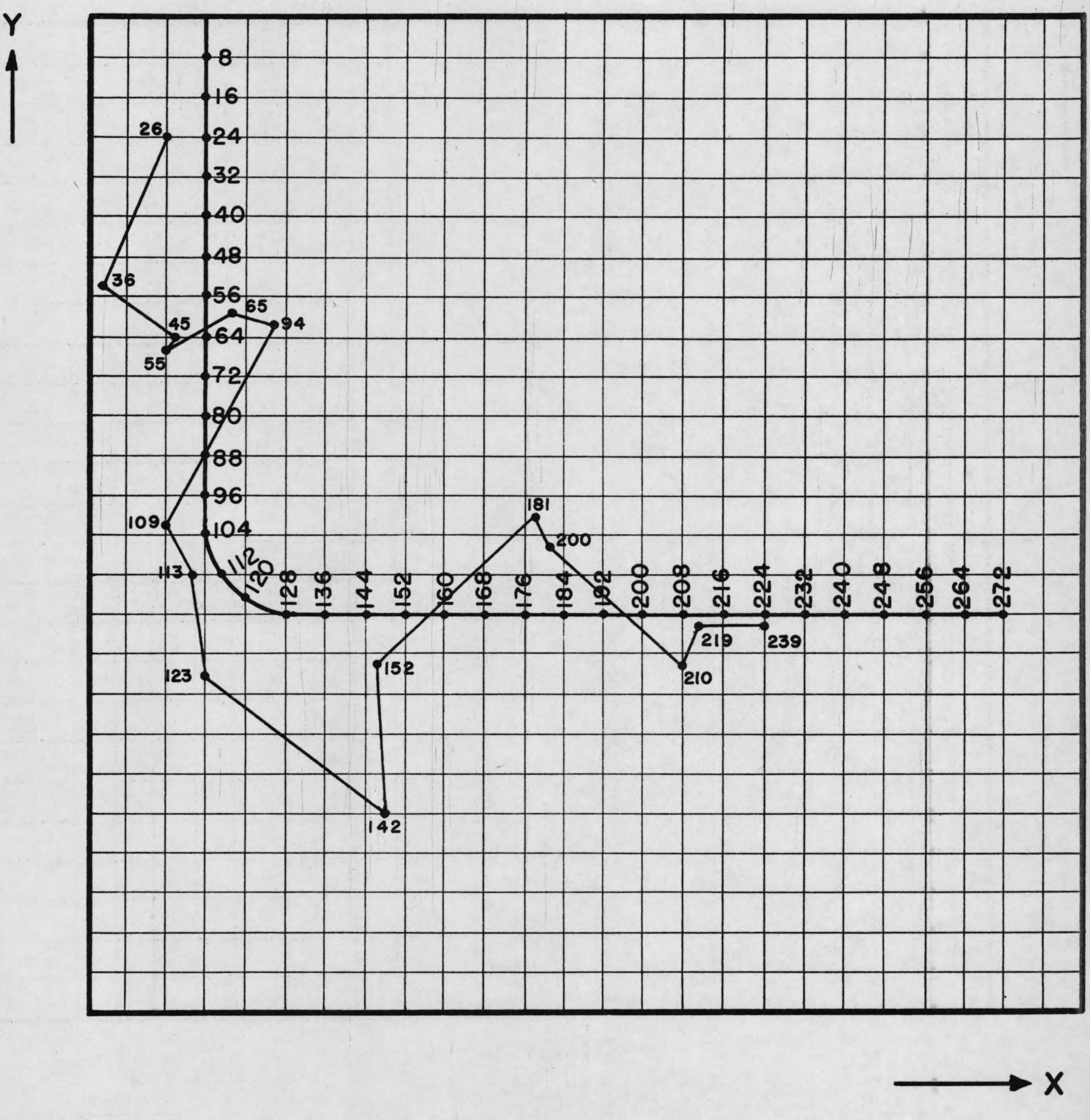

FIG. 27 TRACK HISTORY PLOT OF A 1g, 450 mph FISHOOK EXECUTED IN SINGLE COVER WITH 2 MILE RADAR ERRORS PRESENT.

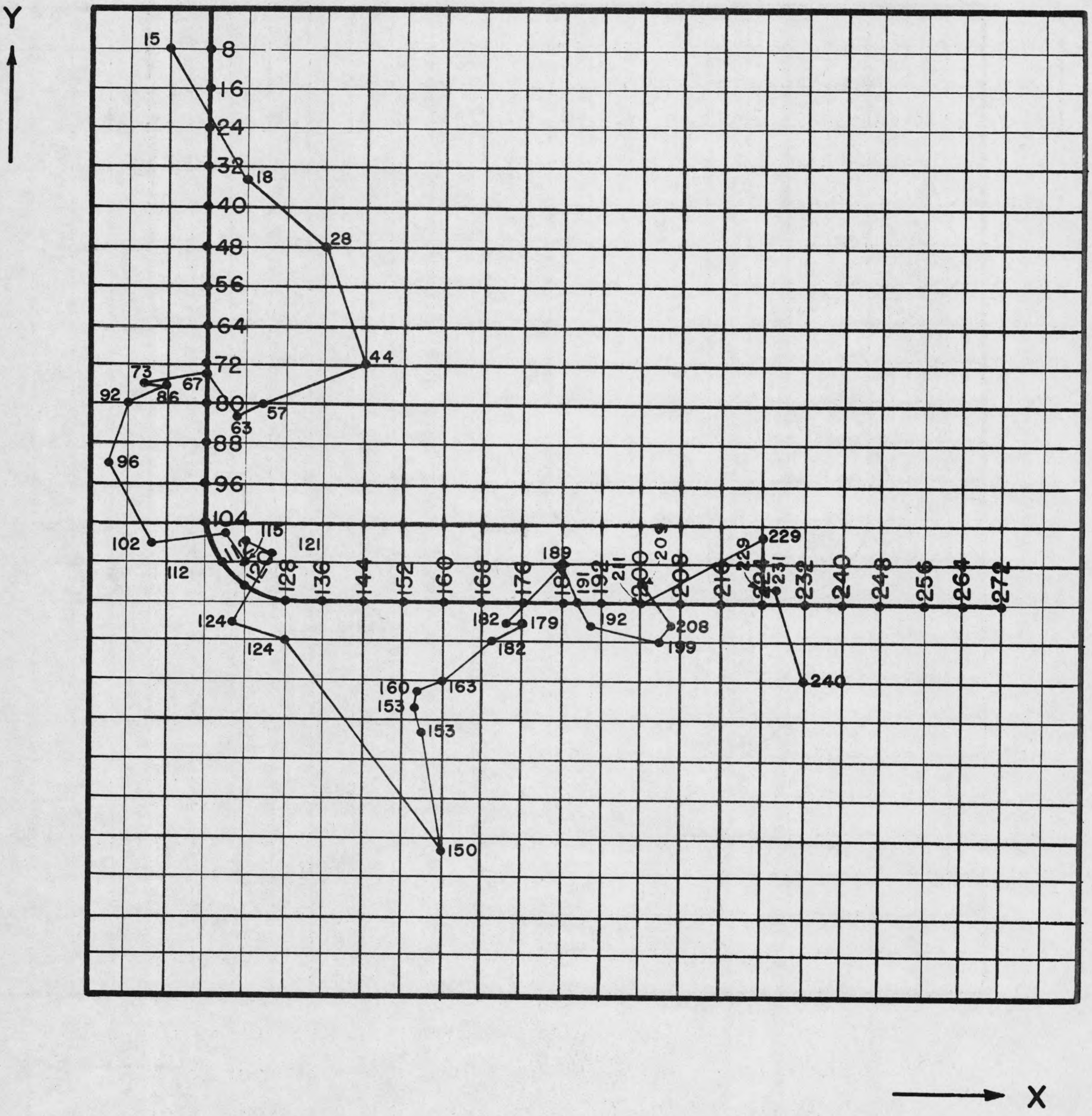

FIG. 28 TRACK HISTORY PLOT OF A Ig, 450mph, FISHOOK EXECUTED IN MULTIPLE COVER WITH 2 MILE RADAR ERRORS PRESENT.

The first group of scissors experiments consists of Exps. I_{135}-I_{158}. In all of these experiments just one radar with 1/4 mile errors was used; it was placed at the center of the 256 mi x 256 mi area with a blip scan ratio of 75 °/o and a priority noise of 2. Since all experiments were run at the reduced report rate this means that the noise rate was just 2 noise reports per second falling in the 256 mi x 128 mi (left half) area called the noisy region. The scan time was varied from experiment to experiment, a total of 4 scan times being used: τ = 6 sec, 8 sec, 10 sec. and 12 1/2 sec. In each experiment a = 1/4 mi (i.e. 1/4 mi radar error) and no double bin sorting was used. In all experiments the planes had a speed of 450 mph. The angle of intersection(θ) of the flight paths was varied. The three angles tested were $\theta = 60^\circ$, 90° and 120°. For each value of θ the above four scan times were used. Finally, for each parameter setting two experiments were run, differing only by the entry to the random number sequence; thus, the set of experiments I_{135}-I_{146} are identical to, but statistically independent of, the set I_{147}-I_{158}.

Classification of the tracks for this group of experiments is presented in Table 20. In the left-most column of the table the identification number of the experiment together with the angle of intersection and scan time is listed. The classes B, C and F, all of which refer to initiation difficulties, have been lumped together into a single class called F^*.

The tracking for 60° scissor is bad in every case. Even under the best circumstances, τ = 6 sec and no noise, 1/3 to 1/2 of the intersections result in loss of one or both of the tracks. The tracking for 90° scissors is improved somewhat over the 60° scissors but is still poor; for I_{151}, τ = 6 sec, in the non-noisy region, 1/3 of the intersections fail. Tracking for the 120° scissors is still not good. Again, under the most favorable conditions, 1/3 of the intersections are failures (I_{155}).

Generally speaking the quality of the tracking is very poor for all of the data rates considered and the three intersection angles. There is no clear evidence that tracking in the non-noisy region is any better than the noisy region (the difference, if any, is small enough to be

Identification	1° Radar (B/S = 75 °/o)				Noise
	A	D	E	F*	
I_{135}	13	5	5	0	Y
60°, τ = 6 sec.	17	4	2	1	N
I_{136}	14	6	3	0	Y
60°, τ = 8 sec.	19	2	3	0	N
I_{137}	14	4	5	0	Y
60°, τ = 10 sec.	14	7	3	0	N
I_{138}	8	5	8	2	Y
60°, τ = 12 1/2 sec.	7	3	12	2	N
I_{139}	17	4	4	0	Y
90°, τ = 6 sec.	22	1	2	0	N
I_{140}	16	6	3	0	Y
90°, τ = 8 sec.	23	2	0	0	N
I_{141}	19	4	0	2	Y
90°, τ = 10 sec.	18	3	4	0	N
I_{142}	11	8	6	0	Y
90°, τ = 12 1/2 sec.	15	3	7	0	N
I_{143}	21	2	2	0	Y
120°, τ = 6 sec.	22	3	0	0	N
I_{144}	16	9	0	0	Y
120°, τ = 8 sec.	21	3	1	0	N
I_{145}	17	6	1	1	Y
120°, τ = 10 sec.	17	7	3	1	N
I_{146}	9	10	4	2	Y
120°, τ = 12 1/2 sec.	12	8	4	1	N
I_{147}	14	1	8	0	Y
60°, τ = 6 sec.	12	4	8	0	N
I_{148}	15	2	5	1	Y
60°, τ = 8 sec.	18	0	5	1	N
I_{149}	7	7	6	3	Y
60°, τ = 10 sec.	15	3	3	3	N
I_{150}	6	6	8	3	Y
60°, τ = 12 1/2 sec.	6	7	9	2	N
I_{151}	20	3	2	0	Y
90°, τ = 6 sec.	19	2	4	0	N

Table 20: Track classification of scissors experiments with different intersection angles and different antenna speeds. (Continued on next page)

Identification	1 Radar (B/S = 75 °/o)				
	A	D	E	F*	Noise
I_{152}	18	6	0	1	Y
90°, τ = 8 sec.	18	2	5	0	N
I_{153}	15	7	3	0	Y
90°, τ = 10 sec.	23	1	1	0	N
I_{154}	8	8	9	0	Y
90°, τ = 12 1/2 sec.	15	5	4	1	N
I_{155}	21	3	1	0	Y
120°, τ = 6 sec.	19	6	0	0	N
I_{156}	21	3	1	0	Y
120°, τ = 8 sec.	20	5	0	0	N
I_{157}	19	5	1	0	Y
120°, τ = 10 sec.	22	3	0	0	N
I_{158}	5	11	7	2	Y
120°, τ = 12 1/2 sec.	6	7	6	6	N

Table 20: Track classification of scissors experiments with different intersection angles and different antenna speeds. (Continued from preceding page.)

masked by the statistical fluctuations), indicating that confusion of reports from the two aircraft contributes as much or more to the poor tracking quality as does the noise. This of course is not at all surprising, for an erroneous association whether it be with a true noise report or with a report from another plane will contribute an error to the tracking which is comparable for the two sources. However, since there is a correlation between reports from a particular plane, and none for true noise reports , an incorrect association with a report from the "wrong" plane increases the probability for more such misassociations and therefore should result in an even greater probability of track loss than an association with a true noise report.

d. The "point-on-line" scissors experiments

One of the main purposes of the scissors experiments is to study what happens when two valid tracks interact. In the scissors experiments described in the previous sections, the interacting tracks represented two planes moving with constant velocity while the angle between the planes as they approached the point of intersection was allowed to assume the values 60°, 90°, and 120°. The set of Exps. I_{192} through I_{195} are a study of the intersection of two tracks when one of these represents a plane moving with constant velocity and the other a fixed target. In particular, the odd-numbered planes moved along a path identical to that in the 90° scissors experiments, while the even-numbered planes became fixed targets located on the midpoint of this path, as indicated below.

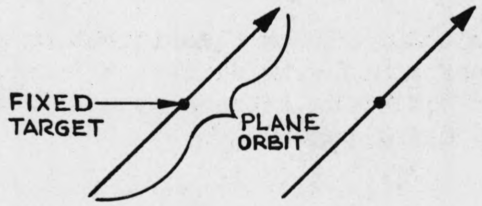

Figure 29: Disposition of the objects in a point-on-line scissors experiment.

The experiments of this group were all 1 radar (B/S = 75 %) experiments and were run at the reduced report rate. (As usual, the noise was restricted to lie in the left half-plane.) The scan-time, τ, of the radar was varied from experiment to experiment and was given the values $\tau = 6$, 8, 10 and 12 1/2 seconds.

The results of Exps. I_{192} through I_{195} are given in Table 21. Again, it is readily seen that the tracking in every case is bad. Even in the most favorable case (I_{192}: $\tau = 6$, no noise) roughly 1/2 of the track-pairs are lost. In Exp. I_{143}, τ = 8, the tracking appears to be slightly better, with only about 1/3 of the track-pairs lost in the non-noisy region, but statistical fluctuations could easily account for this apparent improvement. As before, there appears to be little difference between tracking in the noisy and the no-noise region and the arguments given in the preceding section to explain this phenomenon are most probably applicable here. Also, the tracking appears to improve only slightly as the data rates are increased. The "best" tracking in the noisy region is at τ = 8, while for the no-noise it occurs at τ = 6. For the slowest data rate (τ = 12 1/2 secs.) there appears to be a great amount of difficulty in initiating tracks (cf. F^* column) but for those tracks which get started in time, the tracking is not much worse than with the higher data rates.

e. The point-line experiments

The set of Exps. I_{188} through I_{191} again use the scissors orbit preparer but differ fundamentally from the other scissors experiments. Again, there were two types of objects in the sky, planes moving at constant velocity, and fixed targets, except in these experiments the planes and the fixed targets were placed in such a way that there could be no interaction between their tracks on the (simulated) drum. The disposition of the objects is indicated in Figure 30.

Identification	1 Radar (B/S = 75 °/o)				
	A	D	E	F*	Noise
I_{192}	13	7	5	0	Y
τ = 6 sec.	13	5	6	1	N
I_{193}	11	3	10	1	Y
τ = 8 sec.	15	4	5	1	N
I_{194}	8	10	7	0	Y
τ = 10 sec.	10	5	9	1	N
I_{195}	7	5	7	6	Y
τ = 12 1/2 sec.	7	5	7	6	N

Table 21: Track classification of point-on-line scissors with different antenna speeds.

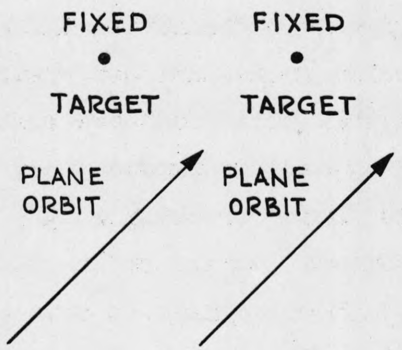

Figure 30: Disposition of the objects in a point-line scissors experiment.

In all other respects these "point-line" experiments were run in the same manner as the point-on-line scissors experiments described in the preceding section. In particular, the experiments were again run with varying antenna speeds τ = 6, 8, 10, 12 1/2 seconds.

The purpose of these experiments was two-fold:

(1) The plane flying the straight line orbit is, from a certain point of view, a degenerate version of a scissors experiment. Scissors experiments represent, as has been pointed out, a study of the effects on tracking of the interaction of two straight line orbits. The nature of the interaction between such tracks was varied to include 60°, 90°, 120° and the point-on-line scissors. In the case at hand, we are studying the tracking of an object moving with constant velocity in which there is no interaction with any other track. A comparison of the results of the present experiments with the previous scissors should yield an estimate of how much of the loss of tracks is due to the actual interaction of the tracks and how much to other causes.

(2) The other aim of this set of experiments was to compare the tracking of fixed targets with the tracking of planes moving at constant velocities.

A priori, it seems that, except for initiation difficulties in the latter case, the tracking of these two types of objects should be nearly identical. Since this hypothesis had been implicit in some of our thinking about other experiments, it was decided to put it to a rough test here.

The results of the point-line experiments, I_{188} through I_{191}, are presented in Table 22. In the left-most column is given the number of the experiment together with the antenna speed τ appropriate to it. In the next column the experiment is divided into two parts: the top two rows for each experiment (labelled: Pt) give the results of track classification for the fixed target; in the bottom two rows (labelled: line) are given the results for the plane moving at constant velocity. The column A refers to targets initiated before time* T_o and still correctly associating after time T_1. The column B refers to targets initiated before time T_o but which were lost before T_1. Column F^* refers to objects which were not initiated before time T_o. The right-most column (labelled: noise) indicates the presence (Y) or absence (N) of noise.

Examination of Table 22 shows the following results: the tracking of the straight line orbits is excellent both in noise and in the no-noise region for data rates $\tau = 6$, $\tau = 8$ and $\tau = 10$. In fact, the tracking is perfect (100 °/o) in the absence of noise (discounting 1 case of initiation difficulty for $\tau = 8$), while in the presence of noise, it is still always 96 °/o or more successful. These results indicate clearly that for these data rates the system encounters essentially no difficulty in tracking straight line orbits even in the presence of 1/4 mile radar error and noise (at the reduced report rate). The bad tracking in the case of the scissors experiments discussed in the preceding sections must therefore be <u>entirely</u> attributed to the interaction of tracks resulting from the intersection of the plane orbits which these tracks represent. That this hypothesis is correct is borne out by the observation (made previously) that tracking in the case of bona fide scissors experiments appears not to be worsened by the introduction of noise. In the case of antenna speed $\tau = 12\ 1/2$, the situation clearly deteriorates somewhat, with a total of 5 planes not successfully initiated and a total of 5

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* Times T_o and T_1 are here used as they refer to the scissors experiments--cf. section 1.

other planes not successfully tracked. This indicates that $\tau = 12\ 1/2$ produces a data rate too low to guarantee successful tracking in the presence of 1/4 mile radar error even when the plane is not maneuvering. This situation worsens somewhat, but not strikingly, by the introduction of noise. That the quality of the tracking, even in the absence of noise and plane maneuvering, depends on the data rate is not surprising. A velocity error will give rise to a position error which increases uniformly until the next piece of data (i.e. radar report) is received; hence, as the data rate decreases, the average position error, and hence the probability of losing the track, increase.

Very little, if any, difference can be noted between the tracking of the fixed targets and the straight line planes. This bears out the hypothesis that the discontinuities in the reports from a target flying in a straight line, due to binary chopping, is a second-order effect. It is interesting to note, too, that with parameters SS-5, there is no apparent difference in initiating tracks for these two kinds of objects. This might be surprising since, it will be recalled, tracks when first initiated are given a velocity of 0 in all cases. For fixed targets this velocity actually represents the correct velocity and no further smoothing of velocity need be undertaken. In the case of the straight lines, however, the velocity must be smoothed to 450 mph. The results in the table seem to indicate that parameters SS-5 can do this job without difficulty.

Identification		1 Radar (B/S = 75 °/o)			
		A	B	F*	Noise
I_{188} $\tau = 6$	Pt.	25	0	0	Y
		25	0	0	N
	line	24	1	0	Y
		25	0	0	N
I_{189} $\tau = 8$	Pt.	24	1	0	Y
		25	0	0	N
	line	25	0	0	Y
		25	0	0	N
I_{190} $\tau = 10$	Pt.	25	0	0	Y
		25	0	0	N
	line	24	1	0	Y
		24	0	1	N
I_{191} $\tau = 12\ 1/2$	Pt.	18	5	2	Y
		20	2	3	N
	line	20	3	2	Y
		20	2	3	N

Table 22: Track classification of the point-line experiments with different antenna speeds.

Appendix 1

Table A-1 below is an index to the tables which list the parameter settings for the experiments described in this report. In addition, this table contains three columns listing the report rate, full report rate (FRR) or reduced report rate (R^3), the area where noise was present, left hand half (LHH) or the whole area (L and R), and the random number entry (a) or (b). There is another column for special identifying remarks. The first column in table A-1 gives the identification number of the experiment. The second column gives the identification of the orbit preparer; the letters F and S stand for fishook and scissors, the number following the letter tells which one of the F or S parameter sets was used and by referring to the corresponding row-entry in table A-2 or A-3 the parameter settings may be found. The third column of table A-1 gives the identification number of the preset parameters and by referring to the corresponding column-entry in table A-4 these parameters settings may be found. The fourth column in table A-1 gives the identification for the smoothing and sorting parameters listed in table A-5. In table A-3 θ stands for the angle between the two velocity vectors. In table A-4 the antenna rotation speed, w, is given in a.u./sec where 1 a.u. $= \frac{2\pi}{128}$ radians. In table A-5 f stands for firmness, and t for time since last association.

Experiment	Orbit Preparer	Preset Parameters	Smoothing and Sorting Parameters	Report Rate	Noise Distribution	Random No. Entry
I_{123}	F-9	12	SS-5	FRR	L and R	a
I_{124}	F-9	13	SS-5	FRR	L and R	a
I_{125}	F-9	14	SS-5	FRR	L and R	a
I_{126}	F-1	7	SS-5	FRR	LHH	a
I_{127}	F-3	7	SS-5	FRR	LHH	a
I_{128}	F-4	7	SS-5	FRR	LHH	a
I_{129}	F-1	7	SS-5	R^3	LHH	a
I_{130}	F-3	7	SS-5	R^3	LHH	a
I_{131}	F-4	7	SS-5	R^3	LHH	a
I_{132}	F-9	14	SS-5	R^3	L and R	a
I_{133}	F-9	15	SS-5	R^3	L and R	a
I_{134}	F-9	16	SS-5	R^3	L and R	a
I_{135}	S-1	8	SS-5	R^3	LHH	a
I_{136}	S-1	9	SS-5	R^3	LHH	a
I_{137}	S-1	10	SS-5	R^3	LHH	a
I_{138}	S-1	11	SS-5	R^3	LHH	a
I_{139}	S-2	8	SS-5	R^3	LHH	a
I_{140}	S-2	9	SS-5	R^3	LHH	a
I_{141}	S-2	10	SS-5	R^3	LHH	a
I_{142}	S-2	11	SS-5	R^3	LHH	a
I_{143}	S-3	8	SS-5	R^3	LHH	a
I_{144}	S-3	9	SS-5	R^3	LHH	a
I_{145}	S-3	10	SS-5	R^3	LHH	a
I_{146}	S-3	11	SS-5	R^3	LHH	a
I_{147}	S-1	8	SS-5	R^3	LHH	b
I_{148}	S-1	9	SS-5	R^3	LHH	b
I_{149}	S-1	10	SS-5	R^3	LHH	b
I_{150}	S-1	11	SS-5	R^3	LHH	b

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Table A-1 (Continued on Next Page)

Experiment	Orbit Preparer	Preset Parameters	Smoothing and Sorting Parameters	Report Rate	Noise Distribution	Random No. Entry
I_{151}	S-2	8	SS-5	R^3	LHH	b
I_{152}	S-2	9	SS-5	R^3	LHH	b
I_{153}	S-2	10	SS-5	R^3	LHH	b
I_{154}	S-2	11	SS-5	R^3	LHH	b
I_{155}	S-3	8	SS-5	R^3	LHH	b
I_{156}	S-3	9	SS-5	R^3	LHH	b
I_{157}	S-3	10	SS-5	R^3	LHH	b
I_{158}	S-3	11	SS-5	R^3	LHH	b
I_{159}	F-1	17	SS-5	FRR	LHH	a
I_{160}	F-3	17	SS-5	FRR	LHH	a
I_{161}	F-4	17	SS-5	FRR	LHH	a
I_{162}	F-1	17	SS-5	R^3	LHH	a
I_{163}	F-3	17	SS-5	R^3	LHH	a
I_{164}	F-4	17	SS-5	R^3	LHH	a
I_{165}	F-1	17	SS-5	FRR	LHH	b
I_{166}	F-3	17	SS-5	FRR	LHH	b
I_{167}	F-4	17	SS-5	FRR	LHH	b
I_{168}	F-1	17	SS-5	R^3	LHH	b
I_{169}	F-3	17	SS-5	R^3	LHH	b
I_{170}	F-4	17	SS-5	R^3	LHH	b
I_{171}	F-3	18	SS-5	R^3	LHH	a
I_{172}	F-3	19	SS-5	R^3	LHH	a
I_{173}	F-3	20	SS-5	R^3	LHH	a
I_{174}	F-3	21	SS-5	R^3	LHH	a
I_{175}	F-3	18	SS-5	R^3	LHH	b
I_{176}	F-3	19	SS-5	R^3	LHH	b
I_{177}	F-3	20	SS-5	R^3	LHH	b

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Table A-1 (Continued on Next Page)

Experiment	Orbit Preparer	Preset Parameters	Smoothing and Sorting Parameters	Report Rate	Noise Distribution	Random No. Entry
I_{178}	F-3	21	SS-5	R^3	LHH	b
I_{182}	F-1	22	SS-5	FRR	LHH	a
I_{183}	F-3	22	SS-5	FRR	LHH	a
I_{184}	F-4	22	SS-5	FRR	LHH	a
I_{185}	F-1	22	SS-5	R^3	LHH	a
I_{186}	F-3	22	SS-5	R^3	LHH	a
I_{187}	F-4	22	SS-5	R^3	LHH	a
I_{188}	S-4	8	SS-5	R^3	LHH	a
I_{189}	S-4	9	SS-5	R^3	LHH	a
I_{190}	S-4	10	SS-5	R^3	LHH	a
I_{191}	S-4	11	SS-5	R^3	LHH	a
I_{192}	S-5	8	SS-5	R^3	LHH	a
I_{193}	S-5	9	SS-5	R^3	LHH	a
I_{194}	S-5	10	SS-5	R^3	LHH	a
I_{195}	S-5	11	SS-5	R^3	LHH	a
I_{196}	F-3	23	SS-5	R^3	LHH	a
I_{197}	F-3	24	SS-5	R^3	LHH	a
I_{198}	F-3	25	SS-5	R^3	LHH	a
I_{199}	F-3	26	SS-5	R^3	LHH	a
I_{217}	F-1	27	SS-6	FRR	LHH	a
I_{218}	F-3	27	SS-6	FRR	LHH	a
I_{219}	F-4	27	SS-6	FRR	LHH	a
I_{220}	F-1	27	SS-6	R^3	LHH	a
I_{221}	F-3	27	SS-6	R^3	LHH	a
I_{222}	F-4	27	SS-6	R^3	LHH	a

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Table A-1 (Continued on Next Page)

Experiment	Orbit Preparer	Preset Parameters	Smoothing and Sorting Parameters	Report Rate	Noise Distribution	Random No. Entry
I_{223}	F-1	27	SS-6	FRR	LHH	b
I_{224}	F-3	27	SS-6	FRR	LHH	b
I_{225}	F-4	27	SS-6	FRR	LHH	b
I_{226}	F-1	27	SS-6	R^3	LHH	b
I_{227}	F-3	27	SS-6	R^3	LHH	b
I_{228}	F-4	27	SS-6	R^3	LHH	b
I_{229}	F-1	28	SS-6	FRR	LHH	a
I_{230}	F-3	28	SS-6	FRR	LHH	a
I_{231}	F-4	28	SS-6	FRR	LHH	a
I_{232}	F-1	28	SS-6	R^3	LHH	a
I_{233}	F-3	28	SS-6	R^3	LHH	a
I_{234}	F-4	28	SS-6	R^3	LHH	a
I_{235}	F-1	28	SS-7	FRR	LHH	a
I_{236}	F-3	28	SS-7	FRR	LHH	a
I_{237}	F-4	28	SS-7	FRR	LHH	a
I_{238}	F-1	28	SS-6	FRR	LHH	b
I_{239}	F-3	28	SS-6	FRR	LHH	b
I_{240}	F-4	28	SS-6	FRR	LHH	b
I_{241}	F-1	28	SS-7	FRR	LHH	b
I_{242}	F-3	28	SS-7	FRR	LHH	b
I_{243}	F-4	28	SS-7	FRR	LHH	b
I_{244}	F-1	27	SS-5	FRR	LHH	a
I_{245}	F-3	27	SS-5	FRR	LHH	a
I_{246}	F-4	27	SS-5	FRR	LHH	a
I_{247}	F-1	28	SS-5	FRR	LHH	a
I_{248}	F-3	28	SS-5	FRR	LHH	a
I_{249}	F-4	28	SS-5	FRR	LHH	a

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Table A-1 (Continued on Next Page)

Experiment	Orbit Preparer	Preset Parameters	Smoothing and Sorting Parameters	Report Rate	Noise Distribution	Random No. Entry
I_{250}	F-1	28	SS-5	R^3	LHH	a
I_{251}	F-3	28	SS-5	R^3	LHH	a
I_{252}	F-4	28	SS-5	R^3	LHH	a
I_{254}	F-1	28	SS-8	FRR	LHH	a
I_{255}	F-1	28	SS-8	R^3	LHH	a
I_{256}	F-3	28	SS-8	FRR	LHH	a
I_{257}	F-3	28	SS-8	R^3	LHH	a
I_{258}	F-3	28	SS-9	FRR	LHH	a
I_{259}	F-3	28	SS-9	R^3	LHH	a

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Table A-1 (Concluded)

	v_{1x} (mi/sec)	v_{1y} (mi/sec)	t_1 (sec)	ω (rad/sec)	R (mi)	t_2-t_1 (sec)	v_{2x} (mi/sec)	v_{2y} (mi/sec)	x_o (mi)	y_o (mi)	Acceleration (g)	Speed (mi/sec)
F-1.	0	-1/8	80	1/80	10	126	1/8	0	3	28	1/4	1/8
F-2.	0	-1/8	100	1/40	5	63	1/8	0	3	28	1/2	1/8
F-3.	0	-1/8	100	1/20	2.5	32	1/8	0	3	28	1	1/8
F-4.	0	-1/8	100	1/5	5/8	8	1/8	0	3	28	4	1/8
F-5.	0	-5/32	64	1/100	16	157	5/32	0	3	31	1/4	5/32
F-6.	0	-5/32	64	2/100	8	78	5/32	0	3	31	1/2	5/32
F-7.	0	-3/16	96	.0323	5.8	49	3/16	0	3	28	1	3/16
F-8.	0	-3/16	96	.1292	1.45	12	3/16	0	3	28	4	3/16
F-9.	0	0	1000	0	0	2000	0	0	3	28	fixed	target

Parameter Sets for Fishook Orbit Preparer

Table A-2

	Odd Plane v_x (mi/sec)	Odd Plane v_y (mi/sec)	Even Plane v_x (mi/sec)	Even Plane v_y (mi/sec)	Odd Plane x_o (mi)	Odd Plane y_o (mi)	Even Plane x_o (mi)	Even Plane y_o (mi)	θ	Speed (mi/sec)
S-1	.108	.0625	.108	-.0625	3	9	3	22	60°	1/8
S-2	.0879	.0879	.0879	-.0879	3	3	3	28	90°	1/8
S-3	-.109	-.0625	.108	-.0625	22.5	22	3	22	120°	1/8
S-4	.0879	.0879	0	0	3	3	15	40	-	-
S-5	.0879	.0879	0	0	3	3	15	15	-	-

Parameter Sets for Scissors Orbit Preparer

Table A-3

	7	8	9	10	11	12	13	14	15	16	17
x_1 (mi)	64					64	64	64	64	64	64
y_1 (mi)	192					192	192	192	192	192	192
w_1 (au/sec)	13.5					13.5	13.5	13.5	13.5	13.5	13.5
R_1 (mi)	80					80	80	80	80	80	80
Q_1	8					8	8	8	8	8	8
N_1	3					2	3	1	1	1	3
σ_1	4					4	4	4	4	4	4
x_2 (mi)	192					192	192	192	192	192	192
y_2 (mi)	192					192	192	192	192	192	192
w_2 (au/sec)	13.25					13.25	13.25	13.25	13.25	13.25	13.25
R_2 (mi)	80					80	80	80	80	80	80
Q_2	8					8	8	8	8	8	8
N_2	1					2	3	1	0	1	1
σ_2	2					2	2	2	2	2	2
x_3 (mi)	128	128	128	128	128	128	128	128	128	128	128
y_3 (mi)	128	128	128	128	128	128	128	128	128	128	128
w_3 (au/sec)	13.25	21.25	16.25	13.25	10.25	13.25	13.25	13.25	13.25	13.25	13.25
R_3 (mi)	80	180	180	180	180	80	80	80	80	80	80
Q_3	8	40	40	40	40	8	8	8	8	8	8
N_3	2	2	2	2	2	2	3	1	0	1	2
σ_3	2	2	2	2	2	2	2	2	2	2	2
x_4 (mi)	64					64	64	64	64	64	64
y_4 (mi)	64					64	64	64	64	64	64
w_4 (au/sec)	13.25					13.25	13.25	13.25	13.25	13.25	13.25
R_4 (mi)	80					80	80	80	80	80	80
Q_4	8					8	8	8	8	8	8
N_4	3					2	3	1	0	0	3
σ_4	2					2	2	2	2	2	2

Preset Parameters

Table A-4 (Continued on Next Page)

	7	8	9	10	11	12	13	14	15	16	17
x_5 (mi)	192					192	192	192	192	192	192
y_5 (mi)	64					64	64	64	64	64	64
w_5(au/sec)	13.5					13.5	13.5	13.5	13.5	13.5	13.5
R_5 (mi)	80					80	80	80	80	80	80
Q_5	8					8	8	8	8	8	8
N_5	1					2	3	1	0	0	1
σ_5	4					4	4	4	4	4	4
σ_o	5	5	5	5	5	5	5	5	5	5	5
f_i	2	2	2	2	2	2	2	2	2	2	2
f_m	6	6	6	6	6	6	6	6	6	6	6
f_o	1	1	1	1	1	1	1	1	1	1	1
f_t	5	5	5	5	5	5	5	5	5	5	5
f_d	1	1	1	1	1	1	1	1	1	1	1
N_o	5	5	5	5	5	5	5	5	5	5	5
t_s	12	12	12	12	12	12	12	12	12	12	12
a	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
E	0	0	0	0	0	0	0	0	0	0	4

Preset Parameters

Table A-4 (Continued on Next Page)

	18	19	20	21	22	23	24	25	26	27	28
x_1 (mi)					64					64	64
y_1 (mi)					192					192	192
w_1 (au/sec)					13.5					13.5	13.5
R_1 (mi)					80					80	80
Q_1					8					8	8
N_1					3					1	1
σ_1					4					4	4
x_2 (mi)					192					192	192
y_2 (mi)					192					192	192
w_2 (au/sec)					13.25					13.25	13.25
R_2 (mi)					80					80	80
Q_2					8					8	8
N_2					1					1	1
σ_2					2					2	2
x_3 (mi)	128	128	128	128	128	128	128	128	128	128	128
y_3 (mi)	128	128	128	128	128	128	128	128	128	128	128
w_3 (au/sec)	21.25	16.25	13.25	10.25	13.25	21.25	16.25	13.25	10.25	13.25	13.25
R_3 (mi)	180	180	180	180	80	180	180	180	180	80	80
Q_3	40	40	40	40	8	40	40	40	40	8	8
N_3	10	10	10	10	2	10	10	10	10	1	1
σ_3	2	2	2	2	2	2	2	2	2	2	2
x_4 (mi)					64					64	64
y_4 (mi)					64					64	64
w_4 (au/sec)					13.25					13.25	13.25
R_4 (mi)					80					80	80
Q_4					8					8	8
N_4					3					1	1
σ_4					2					2	2

Preset Parameters

Table A-4 (Continued on Next Page)

	18	19	20	21	22	23	24	25	26	27	28
x_5 (mi)					192					192	192
y_5 (mi)					64					64	64
w_5 (au/sec)					13.5					13.5	13.5
R_5 (mi)					80					80	80
Q_5					8					8	8
N_5					1					1	1
σ_5					4					4	4
σ_o					5					5	5
f_i	2	2	2	2	2	2	2	2	2	2	2
f_m	6	6	6	6	6	6	6	6	6	6	6
f_o	1	1	1	1	1	1	1	1	1	1	1
f_t	5	5	5	5	5	5	5	5	5	5	5
f_d	1	1	1	1	1	1	1	1	1	1	1
N_o	5	5	5	5	5	5	5	5	5	5	5
t_s	12	12	12	12	12	12	12	12	12	12	12
a	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1	2
E	4	4	4	4	8	0	0	0	0	8	8

Preset Parameters

Table A-4 (Concluded)

SS-5: $\alpha = 0.498$ if $t - 8f \leq -24$

$\alpha = 0.747$ if $-23 \leq t - 8f \leq 14$

$\alpha = 0.996$ if $15 \leq t - 8f$

$\beta/t = 0.03$ if $t \geq 60$

$\beta/t = 0.1$ if $t \leq 15$ and $f = 1$

$\beta/t = 0.04$ otherwise

$\epsilon = 2.3 + \frac{0.18t}{f + 3}$ if $t < 30$ and $f = 1$

$\epsilon = 3.3 + \frac{0.18t}{f + 3}$ if $t \geq 15$

$\epsilon = 1.1 + \frac{4.3}{f + 4}$ if $t < 15$

SS-6: α = (same as for SS-5)

β/t= (same as for SS-5)

$\epsilon = 3.8 + \frac{0.18t}{f + 3}$ if $t < 30$ and $f = 1$

$\epsilon = 4.8 + \frac{0.18t}{f + 3}$ if $t \geq 15$

$\epsilon = 2.6 + \frac{4.3}{f + 4}$ if $t < 15$

SS-7: α = (same as for SS-5)

β/t= (same as for SS-5)

$\epsilon = 3.3 + \frac{0.18t}{f + 3}$ if $t < 30$ and $f = 1$

$\epsilon = 4.3 + \frac{0.18t}{f + 3}$ if $t \geq 15$

$\epsilon = 2.1 + \frac{4.3}{f + 4}$ if $t < 15$

Smoothing and Sorting Parameters

Table A-5 (Continued on Next Page)

SS-8: $\alpha = 0.249$ if $t - 8f \leq -24$

$\alpha = 0.498$ if $-23 \leq t - 8f \leq 14$

$\alpha = 0.747$ if $15 \leq t - 8f$

$\beta/t = 0.02$ if $t \geq 60$

$\beta/t = 0.09$ if $t \leq 15$ and $f = 1$

$\beta/t = 0.03$ otherwise

ϵ = (same as for SS-7)

SS-9: α = (same as for SS-8)

$\beta/t = 0.01$ if $t \geq 60$

$\beta/t = 0.09$ if $t \leq 15$ and $f = 1$

$\beta/t = 0.02$ otherwise

α = (same as for SS-7)

Smoothing and Sorting Parameters

Table A-5 (Concluded)