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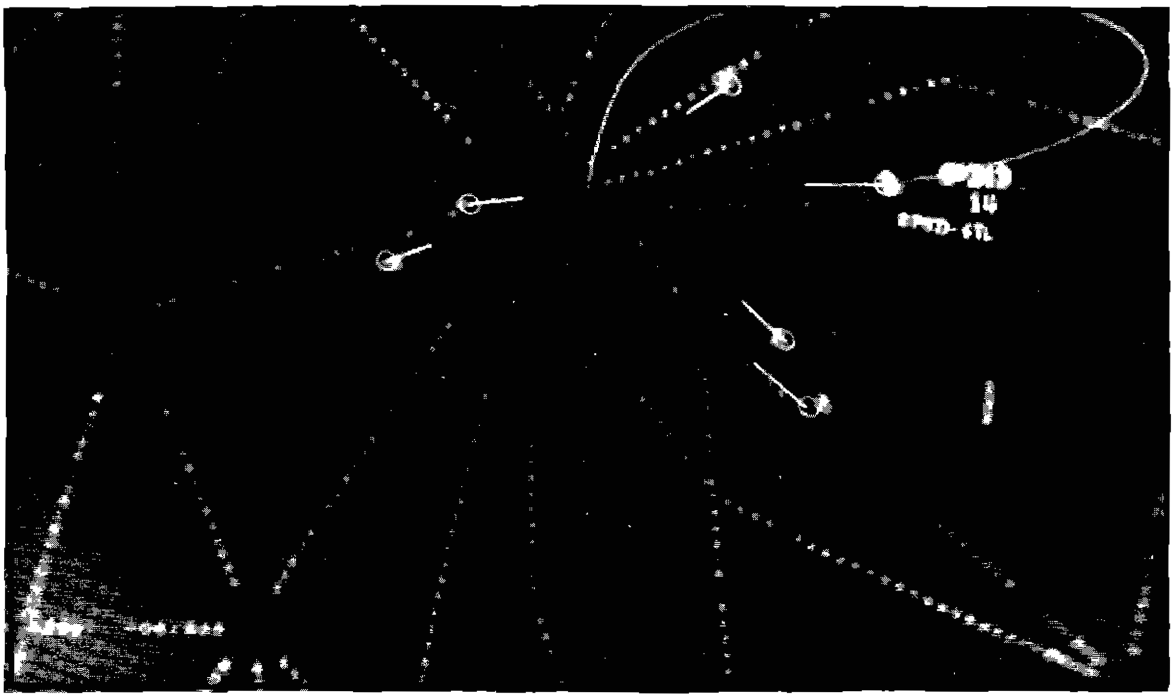

A REPORT ON

FINAL SERIES OF TESTS OF SRS-1 WITH MODIFICATIONS FOR AIR TRAFFIC CONTROL

TECHNICAL DEVELOPMENT REPORT NO 414

MARCH 1960

Prepared by

TEST AND EXPERIMENTATION DIVISION
Atlantic City New Jersey

FINAL SERIES OF TESTS OF SRS-1

WITH MODIFICATIONS FOR AIR TRAFFIC CONTROL

TECHNICAL DEVELOPMENT REPORT NO. 414

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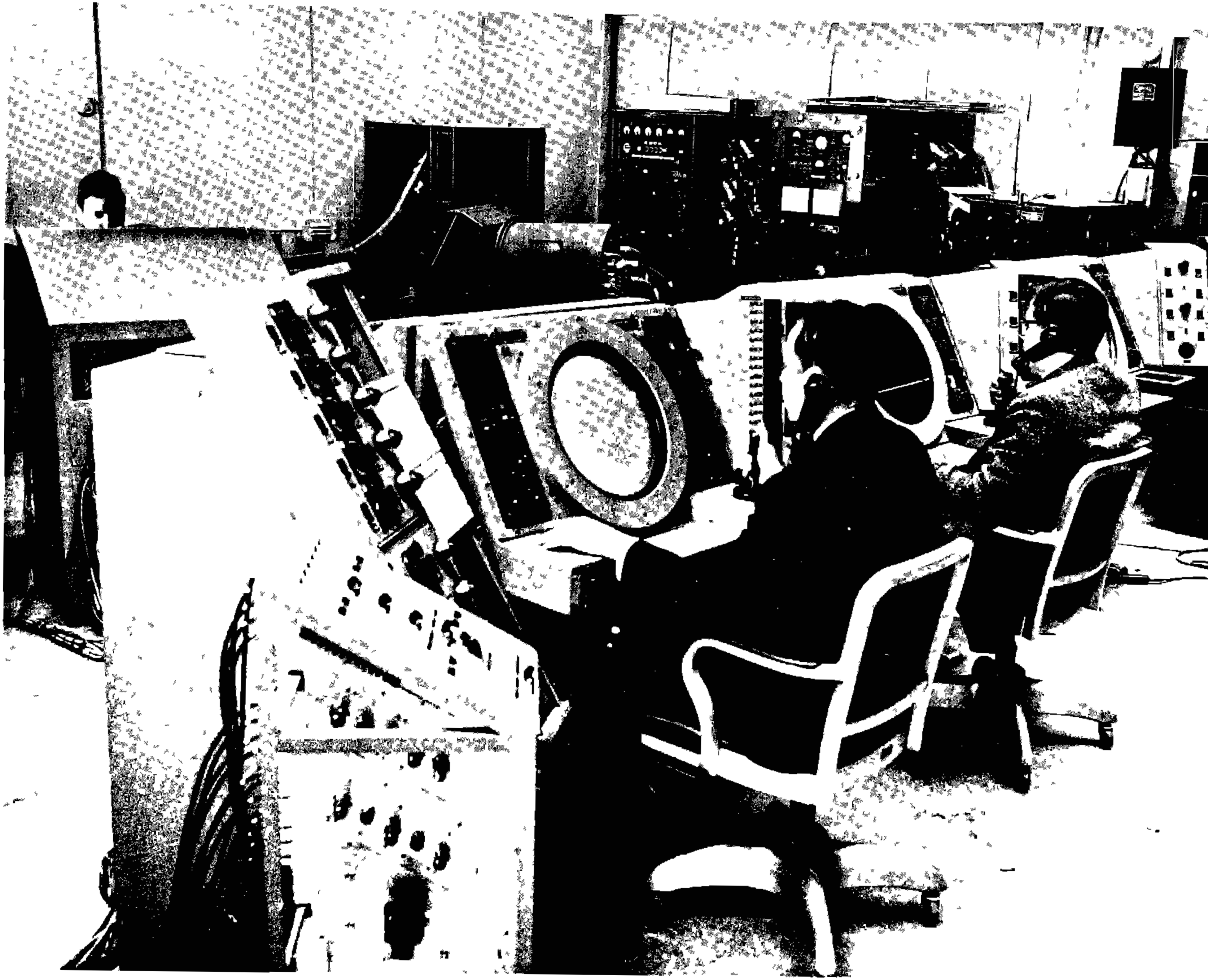

SRS-1 CONSOLES IN OPERATION

FINAL SERIES OF TESTS OF SRS-1 WITH MODIFICATIONS FOR AIR TRAFFIC CONTROL

SUMMARY

This report describes the third and final series of SRS-1 tests conducted by the Technical Development Center under AMB Project SA-1-1111. These tests were conducted from June 1958 through January 1959, with the SRS-1 equipment located at Airborne Instrument Laboratories, Mineola, New York The purpose of these tests was to further simulate and evaluate various display features and operational techniques to aid in recommendations for an air traffic control pictorial display and flight tracking system

In a manual rate-aided flight tracking system it was determined that computer derived velocity corrections, computer inserted flight plan turns, trim tabs with vector for heading controls, a circle as a tracking symbol, and a displacement type tracking stick were more desirable than the various alternatives tested, Hand-off procedures in the SRS-1 type system are a definite advantage over present day verbal procedures. It was determined also, for optimum utilization of personnel and the same manpower, that controllers should do their own tracking If a perfect automatic tracking system were available, tracking workload would be reduced approximately 90 per cent

Display features rated by the controllers as essential were bright tube, trail characteristics, alpha-numeric information (at least two lines) with associated alternate information, vectors for flight path prediction, selectivity controls for alpha-numeric, vectors and altitudes (single and block) The alpha-numeric data should be displayed at least 20 cycles per second. A manually operated course and speed insert device should be provided per console and channel lights should be provided adjacent to and associated with, flight progress strips.

The controllers preferred the slanting face display of the SRS-1 and, with their suggested additional features, believe such an improved system could offer up to 15 or 20 percent improvement in traffic handling capacity over the present radar air traffic control system using VG displays.

INTRODUCTION

The Technical Development Center conducted the first tests[1] of the SRS-1 during May 1957 to investigate the utility of automatic and rate-aided tracking, combined symbolic and radar situation display, and remote tracking for application in an air traffic control system It was concluded from these tests that if the equipment was modified to take advantage of flight plan information, an improved operation and a more realistic air traffic control evaluation would be possible Consequently the SRS-1 was modified to provide for (1) insertion of flight plan course and speed in the tracking channels, (2) course and speed readout from the tracking channels, (3) initial positioning of tracking channels at preselected fixes, (4) push button selection of tracking channels and (5) individual lamp indicators to show tracking channel availability

With the modifications recommended in the first evaluation a second series of tests[2] were conducted during a two week period, September 23 through October 3, 1957, to evaluate these and certain additional modifications of the SRS-1 equipment As a result of these tests it was estimated that a proficient tracker should be able to track up to ten aircraft simultaneously in a defined and localized area with reliability Also, with remote tracking it was estimated that an experienced radar controller could control from 12 to 15 aircraft simultaneously in an enroute or extended terminal area However, it was concluded that the SRS-1, as modified would not offer any advantages over the VG type of radar display unless certain changes were made The changes recommended were (1) a bright display with aircraft trails should be provided, (2) alpha-numeric flight plan data should be associated with the tracking tags, (3) radar hand-off techniques should be provided and (4) improved tracking stability should be provided

This report describes the results of a third series of tests conducted with the SRS-1 at Airborne Instruments Laboratory, Mineola, New York, from June 1958 through January 1959 The objectives of these tests were to evaluate the aforementioned modifications to determine their utility in a pictorial display and flight tracking system[3]

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[1]Charles Dowling, Jr and Fred H Ottersberg, "A Preliminary Evaluation of Surveillance Radar Station (SRS-1) for Air Traffic Control," Technical Development Report No 323, September 1957

[2]A L Ridenour, C E Dowling, F H. Ottersberg, F S McKnight, and R L Sorensen, "Tests of the SRS-1 Equipment Modified for Air Traffic Control Use", Technical Development Report No 407, April 1959

[3]Fred McKnight, "Operational Requirements for ATC Displays, "Technical Development Report No 308, April 1957

This test series was divided into two phases.

Phase I test program included.

1 Tracking Experiment
2 Controller Configuration
3 Hand-offs
4. Automatic Tracking

Phase II test program included·

1 SRS-1 Track Stick Experiment
2 Flight Plan Turns and Trim Tab Plus Vectors
3 Simulated VG Type Display Versus SRS-1
4 Circle Versus Dot as Tracking Symbol

The Franklin Institute Laboratories (FIL) of Philadelphia, represented by Dr Edward P. Buckley with Mr Jack Brinton and Mr Frank McLaughlin, assisted in setting up experimental tests and by making statistical analysis of the measurements taken during the test runs References are made to FIL working papers in this report Copies of these are available directly from FIL

EQUIPMENT

The SRS-1 is a radar target tracking system with special display features The original equipment was built by Airborne Instruments Laboratories (AIL) under contract to the U S Army Signal Corps as a part of the Missile Master System.

There are four situation displays provided with the SRS-1 equipment, three of these consoles were designed to function as tracking consoles and the other as a supervisory console The supervisor's console can be operated in parallel with any of the tracker consoles Originally each console had a 16-inch P-7 CRT PPI indicator for presenting radar returns In Phase I of this test program a P-12 CRT was installed with TI-440 scan conversion equipment giving a bright tube display and trail characteristics to radar targets[4]. In Phase II of this test program a P-4 (PAF) CRT was installed with scan conversion to provide additional brightness and less flicker.

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[4] William E Miller and William G. Covell, "Evaluation of TI-440 Picture Transformer Equipment and Notes on Television Type Air Traffic Control Displays, "Technical Development Report No. 388, March, 1959

The tracking system of the SRS-1 includes 24 channels which may be assigned to 24 individual radar targets These track-while-scan devices accept radar video information and will track along with radar targets after the proper direction and velocity have been determined Analogue computing devices provide the intelligence required From these tracking channels an electrical output can be obtained representing the present position of each radar target being tracked This electrical output from the tracking channel can be used to position special symbols, or letters and numbers, alongside a radar target and cause these to move along automatically with the movement of the target

There are two basic modes of operation of the tracking channels In the "automatic" mode, all of the radar video included within a small block of space defined in azimuth and range is sampled The tracking channel compares this with the position of the target on the previous antenna scan, computes the distance and direction the target has moved, and extrapolates ahead until radar returns are again received on the next scan of the antenna. In theory, a radar tracker using this automatic feature, need only initially position the tracking channel on the desired aircraft target return and the tracking channel will pick up automatically and follow the movement of the aircraft

A second mode of operation is called "manual-rate-aided" or "coast mode" In this mode the tracking operator must position the tracking channel on the desired radar target, wait three or four antenna scans, and reposition the tracking channel to the new position of the radar target The tracking channel computer will then determine the direction and distance the target has moved during the time of the several antenna scans and start extrapolating in a straight line ahead. In this mode of operation the tracking operator must be alert to any changes of direction or speed of the target, and manually insert new positions into the tracking channel so that it will recompute the heading or speed change required.

When an operator selects a radar target he wishes to track, he can move a symbol showing the position of the tracking channel and place it over the target Three symbols are used. A full circle about 3/16" diameter indicates the tracking channel is in the automatic tracking mode, a partial circle, or C, indicates the tracking channel is in the rate-aided or "coast" mode, and a bright dot indicates the target is being tracked at another console. A leader (curved line) from the center of the scope to the symbol indicates which tracking channel is connected to the controls on the display. Joy-stick control permits the controller to reposition the tracking channel to any desired target on the display. A cycling switch permits the tracker to cycle through all tracking channels he is using. In operation the tracker continually cycles from one target to another, checking the alignment of the symbols with the radar targets. As necessary, he repositions the tracking channel to center the symbol on the target A "new" channel button is provided to allow the operator to assign a new tracking channel to a new target, and a "dump" switch is provided so the tracker can release a tracking channel when he has finished tracking a particular target This returns the tracking channel to a standby status so that it can be used for tracking a new target by any of the operators.

Each console was modified to provide a control panel with four dials to insert heading and one dial to insert speed into the tracking channels. In this manner the tracking channels could be started on the basis of flight plan data. In addition the supervisor's console (Fig. 1) was further modified to provide four pre-set positions. Any four positions could be pre-set and quickly inserted in the position storage of any channel by pushing the associated pre-set button. The co-ordinates of the pre-set positions were generally radar hand-off or initial reporting points A read-out device of a selected channel's course and speed was provided also at the supervisory console.

The supervisor's console was provided with a special flight progress board that has a lamp and switch associated with each strip holder position. Each lamp and switch is connected to one of the 24 tracking channels and the lamp is lighted whenever that tracking channel has been selected by the operator. The push button switches alongside the lamps allow an operator to select a particular tracking channel at any time without having to cycle through a number of channels until the desired channel is reached. This feature permits the supervisor to look at his flight progress strips and determine which radar target is being tracked by depressing the push button switch and observing which symbol is connected to the "leader" Conversely, he can identify any particular radar target being tracked on the radar display by cycling until the leader is connected to the tracking symbol on the target, and then observing the strip associated with the lighted lamp.

MODIFICATIONS

As a result of the two previous evaluations it was concluded that further SRS-1 modifications would be required to obtain a valid simulation and evaluation of an advanced ATC display system. These modifications involved display and tracking system features, and were conducted in two pahses Phase I modifications were contracted for on December 31, 1957 and were evaluated during the summer of 1958 Phase II modifications were negotiated during the summer of 1958 and evaluated during the last half of 1958 and the first part of 1959.

Phase I Modifications - Display Features

The recognized needs in this area were, first, the necessity for adapting the system to the scan converted radar presentation, and second, the need for alpha-numeric data to be displayed along with the track symbol.

The TV scan-converted displays were accomplished originally by time sharing the normal TV rate of 60 fields per second on a one to five basis. This provided radar and alpha-numeric information at the rate of 12 fields per second This duty cycle and repetition rate necessitated the use of a long persistence phosphor (P-12) on the display The choice of this phosphor and the 20 per cent duty cycle resulted in less than optimum brightness and necessitated operating in a semi-darkened room In the remaining display time a synchronized industrial closed circuit television system provided six flight identification characters and six altitude indicating characters with each of the 24 tracks However, due to the quality of the industrial television system chosen and the tolerance of the gating circuits, it was not possible during this phase of the evaluation to achieve more than six (6) characters total in a readable format

Phase I Modifications - Tracking System

The mission of the original SRS-1 system was to track uncooperative aircraft. The ATC mission of the other hand deals entirely with cooperative aircraft and therefore ATC tracking equipment can be provided with a quantity of known data It was evident that input devices other than the positioning track stick of the original SRS-1 equipment would be needed to take advantage of information available in the ATC system Recognizing this, the previous modifications provided pre-set input buttons to insert a track into the system at predetermined locations (usually a hand-off acceptance fix), speed and course input devices to insert flight plan speed and course, and selection of a given track by means of buttons associated with flight strip postings rather than serial sequencing

Inherent in the military concept is the need for frequent updating of established tracks, either manually or automatically, to prevent the escape of a maneuvering aircraft from the tracking gate Therefore, the

SRS-1 original tracking equipment was not designed for sufficient stability to allow the tracking gate to follow non-maneuvering aircraft for over a few minutes in the manual mode and in the automatic mode, would frequently lose the aircraft due to noise or interference if not constantly attended.

To allow adequate evaluation of an ideal ATC tracking system, the contract of December 31, 1957 provided for modifying the SRS-1 tracking channels to improve stability (20 to 1 improvement) in the manual tracking mode Since this modification had the effect of making the automatic tracking mode inoperative, the contract further provided for additional modification to six of the 24 channels to allow improved automatic tracking. The target simulators used in the operational evaluation were also reworked and their stability and reliability improved to increase the evaluation accuracy.

A further refinement was to add ten (10) course and speed input devices which were permanently assigned to specific tracking channels and located adjacent to the flight strip postings assigned to their respective tracking channel. This allowed the operator to insert information directly without necessity of channel selection. This was installed on the No 1 console (See Figure 2).

The action of the positioning track stick was altered to allow the operator to determine (by actuating an additional switch) if a new velocity was to be calculated from an incremental reposition of the track. In the original concept of the manual mode a new velocity was computed for each repositioning and this resulted occasionally in unnecessary changes in track velocity. With this modification the operator could bypass the velocity circuits and insert only a position correction if he desired.

During the evaluation of these concepts, it was noted that in the manual tracking mode there was a definite tendency for the calculated velocity to oscillate above and below the true velocity. This resulted because each new velocity calculation was inserted directly into the velocity memory with no weight given to the previously stored information. An error in the last calculation, caused possibly by the operator making an inaccurate positioning, was not modified by the previous experience of the flight A Phase I modification was added, therefore, to allow the track channel to accept an adjustable percentage of the most recently calculated velocities This dampened the fluctuations in computed velocities and prevented large sudden changes in channel velocity

Phase II Modifications - Display Features:

As modifications and evaluations of Phase I progressed it became evident that a different technical approach to achieving a suitable alpha-numeric display was necessary Two of the more significant Phase II modifications required a change in system synchronization and resulted in (1) 40 fields of radar data per second (rather than 12) and (2) increased alpha-numeric format data to a total of 36 characters rather the six characters produced in Phase I.

Associated with the change of the radar information rate to 40 fields per second was the use of a special P-4 type phosphor (PAF) This phosphor is similar to P-4 but has a longer persistence This resulted in adequate display brightness and eliminated flicker altogether The new format consisted of three lines of six characters each Independent control of each line was provided the operator He could select either of two sources of information (primary or alternate) or delete all data in that line as he desired In addition, the operator could elect to have formats on all tracks, only assigned tracks or, only the selected track (Figures 3 through 10) The format of this data was completely adjustable by setup procedures in the equipment The equipment for generating the formats is shown in Figure 13

An additional display feature of Phase II was the addition of a vector showing the direction and relative speed of all tracks A selection feature was provided also to allow the operator to show vectors on all tracks, the selected track or no vectors on any track (Figure 3 through 10) The operator was provided also with control of the vector length Time could be advanced in 15 one-minute increments where the length of the vectors would show the predicted track position at the end of the selected future time (Figure 10)

Another display feature was to give the operator the selection of the altitude strata to be displayed Selection was based on altitude data stored in the track associated with each aircraft One thousand foot increments from 4 000 feet to 21, 000 feet were selectable in any combination for the SRS-1 test program In the simulation of altitude selection, the altitude data was manually inserted in the equipment room (Figure 12) and selection was by means of switches on the console (see Figure1).

Phase II Modifications - Tracking Systems:

Phase II modifications to the tracking system provided improved automatic tracking on six channels The modifications provided more gain in the amplifier to allow it to better control the tracking channel which had been previously modified to give it improved stability under Phase I

Another Phase II tracking modification was the incorporation of a "force" type tracking stick in lieu of the original displacement type stick at one of the operating consoles. The force stick moves only a fraction of an inch. The track channel is moved in the direction that the operator applies force The rate of movement depends on the amount of force applied Coarse and vernier control in the case of the "force" stick was automatic in that light forces (below three (3) pounds) resulted in less gain (1/5th) than forces greater than three pounds. In the "displacement" stick the choice of coarse of vernier control was obtained by depressing a thumb controlled button on top of the stick to different levels This "force" stick (Figure 1) was installed on the supervisor's console

Another Phase II modification was a trim tab type device mounted on the top of the force stick. Through this trim tab the operator could cause the selected channel to increase speed, decrease speed, turn right, and turn left The rate of change of these functions was a fixed maintenance adjustment The trim tab consisted on on-off switches which were conveniently operated by the thumb when the hand gripped the force stick

Another Phase II modification provided a simulated operation of an ATC computer to provide airway changes automatically to the track channel The intent of this was to aid the operator by making gross tracking corrections and allowing the operator to concentrate on vernier tracking corrections It was also possible with this modification to initiate a track at a given point as if from information stored in an ATC computer

PERSONNEL TRAINING AND EXPERIENCE

An operator training period and equipment checkout was conducted simultaneously from June 1958 to August 1958 Four radar rated Air Route Traffic Control Center (ARTCC) controllers were selected as the operators and permanently assigned throughout the SRS-1 test program Two of the operators were from the New York ARTCC and one each from Chicago ARTCC and the Indianapolis ARTCC The selection of the operators corresponds to the typical ATC areas chosen for the SRS-1 test program as :New York for an outbound area, Chicago for an inbound area, and Indianapolis for mixed departures, arrivals and overflights. These operators had an average of 3-1/2 years as rated radar controllers, 5-1/2 years as ARTCC controllers and 9-1/2 years in CAA air traffic control Their ages were 31, 34, 38, and 40

Additional personnel were required during the test program to simulate computer functions, operate the 30 target 15J1C simulator (Figure 11) and as observers collecting test data. These persons, 28 ARTCC controllers of which 14 were radar rated controllers from the Indianapolis ARTCC, were assigned eight at a time for a two to four week period during the test program These controllers averaged 7-1/2 years in CAA air traffic control work

As a result of the June - August period, it was the general opinion of all personnel that they were thoroughly familiar with the SRS-1 system prior to the start of the tests Therefore, the learning factor was virtually eliminated.

OPERATIONAL EVALUATION PROGRAM

The operational evaluation program herein described is divided into two phases Phase I evaluation was conducted following Phase I equipment modifications The operational evaluation program and the equipment modifications of Phase I were derived from conclusions and recommendations of previous SRS-1 work

As Phase I of the evaluation program progressed it became evident certain equipment modifications were necessary to more fully evaluate a track-while-scan and display system for ATC use. From the evaluation program of Phase I, the evaluation program and equipment modifications for Phase II evolved. Each phase of the program is described in the following:

A Phase I

1. Tracking Experiment (manual Rate-Aided or Coast)[5]

a Purpose.

The general purpose of the tracking phase was to examine the accuracy and reliability with which typical air traffic control personnel could track a sample of simulated aircraft using different modes of operation of the SRS-1 equipment.

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[5] "Tracking Experiment," FIL Working Paper No. 2 (Project A-2052)

The three modes of tracking tested were:

Mode No. 1 - Manual rate-aided tracking with the computer calculating velocity corrections based on repositioning of the tracking symbol with the track stick.

Mode No 2 - Manual rate-aided tracking as described in Mode No. 1 but the operator had the option to use the new permanent course and speed controls on Console No. 1 to insert velocity into the tracking channels.

Mode No. 3 - Manual rate-aided tracking with repositionings accomplished by use of the track stick but velocity corrections were inserted from the permanent course and speed controls on Console No. 1 only.

b. Procedure

Three typical air traffic control areas were selected, each area to represent major problems in today's air traffic control system New York, N Y for an outbound area, Chicago, Illinois for an inbound area, and Indianapolis, Indiana for mixed departures, arrivals and overflights. Three radar rated ARTC controllers were selected to be the operators, one from each of the areas

Three problems were constructed, one for each area, representing typical aircraft, as derived from actual traffic tabulations.

A test series was designed in random order, consisting of 27 test runs, of 25 minutes duration Each controller was tested once in each mode of every area (3x3x3= 27) Based on a study by New York University[6] of the SRS-1 equipment and previous TDC reports[7] a conclusion was made that a tracker's capability ranged between eight and twelve targets. Therefore, each test run was constructed to have ten targets on the scope at all times.

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[6]NYU Report "A Comprehensive Report of the Evaluation of AN/SRS-1", Quarterly Report No 17, NYU College of Engineering, Contract DA 36-029-SE-52648, May 31, 1958, AD #304846.

[7]Technical Development Reports No. 323 and 407, op cit

This test series was performed in realistic conditions as both live and simulated radar was mixed

c. Statistical Measurements, Definitions and Data Analysis Appendix A

d Statistical Results

While some statistically significant differences and strong tendencies to differences were shown in the major measures both with respect to comparisons and interactions, none of these were of such a magnitude as to lead to an overwhelming choice of one mode (of those tested) over others It is possible that this conclusion might change if a more stringent tracking problem were used to stress the systems under test

e Controller Preference and Conclusions

Although the three modes of tracking varied in degrees of working difficulty, the tracker's capacity was not reached in any of the modes with only ten targets. As a result of the Phase I dampening modification it is now estimated a tracker could efficiently track 14 to 16 targets. The dampening used in this determination allows two-thirds of the calculated correction to be added to the previously stored channel velocity when nine or less antenna rotations have elapsed since the last repositioning Between 10 and 30 rotations, two-thirds of the correction at twenty, and with a full correction at thirty antenna rotations Throughout the test program this dampening factor was applied

In operation, the operators preferred the use of Mode 1 Mode 1 had the least manual actions or workload and was among the best in accuracy The test results indicate the permanent course and speed inserts (available in Mode 2 and 3) were seldom used if another method of velocity insertion was allowed They appeared too time consuming and required tracker memory as to what correction need be added However, the tracker felt that one course and speed insert per console would be useful in starting new tracks

In summary, there were statistically strong tendencies as well as complete tracker agreement that Mode 1 (computer derived velocity) was the most desirable In addition the operators would like the ability to reposition the tracking symbol without inserting velocity Combining this feature with Mode 1 offers the basic desired tracking method.

2 Controller Configuration.[8]

a Purpose.

The controller configuration tests were performed to determine two major factors

(1) The value of alpha-numeric information written alongside targets on an ATC radar display

(2) The optimum use of manpower in an ATC system using radar tracking

b Procedure

To determine the value of alpha-numeric information, two ATC display configurations were compared. Both configurations included a radar display with associated tabular flight posting strips showing complete flight plan information. In one configuration the aircraft identity, assigned cruising altitude, and current altitudes were associated with the tracking channel and written electronically alongside the radar targets. This alpha-numeric format moved along with the tracking channel symbol. The tracking channel symbol (a partial circle) was placed directly on the radar target with the format appearing to the right and slightly below the radar target The leader from the center of the display indicated with tracking channel had been selected by the controller or tracker. With this display configuration the controller had the association of radar position and altitude and aircraft identity. This data was supplemented by other flight plan information on the fix postings

[8] "Controller Configuration", FIL Working Paper No. 1 (Project A-2221)

For the second display configuration to be tested, the radar display had only the tracking symbols from the tracking channels and the leader in addition to the radar video presented Any target selected by the controller or tracker (indicated by the leader) could be identified with a particular fix posting by lamp indicators alongside the bay of fix postings No alpha-numeric information appeared on the display. It should be carefully noted that, even under this no-alphanumeric condition, the controller was better informed of aircraft identity than he would be in a truly raw radar situation, since the flight strip associated with a particular target-symbol could be located easily by means of the light next to the appropriate flight strip It should be realized, therefore, that a major advantage of the tracking system existed, even in the mode without alpha-numeric data display, over the present ATC radar displays

The other major factor which was evaluated was the optimum use of manpower for performing the controlling and tracking functions using the above display configurations Two modes of operation were tested using the same traffic samples, i.e , same density of traffic and control problems In Mode 1, one controller performed all control functions and a separate operator performed all of the tracking functions at a separate display. In Mode 2, two controllers performed both controlling and tracking functions at individual displays, with the test area being divided into two sectors and with approximately one-half of the traffic in each sector Thus in the Mode 1 the controller had approximately 15 aircraft to control but had no tracking duties, while in the second mode each man had seven or eight aircraft to control and track

It should be carefully noted that the question experimentally evaluated was "Given the same number of personnel for the system, how should the tracking and control functions be assigned?" A question which was not experimentally tested was "How much is controller effectiveness improved by the addition of tracking personnel?" However, an answer to this question can be estimated from the data taken during Mode 1 tests.

All tracking was in the manual rate-aided mode, with machine computation of velocity changes at the option of the operator whenever he repositioned a tracking symbol Initial assignment of tracking channels was accomplished by a simulated tower control position with hand-off of the targets to the simulated Center control positions Thus all tracking channels were started with flight plan velocity (direction and speed) In the remote tracking situation, the two scopes were operated in parallel

The following test conditions were used.

(1) The test area was two adjacent outbound sectors used in the New York Center today for westbound flights from LaGuardia and from Idlewild and Newark. Experience had indicated a heavy radar control workload would be required in these sectors

(2) Two teams consisting of two experienced radar controllers were set up. These personnel worked together throughout the test series with one man always assigned as controller and the other man as tracker for the tests of separate controller-remote-tracker functions

(3) The traffic samples were at the rate of 42 aircraft departures per hour with six overflights crossing the departure tracks. These samples provided an average of 15 targets on the scope at all times with each of the two sectors averaging seven to eight targets at a time. A total of 12 hand-offs were required between sectors in the controller-controller configuration, while none were required in the controller-remote-tracker configuration

(4) Sixteen test runs of 45 minutes duration each were run. Two controllers ran the same problem twice under each of the four experimental system configurations resulting from the combination of the two system variations described above

(5) The test series were performed in realistic conditions with live and simulated radar mixed

c Statistical Measurements, Definitions and Data Analysis. See Appendix B.

d. Statistical Results.

The two controller configuration (each controller doing his own tracking) can handle the same amount of traffic more safely than the controller-remote-tracker configuration There were more conflictions when the same problem was handled by the two-man teams arranged in the controller-remote-tracker configuration than when they were in the controller-controller configuration (each doing his own tracking)

The presence of alpha-numeric information on the scope face versus an indicator light next to the appropriate flight strip did not show a measurable difference in performance in these tests

e Controller Preferences and Conclusions

From the statistical results and the operator preferences, it is concluded that an area to be controlled by two operators could be controlled more efficiently and with less conflictions if the area were divided and each operator did his own controlling and tracking rather than one operator controlling and the other acting as a remote tracker

The statistical analysis of the measurements indicated no advantage with alpha-numeric information on the radar display, at the traffic loads tested However, it was the unanimous opinion of the controllers that alpha-numeric information alongside the radar targets was far preferable to the configuration with only tracking symbol and lamp indicators alongside the fix postings Also, the ability to associate lamp indicators adjacent to flight progress strips in the no alpha-numeric situation appeared to be a major advantage over a raw radar display without this feature From the controller's subjective opinions it appears that alpha-numeric information increases the capacity of the controller up to 50 per cent over a raw radar display

CONTROLLER'S ESTIMATE OF CAPACITY WITH ALPHA - NUMERIC

Conditions	Estimated Results
Scope □ ○ Operator Controller & Tracking; Scope □ ○ Operator Controller & Tracking	2 Scopes 2 Controllers Total Amount of Targets = 24
Scope □ ○ Remote Tracker; Scope □ ○ Controller	2 Scopes 1 Controller 1 Remote Tracker Total Amount of Targets = 14 or 15
Scope □ ○ Remote Tracker; Scope □ ○ Controller; Scope □ ○ Remote Tracker; Scope □ ○ Controller	4 Scopes 2 Controllers 2 Remote Trackers Total Amount of Targets = 28 or 30

Another point noted by the controllers was that in the controller-remote-tracking configuration, with the scopes in parallel, considerable co-ordination between controller and tracker was required In future equipment design it would seem mandatory that both tracker and controller have individual input devices to their scope

The controllers involved estimated that with an improved SRS-1 system, the amount of targets they could control safely were as follows

1 Controller doing his own tracking - without alpha-numeric Estimates ranged from 5 to 10 targets Consensus 7 targets

2 Controller doing his own tracking - with alpha-numeric Estimates ranged from 10 to 20 targets Consensus 12 targets.

3 Controller with remote tracker - without alpha-numeric Estimates ranged from 7 to 12 targets

4 Controller with remote tracker - with alpha-numeric Estimates ranged from 14 to 15 targets

It is estimated that by using alpha-numeric information, two controllers, doing their own tracking, could control safely 24 targets and one controller, with a remote tracker, could control safely 14 to 15 targets

In conslusion, both the statistical results and the controllers' opinions agree that for the optimum utilization of personnel and given the same investment of manpower, controllers should do their own tracking.

HAND-OFF

In the present ATC system when control responsibility for an aircraft, which is operating with radar separation from other traffic, is transferred from one controller to another the procedure for assuring that the aircraft is properly identified can be very time consuming The controller relinquishing control must verbally describe the aircraft's position The controller accepting control must be positive he has the correct aircraft In high traffic densities, particularly in mixed VFR/IFR conditions, the presence of other aircraft may prevent positive identification at the time transfer is desired Since a tracking channel can be used to pin point a particular target, to the exclusion of all others, its transfer from one display to another would quickly transfer a positive identity from one controller to another in the same display system If the co-ordinates of a particular tracking channel in one tracking system were remoted and translated to the co-ordinates of anther tracking system, a means would be provided for the controller at one facility to indicate a particular geographical point to a controller at another facility and thus accomplish a visual inter-facility hand-off

To test the operational concept of the above, two tests were arranged for the SRS-1 system The first used a common pool of track channels for intrafacility hand-off and the second simulated the use of co-ordinate translation equipment for inter-facility hand-off. Each of these tests are described in the following

A Intra-facility (Common Pool of Track Channels)

Tracking channels, in the common pool system, can be transferred with all associated information and velocity from one display to any other display in the system by operating the proper transfer button In this method only the control of the channel is transferred and therefore, there can be no error in the data itself When control is acknowledged by the receiving operator the transfer is completed

In the SRS-1, if adjacent sector displays overlapped five to ten miles, and hand-off points were established between adjacent sectors, a channel dot would be seen approaching the hand-off point indicating the aircraft is being tracked in the adjacent sector For these tests a light signaling system, similar to a three-way light switch, would start flashing on both sectors three to five seconds prior to actual hand-off This alerts the controller that a hand-off is coming from a particular sector at the established hand-off point. As the controller pushes the transfer button the dot would change into a tracking channel symbol and control of this channel with all its associated data is transferred The hand-off light would still be flashing on both consoles. The receiving controller operates a switch turning both lights off, indicating receipt and acknowledgement of control No verbal exchange has taken place and none is required for normal operation.

B Inter-Facility (Co-ordinate Translation)

An inter-facility hand-off requires a positive translation of a particular geographical point from one system to another Data regarding the flight must also be transmitted and acknowledged For this evaluation the co-ordinate translation system was simulated The transferring sector advises the receiving sector via interphone of an approaching hand-off The operator at the transferring sector places a track circle symbol about the target to be handed off and the translated co-ordinate appears as an intensified dot on the receiving sector. Then the operator at the receiving sector takes one of this track channels and places its circle symbol about the target which has been marked by the transfer dot This action causes a dot to appear on the transferring sector display Both operators see their circle and the dot from the other operator on the radar target transferred This allows quick and positive identification and checks possible error in the translation system. With such identification completed, the alpha-numeric data and channel velocity can be entered manually into the receiving tracking channel by means of an input keypack from verbal data passed over the interphone

Throughout the SRS-1 tests, wherever procedures required radar hand-off to either start a new target into the system or to evaluate a control procedure, either the intra-facility or inter-facility hand-off technique was used Statistical data was not collected to compare with the existing verbal system because of the obvious improvement in the SRS-1 system over existing verbal techniques It would appear that one of the more obvious advantages of future display systems will be their inherent positive and time saving methods of making radar hand-offs

AUTOMATIC TRACKING

Theoretically, the automatic track-while-scan mode of operation would be ideal insofar as minimum operator workload is concerned However, in previous tests of the SRS-1 equipment, it was found that most of the time the manual rate-aided mode of tracking was necessary for reliable tracking of targets With present day two-dimensional radars the presence of other aircraft targets, ground clutter and MTI residue, system noise and radar interference prevent errorless tracking If a second aircraft at some other altitude passes near to the target being tracked enters an area of ground clutter, the tracking channel may stop on the ground clutter Similar problems are encountered in the presence of other radar interference or noise Because of these problems, all automatic radar tracking systems include provisions for humans to monitor the system, and to intervene as necessary to assist the tracking gates to follow the proper targets

The above deficiencies notwithstanding, evaluations were conducted to determine the improvements attainable if the theoretically-perfect, automatic, track-while-scan system were available

To simulate a theoretically-perfect tracking environment, radar video was not used, thus eliminating all clutter and random targets All targets tracked were simulated. The problem was set up so that none of the simulated aircraft would come in close proximity to each other The antenna rotation rate was increased to 10 rpm Under these idealized conditions an attempt was made to measure tracking workload The only duties necessary were initial target acquisition No targets were lost in the five test runs conducted and tracking accuracy was excellent. It is estimated that only a small percentage (less than ten per cent) of the tracker workload required for a good manual rate-aided tracking system was necessary to obtain errorless automatic tracking under perfect conditions

B Phase II

1 SRS-1 Track Stick Experiment [9]

a Purpose.

The purpose of this test series was to compare the following types of track sticks

(1) Displacement Stick

Movement of the tracking symbol is directly proportional to the movement of the tracking stick

(2) Force Stick

Rate of movement of the tracking symbol is proportional to the force applied to the tracking stick

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[9] FIL Working Paper No 2 (Project A-2221).

b Procedure

The force stick requires that a force must be exerted on the stick to cause movement of the symbol The force stick has very little physical movement in any direction The track signal button (activates symbol movement) is located on the front of the stick, somewhat like a trigger grip In operation, the track signal button is depressed and a force exerted in any direction will move the symbol in the corresponding direction on the scope at a rate determined by the force applied It is designed so that the rate of symbol movement is proportional to the force applied It is designed so that the rate of symbol movement is proportional to the force applied It is further refined in that there is a faster rate of symbol movement when the force applied reaches a pre-set point The parameters set up for this evaluation were (1) forces up to three pounds will produce a symbol rate of 13 inch/sec / pound of force, and (2) forces of three pounds to five pounds produce a symbol rate of 64 inches/sec /pound of force

The track stick used in the previous experiments is described as the position stick or the displacement stick This relates to the fact that a change in position or displacement of the stick causes a corresponding displacement of the symbol The stick will move in any direction and the symbol is responsive to this motion The track signal button on this model is located on the top of the track stick and must be depressed for symbol movement

In operation, the track signal button is depressed and a displacement of the stick in any direction will displace the symbol in the same direction on the scope The stick is designed so that the distance the symbol moves on the scope is directly proportional to the distance the stick is moved Incorporated in the device are fine and coarse verniers When the track signal button is depressed to the first level (fine vernier), a full motion of the stick will move the symbol one inch In the coarse position (button all the way down) the symbol will move 14 inches for a full stick displacement The rate at which the symbol moves is a function of how fast the operator moves the stick

Two consoles were used in the experiment The two consoles were comparable with the exception that the force stick was installed on one console and the displacement stick on the other Before the experiments started, both sticks were adjusted to function as described in the preceeding paragraphs

In the first experiment 12 runs of 30 minutes duration were made Each of the three trackers did two runs each with both sticks Each run had 18 targets on the scope throughout a 12 minute scoring period. There was no live radar background and no alpha-numeric information displayed The Indianapolis ARTCC airway structure was used The tracking was done in the manual rate-aided mode. All targets were handed-off from a simulated tower or adjacent center with flight plan velocity inserted in the channels The three trackers used in this experiment were trained in the proper use of each stick and had several hours of experience with each type

In addition to the first experiment described above, two other smaller tests were run In the second experiment, the purpose was to make a further check on the effect of equipment familiarity Three controllers who had no previous tracking experience with either stick were given three runs with each stick in random order. An easier problem then that used with the experienced trackers was used with these new trackers

In the third experiment, a brief attempt to check on the data of the first experiment was made The three experienced trackers each made one run on each of the two sticks in random order The same problem and scoring procedures were used as in the first experiment

c Statistical Measurements, Definitions and Data Analysis See Appendix C

d Statistical Results

In Experiment No 1 there was no significant difference at the 05 level (capable of repeating with the same results 95 times out of 100 such experiments) in workload or accuracy measurements. However, there was a strong tendency, reliable at the 10 level (capable of repeating with the same results 90 times out of 100 such experiments) for the force stick to have a greater number of misses In this experiment the trackers averaged 35 more misses per run with the force stick than with the position stick.

In Experiment No. 2 there were no significant differences. However, the trackers averaged eight more misses per run with the force stick than with the position stick

Experiment No 3 was identical to Experiment No. 1 with the exception of having only six runs. In this experiment the trackers averaged 40 more misses per run with the force stick than with the position stick, indicating no learning factor was involved from the first experiment No significant differences were found in Experiments 2 and 3 mainly due to the limited number of runs The strong tendency shown in Experiment No 1 was again indicated in Experiment No. 3

e. Controller Preference and Conclusions

The operators indicated a strong preference for the displacement stick rather than the force stick Some felt the physical co-ordination of individuals might be a factor in their ability to achieve rapid accuracy through the application of force. The strong statistical tendencies, and the operational preference, for the displacement stick lead to the conclusion that it is the better of the two tested.

2 Flight Plan Turns and Trim Tab Plus Vectors[10]

a Purpose

The purpose of this experiment was to determine the contribution of flight plan turns and trim tabs to tracking radar targets in the air traffic control system

b Procedure

Trim tabs are devices which in this case are attached to the track stick and provide an alternate method of inserting

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[10] "Flight Plan Turns and Trim Tab Plus Vectors," FIL Working Paper No. 3 (Project A-2221)

heading and speed changes into the tracking channel. Closely associated with the trim tabs are vectors which are electronically written on the scope The vectors extend from the tracking symbol in a direction indicating the heading of the channel and are proportional in length to the speed of the tracking channel For this test series a vector was displayed representing a one or two minute flight path prediction (less than an inch in length)

By flight plan turns is meant a computer input of flight plan information such as might be envisioned in an advanced computer display system In such a system the tracking channels would turn automatically at airway junctions so as to follow the aircraft's intended path To make an estimate of the effect of such procedures on reducing the tracking effort involved, a method of simulating computer input of flight plan turns was devised. The device was operated by the simulation crew and they were able to turn any of the tracking channels according to the program of the simulation problem

A 16 run experiment was performed Each of two trackers operated twice in each of the four experimental conditions as follows

(1) Flight plan turns and trim tabs
(2) Trim tabs but no flight plan turns
(3) Flight plan turns but no trim tabs
(4) No flight plan turns and no trim tabs

All tracking was in the manual rate-aided mode The traffic load consisted of 18 aircraft simultaneously on the scope The problem was programmed for 25 minutes, but the recording of measurements was delayed till the eighth minute when the load had been built up to 18 targets Therefore, measures were recorded for 17 minutes in each run For realism, there was a live radar background mixed with the simulated targets

c. Statistical Measurements, Definitions and Data Analysis See Appendix D d Statistical Results

The addition of flight plan turns significantly reduced (capable of repeating with the same results at least 95 times out of 100 such experiments) velocity count and misses. Trim tabs significantly reduced (capable of repeating with the same results at least 95 times out of 100 such experiments) track count, velocity count, and sequences The observational data on frequency of use of trim tabs indicated that the speed trim tab was used very infrequently

e Controller Preferences and Conclusions.

The addition of computer derived flight plan turns is a considerable improvement to this type tracking system Track count and velocity count (workload measurements) were materially reduced when flight plan turns were used. Most important, tracking accuracy was improved as misses were reduced significantly

From the results of this evaluation, it is also apparent that the addition of trim tabs and vectors will help the tracker reduce his workload The use of trim tabs and vectors considerably reduces the track count, velocity count, and the sequences required for the tracking

From the statistical results it can be seen that the trim tab control for speed was seldom used It was concluded that the manual-rate-aided mode of velocity insertion, even with slight operator symbol positioning error, offers satisfactory speed insertion However, this symbol positioning error does affect the channel's heading By means of the trim tab and vector, the requirement for velocity corrections (which included heading corrections) was greatly reduced

Therefore, while the trim tab for speed is not essential, the trim tab and vector for heading should be considered as an essential combination feature

3. Simulated VG Type Display Versus SRS-1[11].

a. Purpose This experiment was conducted to compare the operational advantages of future display systems with present day radar displays such as the VG.

b. Procedure Based upon previous conclusions and present day VG operations, controllers worked singly doing their own tracking and controlling. The same traffic sample was controlled using a 22 - inch horizontal TV display, simulating present day VG type of operation, and using all of the features of the final SRS-1 system. Flight progress strips were available in both systems. Traffic problems consisting of an average of twelve aircraft simultaneously on the scope for a continuous 45 minute period were used. The traffic simulated inbounds, outbounds, and overflights in the Indianapolis Area.

There were a total of twelve 45 minute runs. Each of the three permanent controllers operated twice with each of the two display systems Two problems were designed to be as a comparable as possible

The selectivity controls and switches for the many display features were relatively new at the time of this experimental period. The new features included (1) three lines of alpha-numeric information with alternate information per line (2) full alpha-numeric selectivity was provided allowing the operator to select data by line and also to display it only (3) vectors were on the selected or on all channels desired, provided with the full selectivity feature allowing all or just the selected channel to be displayed (4) altitude selectivity, block altitudes and single altitudes. Figures 3 through 10 illustrate these features

Controllers were given two one-half hour familiarization runs on the SRS before the test started. All of the controllers were previously experienced with the VG type system (Figure 14).

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[11] "Simulated VG Type Display Versus SRS-1," FIL Working Paper No. 4 (Project A-2221).

c. Statistical Measurements, Definitions and Data Analysis See Appendix E.

d Statistical Results -

There were significant differences between the SRS and VG type systems in the following measurements -

1 The number of altitude changes imposed by ATC per run averaged eight when the VG system was in use, and four when the SRS system was being used

2 The number of aircraft allowed by controllers to drift off airways, when using the VG system, averaged two aircraft per run This average was four per run in the case of the SRS system

3 Communication was less frequent with the SRS system Communications averaged 114 per run with the SRS system as compared with 130 with the VG system. There was no significant difference in the number of conflictions The SRS averaged 2 6 conflictions per run, while the VG system averaged 3.1 conflictions per run. It was noted that some controllers were better able to work safely with one system, while others were better able to work safely with the other For example, Controller 1 averaged four conflictions with both systems, Controller 2 averaged two conflictions with the VG, four with the SRS, Controller 3 averaged three conflictions with the VG system and one with the SRS system

e. Controller Preference and Conclusions -

It was apparent to observers of the test that the controllers were much more facile and proficient in the manner in which they worked with the VG as opposed to the SRS system They seemed to have some difficulty in handling the many available features of the SRS system

It appears that more experience and development of standardized operating techniques are required to obtain optimum results from more complex systems such as the

SRS-1 Considerable effort should be devoted to the human engineering of automatic systems, as it appears possible to provide too many options or inconveniently located controls

The differences between the systems as measured here were less dramatic than might have been expected Perhaps if more sensitive measurement criteria had been available, more significant differences between the systems might have been detected. For example, there were no controller co-ordination problems between scopes in these tests and this may be one of the stronger points in favor of the SRS type system because of its superior hand-off ability

Each of the controllers and observers were asked to rate the features of the SRS-1 system to indicate the desirability in a future display system The results of this questionaire are summarized below

CONTROLLERS' OPINION

Feature	Rating Category			
	Not Required	Slightly Useful	Desirable	Essential
1 Bright tube display				X
2 Trail characteristics				X
3. Alpha-numeric (line one identify and line two altitude)				X
4 Alpha-numeric (line three route information)		X		
5. Read-out devices per console (Heading and speed in bright numbers)			X	

	Not Required	Slightly Useful	Desirable	Essential
6 Selectivity (lines one and/or two with assigned or select channels)				X
7 Selectivity (line three with assigned or selected channels)		X		
8 Selectivity formats whether assigned or all			X	
9 Alternate information per line				X
10 Alpha-numeric cycle rate at 20 cycles or more				X
11 Ability to blank all formats and/or video	X			
12 Vectors				X
13 Vectors prediction 0 to 10 minutes ahead				X
14 Vectors prediction 10 to 15 minutes ahead			X	
15 Vector selectivity (assigned or select)				X
16 Vector selectivity (all position)			X	
17 Trim tab control for channel headings				X
18 Trim tab speed control for use in tracking		X		
19 Trim tab speed control for use in controlling			X	

	Not Required	Slightly Useful	Desirable		Essential
20 Altitude selectivity (single altitude and block levels)					X
21 Flight plan turns			X	To	X
22. Course and speed insert (one per console)					X
23 Permanent course and speed insert for each channel	X				
24 Predetermined positioning of channel to a fix			X		
25 Channel light next to flight progress strip					X

In addition to providing the above answers, participating personnel suggested that several of these items appear very desirable from previous test results while others would require future testing to determine their value These are

1 Ability to move formats anywhere on the scope as freely as the tracking channels A leader must be provided from the format to the tracking symbol

2 Ability to insert vector delay information into the tracking channels (by means of a key pack or other devices) to insert standard hold patterns of different time intervals

3 Have the format indicate present altitude and assigned altitude during climbs or descent

4 When sequencing to have the ability to see only those aircraft at the altitude of the selected target and those passing through the selected altitude strata.

5 Prediction vector to follow route of the planned flight rather than extrapolating in a single direction

6 Make the trim tab rate of turn 25 degrees per second

7 Ability to sequence flight progress strip and associated tracking channel light as controller may desire

8 A method of indicating an altitude block on the display when the radar is unable to detect or identify a target

9. Velocity should be added on each repositioning with a switch to allow repositioning without adding velocity rather than the reverse as it was during the test.

10 Considerable improvement in the legibility of the alpha-numeric information presented would be desirable in the final system

The controllers like the slanting face display of the SRS-1 system rather than standing over the VG horizontal display Also, the controllers felt they could handle between 15 and 20 percent more traffic, with the same or improved safety, using a display having the full SRS-1 type features, plus their suggested changes, as compared to the present VG type of display

4 Circle Versus Dot as Tracking Symbol[12]

Purpose To compare circles and dots for effectiveness as tracking symbols

Procedure: Tests were run to compare circles and dots as tracking symbols with regard to three aspects of effectiveness:

a Target initial capture
b Velocity insertion
c Tracking.

a Target initial capture. Ten targets were placed in a general form of a circle at various ranges about the scope face Subjects were instructed to acquire these ten targets as rapidly as possible Each of three subjects did three runs with circles and three runs with dots The targets were to be acquired by placing the dots at the center of the targets

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[12] "Circle Versus Dot as Tracking Symbol," FIL Working Paper No. 6 (Project A-2221)

In the case of the circles and targets were to be acquired by placing the circles so that the circle surrounded the center of the target. The measure taken was the total time in seconds required to capture all ten targets

Results The following table presents the scores in seconds obtained

	Dots		Circles	
Operator 1	1	81	1.	59
	2	68	2	64
	3	60	3	52
Operator 2	1	82	1	76
	2	83	2	74
	3.	89	3.	66
Operator 3	1	76	1	50
	2.	76	2	57
	3	67	3	54
	Average	77 sec		61 sec.

It can be seen that the difference between the mean scores is 16 seconds. This difference is very reliable statistically (.002 level, sign test), indicating that the conclusion would be the same 998 times out of 1000

It is concluded that circles are significantly faster for initial acquisition of targets

b <u>Velocity insertion</u> Matching the tracking channel velocity with target velocity is the most important aspect of tracking. The circle and dot symbols were checked to see if the symbol had any effect on the speed or accuracy of this velocity matching proceedure A test was set up which measured the time it took the subjects to adjust tracking channel speed to target speed. The channels were initially set at speeds different from the targets to be tracked Four targets with associated tracking channels were presented to the tracker at the beginning of each run. Each target was going in a different direction, i.e. one was going east to west, one west to east, one north to south, one south to north.

A total of 16 runs was made Each of the two subjects did four runs with circles and four with dots In two of these runs, the tracking channels were initially set at 100 knots faster than the target, and in two of the runs the tracking channels were 100 knots slower than the targets All targets were 300 knots in speed The subjects were not given any of this velocity information

Results: The basic data from the experiment is reported in another report[13] A summary is shown in the following table titled, "Time in Minutes To Achieve and Maintain True Speed (± 100%)

An analysis of the time required to achieve the true velocity shows no consistency regardless of symbol, tracker, or whether a faster or slower velocity is required It must be concluded therefore, that neither symbol is significantly faster than the other This is probably due to the fact that the resultant velocity calculation is weighted against the previously stored information and therefore, if either symbol did result in more accuracy, it would not be apparent in the result

c Tracking To determine which symbol is the most operationally desirable, a series of test runs, simulating actual conditions, was established requiring the use of both symbols Subjects were required to track twelve targets with varying courses and speeds. Tests of 30 minutes duration were run with each symbol being used one half of a test period was reversed for the next subject

Results In tracking the dot is not as readily located on the scope as the circle symbol If the dot is intensified, targets near the center of the radar scope are nearly obscured by the dot symbol It was the unanimous opinion of all subjects that a small circle or partial circle should be used as the tracking symbol

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[13]FIL Working Paper No 6 (Project A-2221)

TIME IN MINUTES TO ACHIEVE AND MAINTAIN TRUE SPEED (10%)

Target	Circle Symbol				Dot Symbol			
	TRACK CHANNEL INITIALLY 100 KNOTS GREATER THAN TARGET							
	Tracker No 1		Tracker No. 2		Tracker No. 1		Tracker No. 2	
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1	1 50	4.08	7.25	3.33	4.33	3 50	5.58	3.16
2	2.25	2.00	4.25	3.58	1.08	6.08	1 17	3.33
3	2.33	2.25	4.54	4.30	2.60	2.83	3.42	2.02
4	3.75	4.58	6.42	5.95	1.78	2.00	2.03	1.50
	TRACK CHANNEL INITIALLY 100 KNOTS LESS THAN TARGET							
	Run 9	Run 10	Run 11	Run 12	Run 13	Run 14	Run 15	Run 16
1	1.08	1.41	1.25	0.58	4.50	3.42	2 50	0.50
2	1.08	1.41	7.66	2.00	4.50	2.00	0.67	0.66
3	5.75	6.83	5.80	6 13	5.83	5.83	6.75	6.53
4	2.80	1.50	6.08	2 05	4.00	2.50	3.75	4.33

Conclusions.

1. The dot symbol required significantly more time to capture a target or to reposition when required than the circle symbol

2 Neither symbol is significantly faster than the other in correcting the stored velocity to its true value. This conclusion is based on a system where the new calculation is weighed against previously stored velocity in accordance with Controller Preference and Conclusions Section of the Tracking Experiment of this report (see Page 12)

3 Personnel tested preferred to use the circle rather than the dot

CONCLUSIONS

1. In a manual rate-aided tracking system the preferred basic mode of operation is that in which the controller repositions the tracking symbol with a track stick, and the computer calculates velocity corrections based upon these new positions. Some dampening factor should be added to the velocity corrections The operator should have the ability to reposition without the machine automatically computing new velocities, if he desires

2 The displacement stick showed a significant difference in tracking accuracy over the force stick at the 10 level (capable of repeating 90 times out of 100) Some of the operators felt the physical co-ordination of individuals might be a factor in their ability to proficiently use a force type stick The operators preferred the displacement stick

3 Flight plan turns significantly[14] reduce workload and are desirable in a manual rate-aided tracking system.

4 Trim tab and vectors significantly[14] reduce workload and are essential in a manual rate-aided tracking system The trim tab control for speed is not essential Trim tabs and vectors should be used in combination for maximum effectiveness.

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[14]Test results were considered statistically significant at the .05 level (capable of repeating 95 times out of 100) unles otherwise stated

5 The use of a circle as a tracking symbol was significantly better than the dot The operators unanimously preferred the circle as the tracking symbol.

6 If a perfect automatic tracking system were available, the tracker's workload would be only a small percentage (less than ten per cent) of the workload required for a good manual rate-aided tracking system.

7 The hand-off procedures in the SRS-1 system reduce co-ordination time, are less time consuming, and offer more positive identification during transfer than present day verbal procedures.

8 It was the controller's opinion that alpha-numeric information on the scope increased their traffic handling capabilities up to 50 per cent over a raw radar display. However, in these tests, the presence of alpha-numeric information on the scope versus an indicator light next to the appropriate flight progress strip did not show a significant[14] difference in performance

9. Test results were statistically significant[14] indicating that for the optimum utilization of personnel, and given the same investment of manpower, controllers should do their own tracking It was the controller's estimate that by using alpha-numeric information, two controllers, doing their own tracking, could control safely 24 targets One controller, with a remote tracker, could control safely 14 to 15 targets

10 In future equipment design requires both a tracker and controller, it would seem mandatory to have individual input devices to their scope

11 There were significant[14] differences between the SRS-1 and the VG type systems in the following measurements:

a. The SRS-1 averaged four altitude changes imposed by ATC while the VG type system averaged eight per run

b The SRS-1 allowed four aircraft per run to drift off airways while the VG type system averaged two per run

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[14] Test results were considered statistically significant at the 05 level (capable of repeating 95 times out of 100) unless otherwise stated

c The SRS-1 averaged 114 communications contacts while the VG type system averaged 130 contacts per run

There were no significant differences in the number of conflictions The SRS-1 system averaged 2 6 conflictions per run, while the VG type system averaged 3 1 conflictions per run

12 The controllers like the slanting face display of the SRS-1 and with their suggested additional features, believe such an improved system could offer up to 15 or 20 per cent improvement over the present VG type system However, considerable effort should be devoted to the human engineering of automatic systems, as it appears possible to provide too many options or to located controls inconveniently

LIST OF ILLUSTRATIONS

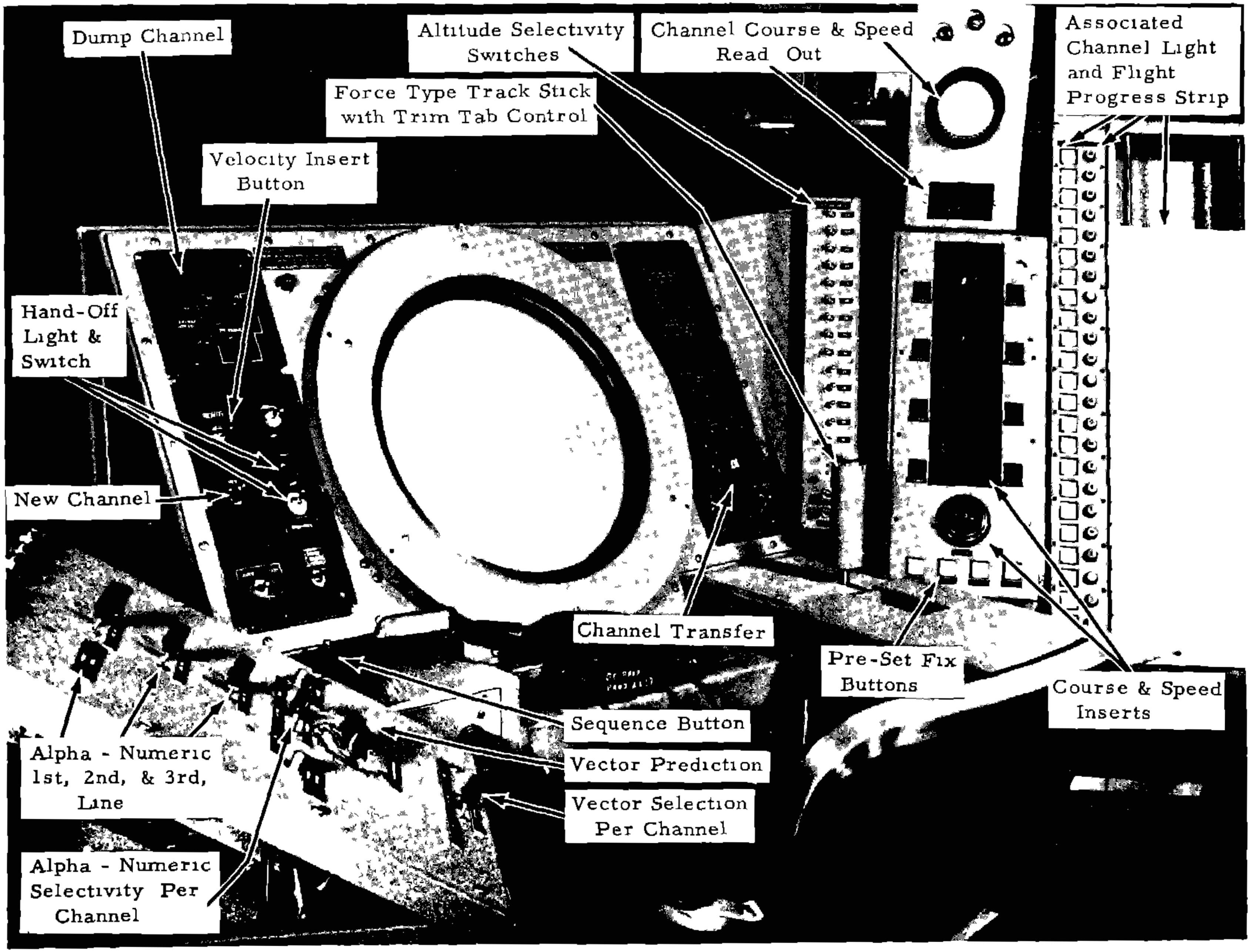

FIG 1 - SRS-1 SUPERVISORS CONSOLE - BRIGHT TUBE DISPLAY

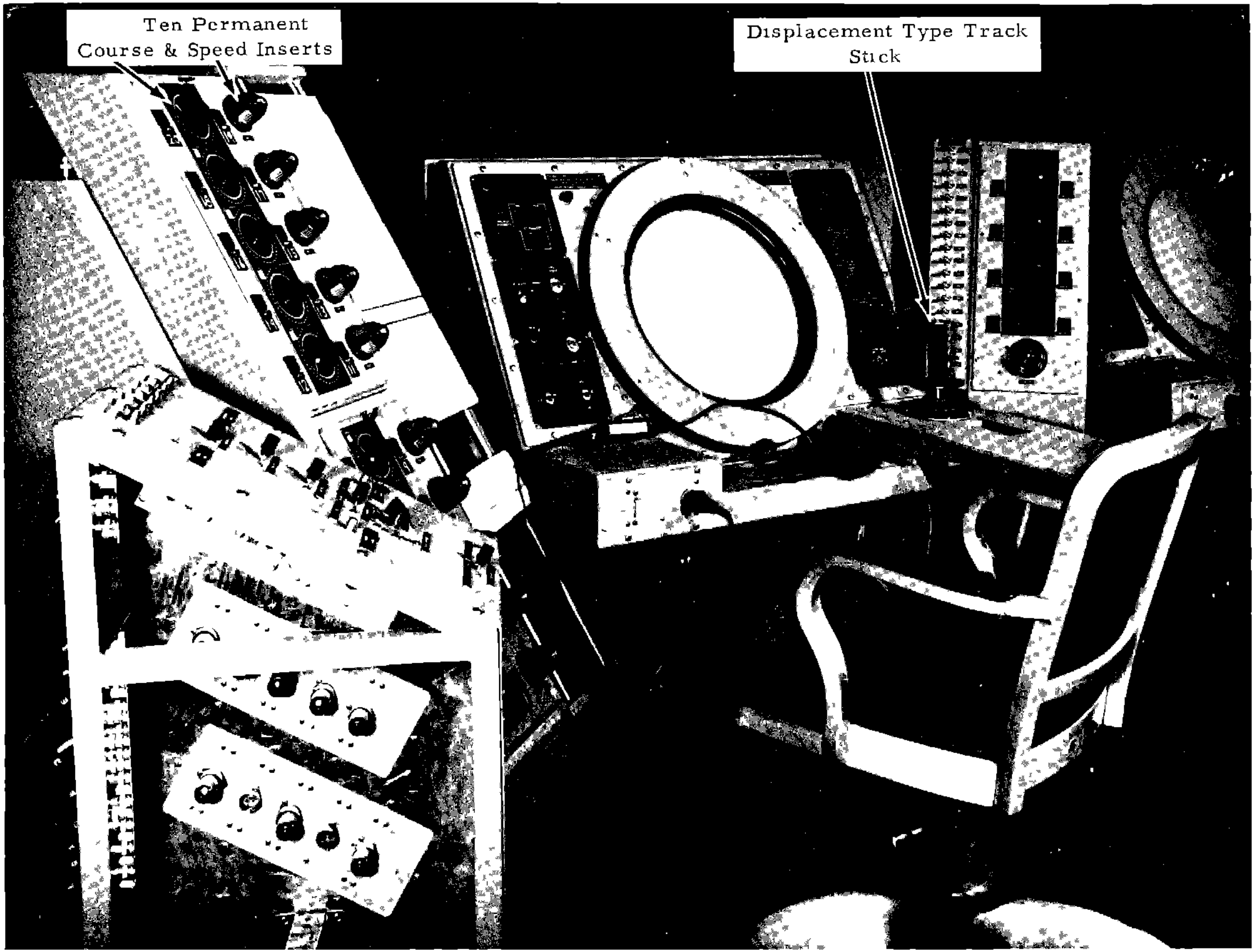

FIG 2 - SRS CONSOLE NO 1 BRIGHT TUBE DISPLAY

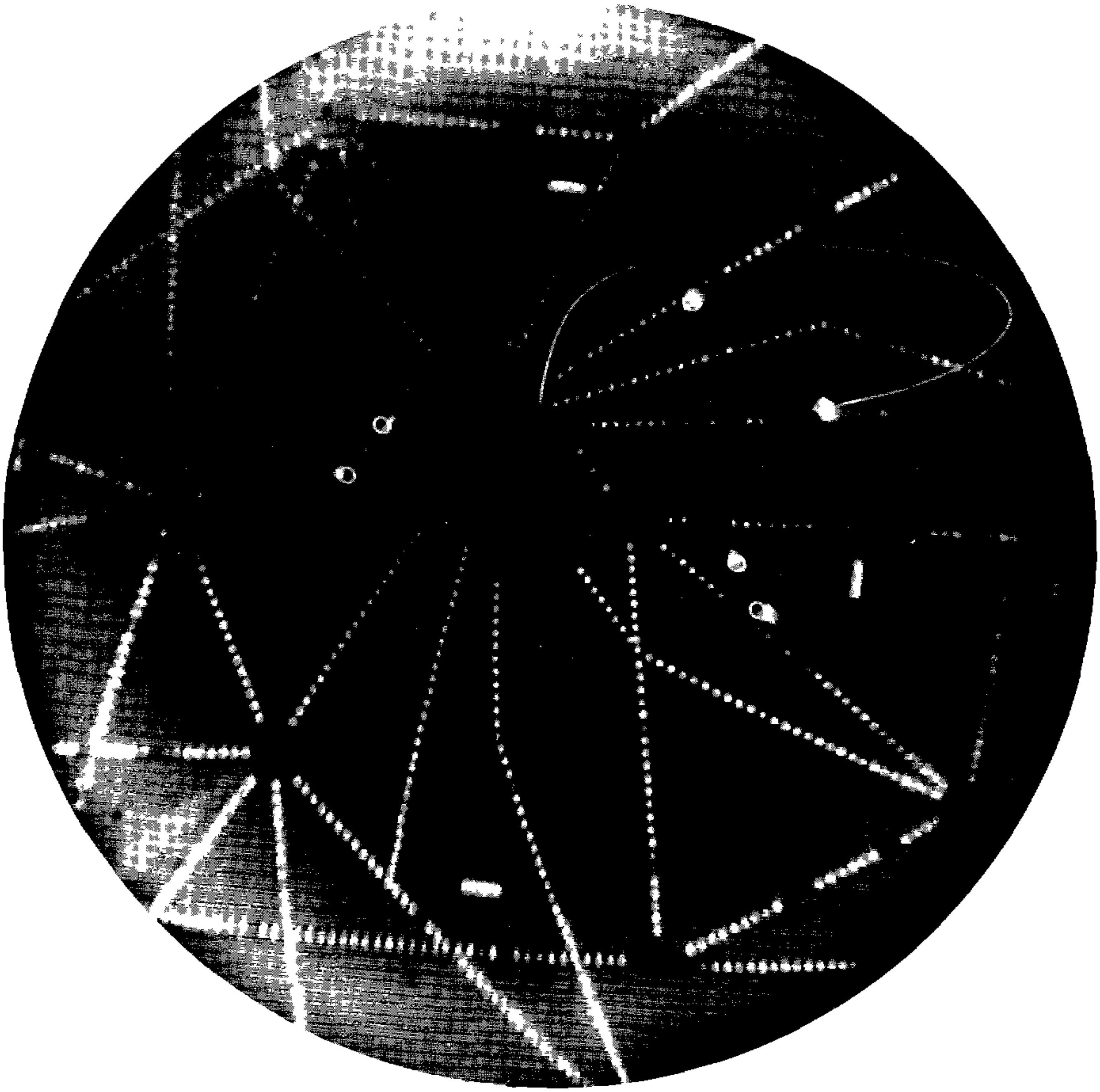

FIG 3 - SCOPE PRESENTATION SHOWING TRACKING CHANNEL SYMBOLS OF SRS-1 BRIGHT TUBE DISPLAY

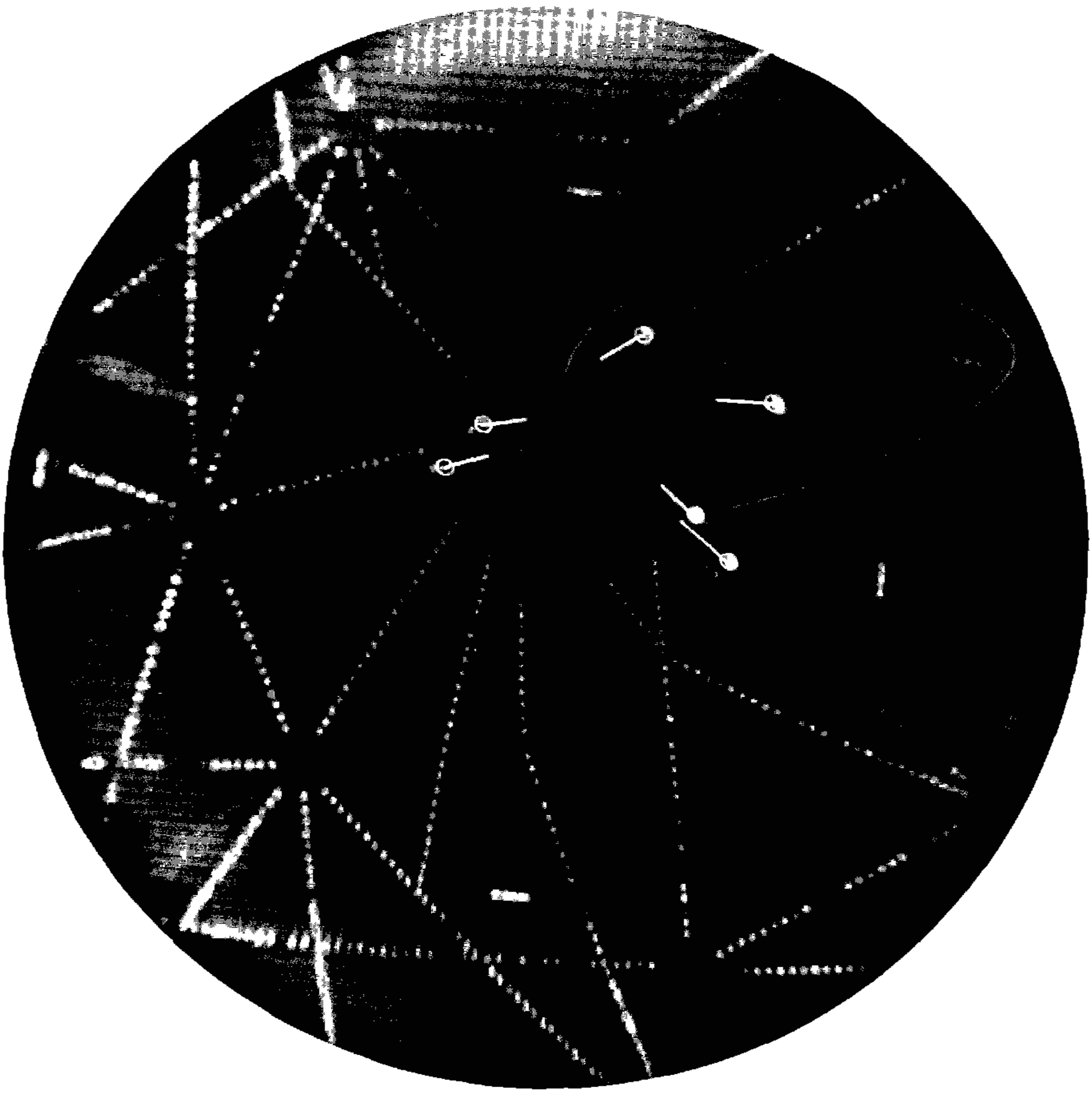

FIG 4 - SCOPE PRESENTATION SHOWING CHANNELS AND VECTORS OF SRS-1 BRIGHT TUBE DISPLAY

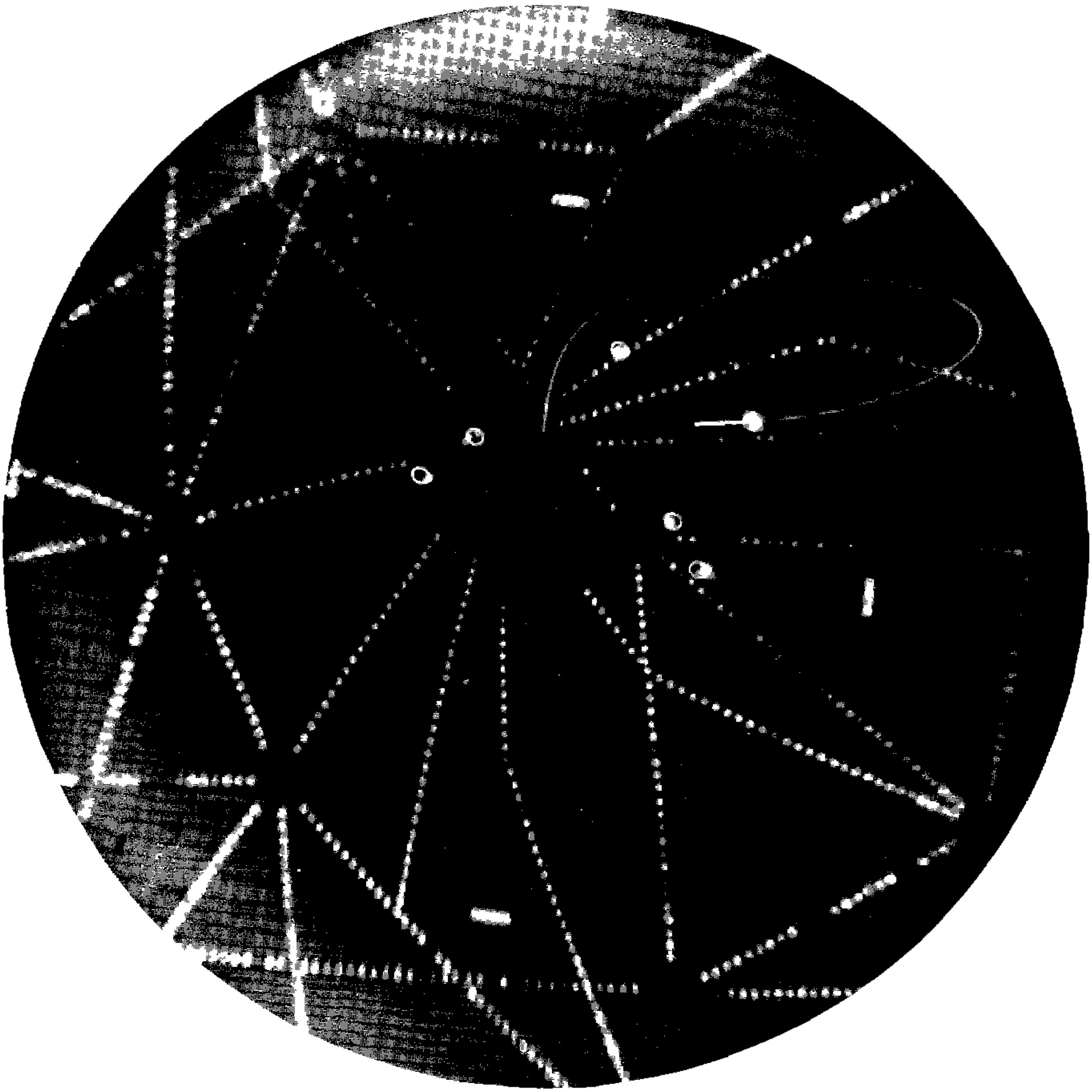

FIG 5 - SCOPE PRESENTATION SHOWING SELECTED CHANNEL VECTOR OF SRS-1 BRIGHT TUBE DISPLAY

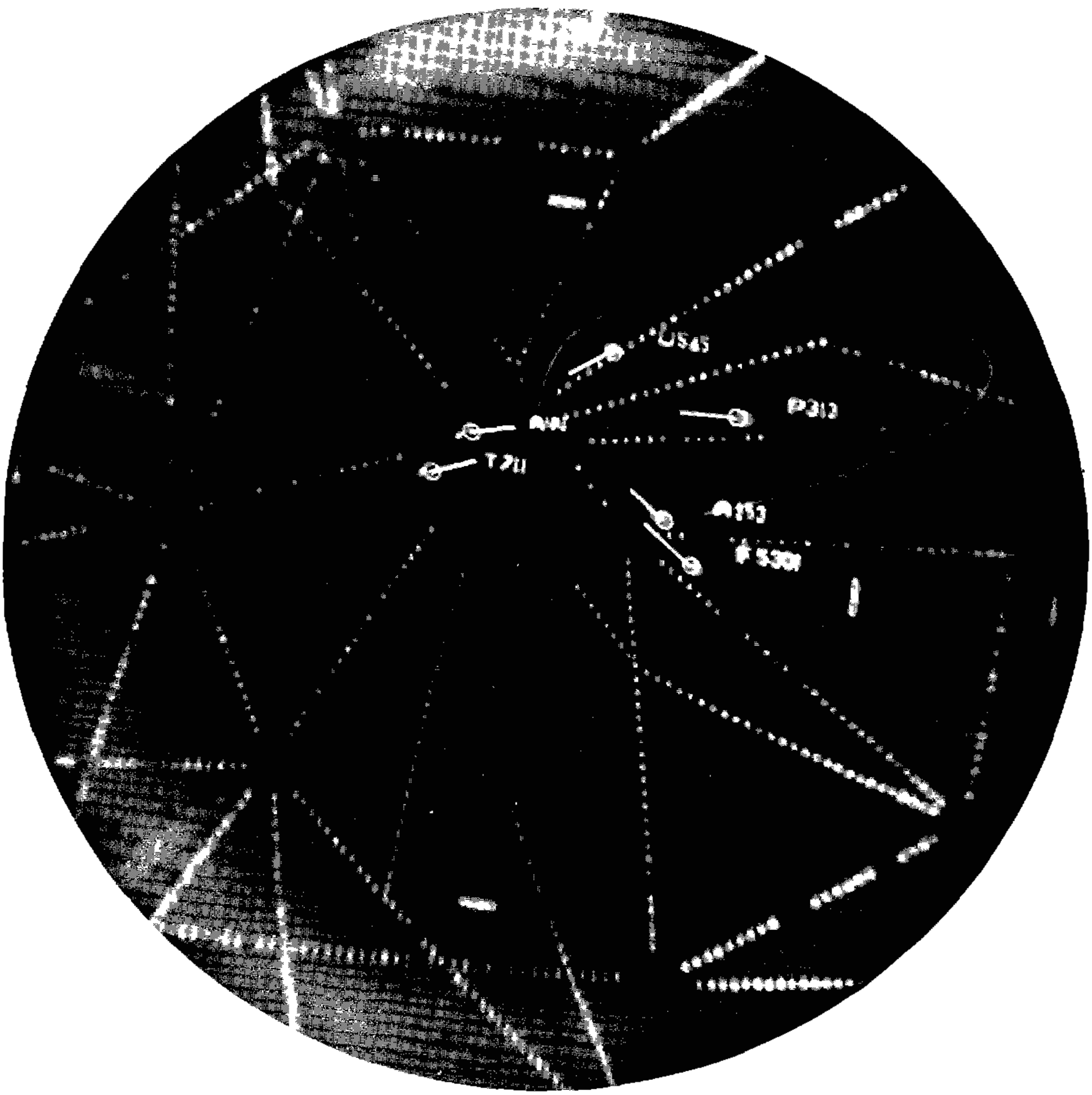

FIG 6 - SCOPE PRESENTATION SHOWING TARGET IDENTIFICATION OF SRS-1 BRIGHT TUBE DISPLAY

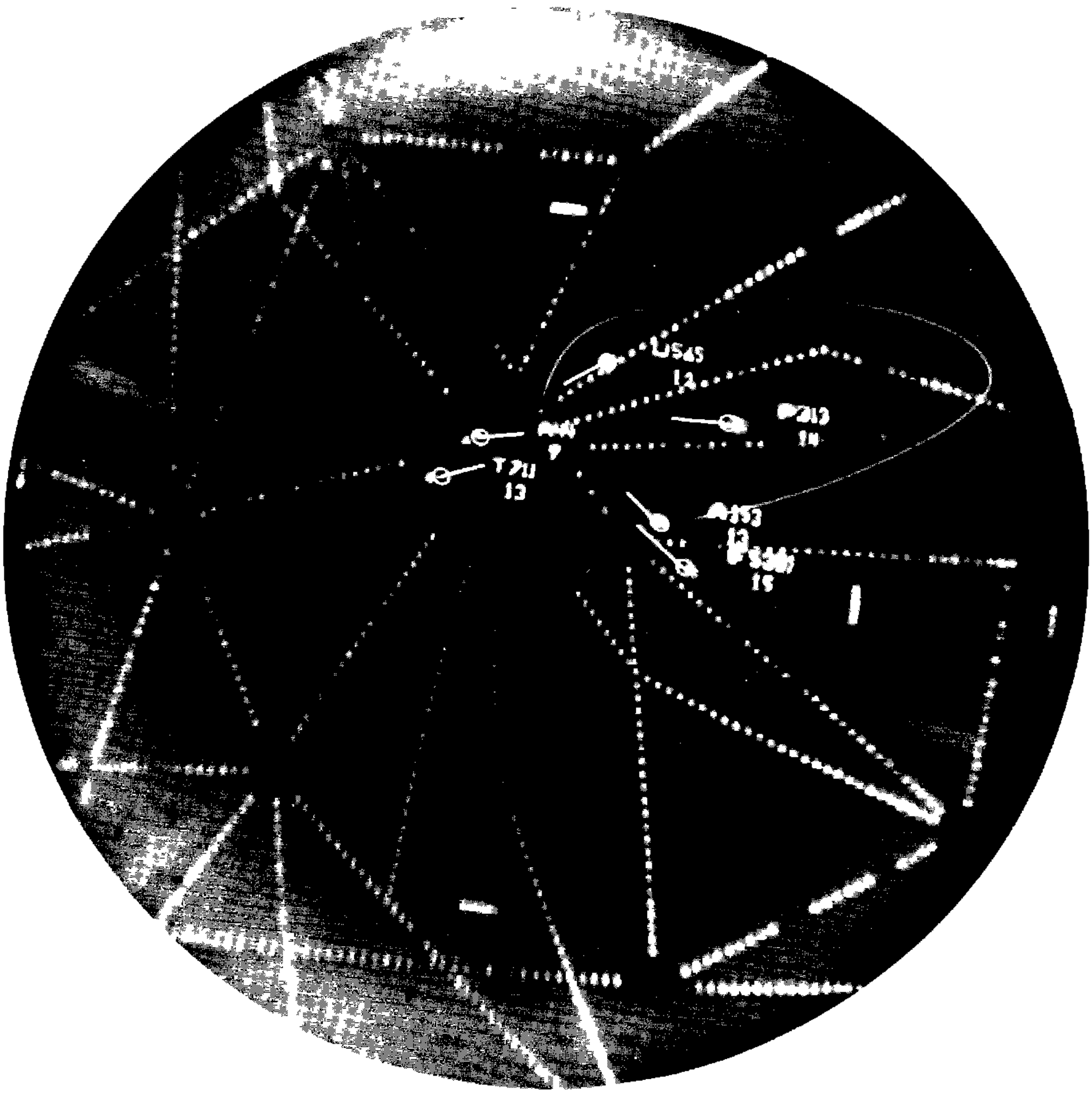

FIG 7 - SCOPE PRESENTATION SHOWING IDENTIFICATION AND ALTITUDE OF SR[illegible] BRIGHT TUBE DISPLAY

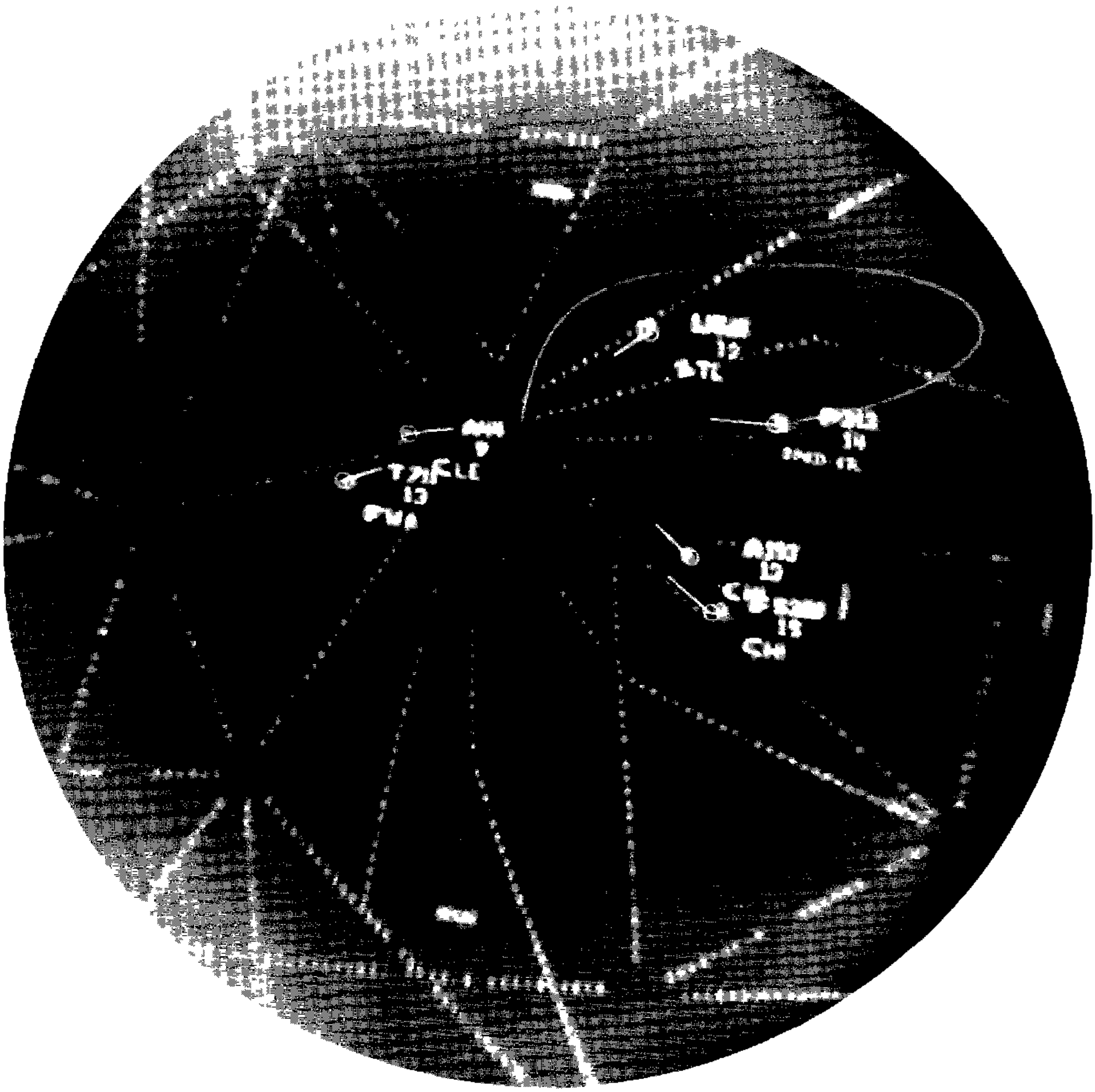

FIG 8 - SCOPE PRESENTATION SHOWING IDENTIFICATION - ALTITUDE - ROUTE INFORMATION OF SRS-1 BRIGHT TUBE DISPLAY

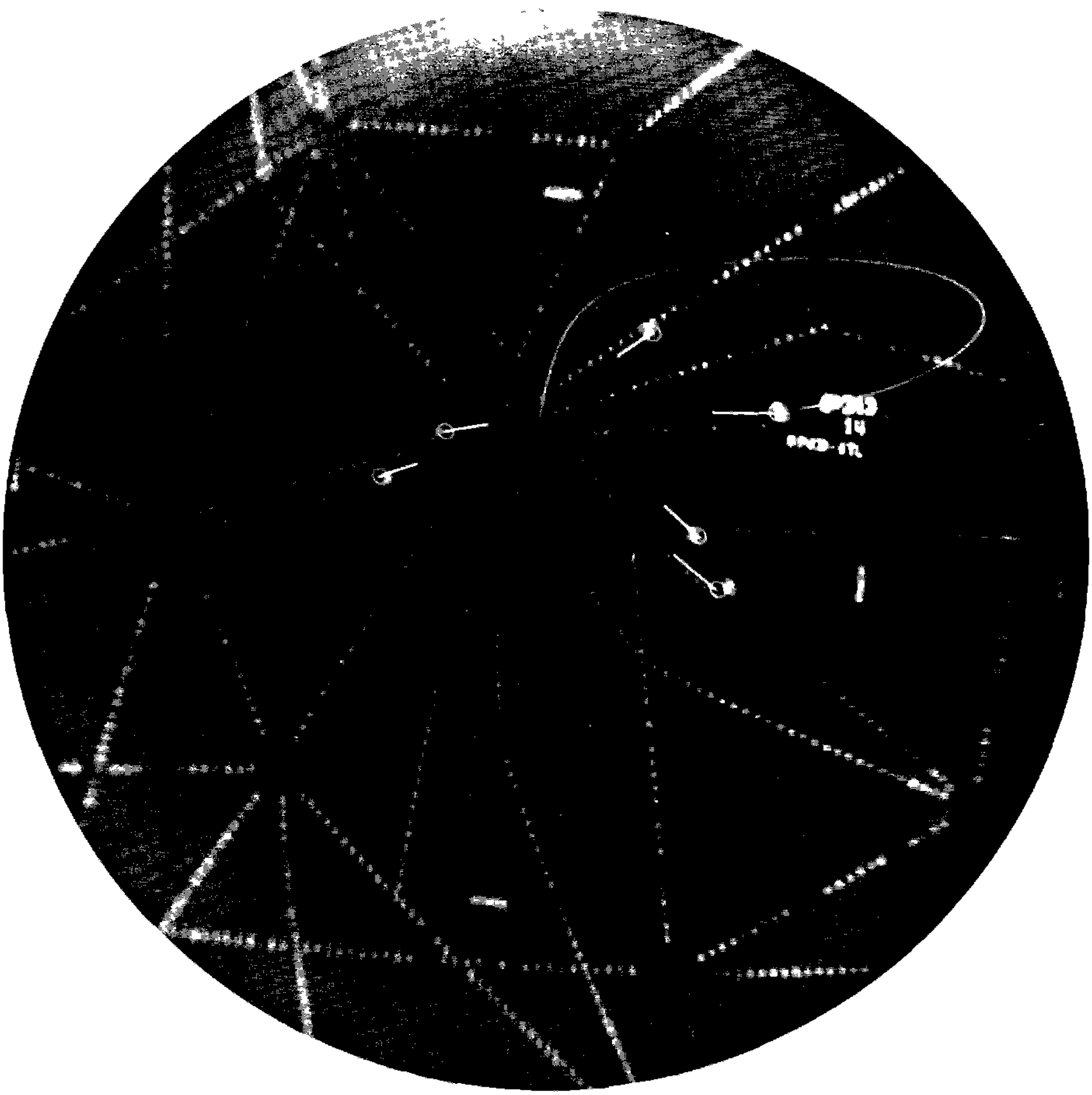

FIG. 9 - SCOPE PRESENTATION SHOWING ALPHA-NUMERIC PER SELECTED CHANNEL OF SRS-1 BRIGHT TUBE DISPLAY

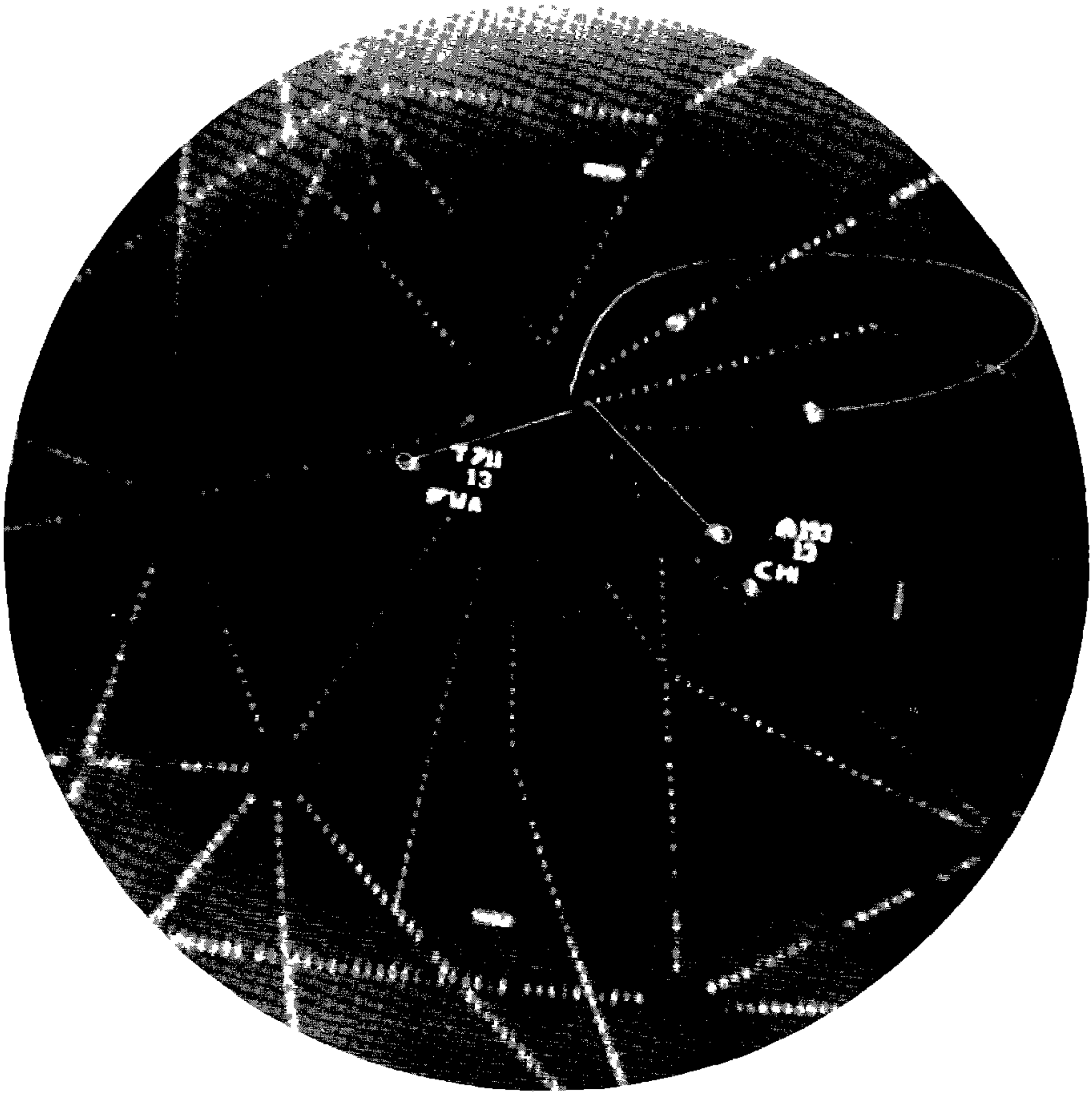

FIG 10 - SCOPE PRESENTATION SHOWING PREDICTION VECTORS WITH SELECTED ALTITUDE OF SRS-1 BRIGHT TUBE DISPLAY

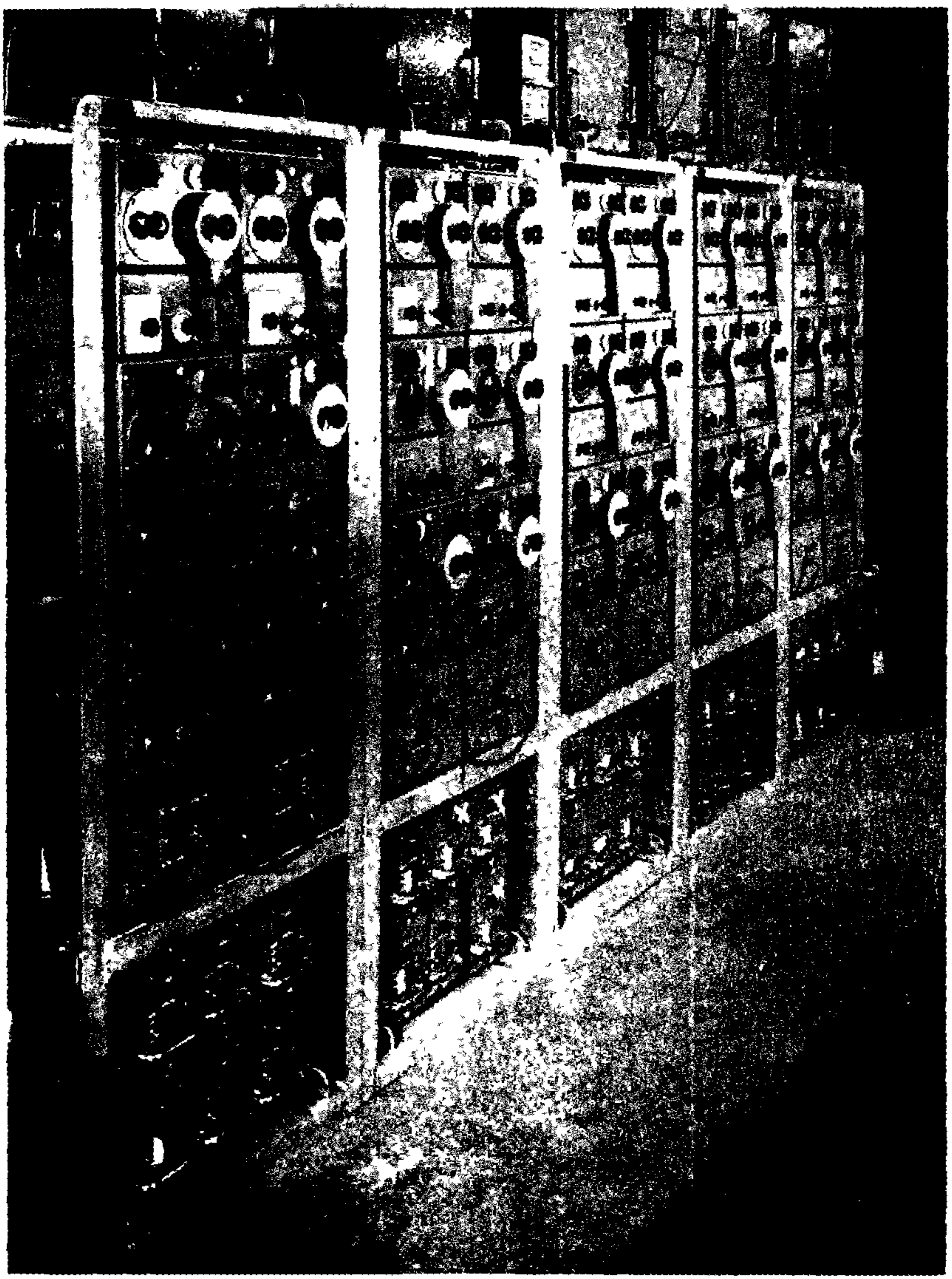

FIG. 11 - 15J1C TARGET SIMULATOR USED DURING EVALUATION OF SRS-1 FEATURES

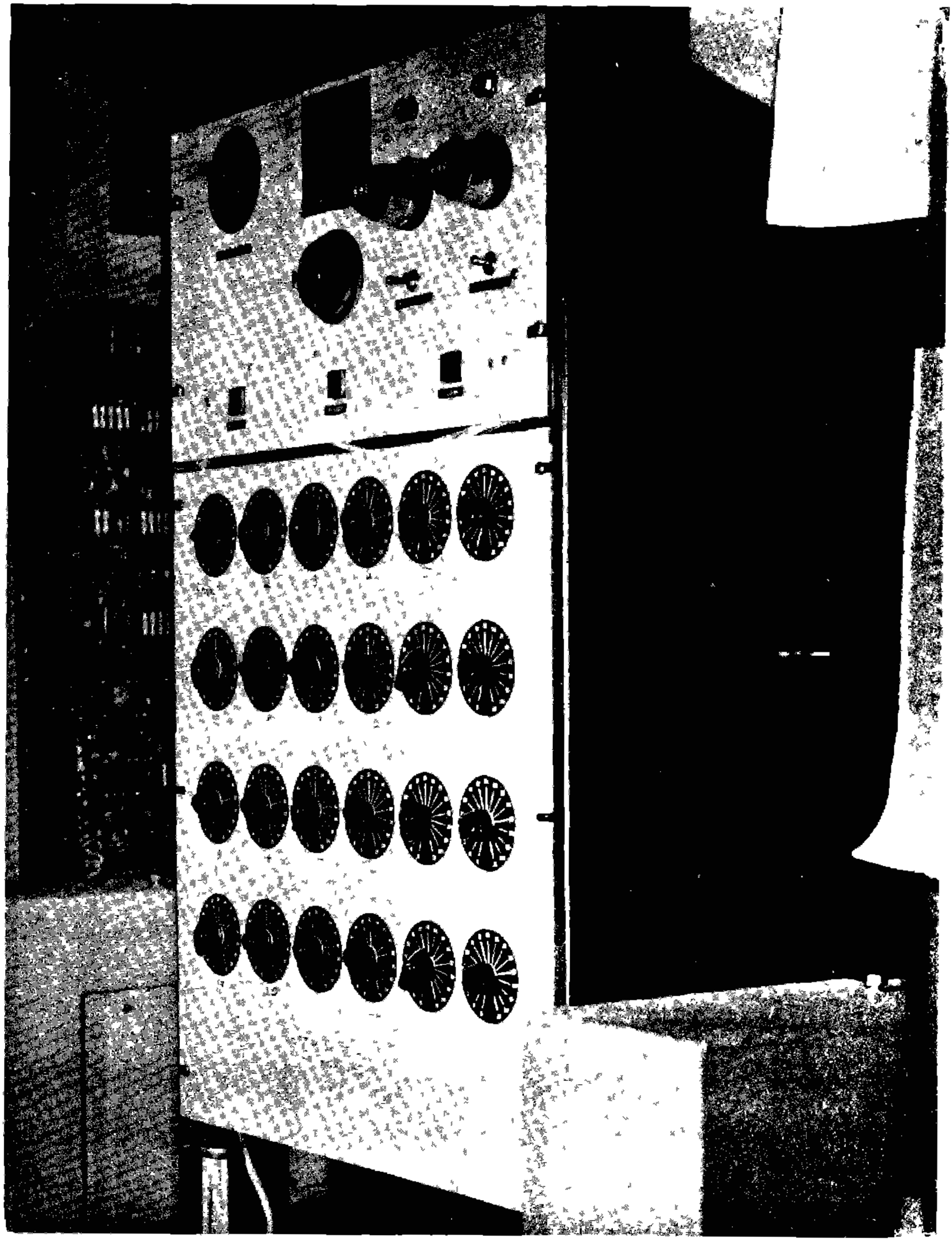

FIG. 12 - ALTITUDE AND FLIGHT PLAN ENTRY DEVICE USED DURING EVALUATION OF SRS-1 FEATURES

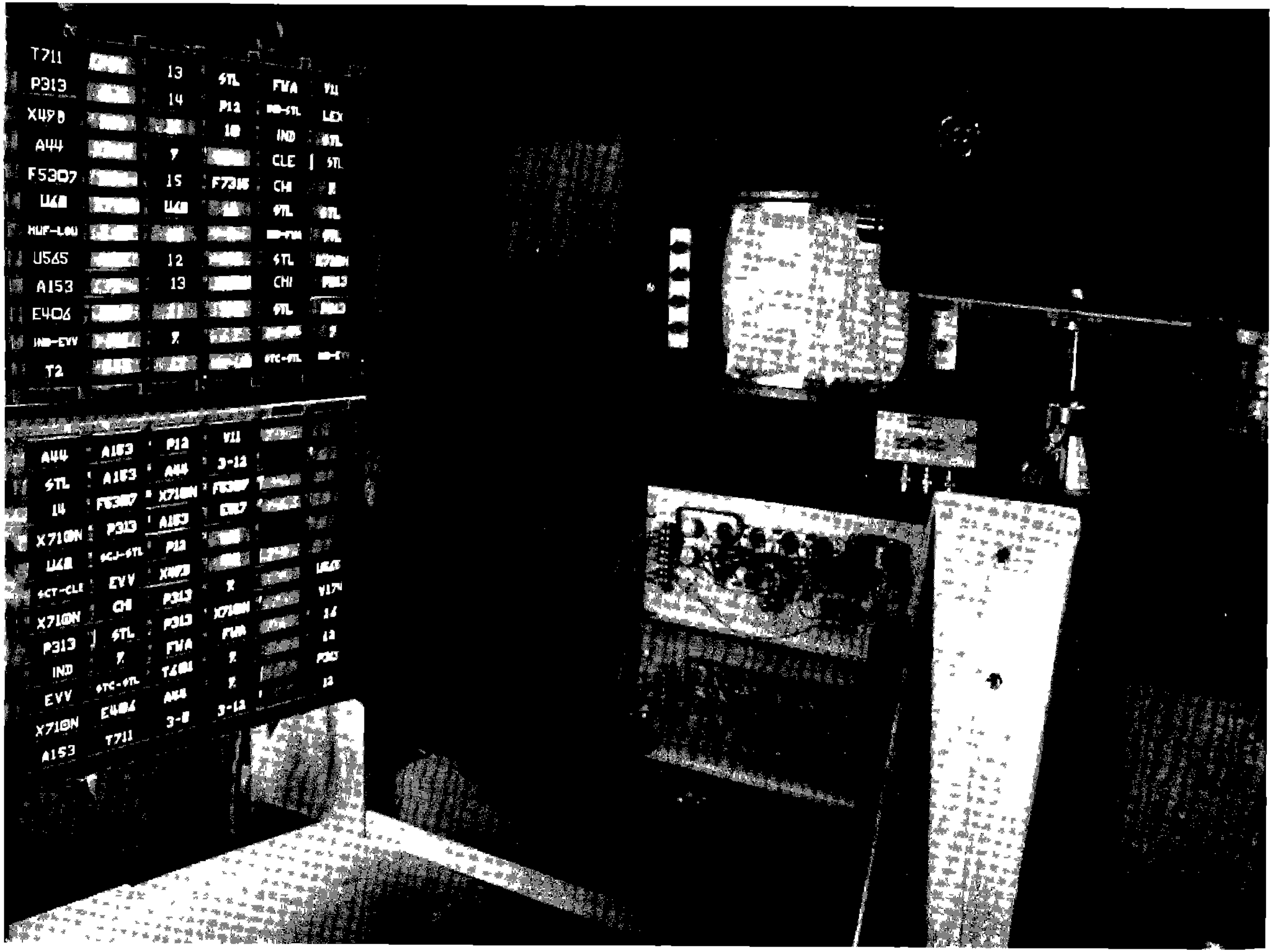

FIG. 13 ALPHA- NUMERIC ENTRY

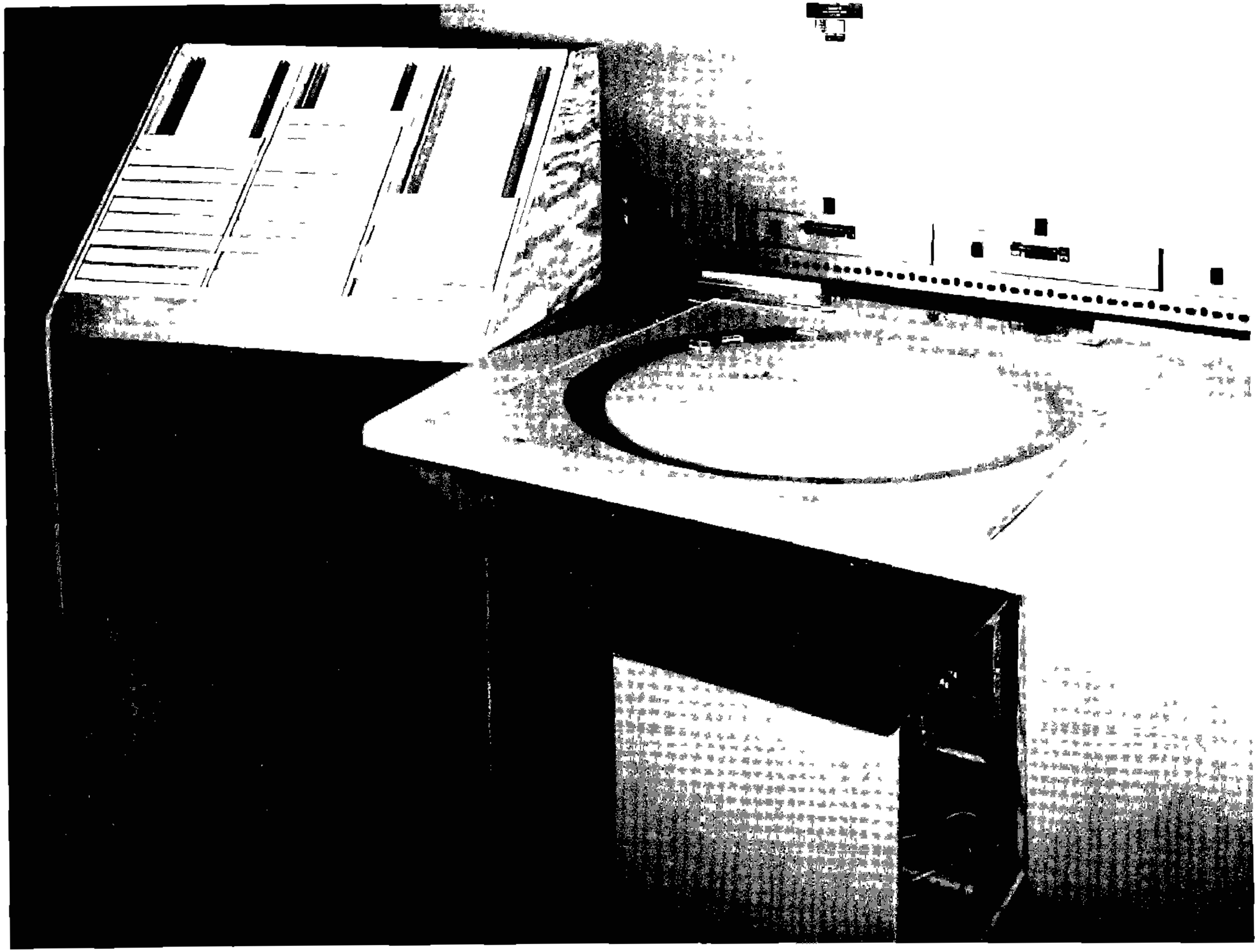

FIG 14 - SIMULATED VG - TV DISPLAY USED DURING EVALUATION OF SRS-1 FEATURES

APPENDIX A

TRACKING EXPERIMENT

STATISTICAL MEASUREMENTS, DEFINITIONS AND DATA ANALYSIS

This appendix contains the definition of measurements and basic data results obtained in the tracking experiment performed during Phase I of the test program from August 19 through August 29, 1958 Contained herein are the results of this experiment as analyzed by FIL

A Measurements - Definitions

The definitions of the measures of performance and workload made in this experiment appear below In all cases except misses and re-idents, the data were taken automatically with counters

1 Misses

The number of sweeps a tracking symbol was "off" the target Being off the target was defined as when the center of the target was not enclosed or touched by the "C" tracking symbol These data were taken by assigned observers

2 Re-idents

The number of times the tracker felt he had lost track of the target identities and would have had to call for identity turns in an operating ATC system Since alpha-numeric information was not to be associated with each tracking symbol, it was not possible to use a more objective method of recording identity confusion

3 Sequences·

The number of times the tracker pushed his sequence button This button moved the sumbol leader and control from one target to the other, so that tracking adjustments could be made In this test series, it was necessary to go through all targets in fixed order

4. Manual Actions

This was a count of all manual actions involved in tracking, with the exception of sequencing. It is the sum of the following kinds of manual action which will be further defined below

(a) Independent Symbol Repositionings.
(b) Total Course and Speed Corrections

5 Independent Symbol Repositionings

This is a count of the times symbols were repositioned without course or speed insertion

6 Total Course and Speed Corrections·

This measure is the sum of both kinds of course and speed correction, those made with the stick, and those made with the course and speed inserts.

7 Manual Course and Speed Corrections

This measure is a count of the course and/or speed corrections made using the course and speed inserts.

8 Stick Insertions of Course and Speed

This is the number of course and/or speed insertions made using the tracking stick

The basic purpose of the experiment was the comparison of the three modes of tracking. In this comparison, two essential aspects of performance were considered: tracking effectiveness, and tracker workload, or effort expenditure

In this study tracking effectiveness was evaluated by two measures

(a) The ability to effectively keep the gate symbol at the actual location of the target, which was measured by misses, as defined above, and

(b) The ability to track targets with a minimum of confusion measured by re-idents, as defined above

Tracker effort was a more nebulous criterion and was scored by two measures also

(a) The total corrective action performed to insure the positioning of the symbol with its appropriate target which was determined by total manual action measures, as defined above, and

(b) The effort which was expended to get the target-symbol pair requiring correction

This latter measure was determined by sequencing movements, as defined above

In a sense, these two criteria are functionally related in than an increase in tracking effectiveness would usually be expected to require an increase in tracker effort The optimum is to obtain maximum effectiveness in tracking with a minimum of tracker effort. The above four measures were considered the major measures of the experiment.

B Statistical Results.

While some statistically significant differences and strong tendencies to differences were shown in the major measures both with respect to comparisons and interactions, none of these were of such magnitude as to lead to an overwhelming choice of one mode (of those tested) over others It is possible that this conslusion might change if a more stringent tracking problem were used to stress the systems under test

C. Basic Data

The analysis of variance was performed for each of the eight measures The significance of the three main variables and their three first order interaction was examined Ten statistically significant results (i.e., **P** = 05 indicating results capable of being repeated at least 95 times out of 100 such experiments) were found The significance level is the probability that one will incorrectly state the difference exists, when none exists.

The significant results were

1 Modes differed in number of misses

2 Modes differed in the number of manual actions (excluding sequencing movements) they required.

3 Modes differed in total course and speed insertions or corrections.

4 Modes differed in manual course and speed insertions or corrections

5 Modes differed in course and speed insertions using the track stick.

6 Modes differed in the number of simple repositionings

7 Trackers differed in the number of re-idents they required

8. Trackers differed in the average numbers of simple repositionings they made

9 Areas differed in the re-idents required

10 There was an interaction (which is to say the result is a mutual or reciprocal action between the two variables) between modes and trackers with regard to the number of simple repositionings.

The following are summary tables for the above mentioned differences

	MODES		
NUMBER	I	II	III
Misses	6	6	12
Manual Actions	50	60	70
Total C/S	49	37	21
Manual C/S	0	1	20
Track Stick C/S	49	34	0
Simple Rep.	0	18	49

	TRACKERS A	B	C
Re-idents	3	2	3
Simple Rep.	21	16	12

	AREAS NEW YORK	CHICAGO	INDIANAPOLIS
Re-idents	2	5	2

Simple Rep TRACKER	MODE I	II	III
A	0	36	48
B	0	28	35
C	0	1	66

These data were normalized before analysis. The table entries represent the values re-transformed into their original form Therefore, the column or row averages are not necessarily the arithmetic average of the entries in the respective row or column in the basic data table following

WORK LOAD MEASUREMENTS
MINOR MEASURES

		INDEPENDENT SYMBOL REPOSITION			TOTAL COURSE OR SPEED CORRECTION			MANAUL COURSE OR SPEED INSERTION			STICK COURSE OR SPEED CORRECTION		
	MODE	I	II	III	I	II	III	I	II	III	I	II	III
	TRACKER AREA												
A	NEW YORK	12	27	35	50	43	28	0	1	28	50	42	0
A	CHICAGO	0	61	41	58	17	23	0	3	23	58	14	0
A	INDIANAPOLIS	4	26	71	57	40	10	0	3	10	57	37	0
B	NEW YORK	0	21	35	43	29	23	0	0	23	43	29	0
B	CHICAGO	0	30	35	54	27	23	0	5	23	54	22	0
B	INDIANAPOLIS	0	34	35	49	45	41	0	0	41	49	45	0
C	NEW YORK	0	1	60	45	49	13	0	0	13	45	49	0
C	CHICAGO	0	4	63	46	57	6	0	1	6	46	56	0
C	INDIANAPOLIS	0	0	76	43	27	24	0	1	24	43	26	0

WORK LOAD MEASUREMENTS
MAJOR MEASURES

		TRACKER EFFECTIVENESS						TRACKER EFFORT					
		RE IDENT			MISS			SEQUENCES			MANUAL ACTION		
	MODE	I	II	III	I	II	III	I	II	III	I	II	III
	TRACKER AREA												
A	NEW YORK	3	3	1	19	5	13	144	134	129	29	70	63
A	CHICAGO	3	6	7	10	2	13	130	155	130	58	78	64
A	INDIANAPOLIS	1	4	4	6	4	14	207	162	165	61	66	81
B	NEW YORK	2	1	3	0	8	10	168	199	141	43	50	58
B	CHICAGO	3	2	4	10	15	10	159	128	105	54	57	58
B	INDIANAPOLIS	1	1	0	0	5	5	145	179	172	49	79	76
C	NEW YORK	3	2	3	5	8	10	140	125	140	45	50	73
C	CHICAGO	5	4	12	14	15	17	158	155	148	47	61	69
C	INDIANAPOLIS	4	0	6	2	1	26	117	158	172	43	27	100

APPENDIX B

CONTROLLER CONFIGURATION

STATISTICAL MEASUREMENTS, DEFINITIONS AND DATA ANALYSIS

This appendix contains the definition of measurements and basic data results obtained in the controller configuration experiment performed during Phase I of the test program from September 8 through September 19, 1958. Contained herein are the results of this experiment as analyzed by FIL.

A. Measurements - Definitions

The measurements taken for the controller configuration test series were combined into five summary measures

1. Tracking Actions This is the sum total of all the manual actions performed by the teams in the course of each problem run These consisted of velocity correction count, and the sequence count Re-identification occasions were dropped out because of the small count However, the vectors that made up these turns were included in the vector count under control actions.

2. Control Actions This is the sum total of all the actions used to maneuver aircraft to provide separation. These consisted of vectors, altitude changes, and holds There were no holds recorded during the problem to include in this measure.

3 Conflictions. Conflicting aircraft were those having less than five miles lateral separation and within 1000 feet vertical separation. An un-coordinated crossing of sector boundaries were also considered a confliction

4. Communication count is defined as the total number of times the teams pushed the buttons on their head sets to talk during each 45 minute run.

5. Communication time is defined as the total length of time in seconds the push to talk buttons were held down by the

teams during each 45 minute run This measure included both air-ground and ground-ground communication Recording methods prevented separation of the two message types

B Statistical Results

The two controller configuration (each controller doing his own tracking) can handle the same amount of traffic more safely than the controller-remote-tracker configuration. There were more conflictions when the same problem was handled by the two-man teams arranged in the controller-remote-tracker configuration than when they were in the controller-controller configuration (each doing his own tracking)

The presence of alpha-numeric information on the scope face versus an indicator light next to the appropriate flight strip did not show a measurable difference in performance in these tests

C Basic Data

The analysis of variance was performed for each of the five summary measures and some sub-measures that were deemed important

The significance of the three main variables and their three first order interactions was examined. Seven statistically significant results were found The significance level is the probability that one will incorrectly state a difference exists, when none exists. In this report, the 05 level (capable of repeating the results at least 95 times out of 100 such experiments) was considered statistically significant and the 10 level (capable of repeating the results at least 90 times out of 100 such experiments) was considered deserving of some mention as a trend indication

The significant results were

1 Configurations differed in the average number of conflictions occurring per run

2 Configurations differed in the number of control vectors (or heading changes) given per run This is a sub-measure of control actions

3. Configurations differed in the number of tracking actions per run However, when total tracking actions is further subdivided, it is found that this difference is due only to sequencing and not to other tracking actions

4 Teams differed in the number of conflictions occuring per run

5. Teams differed in the number of communications per run.

6 There was an interaction (which is to say the result is a mutual or reciprocal action between the two variables) between configurations and alpha numeric condition with regard to frequency of communications.

7. Configurations interacted with teams with regard to the duration of communications There was some tendency for configurations to differ in the number of control actions given per run.

Configurations did not differ in communication frequency or duration None of the five summary measures showed any difference, between the operation with and without alpha numeric information

The following are a summary tables for the above mentioned differences

Number	Configuration CC*	Configuration CT*	
Conflictions	1	3	.05 level
Tracking Actions	710	858	05 level
Control Vectors	35	27	05 level
Control Actions	38	30	.10 level

	Teams #1	Teams #2	
Conflictions	1	3	05 level
Communication Count	152	103	01 level

	Configuration CC	CT	
Total Tracking Actions	710	858	05 level
Sequencing	351	446	05 level
Total T.A minus Sequencing	359	412	Not Significant

The remaining tables concern interactions

Communication Count		Configuration CC	CT	
	Alpha	110	131	.01 level
	No Alpha	155	112	

Communication Time		Configuration CC	CT	
	Team 1	514	361	01 level
	Team 2	438	440	

*CC - 2 controller configuration
*CT - Controller-tracker configuration

These data were normalized before analysis. The Table entries represent the values re-transformed into their original form. Therefore, the column or row averages are not necessarily the arithmetic average of the entries in the respective row or column in the basic data table following

BASIC DATA TABLE

CONTROL ACTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	40	40	36	16
	T_2	36	33	40	27
No Alpha	T_1	38	39	29	22
	T_2	48	32	34	36

CONTROL VECTORS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	34	36	30	15
	T_2	31	28	37	25
No Alpha	T_1	34	39	25	21
	T_2	45	31	33	27

CONFLICTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	0	0	2	1
	T_2	0	5	3	2
No Alpha	T_1	1	0	4	2
	T_2	3	2	9	7

TOTAL TRACKING ACTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	709	752	938	803
	T_2	555	669	999	787
No Alpha	T_1	688	683	904	662
	T_2	767	856	940	831

SEQUENCING

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	322	298	366	344
	T_2	294	347	524	441
No Alpha	T_1	364	293	593	319
	T_2	456	432	483	504

COMMUNICATION COUNT

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	142	146	151	156
	T_2	68	84	122	96
No Alpha	T_1	195	176	145	86
	T_2	134	116	102	116

COMMUNICATION TIME

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	497	530	373	413
	T_2	318	450	466	358
No Alpha	T_1	550	490	390	266
	T_2	525	452	405	531

CC - 2 Controller Configuration
CT - Controller - Tracker - Configuration
T - Team
R - Replications

APPENDIX C

SRS-1 TRACK STICK EXPERIMENT

STATISTICAL MEASUREMENTS, DEFINITIONS AND DATA ANALYSIS

This Appendix contains the definition of measurements, and basic data results obtained in the Track Stick Experiment performed during Phase II of the test program from November 10 through November 21, 1958 Contained herein are the results of this experiment as analyzed by FIL

A Measurement Definitions

1 Misses· The number of sweeps a tracking symbol was "off" the target Being off the target was defined as when the center of the target was not enclosed or touched by the "C" tracking symbol These data were taken by assigned observers

2 Tracking Actions

(a) Sequence Count The number of times the trackers pushed the sequence button to obtain a desired tracking channel during the 12 minute recording period

(b) Track Signal Count. The number of times the trackers pushed the track signal to reposition the symbol on the target during the 12 minute recording period

(c) Velocity Correction· The number of times the trackers pushed the velocity correction button to insert a velocity change in a tracking channel

B Statistical Results

In Experiment No 1 there was no significant difference at the 05 level (capable of repeating with the same results 95 times out of 100 such experiments) in workload or accuracy measurements However, there was a strong tendency, reliable at the 10 level (capable of repeating with the same results 90 times out of such experiments) for the force stick to have a greater number of misses In this experiment the trackers averaged 35 more misses per run with the force stick than with the position stick

In Experiment No 2 there were no significant differences However, the trackers averaged eight more misses per run with the force stick than with the position stick

Experiment No 3 was identical to Experiment No 1 with the exception of having only six runs In this experiment the trackers averaged 40 more misses per run with the force stick than with the position stick, indicating no learning factor was involved from the first experiment No significant differences were found in Experiments 2 and 3 mainly due to the limited number of runs. Th strong tendency shown in Experiment No 1 was again indicated in Experiment No 3

C Basic Data

The following were the significant results in the track stick experiments

Experiment 1.

1 Track sticks were not significantly different in velocity count, sequence count, or track signal count The miss count was not significantly different for the two sticks, although there was a strong tendency for the force stick to have a greater number of misses The difference was reliable at the 90 level of confidence (capable of repeating 90 times out of 100), not quite reaching the 95 level (capable of repeating 95 times out of 100) arbitrarily defined as establishing significance for this series of experiments

2 There were significant differences among the trackers (subjects) in the experiment in the track count, velocity count, and sequence count measures The trackers did not differ in the number of misses, however

3 The interaction of sticks and trackers was not significant

Experiment 2

In the experiment with the untrained or unpracticed trackers, no significant differences were found between sticks or trackers in any of the measures (misses, track signal, velocity count, sequences) It was not possible to make a statistical test on the interaction

Experiment 3

No differences were found significant in the third experiment which was done with the experience trackers It was not possible to make a statistical test of the significance of the interaction between sticks and trackers because of the limited number of runs

APPENDIX C
BASIC DATA TABLE

EXPERIMENT NO 1 - TRACK STICKS

MISSES

	Force Stick		Position Stick	
	R1	R2	R1	R2
Tracker 1	130	118	136	104
Tracker 2	170	198	130	160
Tracker 3	162	184	82	142

VELOCITY COUNT

	Force Stick		Position Stick	
	R1	R2	R1	R2
Tracker 1	163	137	167	174
Tracker 2	98	137	87	144
Tracker 3	138	126	116	117

TRACK COUNT

	Force Stick		Position Stick	
	R1	R2	R1	R2
Tracker 1	163	156	172	189
Tracker 2	99	139	99	163
Tracker 3	139	127	136	147

SEQUENCES

	Force Stick		Position Stick	
	R1	R2	R1	R2
Tracker 1	272	267	278	287
Tracker 2	199	191	195	175
Tracker 3	171	206	174	259

APPENDIX C
BASIC DATA TABLES

EXPERIMENT NO 2 - TRACK STICKS

	Sequences		Misses		Velocity Count		Track Count	
	Force	Position	Force	Position	Force	Position	Force	Position
Tracker 1	144	158	94	52	91	60	91	80
Tracker 2	169	140	60	78	76	38	93	105
Tracker 3	159	177	76	76	96	83	103	84

EXPERIMENT NO 3 - TRACK STICKS

	Sequences		Misses		Velocity Count		Track Count	
	Force	Position	Force	Position	Force	Position	Force	Position
Tracker 1	285	241	207	110	127	113	126	116
Tracker 2	228	284	143	122	126	101	12[illegible]	152
Tracker 3	297	295	118	115	142	141	171	153

APPENDIX D

FLIGHT PLAN TURNS AND TRIM TAB PLUS VECTORS

STATISTICAL MEASUREMENTS, DEFINITIONS AND DATA ANALYSIS

This Appendix contains the definition of measurements and basic data results obtained in the Flight Plan Turns and Trim Tab plus Vectors experiment performed during Phase II of the test program from December 1 through December 12, 1958. Contained herein are the results of this experiment as analyzed by FIL.

A Measurement Definitions

1 Misses The number of sweeps a tracking symbol ~as off the target, defined as when the center of the targe not enclosed or touched by the "C" tracking symbol These data were taken by assigned observers.

2 Reidentifications. The number of times the tracker felt he had lost track of the target identifies and would have had to call for identity turns in an operating ATC system.

3 Tracking Actions

(a) Sequence Count The number of times the trackers pushed the sequence button to obtain a desired channel during the 17 minute period.

(b) Track Signal Count The number of times the trackers pushed the track signal button to allow the track stick to reposition the symbol

(c) Velocity Correction The number of times the trackers pushed the velocity correction button to insert a velocity change in a tracking channel

(d) An additional type of measure was taken as a check on the utility of the equipment. The number of times the operator used the heading and speed features of the trim tabs was recorded Obviously this was only an observation and not as a quantitative measurement

B Statistical Results

The addition of flight plan turns significantly reduced (capable of repeating with the same results at least 95 times out of 100 such experiments) velocity count and misses Trim tabs significantly reduced (capable of repeating with the same results at least 95 times out of 100 such experiments) track count, velocity count, and sequences. The observational data on frequency of use of trim tabs indicated that the speed trim tab was used very infrequently

C. Basic Data.

The analysis of variance was performed for each of the five measures. The significance of the three main variables and their three first order interactions was examined Eleven statistically significant results were found. The significance level is the probability that one will incorrectly state a difference exists, when none exists. In this report, the 05 level (capable of the results repeating at least 95 times out of 100 such experiments) was considered statistically significant and the .10 level (capable of the results repeating at least 90 times out of 100 such experiments) was considered deserving of some mention as a trend indication. One such result was found.

The significant results were

1. Trackers differed in all the five measures taken (track count, velocity count, sequences, re-idents, and misses)

2. Flight plan turns differed in velocity count and misses

3. Trim tabs differed in track count, velocity count and sequences.

4. There was an interaction (which is to say the result is a mutual or reciprocal action between the two variables) between trim tabs and trackers with regard to sequences.

The important trend result was·

1 Flight plan turns differed in track count.

Average Number of	TRACKER 1	TRACKER 2
Track Count	113	175
Velocity Count	62	155
Sequences	180	302
Re-Idents	0	2
Misses	36	22

	FLIGHT PLAN TURNS With	FLIGHT PLAN TURNS Without	
Track Count	128	160	(Trend)
Velocity Count	98	119	
Misses	21	36	

	TRIM TABS With	TRIM TABS Without
Track Count	126	161
Velocity Count	88	128
Sequences	202	280

The remaining table concerns an interaction

		TRIM TABS With	TRIM TABS Without
Sequences	Tracker 1	154	206
	Tracker 2	248	355

BASIC DATA TABLE

		TRACK COUNT				VELOCITY COUNT			
		Flight Plan Turns		Without Flight Plan Turns		Flight Plan Turns		Without Flight Plan Turns	
		R1	R2	R1	R2	R1	R2	R1	R2
Trim Tabs + Vectors	Tracker 1	85	91	105	105	29	55	15	76
	Tracker 2	154	142	170	160	132	108	151	141
Without Trim Tabs + Vectors	Tracker 1	99	89	97	233	69	74	94	83
	Tracker 2	196	169	209	200	169	148	192	197

		SEQUENCES				RE-IDENTS			
		Flight Plan Turns		Without Flight Plan Turns		Flight Plan Turns		Without Flight Plan Turns	
		R1	R2	R1	R2	R1	R2	R1	R2
Trim Tabs + Vectors	Tracker 1	136	156	177	150	0	0	0	4
	Tracker 2	279	201	266	247	2	2	3	0
Without Trim Tabs + Vectors	Tracker 1	206	182	193	242	0	0	0	0
	Tracker 2	386	338	360	338	3	1	2	2

		MISSES			
		Flight Plan Turns		Without Flight Plan Turns	
		R1	R2	R1	R2
Trim Tabs + Vectors	Tracker 1	35	26	52	24
	Tracker 2	8	12	25	33
Without Trim Tabs + Vectors	Tracker 1	30	24	50	43
	Tracker 2	14	18	32	32

APPENDIX E

SIMULATED VG TYPE DISPLAY VERSUS SRS-1

STATISTICAL MEASUREMENTS, DEFINITIONS AND DATA ANALYSIS

This Appendix contains the definitions of measurements and basic data results obtained in the simulated VG type Display versus SRS-1 experiment performed during Phase II of the test program from January 5 through January 16, 1959 Contained herein are the results of this experiment as analyzed by FIL

A Measurement Definitions

1 Flight maneuvers imposed on aircraft by ATC A count was made of controller vectors given for re-identification, separation, or return to airways

2 Altitude changes imposed by ATC Pilot requested altitude changes were not included

3 Conflictions occurring were counted A confliction was defined here as any case in which two or more aircraft were within 1000 feet vertical separation and at less than five miles lateral separation

4 Aircraft off airways instances were counted It was considered the controller's responsibility to warn aircraft when they were drifting off airway boundaries defined as seven miles on either side of the centerline Instances when aircraft drifted outside of these limits were tallied

5 Communication Count Defined as the total number of times the controllers pushed the microphone button to talk during each 45 minute run

6 Communication Time Defined as the total length of time in seconds the microphone buttons were held down by the controllers during each 45 minute run This measure included both air-ground and simulated ground/ground communications to adjacent centers and towers

B Statistical Results

There were significant differences between the SRS and VG type systems in the following measurements

1 The number of altitude changes imposed by ATC per run averaged eight when the VG system was in use, and four when the SRS system was being used

2 The number of aircraft allowed by controllers to drift off airways When using the VG system, these averaged two aircraft per run This average was four per run in the case of the SRS system

3 Communication was less frequent with the SRS system Communications averaged 114 per run with the SRS system as compared with 130 with the VG system There was no significant difference in the number of conflictions The SRS averaged 2 6 conflictions per run, while the VG system averaged 3 1 conflictions per run It was noted that some controllers were better able to work safely with one system, while others were better able to work safely with the other For example, Controller 1 averaged four conflictions with both systems, Controller 2 averaged two conflictions with the VG, four with the SRS, Controller 3 averaged three conflictions with the VG system and one with the SRS system

C Basic Data

The analysis of variance was performed for each of the six measures as follows

Number of conflictions
Altitude changes imposed by ATC
Vectors imposed by ATC
Message frequency
Message time duration per run
Number of aircraft not redirected to airways

The experimental design allowed the testing of the statistical significance of the following factors:

Differences between the SRS and VG
Differences between controllers

Interactions between controllers and scope (i e SRS and VG)
Interactions between controllers and problems
Interactions between scopes and problems

The fact that the experimental design allowed the testing of these factors for such of the five variables listed above meant that the total number of hypotheses which could be examined was 30

Of the 30 significance tests made, 11 were significant at the 95 per cent level of confidence The significant results were as follows:

SRS and VG differed in

Altitude changes
Number of aircraft off airways
Message frequency

Controllers differed in

Conflictions
Number of aircraft off airways.
Message frequency

Problems differed in.

Vectors imposed
Altitude changes
Number of aircraft off airways

There were significant interactions between

Controllers and scopes in number conflictions
Scopes and problems in number aircraft off airways.

There was a tendency for the interaction between scopes and problems to be significant with regard to conflicts

Observations of "hold" or delays to aircraft were made, but these occurred so infrequently that an analysis was not made Note: Identity confusions were also so infrequent as to prevent analysis Note: The three kinds of vectors were combined The significant results are presented in tabular form below:

	SRS	VG
Altitude Changes	4	8
Number Aircraft off airways	4	2
Message Frequency	114	130

	CONTROLLER		
	1	2	3
Conflictions	4	3	2
Number Aircraft off airways	2	2	3
Message Frequency	112	150	104

	PROBLEMS	
	1	2
Vectors Imposed	20	28
Altitude Changed	7	5
Number Aircraft off airways	2	3

SIGNIFICANT INTERACTIONS

Controllers and Scopes in Conflictions		SRS	VG	Av
	1	4	4	4 (3 9)
	2	4	2	3 (2 9)
	3	1	3	2 (1 9)
	Av	3 (3 1)	3 (2 6)	

Scopes and Problems In Number of Aircraft off Airways		SRS			VG			
		C_1	C_2	C_3	C_1	C_2	C_3	
	Problem 1	3	2	5	1	0	2	2
		C_1	C_2	C_3	C_1	C_2	C_3	
	Problem 2	3	4	4	2	2	3	3

WORKING PAPERS ON THE FAA SRS-1 PROJECT

Appendix 1 to DR 414

May 5, 1959

Performed Under

Contracts C13ca-607 and C13ca-685
with FAA Technical Development Center

51

THE FRANKLIN INSTITUTE

LABORATORIES FOR RESEARCH AND DEVELOPMENT

PHILADELPHIA PENNSYLVANIA

WORKING PAPERS ON THE FAA SRS-1 PROJECT

May 5, 1959

Performed under

Contracts C13ca-607 and C13ca-685
with FAA Technical Development Center

FOREWORD

The following six working papers are the reports made by the Franklin Institute Laboratories to the SRS-1 project working group of the Technical Development Center, Federal Aviation Agnecy, Indianapolis, Ind.

It was the function of the Franklin Institute Laboratories' personnel to serve as consultants concerning the statistical design and analysis of experiments for the SRS-1 project. A summary report of the project is being prepared and published by FAA. With TDC cooperation, these working papers are being published so as to be available for those readers who wish greater detail about the statistical aspects of the project than could be conveniently included in the TDC summary report.

Those listed below wish to extend their appreciation to Mr. Fred Pickett, Mr. Fred McKnight, and Mr. Robert Sorenson of FAA, for their excellent teamwork with FIL during the project. We feel that a good deal was accomplished by the project within the prevailing time and equipment limitations.

E. P. Buckley
F. X. McLaughlin
J. H. Brinton

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PRELIMINARY EVALUATION OF THE APPLICATION OF SRS EQUIPMENT AS A COMMON SYSTEM AIR TRAFFIC CONTROL AID

Phase 1

Tracking Experiment

by

E. P. Buckley
F. X. McLaughlin
J. H. Brinton

Working Paper No. 2 (Project A-2052)

(Under Contract No. C13ca-607 with)
(CAA Technical Development Center)

October 15, 1958

WORKING PAPER

<u>NOT AN OFFICIAL MEMO OR REPORT</u>

INTRODUCTION

The SRS equipment was developed by Airborne Instruments Laboratory for the Army Signal Corps SRS is an electronic system which enables an operator to position a tracking symbol or gate over radar targets. The basic control is the tracking stick through which the operator repositions the symbol. When he does this the machine automatically computes a new velocity vector that can be inserted in the tracking channel by pressing a button. Thus, once the gate has been placed on a target and the correct velocity inserted, it will stay with the target unless an abrupt change of course is made by the target. Manual velocity and course corrections may be made in a computer which is part of the system. In addition to rate-aided tracking, automatic tracking is available. It was felt by interested people that it would have some value in air traffic control. From this developed a TDC project to evaluate the equipment for possible application to air traffic control.

The evaluation tests are being conducted by the Technical Development Center, assisted by Franklin Institute Laboratories personnel, at AIL, Mineola, L. I. This report covers the first phase of the evaluation, the tracking experiment.

PURPOSE

The general purpose of the tracking phase was to examine the accuracy and reliability with which typical air traffic control personnel could track a sample of simulated aircraft using different modes of operation of the SRS equipment.

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METHOD AND PROCEDURES

The variables that were included in this phase are as follows:

(1) Trackers

(2) Area maps (Indianapolis, New York, and Chicago). An appropriate traffic sample of the same size was used in each area. Each area map was a separate problem in itself. That is, the simulated traffic on the Indianapolis map was intended to represent a typical overflight problem area. New York was an outbound problem and Chicago an arrival problem.

(3) Modes of operation. The 3 modes were as follows:

(a) Mode 1 - The tracker repositions the gate symbol with a position stick and the machine automatically computes speed and course. The tracker never uses course and speed inserts of any type.

(b) Mode 2 - The tracker repositions the gate symbol with the stick and the machine computes course and speed, or the tracker may use the "new" type course and speed inserts to set these data into the machine.

(c) Mode 3 - The tracker uses the stick for repositioning only and he uses the "new" course and speed inserts to put speed and course into the system. The machine does not compute course and speed.

Three levels of the three variables yielded 27 combinations of conditions, each one of which was run once in random order in a factorial design as sketched below:

OPERATOR	MODE I	MODE II	MODE III	AREA
A B C				1
A B C				2
A B C				3

The two consoles were rendered approximately comparable equipment-wise by covering over certain features unique to each console. The experiment was done with live and simulated radar mixed. This is advantageous in that tracking is done in realistic clutter. A disadvantage is that the clutter varies from time to time or day to day and thus leads to less stable data. Except for this instability of the data this situation may not seriously affect the interpretation of the data since the sequence of runs is randomized.

The subjects were 3 radar controllers, one from N Y., one from Indianapolis, and one from Chicago. They had extensive practice with the equipment before the experiment started. The subjects were aware of the purpose of the experiment and the fact that the same three traffic samples would be used throughout the experiment.

DEFINITIONS OF MEASURES TAKEN

The definitions of the measures of performance and workload made in this experiment appear below. In all cases except misses and re-idents, the data were taken automatically with counters.

1. Misses:

   The number of sweeps a tracking symbol was "off" the target. Being off the target was defined as when the center of the target was not enclosed or touched by the "C" tracking symbol. These data were taken by randomly assigned observers.

2. Re-idents:

   The number of times the tracker felt he had lost track of the target identities and would have had to call for identity turns in an operating ATC system. Since alpha-numeric information was not to be associated with each tracking symbol, it was not possible to use a more objective method of recording identity confusion.

3. Sequences:

   The number of times the tracker pushed his sequence button. This button moved the symbol leader and control from one target to the other, so that tracking adjustments could be made. It was necessary to go through all targets in fixed order.

4. Manual actions:

This was a count of all manual actions involved in tracking, with the exception of sequencing. It is the sum of the following kinds of manual action which will be further defined below:

(a) Independent Symbol Repositionings

(b) Total Course and Speed Corrections

5. Total Course and Speed Corrections

This measure is the sum of both kinds of course and speed correction; those made with the stick, and those made with the course and speed inserts.

6. Manual Course and Speed Corrections

This measure is a count of the course and/or speed corrections made using the course and speed inserts.

7. Stick insertions of Course and Speed

This is the number of course and/or speed insertions made using the tracking stick.

8. Independent Symbol Repositionings:

This is a count of the times symbols were repositioned without course or speed insertion.

RESULTS

The basic data appear in Appendix A.

The analysis of variance was performed for each of the eight measures. The significance of the 3 main variables and their three first order interaction was examined. Ten statistically significant results (i.e., P = .05 or less) were found. The significance level is the probability that one will incorrectly state that a difference exists, when none exists.

The significant results were:

1. Modes differed in number of misses.
2. Modes differed in the number of manual actions (excluding sequencing movements) they required.
3. Modes differed in total course and speed insertions or corrections
4. Modes differed in manual course and speed insertions or corrections
5. Modes differed in course and speed insertions using the track stick.
6. Modes differed in the number of simple repositionings
7. Trackers differed in the number of re-idents they required
8. Trackers differed in the average numbers of simple repositionings they made.
9. Areas differed in the re-idents required.
10. There was an interaction (which is to say the result is a mutual or reciprocal action between the two variables) between modes and trackers with regard to the number of simple repositionings.

The following are summary tables for the above mentioned differences

NUMBER	MODES I	II	III
Misses	6	6	12
Manual Actions	50	60	70
Total C/S	49	37	21
Manual C/S	0	1	20
Track Stick C/S	49	34	0
Simple Rep.	0	18	49

	TRACKERS A	B	C
Re-idents	3	2	3
Simple Rep	21	16	12

	AREAS NEW YORK	CHICAGO	INDIANAPOLIS
Re-idents	2	5	2

	TRACKER	MODE I	II	III
Simple Rep.	A	0	36	48
	B	0	28	35
	C	0	1	66

These data were normalized before analysis. The table entries represent the values re-transformed into their original form. Therefore the column or row averages are not necessarily the arithmetic average of the entries in the respective row or column in the basic data table in Appendix A.

There were 5 results which approached statistical significance and should be mentioned in this report to show additional tendencies noticed in the data:

(1) The three map areas differed in the number of tracking symbol misses.

(2) The trackers and modes showed some interaction when related to the number of tracking symbol misses.

(3) The three map areas again showed some differences when related to the numbers of sequencing actions.

(4) With regard to manual actions, trackers and modes showed some interaction.

(5) When related to independent symbol repositioning, modes and areas showed some interaction.

INTERPRETATION OF RESULTS

The basic purpose of the experiment was the comparison of the three modes of tracking. In this comparison, two essential aspects of performance were considered: tracking effectiveness and tracker workload or effort expenditure.

In this study tracking effectiveness was evaluated by two measures:

(a) the ability to effectively keep the gate symbol at the actual location of the target, which was measured by misses, as defined above, and

(b) the ability to track targets with a minimum of confusion measured by re-idents, as defined above.

Controller effort was a more nebulous criterion and was scored by two measures also:

(a) the total corrective action performed to insure the positioning of the symbol with its appropriate target which was determined by total manual action measures, as defined above, and

(b) the effort which was expended to get to the target - symbol pair requiring correction. This latter measure was determined by sequencing movements, as defined above.

In a sense these two criteria are functionally related in that an increase in tracking effectiveness requires an increase in controller effort. We would like to obtain maximum effectiveness in tracking with a minimum of tracker effort.

MODES

Considering the comparison of modes in terms of the variables above, some differences of statistical significance were shown. As shown above, there were different average numbers of misses per run with the three different modes. (Mode I, 6: Mode 2, 6; Mode 3, 12). In interpreting this result it must be remembered that a difference of 6 misses while statistically significant, possesses little practical significance. Every target during every scan of the test run represented an opportunity for the scoring of a miss. Since there were approximately ten targets on the scope at all times and since the test run lasted for approximately 50 scans, there were therefore 500 opportunities for scoring a miss in each test run. Considering this fact, a difference of 6 misses per test run does not seem of such a magnitude as to represent a criterion for choice between modes.

There were no differences or tendencies toward differences between modes in the number of re-identifications required or in the number of sequencing actions required. The numbers of manual actions other than sequences required were different as follows: (I, 50; II, 60, III, 70). The maximum difference shown here is again relatively slight, being of the order of twenty manual actions of very short duration.

In general, therefore, it appears that, in terms of the measures of major importance taken in this experiment, there were no differences shown between modes. It is possible that the differences between modes may not be completely shown here because, contrary to the experimenter's expectations, the problem given the subjects for tracking turned out to be a rather easy one. It is possible that if these modes were compared under conditions more stressful for the systems, greater differences would appear. Another aspect of the situation is that the use of background live radar probably increased the variability of the data, thus making it more difficult to detect differences.

TRACKERS

A significant difference was found between the three trackers with

TRACKERS (continued)

regard to only one of the four major measures, the number of re-identifications required. This difference, while statistically significant, amounted to an average value of only one re-identification per run.

GEOGRAPHICAL AREAS

There was a statistically significant difference in the number of re-identifications required; New York and Indianapolis required an average of 2 per run, while Chicago required an average of 3 per run. This difference may be due to the airway configurations, the specific samples used for the areas, or the superimposition of live radar. The traffic load was roughly comparable in all 3 areas, however. While these measures are statistically important, the practical significance of the difference appears to be trivial.

INTERACTIONS

There was a tendency toward interaction between trackers and modes on two of the four major measures, misses and total manual actions. This means that some trackers tended to make more misses in some modes than in others and to execute more manual actions in some modes than in others.

No tendencies toward interaction were shown in the four major measures between modes and areas, or between trackers and areas.

SUMMARY OF MAJOR MEASURES

While some statistically significant differences and strong tendencies were shown in the major measures both with respect to comparisons and interactions, it seems clear that none of these were of such a magnitude as to lead to an overwhelming choice of one mode (of those tested) over others. It is possible that this conclusion might change if a more stringent tracking problem were used to stress the systems under test.

MINOR MEASURES

There were several subsidiary measures made which might lead us to better understand the operations involved in the tracking situation. What these measures do is enable us to subdivide the manual actions into its component parts: symbol reposition, use of course and speed inserts, and course and speed insertion by the track stick. From the mode definitions it is obvious that the differences between the modes should be significant for these three measures. However, if one examines the data as a totality certain inferences can be made about the tracking modes. (Refer to P. 7 for summary tables for the following analysis.)

We have seen above that the modes are approximately equal in tracking effectiveness and in controller workload, as measured here by total manual actions. We notice, however, that in Mode II where the trackers were given the opportunity to use either the manual course and speed inserts or the velocity stick, they predominantly used the tracking stick

(34 times vs once were the average figures). Except, therefore, in Mode III where its use was mandatory, the manual course and speed inserts were hardly used; i.e., an average of once or less per run.

On the other hand, we may examine the use of the stick for making course and speed insertions and for simple repositioning. In Mode III for instance, we see that the stick was used 49 times for simple repositioning. By the definition of the mode, the use of the stick was restricted to this purpose. The stick was also used 49 times in Mode I, but by definition of the mode it could not be used for simple repositioning. This is approximately 15 more times than it was used in Mode II (34) where the simple repositioning option was available. This difference is probably due to the fact that there are times when a simple repositioning action without a course and speed correction is desirable.

It would appear, therefore, that manual course and speed inserts would remain relatively unused in a system and that the provision of a simple repositioning option would be desirable. However, it might be well to provide a comparatively simple manual course and speed insert to take care of occasional sharp turns and similar occurrences.

WORK LOAD MEASUREMENTS

MAJOR MEASURES

		TRACKER EFFECTIVENESS						TRACKER EFFORT					
		RE IDENT			MISS			SEQUENCES			MANUAL ACTION		
TRACKER AREA	MODE	I	II	III	I	II	III	I	II	III	I	II	III
A	NEW YORK	3	3	1	19	5	13	144	134	129	29	70	63
	CHICAGO	3	6	7	10	2	13	130	155	130	58	78	64
	INDIANAPOLIS	1	4	4	6	4	14	207	162	165	61	66	81
B	NEW YORK	2	1	3	0	8	10	168	199	141	43	50	58
	CHICAGO	3	2	4	10	15	10	159	128	105	54	57	58
	INDIANAPOLIS	1	1	0	0	5	5	145	179	172	49	79	76
C	NEW YORK	3	2	3	5	8	10	140	125	140	45	50	73
	CHICAGO	5	4	12	14	15	17	158	155	148	47	61	69
	INDIANAPOLIS	4	0	6	2	1	26	117	158	172	43	27	100

WORK LOAD MEASUREMENTS

MINOR MEASURES

TRACKER AREA		INDEPENDENT SYMBOL REPOSITION			TOTAL COURSE OR SPEED CORRECTION			MANAUL COURSE OR SPEED INSERTION			STICK COURSE OR SPEED CORRECTION		
	MODE	I	II	III	I	II	III	I	II	III	I	II	III
A	NEW YORK	12	27	35	50	43	28	0	1	28	50	42	0
	CHICAGO	0	61	41	58	17	23	0	3	23	58	14	0
	INDIANAPOLIS	4	26	71	57	40	10	0	3	10	57	37	0
B	NEW YORK	0	21	35	43	29	23	0	0	23	43	29	0
	CHICAGO	0	30	35	54	27	23	0	5	23	54	22	0
	INDIANAPOLIS	0	34	35	49	45	41	0	0	41	49	45	0
C	NEW YORK	0	1	60	45	49	13	0	0	13	45	49	0
	CHICAGO	0	4	63	46	57	6	0	1	6	46	56	0
	INDIANAPOLIS	0	0	76	43	27	24	0	1	24	43	26	0

SECTION II

PRELIMINARY EVALUATION OF THE APPLICATION OF SRS EQUIPMENT AS A COMMON SYSTEM AIR TRAFFIC CONTROL AID. Configuration Experiment

THE FRANKLIN INSTITUTE
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Aeronautics Branch

PRELIMINARY EVALUATION OF THE APPLICATION OF SRS EQUIPMENT AS A COMMON SYSTEM AIR TRAFFIC CONTROL AID

Phase 2

Configuration Experiment

by

E. P. Buckley
F. X. McLaughlin
J. H. Brinton

Working Paper No. 1 (Project A-2221)

(Under Contract No. C13ca-685 with)
(CAA Technical Development Center)

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WORKING PAPER

NOT AN OFFICIAL MEMO OR REPORT

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INTRODUCTION

This report concerns the second in a series of experiments studying the values of semi-automatic radar tracking systems in air-traffic-control. A modified SRS-1 system built by Airborne Instruments Laboratories for the Army Signal Corps was used in this study. The SRS-1 system is an electronic rate-aided tracking system which enables an operator to maintain the position of a tracking symbol or gate over selected radar targets. The basic controls are a tracking stick by which the operator positions the symbol and a velocity control by which the operator controls the rate of symbol movement. Once the gate has been placed on a target and the correct velocity vector inserted, the gate will stay with the target unless an abrupt change in heading and/or speed is made by the target. Corrections to the velocity vector may be made manually by means of course and speed dial inserts or semi-automatically by the systems computer from the tracking symbol's displacement. In addition to the semi-automatic or rate-aided tracking mode, automatic or track-while-scan tracking can be performed.

A major benefit derived from this equipment is the creation of displays in which alphanumeric information is associated with particular radar signals. This means that information such as identity, altitude, destination, etc. can be displayed adjacent to the radar return of the appropriate aircraft.

PURPOSE

The first experiment of this program studied the various modes or methods of using the equipment to track targets. The major interest was the accuracy with which the tracking symbol could be maintained over the appropriate target. In the present experiment the interest shifted to the actual control of aircraft.

Two points of interest were investigated. The first question studied was the effect on air traffic control performance of associating alphanumeric information with each of the radar targets over which the controller exercised authority. Target identity and some altitude information were displayed on the scope with the target; while flight progress strips, containing additional information, were available in a bay adjacent to the radar display. The appropriate flight strip was indicated by a light next to the strip which was illuminated when the controller was leadered to the corresponding tracking symbol. The above outlined situation was contrasted with that in which no alphanumeric data were displayed on the scope. It should be carefully noted that, even under these latter conditions, the controller was better informed of aircraft identity than with the use of raw radar alone, since the flight strip associated with a particular symbol-target pair could be located easily. It should be realized, therefore that a major advantage of the tracking system existed even in the mode without alphanumeric data display.

The second question investigated was manpower utilization in a system composed of the same general type of equipment as the SRS system. Systems of this type are particularly well adapted to remote tracking; i.e., a system in which the tracking task is done by another member of the system and the controller is only concerned with the control of the aircraft. This configuration of personnel, it would certainly seem, would lessen the controller's workload considerably and enable him to control more aircraft at the same level of effectiveness.

There is another aspect of this idea to be considered, however, and that is the investment of manpower involved. To add one tracker for every controller would mean about twice as many people in the system, even though both types would not, in all probability, have to be of the same training and skill level.

Consequently, there were two questions which could be put to the test here:

1. How much is controller effectiveness improved by the addition of a tracker?

2. Given the same number of personnel for the system, how should the tracking and control functions be allotted?

The choice made here was to investigate the second of the above questions. The alternatives studied were parallel versus serial operation for the functions of controlling and tracking; i.e., in one case a system was visualized in which all controllers did their own tracking; and, in the other case, a system was visualized in which half the personnel in the system performed the tracking function and the other half performed the controlling function. As the problem is defined here, in both cases the number of personnel involved in the system is the same.

The two questions listed above are very easily confused, and since the conclusions with regard to the desirability of remote tracking are likely to be different depending on which question is involved, the distinction should be kept in mind.

In sum, four conditions were studied in the experiment:

1. Scope alphanumeric information available - controllers acting as own trackers.

2. Scope alphanumeric information available - controllers not acting as trackers, remote trackers provided.

3. No scope alphanumeric information available - controllers acting as own trackers.

4. No scope alphanumeric information available - controllers not acting as trackers, remote trackers provided.

The manpower utilization question was tested in the following manner. Two teams, of two men each, were established in the two manpower configurations of the study. The two men in each team were assigned to different tasks. Given the same geographical area, in one case the controller controlled all of the aircraft and the tracker tracked all the aircraft; while in the other configuration each of the two controllers was responsible for all tracking and all control in only one half of the geographical area. Thus, the airspace and the number of aircraft covered and the number of personnel used remained the same while the manner in which the personnel were assigned to tasks was the variable factor in the situation.

In the case of the alphanumeric variable, the two conditions contrasted were the availability and non-availability of video-displayed alphanumeric information. The alphanumeric information involved was the identity, assigned final cruising altitude of the departing aircraft, and current altitude of the aircraft posted in 2,000 foot increments. The controller had access to this alphanumeric information on every target, but he was not required to have it displayed at all times. Normally all tracking video data were presented but the controller could temporarily blank all formats, except the one connected with a selected tracking channel, by depressing a switch on top of the track stick.

PROCEDURE

The experiment was performed at Airborne Instrument Laboratories, Mineola, L. I., where the SRS equipment is located. Two consoles were used in the experiment, which may be designated as the C_S and C_1 consoles. The consoles were generally comparable. Both consoles had bright display tube scopes, and an adjoining bay of flight strips.

For simulation of aircraft, twenty 15-J-1C simulators were used. The alphanumeric information was produced on the scopes by means of a television camera and a board on which aircraft identities and other information was posted. A video mapper was used to display the New York outbound airway structure on each scope. The simulated problem was superimposed upon a live radar picture of the New York area. This procedure introduced a large and varying number of 'VFR' aircraft into the problem and also variable amounts of radar clutter.

The traffic load consisted of an average of fifteen aircraft simultaneously displayed on the scope. The problem concerned departures climbing out of the New York area. The departure rate was 42 aircraft an hour with six overflight aircraft crossing the departure routes. The New York area map was divided into a North and South sector. Each of the sectors averaged seven to eight targets at a time. The New York area map was rotated ninety degrees meaning that the airways ran north and south instead of east and west. This was done to lessen the mutual interference among various targets' alphanumeric information. Rotating the map resulted in less interference because the alphanumeric data ran from left to right on the scope face and, in the case of the rotated map, it appeared off to the side of the airways and not on them, as would have been the case if the airways had run east-west. In an operational system of this type, such interference would not be a problem since arrangements for displacement of the alphanumeric symbols would be readily available.

There was a total of sixteen 45 minute runs. Each of the permanent two controller teams operated twice in each of the four experimental conditions described above. The runs were performed in random order. When the teams operated in the CC, or two controller configuration, the same team member always handled the same geographical sector. When the teams operated in the C-T, or controller-tracker configuration, the same team member always served as the tracker. The use of the two available scopes was arranged as follows: During the C-T runs, the scope used for the controller and for the tracker was varied so that each team used each of the two scopes for the control function twice during the experiment in a randomly assigned order. During C-C runs, both scopes were used for control purposes, and the scopes were permanently assigned to sectors. In both configurations, each of the scopes was used equally for controlling.

All tracking was in the manual rate-aided mode. Machine computation of velocity changes occurred when the controller repositioned a tracking symbol and also operated a switch requesting recomputation of velocity. Initial assignment of tracking channels was accomplished by a simulated tower control position with hand-off of the targets to the simulated center control positions. Thus all tracking channels were started with flight plan direction and speed.

The design of the experiment is sketched below:

		2 Controller Configuration				Controller-Tracker Configuration			
		Run #	Control Scope	Run #	Control Scope	Run #	Control Scope	Run #	Control Scope
ith Alpha-imeric nformation nd Flight trips	Team 1	2	C_s and C_1	9	C_s and C_1	10	C_1	12	C_s
	Team 2	1		6		3	C_s	13	C_1
light-Strips lone no lphanumeric nformation	Team 1	7		14		5	C_s	16	C_1
	Team 2	11		15		4	C_s	8	C_1
									16

All subjects were briefed on the purpose of the tests and the definition of the experimental conditions before the experiment started. Insofar as possible, the subjects were isolated from the mechanics of simulation so as to minimize their exposure to the details of the traffic sample and to the artificialities of the situation. However, due to a shortage of support personnel, this point had to be compromised. It was found that two more men were needed in the simulation crew and the only two men available were the subjects who were not working in each run.

A rule was made that the subjects and support personnel were not to discuss the experiment or the traffic sample. It soon became apparent, however, that the subjects realized that they were getting the same traffic sample every run, and that there was a considerable learning effect.

SYSTEM PERFORMANCE MEASURES

The following measures were taken during the experiment:

1. Flight Maneuvers imposed on aircraft by A.T.C.

(a) Vectors - defined as heading clearances imposed by ATC. All vectors were recorded. These included vectors given for re-identification turns, and to maintain separation.

(b) Altitude Changes - defined as altitude clearances imposed by ATC.

All altitude clearances were recorded. These included altitude clearances to stop climb or continue climb, and clearances to other than requested altitude.

(c) Holds - defined as holding clearances imposed by ATC. All holds were recorded. These included 360° turns and normal holding patterns to avoid conflicts.

2. Conflictions

All conflictions were recorded. Conflicting aircraft were those having less than 5 miles lateral separation and within 1000 feet vertical separation. An uncoordinated crossing of sector boundaries was also considered a confliction.

3. Communication Measures

(a) Communication count - defined as the total number of times the teams pushed the buttons on their head sets to talk during each 45 minute run.

(b) Communication Time - defined as the total length of time in seconds the push to talk buttons were held down by the teams during each 45 minute run. This measure included both air-ground and ground-ground communication. Recording methods prevented separation of the two message types.

4. Tracking actions

(a) Sequence Count - defined as the number of times the teams pushed the sequence button to obtain a desired tracking channel during each 45 minute run.

(b) Velocity Correction - defined as the number of times the teams pushed the velocity correction button to insert a velocity change in a tracking channel during each 45 minute run.

(c) Tracking signal count - defined as the number of times the teams pushed the button on top of the tracking stick to reposition the symbol on the target during each 45 minute run.

(d) Insert signal - defined as the number of times the team pushed the insert button to insert a new course or speed into a tracking channel during each 45 minute run.

(e) Change signal - defined as the number of times the teams pushed the change button to insert a new course into a tracking channel during each 45 minute run.

(f) Re-identification - The number of occasions on which the teams required re-identification turns of an aircraft. The number of actual turn vectors involved, is counted in 1 (a) above.

DEFINITION OF SUMMARY MEASURES

Several of the measures that were recorded were then combined into 5 summary measures.

1. Tracking actions, the sum total of all the manual actions performed by the teams in the course of each problem run. These consisted of velocity correction count, tracking signal count, insert signal count, change signal count, and the sequence count. Re-identification occasions were dropped out because of the small count. However, the vectors that made up these turns were included in the vector count under control actions.

2. Control actions, the sum total of all the actions used to manuever aircraft to provide separation. These consisted of vectors, altitude changes, and holds. There were no holds recorded during the problem to include in this measure.

3. Conflictions, as defined in previous paragraph.

4. Communication count, as defined in previous paragraph.

5. Communication time, as defined in previous paragraph.

These were the 5 summary measures used in the analysis of the experiment. Some mention is also made of the important sub-measures.

OBSERVATIONS OF VARIATIONS AMONG RUNS

A log was kept of all events occurring during the runs. During runs 4, 5, and 6 the live radar background went off several times. In run 12 there were some missing targets in the middle of the run. Also run numbers 12 and 13 were completed with the antenna rotation rate set at 10 RPM instead of 5 RPM by mistake. This would change the velocity correction computed by the equipment in tracking. Runs 12, 13, and 14 had unusual amounts of precipitation clutter which might have had some effect on the data.

RESULTS

The basic data appear in Appendix A.

The analysis of variance was performed for each of the 5 summary measures and some sub-measures that were deemed important.

The significance of the 3 main variables and their three first order interactions was examined. Seven statistically significant results were found. The significance level is the probability that one will incorrectly state a difference exists, when none exists. In this report, the .05 (or less) level was considered statistically significant and the .10 level was considered deserving of some mention as a trend indication.

The significant results were:

1. Configurations differed in the average number of conflictions occurring per run.

2. Configurations differed in the number of control vectors (or heading changes) given per run. This is a sub-measure of control actions.

3. Configurations differed in the number of tracking actions per run. However, when total tracking actions is further subdivided, it is found that this difference is due only to sequencing and not to other tracking actions.

4. Teams differed in the number of conflictions occurring per run.

5. Teams differed in the number of communications per run.

6. There was an interaction (which is to say the result is a mutual or reciprocal action between the two variables) between configurations and alphanumeric condition with regard to frequency of communications.

7. Configurations interacted with teams with regard to the duration of communications.

There was some tendency for configurations to differ in the number of control actions given per run.

Configurations did not differ in communication frequency or duration. None of the 5 summary measures showed any difference between the operation with and without alphanumeric information.

The following are summary tables for the above mentioned differences.

Average Number	Configuration CC*	CT*	
Conflictions	1	3	.05 level
Tracking Actions	710	858	.05 level
Control Vectors	35	27	.05 level
Control Actions	38	30	.10 level

	Teams #1	#2	
Conflictions	1	3	.05 level
Communication Count	152	103	.01 level

	Configuration CC	CT	
Total Tracking Actions	710	858	.05 level
Sequencing	351	446	.05 level
Total T.A. minus Sequencing	359	412	Not significant

The remaining tables concern interactions.

		Configuration CC	CT	
Communication Count	Alpha	110	131	.01 level
	No Alpha	155	112	.01 level

		Configuration CC	CT	
Communication Time	Team 1	514	361	.01 level
	Team 2	438	440	.01 level

*CC - 2 controller configuration

*CT - Controller-tracker configuration

These data were normalized before analysis. The table entries represent the values re-transformed into their original form. Therefore the column or row averages are not necessarily the arithmetic average of the entries in the respective row or column in the basic data table in Appendix A.

DISCUSSION OF RESULTS

Configurations:

There were less conflictions and more vectors given in the CC configuration. Control actions, the sum of vectors and altitude changes, tended to be greater in the CC configuration.

The difference in conflictions makes the CC configuration considerably greater in effectiveness or desirability as a system. While one would tend to say that the better system was that which imposed a lesser number of control vectors, in this case the additional control vectors apparently had the desirable result of avoiding conflictions.

In further analysis of the tracking actions, the sequencing is found to have an important effect. With sequencing included in the tracking actions, there is a significant difference between configurations. With sequencing removed, there is no difference. Considering sequencing by itself, there is a significant difference between configurations (.05 level). The CT configuration has an average of 446 sequences per run while the CC configuration has an average of 351 sequences per run. These 95 extra sequences per run in the CT configuration are probably due to controller action to obtain necessary identity information for aircraft under control.

In the CT configuration runs, by definition, one man does the controlling and the other does the tracking, and in most cases this was true. However, in a few cases the controller did some tracking. Considering tracking actions with sequencing removed (it was not possible to subdivide sequencing), in one run the controller performed 35 tracking actions and the tracker 276 tracking actions. In the worst case, the controller did more tracking than the tracker (Controller-234 - Tracker-109 tracking actions). Both of these cases were runs by the same team in the no alphanumeric condition. This departure from the definition of the configurations under study in the experiment may have affected the results.

It should be noted in this connection that the CT configuration was operated with the 2 scopes in parallel. This meant that when the controller wished to re-establish identities of only 2 aircraft, he had to assume tracking of all the aircraft. (Thus when this occurred frequently, the tracker tended to fall behind.)

The fact that there is no interaction between configurations and either teams or alphanumeric condition is notable. This means that the number of conflictions was smaller in the CC configuration, regardless of which team was working or whether the men had or did not have alphanumeric displays. Although the teams differed in the number of conflictions they permitted, both teams allowed less conflictions when they worked in the CC configuration.

It appears from the data and from observing the experiment that the tracking task is much less difficult than the controlling task. If a man is controlling eight aircraft, the additional burden of tracking does not affect his performance in the same way as adding 8 aircraft to control and relieving him of the tracking task. This is further borne out by the fact that CT apparently was not able to make as many control vectors as CC, possibly because of the overload.

Alphanumeric Display

The addition of alphanumeric data to the controller's display apparently had no direct effect on traffic control performance as measured by the number of control actions required or the number of conflictions occurring.

The alphanumeric data had an effect on communication frequency in the sense that it interacted with configuration. It was found that when alphanumeric data was available, less frequent communication by the team members was necessary in the CC configuration as opposed to the CT configuration. Without alphanumeric data, however, more frequent communication by the team members was necessary in the CC configuration. It is noteworthy that the arrangement requiring most communication (155) was the CC-No Alphanumeric combination. It is probable that this combination required a good deal of communication merely to maintain identity.

We should note here that the communication frequency of which we speak includes both air-ground and ground-ground communication. In any case, it has been found that these two conditions (configurations and alphanumeric) affect each other with regard to the frequency of communication required of members of the system. This fact should be kept in mind in future system design.

Teams

The differences between the teams of subjects used are of little interest here. The fact mentioned previously that, regardless of the difference between the teams in the number of conflictions suffered, both teams had more in the CT configuration is of some importance.

CONCLUSIONS

The most general conclusions of the study are:

1. The two controller configuration can handle the same amount of traffic more safely than the controller-tracker configuration.

2. The presence of alphanumeric information on the scope face vs. an indicator light next to the appropriate flight strip as studied here seems to bear little relation to system performance.

With regard to these conclusions one should note that the experiment was a fairly brief and limited one. Of even more importance is the notation of the exact questions put to test here. In the case of the configurations it should be remembered that the number of men was kept constant. In one case one man was controlling about twice as many aircraft as in the other configuration. The conclusion drawn, therefore, does not mean that adding a man to act as remote tracker for a controller would not considerably increase the controller's capacity. Also, from a practical point of view, the added tracker might not necessarily have to be a qualified controller.

In the case of the alphanumeric display feature, it should be remembered that the alphanumeric data display was here added to a system in which the association of radar signal and flight data was already being accomplished to some degree by the tracking system. This is quite different from the raw radar situation.

In sum, it is evident that some further interesting questions regarding remote tracking and alphanumeric data display still remain to be studied.

APPENDIX A

Basic Data Table

CONTROL ACTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	40	40	36	16
	T_2	36	33	40	27
No Alpha	T_1	38	39	29	22
	T_2	48	32	34	36

CONTROL VECTORS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	34	36	30	15
	T_2	31	28	37	25
No Alpha	T_1	34	39	25	21
	T_2	45	31	33	27

CONFLICTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	0	0	2	1
	T_2	0	5	3	2
No Alpha	T_1	1	0	4	2
	T_2	3	2	9	7

TOTAL TRACKING ACTIONS

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	709	752	938	803
	T_2	555	669	999	787
No Alpha	T_1	688	683	904	662
	T_2	767	856	940	831

SEQUENCING

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	322	298	366	344
	T_2	294	347	524	441
No Alpha	T_1	364	293	593	319
	T_2	456	432	483	504

COMMUNICATION COUNT

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	142	146	151	156
	T_2	68	84	122	96
No Alpha	T_1	195	176	145	86
	T_2	134	116	102	116

COMMUNICATION TIME

		CC		CT	
		R_1	R_2	R_1	R_2
Alpha	T_1	497	530	373	413
	T_2	318	450	466	358
No Alpha	T_1	550	490	390	266
	T_2	525	452	405	531

CC - 2 Controller configuration
CT - controller-tracker configuration
T - Team
R - Replications

SECTION III

SRS TRACK STICK EXPERIMENTS

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SRS TRACK STICK EXPERIMENTS

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INTRODUCTION

This report concerns the third in a series of experiments studying the values of semi-automatic radar tracking systems in air-traffic control. A modified SRS-1 system built by Airborne Instruments Laboratories for the Army Signal Corps was used in this study.

The SRS-1 system has been explained briefly in the Phase 2 configuration experiment report. Although the system is neither new nor unique, it is more than adequate to study the methods of tracking and different scope displays to aid the controlling of aircraft in future systems.

PURPOSE

The first two experiments dealt with modes of tracking and with control of aircraft. In this experiment the evaluation shifted back to tracking but not with respect to modes. A new type of track stick was developed. The purpose of this experiment was to compare the new track stick with the old.

The new stick has been named the force stick, because a force must be exerted on the stick to cause symbol movement. Although the force stick has very little physical movement in any direction, the symbol is responsive to the force exerted on it. The track signal button, which activates symbol movement, is located on the front of the stick, somewhat like a trigger grip. In operation, the track signal button is depressed and a force exerted in any direction will move the symbol in the corresponding direction on the scope. Actually the track stick could be called a rate stick since the amount of force determines the rate of movement of the symbol. The new stick unit is designed so that the rate of symbol movement is directly proportional to the force applied. A further refinement is a faster rate of symbol movement when the force applied reaches a pre-set point. The parameters set up for this evaluation were: any force up to 3 pounds will produce a symbol rate of .13 in./sec/lb of force; from 3 pounds to 5 pounds the symbol rate changes to .64 in./sec/lb of force. The pre-set limit was 3 pounds.

The track stick used in the previous experiments is described as the position or displacement stick. This relates to the fact that a change in position or displacement of the stick causes the motion of the symbol. The stick moves through an arc of about 120° in any direction and the symbol is responsive to this motion. The track signal button on this model is located on the top of stick and must be depressed for symbol movement. This pushbutton is a two level switch.

Under operating conditions, the track signal button is depressed and a motion of the stick in any direction will move the symbol in the same direction on the scope. The stick unit is so designed that the distance the symbol moves on the scope is directly proportional to the movement of the stick. Also incorporated in the device is a fine and coarse displacement of the symbol. When the track signal button is depressed to the first level, a full motion of the stick will move the symbol 1". This is the fine position. In the coarse position, button all the way down, the symbol will move 14". How fast the symbol moves, the rate, is a function of how fast the operator moves the stick.

When velocity is inserted, through repositioning, the velocity switch must be activated during the repositioning. When this is done there is an additional 20 to 1 attenuation of the symbol rate or the symbol movement depending upon which stick is in use. Appendix A is a further description of the track sticks.

The evaluation was to determine if the force-rate stick had any advantages over the present displacement type stick. In this the main interest was if the controller would be able to track the targets more easily and faster with this new stick and thus leave more time for the actual controlling of the aircraft. Three experiments were completed on this evaluation problem.

PROCEDURE

Two consoles which were designated as the C_S and C_1 consoles were used in the experiment. These two consoles were comparable with the exception that the force-rate stick was installed on the C_S console and the displacement stick on the C_1 console.

For the simulation of aircraft, twenty 15-J-1C target simulators were used. In this problem, alpha-numeric information was not used. A video mapper was used to display the Indianapolis airway structure on each scope. There was no live radar used during these experiments.

The traffic load consisted of an average of 18 aircraft simultaneously displayed on the scope during the time measurements were being recorded. The problem was designed to run for 30 minutes. However, the recording of the measures did not begin until the 12th minute when the load reached 18 targets. Recordings were made until the load dropped off, which occurred after 12 more minutes. Therefore, measures were recorded for 12 minutes in each run.

There was a total of 12 runs in the first experiment. Each of the 3 permanent trackers operated twice in each of the two experimental conditions. The two conditions were the force-rate stick and the displacement stick. The runs were performed in random order.

All tracking was in the manual rate-aided mode. Machine computation of velocity changes occurred when the tracker operated the velocity switch and then repositioned the tracking symbol. Initial assignment of tracking channels was accomplished by a simulated tower control position with hand-off of the targets to the simulated center control positions. Thus all tracking channels were started with flight plan direction and speed.

The design of the experiment is shown below:

	C_S Console Force Stick		C_1 Console Position Stick		
	R_1	R_2	R_1	R_2	
Tracker 1	7	9	6	10	
Tracker 2	4	11	2	12	
Tracker 3	3	5	1	8	
					12

All subjects were briefed on the purpose of the tests and the definition of the experimental conditions before the experiment started.

The three trackers used in this experiment were experienced men in that they had been used in the previous experiments. Therefore, they were quite proficient in the use of the displacement type track stick, but did not have any operating experience with the force-rate stick. In order to obtain valid data relating only to the characteristics of the two track sticks, the learning factor should be eliminated as a variable in the experiment. It would have been desirable that the trackers be given enough practice to eliminate this factor. However, due to the pressure of time, the practice runs were limited to 3 for each tracker. For one of the trackers an added practice run was made to improve his proficiency a little further. In the data for the measures taken during the practice runs shown in the Appendix, there was a tendency toward leveling out. It was hoped that any more learning would have a negligible effect on the results of the experiment.

Additional Experiments

In addition to the main experiment described above, two other experiments were performed. The procedure for these is described below.

In the second experiment, the purpose of which was to make a check on the effect of familiarity with the equipment, three trackers who had no tracking experience with either tracking system were given six runs in random order with the two sticks. Each tracker did one run with each stick. It was discovered that these novice trackers were severely handicapped (or felt that they were) in the use of the fine-coarse switch on the position stick. The switch was modified, the data discarded, and the experiment repeated. The three trackers were given another six runs (one run with each stick) in random order. An easier problem than the one used with the experienced trackers was designed for this experiment. This problem consisted of twelve targets on the scope at all times. The scoring period here was twelve minutes as in Experiment 1.

In the third experiment, a brief attempt to check on the data of the first experiment was made. The experiment was repeated with three trackers but without any replication. The same problem and scoring procedures as in the first experiment were used with the same subjects.

SYSTEM PERFORMANCE MEASURES

The following measures were taken during the experiment:

1. Misses -

The number of sweeps a tracking symbol was "off" the target. Being off the target was defined as when the center of the target was not enclosed or touched by the "C" tracking symbol. These data were taken by assigned observers.

2. Re-idents -

The number of times the tracker felt he had lost track of the target identities and would have had to call for identity turns in an operating ATC system. Since alpha-numeric information was not used in this experiment, it was not possible to use a more objective method of recording identity confusion. The tracker informed the observer of the re-identifications. Upon examination it was decided to drop this data. Analysis showed the measure non-significant in Experiment 1, not recorded in Experiment 2, but significant between sticks in Experiment 3. However, the Experiment 3 data on re-idents was so extremely lopsided as to raise a suspicion that there was an observer error.

3. Tracking Actions -

   (a) Sequence Count - The number of times the trackers pushed the sequence button to obtain a desired tracking channel during the 12 minute recording period.

(b) Track Signal Count - The number of times the trackers pushed the track signal button to reposition the symbol on the target during the 12 minute recording period.

(c) Velocity Correction - The number of times the trackers pushed the velocity correction button to insert a velocity change in a tracking channel.

RESULTS

The basic data appear in Appendix B. The following were the results in the track stick experiments:

Experiment 1:

1. Track sticks were not significantly different in velocity count, sequence count, or track signal count. The miss count was not significantly different for the two sticks, although there was a strong tendency for the force stick to have a greater number of misses. The difference was reliable at the .90 level of confidence, not quite reaching the .95 level arbitrarily defined as establishing significance for this series of experiments.

2. There were significant differences among the trackers (subjects) in the experiment in the track count, velocity count, and sequence count measures. The trackers did not differ in the number of misses, however.

3. The interaction of sticks and trackers was not significant.

Experiment 2:

In the experiment with the untrained or unpracticed trackers, no significant differences were found between sticks or trackers in any of the measures (misses, track signal, velocity count, sequences). It was not possible to make a statistical test on the interaction.

Experiment 3:

No differences were found significant in the third experiment which was done with the experienced trackers. It was not possible to make a statistical test of the significance of the interaction between sticks and trackers. The following are summary tables for the above mentioned differences.

EXPERIMENT 1

	Trackers		
Avg. No. of	1	2	3
Track Count	170	125	137
Velocity Count	160	116	124
Sequences	276	190	203

	Sticks	
	Force-Rate	Position
Misses	160	126

INTERPRETATION OF RESULTS

In the entire series of three experiments, there was never a demonstrated difference between the two types of stick in any of the measures of tracker 'workload', (track count, velocity count, sequences).

In the first experiment of the series, there was a strong tendency for more misses to occur when the force stick was being used. In this case, the position stick averaged 126 misses per run, while the force stick averaged 160 misses per run. There were 1,080 chances for misses per run (12 minute runs, 18 targets at all times, 5 scans per minute.)

There are some general ideas which must be kept in mind in interpreting the data from these tracking experiments. The first of these is that because of the pressure of time it was not possible to do exhaustive experiments; perhaps the results would have been more conclusive if more replications had been possible. This is especially true of the second and third experiments in which no replications were made. This comment has special reference to the fact that it is possible that, with more replications, the difference in misses between the two sticks might have been statistically significant. Another fact which this comment has bearing on is the matter of interactions. On an observational basis and from an examination of the scores, it would seem that there are considerable individual differences in the way people take to these sticks. Although the test of interactions in the first experiment did not confirm this, it is possible that more data would have brought this out more clearly.

Another general consideration which should be kept in mind is the matter of practice. The controllers who acted as trackers in the first and third of this series of experiments were really quite highly practiced in the use of the position sticks. Although they were given practice sessions in the use of the new force stick before the experiment began, it could always be argued that this was not quite sufficient to equalize the positions of the two sticks before the comparative test began. The data from the practice sessions appear in Appendix B. It is possible that further familiarization might have been advisable, if time had permitted. Another approach to the practice problem is embodied in Experiment 2. Experiment 2 used controllers who had previously used neither stick. The results with these fresh subjects again indicated no difference between the two sticks in any of the measures. In this case it should be remembered that there was no replication, so that differences had to be large to be significant.

The third, and most important general consideration which should be kept in mind in interpreting these data involves the nature of the system with which we are dealing. There are two aspects to this thought: 1) any conclusion about tracking sticks can apply only in the light of the remainder of the systems studied, since the stick becomes an integral part of the tracking system and interacts with the other components of the system. A diagram is presented in Appendix A which sketches the major elements of the system involved here; and 2) it must also be remembered that especially within the force stick arrangement a great many parameters are capable of adjustment, for example the relation between pounds of pressure and voltage displacement. It was necessary in this instance for the experimenters to arbitrarily set some of these parameters after some preliminary trials. It is believed that some fairly good settings of the various parameters involved were arrived at in this manner. It should be kept in mind as a caution, however, that other settings of these parameters could conceivably have yielded different performance.

CONCLUSIONS

From a statistical point of view, and subject to the interpretive comments above, it is concluded that: 1) there were no differences between the sticks in the tracking workload measures, and 2) there was an accuracy difference favoring the position stick which was of high statistical reliability. The subjects of the experiment expressed a strong preference for the position stick.

A P P E N D I X   A

DESCRIPTIONS OF THE TWO TRACKING STICKS STUDIED IN THE SRS PROGRAM

A. Position Stick

The transfer function for the controlled element is $\theta_o/\theta_i = k$, where θ_i is a position input. The stick is in neutral after each correction, so that corrections are always incremental. There are two values for k, fine and coarse:

(a) fine. $k = \sim .025$ degrees/inch

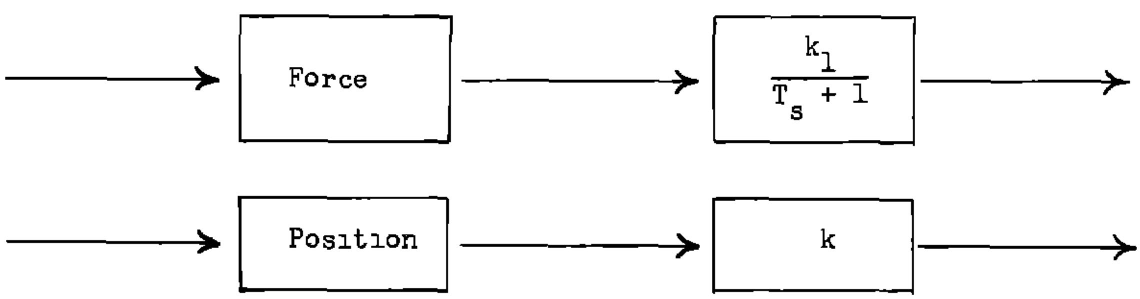
(b) coarse· $k = \sim .175$ degrees/inch

B. Force Stick

The transfer function for the controlled element *after* the stick is $\frac{k_1}{T_s + 1}$ where $\frac{k_1}{T_s + 1} \simeq \frac{k_1}{s}$. Consequently, $\theta_o/\theta_i = k/s$ where θ_i is a force in pounds and θ_o is measured in degrees/second or equivalently miles/second. The force characteristic of the stick is describable in two linear segments as shown in Figure 1.

C. Summary

The two sticks, then, may be described as follows·



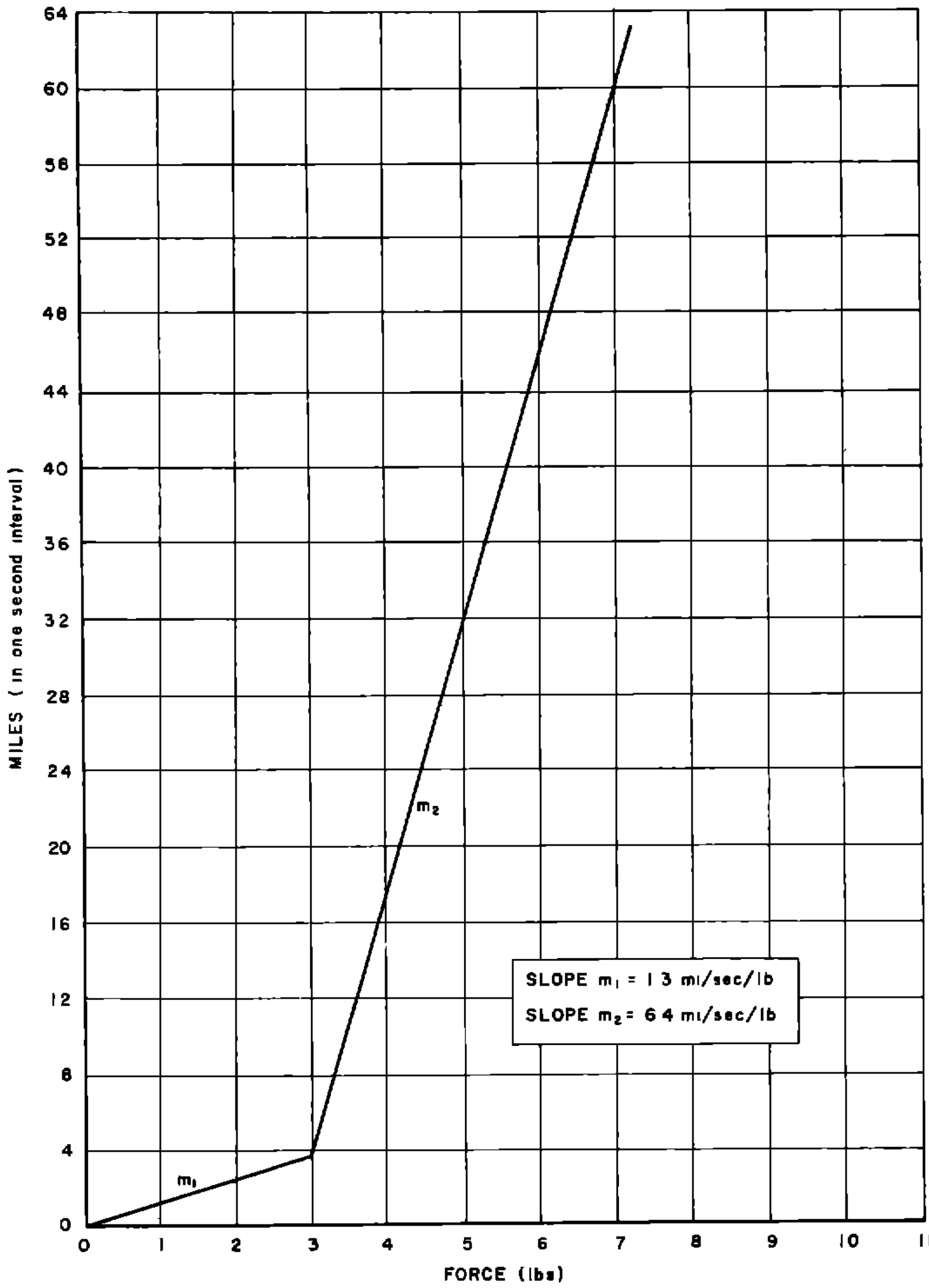


FIGURE 1 MILES IN ONE SECOND VERSUS FORCE ON TRACKING STICK

A P P E N D I X B

BASIC DATA TABLE
DATA FROM PRACTICE SESSIONS

EXPERIMENT 1

RE-IDENTS

	Force		Position	
	R_1	R_2	R_1	R_2
Tracker 1	3	4	4	3
Tracker 2	3	2	4	2
Tracker 3	3	1	2	1

VELOCITY COUNT

Force		Position	
R_1	R_2	R_1	R_2
163	137	167	174
98	137	87	144
138	126	116	117

TRACK COUNT / SEQUENCES / MISSES

	TRACK COUNT Force		TRACK COUNT Position		SEQUENCES Force		SEQUENCES Position		MISSES Force		MISSES Position	
	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2	R_1	R_2
Tracker 1	163	156	172	189	272	267	278	287	130	118	136	104
Tracker 2	99	139	99	163	199	191	195	175	170	198	130	160
Tracker 3	139	127	136	147	171	206	174	259	162	184	82	142

EXPERIMENT 2

	SEQUENCES Force	SEQUENCES Position	MISSES F	MISSES P	VELOCITY COUNT F	VELOCITY COUNT P	TRACK COUNT F	TRACK COUNT P
Tracker 1	144	158	94	52	91	60	91	80
Tracker 2	169	140	60	78	76	38	93	105
Tracker 3	159	177	76	76	96	83	103	84

EXPERIMENT 3

	SEQUENCES F	SEQUENCES P	MISSES F	MISSES P	VEL. COUNT F	VEL. COUNT P	TRACK COUNT F	TRACK COUNT P	RE-IDENTS F	RE-IDENTS P
Tracker 1	285	241	207	110	127	113	126	116	0	3
Tracker 2	228	284	143	122	126	101	123	152	0	5
Tracker 3	297	295	118	115	142	141	171	153	0	3

DATA FROM PRACTICE SESSIONS

	Subject	Session 1	Session 2	Session 3	Session 4
SEQUENCES	1	178	233	279	
	2	149	164	177	212
	3	216	241	298	
	Avg.	181	212.7	251.3	
MISSES	1	74	48	49	
	2	67	69	61	66
	3	68	55	42	
	Avg.	69.7	57.3	50.7	
TRACK SIGNAL	1	100	144	134	
	2	142	96	104	
	3	141	132	123	
	Avg.	127.7	124	120.3	
VELOCITY COUNT	1	80	138	133	
	2	64	84	111	
	3	82	117	118	
	Avg.	75.3	113	120.7	

SECTION IV

SRS TRIM-TAB WITH VECTORS AND FLIGHT PLAN TURN EXPERIMENT

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SRS TRIM-TAB WITH VECTORS

AND FLIGHT PLAN TURN EXPERIMENT

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Working Paper No. 3 (Project A2221)
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WORKING PAPER

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INTRODUCTION

This report concerns the fourth in a series of experiments studying the use of semi-automatic radar tracking systems in air-traffic-control. A modified SRS-1 system built by Airborne Instruments Laboratories for the Army Signal Corps was again used in this study.

The SRS-1 system was further modified for this series of experiments so that new techniques and sub-systems might be evaluated for possible use in future tracking systems.

PURPOSE

In this experiment the emphasis was again on the tracking of the targets. Two modifications were made and it was planned to evaluate these changes during this experimental period.

The first modification was related to flight plan information. There is the possibility of programming the computers, in the "ultimate" air traffic control system, with flight plan information so that the tracking gates would follow the target's intended path with some updating during the flight. To check the addition of flight plan information in this experiment, a device was built to simulate a flight plan turn only. This device was operated by the simulation crew, and they were able to turn any of the tracking channels according to the programming of the simulation problem.

The second modification to the equipment to aid the tracking of the targets is the trim-tab. This device controls the speed and the heading of the tracking channel by a four position sliding switch. Used with the trim-tab control is a vector which is displayed on the scope as a thin line starting at the symbol and showing at a glance the heading of the tracking channels. In addition, the length of the vector is proportional to the speed of the tracking channels. For this test series, a vector was displayed representing a one or two minute flight path prediction. (The vector was slightly less than an inch in length.) The button is slid forward to increase the speed and backwards to decrease the speed. By watching the vector on the channel being "trimmed" the operator can see the vector increase or decrease in length depending on the position of the trim-tab button. In a heading adjustment, when the button is pushed to the left, one can see the vector swing counterclockwise showing a heading change in that direction. When the trim-tab is pushed to the right, the vector and heading change is in a clockwise direction.

One good feature of this control is that the changes are made as soon as the control is activated, while changes made by inserting velocity, when repositioning the symbol, do not register on the scope until one sweep goes by.

In summary, there were two modifications to be evaluated, trim-tabs and flight plan turns.

The evaluation was to determine if the addition of either of these two modifications would be advantageous to the controller; i.e., would his tracking workload be reduced and his accuracy improved so that he could devote more of his time to the important control decisions?

PROCEDURE

Trim-tabs with vectors were available on both consoles. The controls were mounted on top of the force stick on the C_S console. On the C_1 console, the controls were mounted on the control panel in a readily accessible position. The displacement or position stick was installed on the C_1 console. The C_1 console was used in this experiment for two reasons. It was felt that the displacement stick would cause less variability in the results because of greater operator experience in the use of this stick. The other reason was that the trim-tabs controls were installed in such a way that the observer was able to record the use of this device more readily on the C_1 console than on the C_S console.

For the simulation of aircraft, twenty 15-J-1C target simulators were used. Alpha-numeric information was not used in this experiment. A video mapper was used to display the Indianapolis airway structure on each scope. No live radar was used during the experiment.

The traffic load consisted of an average of 18 aircraft simultaneously displayed on the scope during the time measurements were being recorded. The problem was programmed for 25 minutes. The recording of the measures began at the 8th minute when the traffic load reached 18 targets. Therefore, measures were recorded for 17 minutes in each run.

There was a total of 16 runs in this experiment. Each of the two experienced trackers operated twice in each of the four experimental conditions. The four experimental conditions are as follows:

(1) Flight-Plan-Turns and Trim-Tabs + Vectors

(2) No Flight-Plan-Turns, Just Trim-Tabs + Vectors

(3) Flight-Plan-Turns, no Trim-Tabs + Vectors

(4) No Flight-Plan-Turns, no Trim-Tabs + Vectors

The runs were performed in random order. All tracking was in the manual rate-aided mode. Machine computation of velocity changes occurred when the tracker operated the velocity switch and then repositioned the tracking symbol.

Initial assignment of tracking channels was accomplished by a simulated tower control position with hand-off of the targets to the simulated center control positions. Thus all tracking channels were started with flight plan direction and speed.

The design of the experiment is shown below.

		Flight Plan Turns		Without Flight Plan Turns	
		R_1	R_2	R_1	R_2
Trim-Tabs + Vectors	Tracker 1	11	9	12	8
	Tracker 2	6	1	2	4
Without Trim-Tabs + Vectors	Tracker 1	15	5	16	13
	Tracker 2	7	14	3	10

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All subjects were briefed on the purpose of the tests and the definition of the experimental conditions before the experiment started. Insofar as possible, the subjects were isolated from the mechanics of simulation so as to minimize their exposure to the details of the traffic sample and to the artificialities of the situation.

The two trackers used in this experiment were experienced men in that they had been used on the previous experiments, and were well trained in the use of the displacement type track stick.

To further check on the trim-tab results a second brief experiment was done. Two trackers were used, one of whom had also worked in the first experiment. Trim-tabs were compared to no trim-tabs and flight plan turns were used throughout. The same problem was used and one replication was made.

SYSTEM PERFORMANCE MEASURES

The following measures were taken during the experiment.

1. Misses

The number of sweeps a tracking symbol was "off" the target. Being off the target was defined as when the center of the target was not enclosed or touched by the "C" tracking symbol. These data were taken by assigned observers.

2. Re-identifications

The number of times the tracker felt he had lost track of the target identities and would have had to call for identity turns in an operating ATC system. Since alpha-numeric information was not used in this experiment, it was not possible to use a more objective method of recording identity confusion. The tracker informed the observer of the re-identifications.

3. Tracking Actions

(a) Sequence Count - The number of times the trackers pushed the sequence button to obtain a desired tracking channel during the 17 minute recording period.

(b) Track Signal Count - The number of times the trackers pushed the track signal button to reposition the symbol on the target during the 17 minute recording period.

(c) Velocity correction - The number of times the trackers pushed the velocity correction button to insert a velocity change in a tracking channel.

These measures can be considered workload measurements. In other words, these are measures of the work done by the tracker while tracking aircraft.

4. An additional type of measure was taken as a check on the utility of the equipment. The number of times the men used the heading and speed features of the trim tabs were recorded. Obviously this could only be used as an observation, not as comparative data, since the trim-tab count was available for only half of the experiment.

RESULTS - TRIM-TABS

The basic data appear in Appendix A.

The analysis of variance was performed for each of the 5 measures.

The significance of the 3 main variables and their three first order interactions was examined. Eleven statistically significant results were found. The significance level is the probability that one will incorrectly state a difference exists, when none exists. In this report, the .05 (or less) level was considered statistically significant and the .10 level was considered deserving of some mention as a trend indication.

The significant results were:

(a) Trackers differed in all the five measures taken (track count, velocity count, sequences, re-idents, and misses).

(b) Flight Plan turns differed in velocity count and misses.

(c) Trim-tabs differed in track count, velocity count and sequences.

(d) There was an interaction (which is to say, the result is a mutual or reciprocal action between the two variables) between trim-tabs and trackers with regard to sequences.

The important results were:

(a) Flight Plan turns differed in track count.

The following are summary tables for the above mentioned differences.

TRACKER

Average Number of	1	2
Track Count	113	175
Velocity Count	62	155
Sequences	180	302
Re-Idents	0	2
Misses	36	22

FLIGHT PLAN TURNS

	With	Without
Track Count	128	160
Velocity Count	98	119
Misses	21	36

TRIM-TABS

	With	Without
Track Count	126	161
Velocity Count	88	128
Sequences	202	280

The remaining table concerns the significant interaction, indicating that one tracker is aided more than the other through the use of the trim-tabs.

		TRIM-TABS	
		With	Without
Sequences	Tracker 1	154	206
	Tracker 2	248	355

These data were normalized before analysis. The table entries represent the values re-transformed into their original form. Therefore, the column or row averages are not necessarily the arithmetic average of the entries in the respective row or column in the basic data table in Appendix A.

In the second brief experiment on trim-tabs mentioned above, the results were that no differences between trim-tabs and no trim-tabs were significant. This is a different result from that of the first experiment where some workload measures were found to show significant differences. While this may appear contradictory, the second experiment was less powerful statistically than the first, and differences in such a case must be larger to be significant. The results of experiment 1 are accepted here, and the experiment 2 results discounted for the reasons mentioned above.

DISCUSSION OF RESULTS

Flight Plan Turns

The addition of flight plan turns to this type tracking systems is apparently of assistance in tracking as measured by the number of tracking actions required and by the tracking accuracy attained. Track count and velocity count were both materially reduced when flight-plan-turns were used. Most important, misses were reduced significantly.

From these results one may conclude that with high density traffic (as was used in this problem), keeping symbols on targets that are turning on different airways is one of the more difficult phases of tracking aircraft. When this is done automatically with flight plan information, there is a considerable drop in the workload of the tracker and the tracking accuracy is improved.

Trim-Tabs - With Vectors

From the results of this evaluation it is also apparent that the addition of trim-tabs with vectors will help the tracker reduce his workload. The use of trim-tabs with vectors considerably reduced the track count, velocity count, and the sequences required for the tracking. There was no apparent improvement in the tracking accuracy. Examination of the data on the frequency of trim-tab use indicates that the speed trim-tabs were used very infrequently.

Trackers

There was a difference between trackers in all the measures recorded. Looking at this difference more closely, it can be seen that it was the result of the same subject (tracker No. 2) having a higher average number of counts in those measures that can be considered the workload measurements. These are track count, velocity count, and sequences. However, in the analysis of the number of misses, tracker 2 averaged fewer misses than tracker 1. From this, one can conclude that although tracker 2 did more work throughout the problem, he got better results in keeping the symbol on the target. Tracker 2 also averaged more re-idents than tracker 1.

CONCLUSIONS

The most general conclusions of the study are:

(1) The use of Flight-Plan-Turns in a tracking system of the type evaluated, improved the tracking accuracy and cut the workload involved.

(2) The use of Trim-Tabs with vectors also considerably reduced the tracker workload but showed no effect on the accuracy of tracking.

APPENDIX A

BASIC DATA TABLE — TRIM-TABS

TRACK COUNT

		FLIGHT PLAN TURNS		WITHOUT FLIGHT PLAN TURNS	
		R_1	R_2	R_1	R_2
TRIM-TABS + VECTORS	TRACKER 1	85	91	105	105
	TRACKER 2	154	142	170	160
WITHOUT TRIM-TABS + VECTORS	TRACKER 1	99	89	97	233
	TRACKER 2	196	169	209	200

VELOCITY COUNT

		FLIGHT PLAN TURNS		WITHOUT FLIGHT PLAN TURNS	
		R_1	R_2	R_1	R_2
TRIM-TABS + VECTORS	TRACKER 1	29	55	15	76
	TRACKER 2	132	108	151	141
WITHOUT TRIM-TABS + VECTORS	TRACKER 1	69	74	94	83
	TRACKER 2	169	148	192	197

SEQUENCES

		FLIGHT PLAN TURNS		WITHOUT FLIGHT PLAN TURNS	
		R_1	R_2	R_1	R_2
TRIM-TABS + VECTORS	TRACKER 1	136	156	177	150
	TRACKER 2	279	201	266	247
WITHOUT TRIM-TABS + VECTORS	TRACKER 1	206	182	193	242
	TRACKER 2	386	338	360	338

RE-IDENTS

		FLIGHT PLAN TURNS		WITHOUT FLIGHT PLAN TURNS	
		R_1	R_2	R_1	R_2
TRIM-TABS + VECTORS	TRACKER 1	0	0	0	4
	TRACKER 2	2	2	3	0
WITHOUT TRIM-TABS + VECTORS	TRACKER 1	0	0	0	0
	TRACKER 2	3	1	2	2

MISSES

		FLIGHT PLAN TURNS		WITHOUT FLIGHT PLAN TURNS	
		R_1	R_2	R_1	R_2
TRIM-TABS + VECTORS	TRACKER 1	35	26	52	24
	TRACKER 2	8	12	25	33
WITHOUT TRIM-TABS + VECTORS	TRACKER 1	30	24	50	43
	TRACKER 2	14	18	32	32

TRIM-TAB USE

		FLIGHT PLAN TURNS				WITHOUT FLIGHT PLAN TURNS			
		R_1		R_2		R_1		R_2	
		SPD	HD	SPD	HD	SPD	HD	SPD	HD
TRIM-TABS + VECTORS	TRACKER 1	0	35	0	20	0	34	0	25
	TRACKER 2	10	70	0	7	7	62	17	101
WITHOUT TRIM-TABS + VECTORS	TRACKER 1								
	TRACKER 2								

SECTION V

SIMULATED VG vs SRS EXPERIMENT

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SIMULATED VG vs SRS EXPERIMENT

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INTRODUCTION

This report concerns the fifth in a series of experiments studying the values of semi-automatic radar tracking systems in air traffic control. A modified SRS-1 system build by Airborne Instruments Laboratories for the Army Signal Corps was used and compared with a simulated VG scope.

PURPOSE

This experiment was designed to make a comparison between control procedures and effectiveness in the SRS system and the present VG system.

EQUIPMENT

The SRS-1 is a semi-automatic radar tracking system, modified to include display information and other aids to the controller. In this experiment all of these aids were available to the controller to use as he felt necessary during the problem. The display information included alpha-numeric data, as well as course and speed vectors. The alpha-numeric data was positioned next to the tracking channel symbol and included the following: (1) aircraft identification, (2) present altitude, and (3) origin and destination. This information appeared on three lines. The controller had the option of selecting whichever line or lines he believed to be most helpful or none at all. The course and speed vector was shown as a thin straight line starting at the channel symbol. This vector was controlled by the trim-tabs as explained in the previous report. It suffices to say that it gave visual indication of course and speed of the tracking channel. With these vectors conflictions were predicted within the same altitude by projecting the vectors 10 to 15 minutes ahead and checking for separation. There was also a switch panel that enabled the controller to select those altitudes he wanted displayed on the scope. For example, with quite a few targets and alpha-numeric data on the scope, the controller might want to know which aircraft are at 5000 and 6000 feet. By throwing a couple of switches all the alpha-numeric information drops out except for those targets at 5000 and 6000 feet. This can be done for any altitude or altitudes desired.

The other features of the SRS-1 that should be mentioned for review are the course and speed inserts for each channel (to make adjustments of channels if necessary) and the drop out of all alpha-numeric information, except on the channel leadered to, when the track stick button is pushed.

There are many aids for the controller in the SRS-1 system, and to control aircraft efficiently they must be used in the proper sequence and suitable combinations. All controls and switches for these aids must become an automatic function for the controller. Naturally this takes time and practice.

The VG portion of the experiment was simulated by means of a 21" flat-face TV tube set in a console similar to the normal VG scope. The VG in use in most ARTCC's is a projection type of display and therefore the 21" TV tube gave a much brighter picture. In fact the brightness was approximately equal to that of the SRS tube. Flight progress strips, containing all necessary information, were available in a bay adjacent to the radar display. The only aids in this system are the flight progress strips and small plastic chips on which the controller is to write the target identities and keep them on the proper targets.

PROCEDURE

The experiment was performed at Airborne Instruments Laboratories, Mineola, L. I., where the SRS equipment was located. Two consoles were used in the experiment. The SRS-1 console used was designated the C_S console. This console was equipped with the force or rate type track stick. The other console was a simulated VG console with a 21 inch flat-face tube. Both consoles had an adjoining bay of flight progress strips and bright display tube scopes. However, the SRS-1 had a 14 inch tube while the simulated VG console used a 21 inch tube. This display size difference should be remembered in interpreting the results.

For simulation of aircraft, 15-J-1C simulators were used. The alpha-numeric information was produced on the SRS scope by means of a vidicon television camera time sharing with the radar picture. The camera picked up the information from a board upon which the aircraft identities, altitudes, etc. were posted. The board was operated by the simulation crew and updated according to the progress of the simulation problem.

When it came to developing the simulation problem, an obstacle was encountered. This was due to the time sharing rate of the alpha-numeric data display. Several tests were run using a 10 cycle per second rate for the alpha-numeric display. It was found that this rate was unusable due to flicker. After about 10 minutes, the operators experienced severe eyestrain. The alpha-numeric data, therefore, had to be displayed at the more comfortable 20 C.P.S. rate. However, the number of tracking channels that could be used was reduced to 12 with the 20 cycle per second rate. It became an exacting job for the simulation crew to produce and run a difficult simulation problem with only 12 tracking channels available.

A video mapper was used to display the Indianapolis airway structure on each scope. The problems were designed on this airway structure. The range of the display was set at 80 miles radius. There was no live radar used in this experiment.

The traffic load consisted of an average of twelve aircraft simultaneously displayed on the scope. The simulation problems consisted of flights through the Indianapolis ARTCC area. The altitudes were restricted to between 9000 and 12,000 feet to make the problem more difficult.

There was a total of twelve 45 minute runs. Each of the 3 controllers operated twice in each of the two experimental conditions (scopes). Two traffic samples were used. These were constructed to be as comparable as possible. Both samples were programmed with a minimum of 8 occasions for conflictions.

The measures were recorded for 45 minutes during each run. The runs were performed in random order.

When using the SRS system, all tracking was in the manual rate-aided mode and controllers did all their own tracking of the targets. Machine computation of velocity changes occurred when the tracker operated the velocity switch and then repositioned the tracking symbol. Initial assignment of tracking channels was accomplished by a simulated tower control position with hand-off of the targets to the simulated center control positions. Thus all tracking channels were started with flight plan direction and speed.

When the problems were run on the simulated VG system, the controller also did all his own tracking. Hand-off of targets was simulated by a man sitting next to the controller, informing him of the identities of the targets when they appeared on the display scope as the problems progressed.

The design of the experiment is sketched below.

	Simulated VG		SRS - 1	
	Problem 1	Problem 2	Problem 1	Problem 2
Controller 1	12	11	7	1
Controller 2	5	2	10	4
Controller 3	8	6	3	9

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All subjects were briefed on the purpose of the tests and the definition of the experimental conditions before the start of the experiment. Subjects had worked with the tracking features of the equipment in the previous experiments. Controls for alpha-numeric information and switches for the altitude selectivity display features were relatively new at the time of this experimental period; therefore, the controllers were given some informal practice on all the devices. Unfortunately the time was short and they were only able to finish two one-half hour test runs per controller. A longer period of practice undoubtedly would have reduced the variability of the experiment. This period of testing was also used to get a smoother simulation operation and acquaint the observers with all the measures to be recorded.

There was no practice on the simulated VG presentation, outside of procedure explanations, because all the subjects had at least 2 years experience with VG type of presentation and control.

Insofar as possible, the subjects were isolated from the mechanics of simulation so as to minimize their exposure to the details of the traffic sample and to the artificialities of the situation. It was planned that the learning factor, as far as the problem was concerned, would be reduced considerably through the use of two different (appearance) but equal (traffic load) problems. However, as indicated in the Results section, the problems were slightly different in difficulty.

As a further test of the learning factor and to test the repeatability of the operators, the first two runs were re-run as the 13th and 14th runs of the test series. A comparison of these two sets of runs is given in Appendix A. It is apparent from this data that the controllers did not learn or memorize the problem and that they replicate themselves readily.

SYSTEM PERFORMANCE MEASURES

The following measures were taken during the experiment:

1. Flight maneuvers imposed on aircraft by A.T.C.

   (a) Vectors - defined as heading clearances imposed by A.T.C. All vectors were recorded.

   (b) Altitude changes - defined as altitude clearances imposed by A.T.C. All altitude changes except pilot requested altitude changes were recorded.

   (c) Hold - defined as holding patterns imposed by A.T.C. All holds were recorded. These included 360° turns and normal holding patterns to avoid conflicts

2. Conflictions - defined as those aircraft having less than 5 miles lateral separation and within 1000 feet vertical separation. The 5 mile lateral separation standard was chosen over the legal 3 mile separation standard to make the control problem more difficult.

3. Aircraft off airways - defined as aircraft crossing airway boundaries. This was seven miles on either side of the center line for this problem.

4. Communication Measures

(a) Communication count - defined as the total number of times the controllers pushed the microphone button to talk during each 45 minute run.

(b) Communication duration - defined as the total length of time in seconds during which the microphone buttons were held down by the controllers during each 45 minute run. This measure included both air-ground and ground-ground communications, and communications to simulate interphone conversations to adjacent towers and centers.

5. Confused identities at the end of problem - defined as the number of interchanged identities and targets, caused by target merges, etc., at the end of problem.

6. Altitude change requests

This measure was introduced to put more realism into the simulation problem and get an additional measure of the two systems.

There were seven such requests at various times in each problem. The aircraft initiated the altitude change request. The time interval between the end of the pilot's request and the end of the initial clearance given by the controller was recorded by the observer. If the aircraft was not cleared to the requested altitude in the initial clearance or within 3 minutes of the initial clearance, the pilot would repeat his request. This was done every 3 minutes until the pilot was cleared to his requested altitude. The observer recorded all this data. The data available were the time delays between the pilot request and the initial clearance.

RESULTS

The basic data appear in Appendix A.

The analysis of variance was performed for each of the seven measures as follows:

1. Number of conflictions
2. Altitude changes imposed by ATC
3. Vectors imposed by ATC
4. Message frequency
5. Message time duration per run
6. Number of aircraft not redirected to airways
7. Number of control actions (the sum of altitude changes and vectors).

The experimental design allowed the testing of the statistical significance of the following factors:

1. Differences between the SRS and VG
2. Differences among controllers
3. Differences between problems

4. Interactions between controllers and scopes (i.e., SRS and VG)

5. Interactions between controllers and problems

6. Interactions between scopes and problems.

The fact that the experimental design allowed the testing of these factors for each of the seven variables listed above meant that the total number of hypotheses which could be examined was forty-two (42).

Of the forty-two significance tests made, thirteen were significant at the 95% level of confidence. The significant results were as follows:

SRS and VG differed in:

1. Altitude changes

2. Number of aircraft off airways

3. Message frequency.

Controllers differed in:

1. Conflictions

2. Number of aircraft off airways

3. Message frequency.

Problems differed in:

1. Control actions imposed

2. Vectors imposed

3. Altitude changes

4. Number of aircraft off airways.

There were significant interactions between:

1. Controllers and scopes in number of control actions imposed

2. Controllers and scopes in number of conflictions

3. Scopes and problems in number of aircraft off airways.

There was a tendency for the interaction between scopes and problems to be significant with regard to conflictions.

Observations of holds and confused identities were made, but these occurred so infrequently that an analysis was not made. The data on altitude change time delays were not distributed in such a form as to allow analysis, even with transformation. Most delays were well within two minutes.

DISCUSSION OF RESULTS

The present experiment was concerned with determining in which aspects of system performance the operations of the SRS type radar processing device and the VG type device were comparable or different. There are many aspects in which the two equipments differ; and the attempt was made here to determine what effects, if any, these differences had on some criteria of air traffic control performance. It should not be necessary to recount in detail the aspects in which these equipments differ. Some of the major ones, however, are the size of the scopes; e.g., the SRS has a 14 inch diameter while the horizontal display is 21 inches in diameter; tracking in the VG system is done with plastic chips and the information is handwritten on these chips; tracking in the SRS system is done with a tracking stick and electronic tracking gates. The identifying information is presented directly on the display and it is not necessary to put this information on the display by hand.

With this brief review of the differences in the two equipments involved, which have been discussed in more detail in other parts of this report, we may proceed to an examination of the results.

A word about the criteria used is in order. The general rationale behind these criteria is one most frequently used in connection with the air traffic control systems; i. e., the familiar phrase which states the objective of the air traffic control system is to move air traffic in the safest and most expeditious manner.

On the basis of this rationale, the most important criterion used is that of conflictions, which is in essence a euphemism for air collisions. Subsidiary criteria involve expeditiousness; i. e., minimizing delays to the aircraft and changes of course and altitude to the aircraft which might inconvenience them.

The other criteria used were not directly related to the objective of the system. One of these was concerned with the amount of voice communication required between the controller and the pilots of the aircraft under control. It would be desirable to keep this to a minimum. Another criterion applied was concerned with a task which controllers probably are required to perform less in real operations than they were in these tests. This concerned notifying pilots when they have drifted off the airways. Because of the drift in the J-1-C simulators this drifting off the airways occurred with some frequency. This created an opportunity to score the controllers' performance on the two systems in this kind of task.

SAFETY

There was no significant difference between the two systems in the number of conflictions which occurred between aircraft. There was an average of approximately three conflictions per run in the case of both the SRS and VG type systems. The computed averages were 3.1 conflictions for the VG system and 2.6 conflictions for the SRS system. It is also notable that there was an interaction of sufficient strength to be statistically significant between the controllers and the systems. This means that some controllers were able to control more safely with one type of equipment while other controllers were able to control more safely with the other type of equipment. This is indicated by the average confliction data appearing in the following table:

CONFLICTIONS

	C_1	C_2	C_3	Average
Simulated VG	4	2	3	3 (3.1)
SRS	4	4	1	3 (2.6)
Average	4	3	2	

C_1 - Controller 1
C_2 - Controller 2
C_3 - Controller 3

EXPEDITIOUSNESS

Given the fact that the systems under study were equivalent with regard to the safety they provided to the aircraft under their control, primary reference must now be had to the expeditiousness criterion. It will be recalled that under this criterion, the better system would have fewer delays and require fewer changes in course and/or altitude of the aircraft in the system. In the current experiment, delays were studied. Only three holds occurred during the experiment and this was insufficient data for any analysis.

With regard to the aircraft maneuvers occasioned by the ATC system, the number of vectors given pilots per run was not statistically different between the systems. The only statistically significant difference in vectors which occurred was between the two traffic samples used (20 vs 28). Both systems involved scored about 24 vectors per run, (VG 23.8, SRS 25.0).

The other type of maneuver involved was altitude changes. The two systems did differ statistically in the number of altitude changes imposed by the air traffic system. The VG type system averaged 8 altitude changes per run, while the SRS system averaged 4 altitude changes per run.

Considering both types of maneuvers in combination, as control actions required by ATC, there was no statistical difference between the two systems. There was however a statistical difference between the two problems used. The interaction between the problems and controllers was also significant. Examination of the control action data shows, however, that the important factor in both significant effects was the high number of vectors imposed by Controller 3 when subjected to Problem 2. In all other conditions equality existed between all factors.

In summary, we have found that the two systems are approximately equal in the safety they provide, that there are no differences in the total number of maneuvers the aircraft must perform to obtain this safety and that the two systems are equal in expeditiousness. It should be noted, however, that the controllers resorted to altitude changes as the separating tool more often when using the VG system.

With regard to the communications required between pilots and controllers, communication was more frequent with the VG system (VG averaged 130 messages per run; SRS averaged 114 messages per run). Although the frequency differed, the total time duration of these messages was not different. From a practical point of view, it does not seem that it would be fair to say that one or the other system is more demanding with regard to the communication load required within the system.

The only criterion measure remaining for examination is that involving the vigilance of the controllers in suggesting to pilots that they return to the airway from which they have drifted. The manner in which this was scored was that the observer would watch for aircraft drifting off the airway and note whether the controller caught this and informed the pilot of it. The times that aircraft drifted off airways and the controller did not inform the pilot of it before the aircraft got more than seven miles off the airway were tallied. There were statistically different scores in this measure between scopes, controllers, and problems. There was also a significant interaction in this measure between scopes and problems. The average data are presented in the following table:

CONTROLLERS

	C_1	C_2	C_3
A/c off airways	2	2	3

SCOPES

	VG	SRS
A/c off airways	2	4

PROBLEMS

	P_1	P_2
A/c off airways	2	3

SCOPES x PROBLEMS INTERACTION

		VG	SRS
A/c off airways	P_1	1 (1)	3 (3.4)
	P_2	2 (2.3)	4 (3.6)
Average		(2)	(3.5)

Little interest attaches to the difference in problems, controllers, or the interaction between scopes and problems. The fact that the SRS runs averaged 4 such events and the VG runs averaged two such events may be of some importance. This could indicate that the controllers were busier using the SRS system and so less alert in their vigilance. This possibility would alert us to the danger of building systems with so many options and features that the man becomes a "dial twister." On the other hand, a more probable explanation might be that the operation of the SRS system requires less preoccupation with the exact physical location of the aircraft and the airways than the chip pushing operation on the VG scope does.

SUMMARY

In summary, then, the experimental data indicates some value in the SRS system from the point of view of requiring less altitude changes of the aircraft in the system. This might be a function of the altitude selective display possible with the SRS system. This may enable the reduction of unnecessary altitude changes. The fact that more altitude changes were required while using the VG type display is probably due to the controller's changing altitudes on a pre-planning basis according to strip estimates with the VG rather than using the current altitude display in the SRS type display. There is no difference in the communications required (of a degree to be practically important) and, there is no difference in the controller's ability to safely handle a traffic volume with the two systems. There is some tendency on the part of controllers to let aircraft drift more off the airway when using the SRS system.

In interpreting these data, perhaps the most important general conclusion is that there is very little appreciable difference found in this experiment between the two systems studied. This conclusion, however, must be viewed in context. To begin with, the experiment was of limited size and generality. It is rare that we can place a great deal of reliance on an experiment consisting of twelve 45 minute tests. This was primarily an exploratory study. This sort of experiment forms a guide for policy decisions but should not be the exclusive basis of policy decisions. A further fact is that the SRS system used here cannot be validly taken to be representative of all semi-automatic ATC tracking and display systems. The particular piece of gear used was a shop modified device in which the major effort was to more or less simulate the features which would be available in later systems. In doing this it was impossible to be very careful about arranging the features of the tracking and display systems for the convenience of the operator.

Another fact to remember is that this experiment considered a controller working alone. If the experiment were done with several controller positions where controllers required coordination, it is possible that the SRS system might have shown up more advantageously because of its special features for handling traffic between sectors.

It is also necessary to point out that when questioned after the experiment, the controllers who had operated the equipment expressed the opinion that a system of the general type represented by the SRS, but of an improved design, could give them an increased traffic handling capacity of up to 20% over the VG type operation

Finally, we must remember a factor which is always with us in ATC systems experimentation. This is an art which is progressing considerably, but has a long way to go. Parenthetically, the writers feel that the present series of experiments has made some contribution to the further development of ATC simulation technique by its employment of methods of experimental design and analysis even within the limits of what was essentially a crash program. Nonetheless, we still suffer from a major problem in ATC work which has yet to be solved and will probably never be solved unless some basic research on the problem is sponsored; namely, the criterion problem. In other words, it is probable that our criteria have not been sensitive enough to detect differences existing in the two systems. That the systems do not differ in a global measure like conflictions should not come as a complete surprise. Indeed, it is possible even in the case of any dramatically improved system, the value of the system might not be apparent through the measurement of conflictions. It is, on the other hand, probable that the major area of improvement will be in reducing the stress under which the controller works. It is in this area that the criterion problem lies since it is possible that a dedicated controller can overcome any deficiencies in his equipment through sheer effort. It is this effort which we are unable to measure at this time. Finding a way to measure it is not going to be an easy or quick operation.

APPENDIX A

Basic Data Tables

SRS vs VG

ALTITUDE CHANGES

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	10	6	4	3
Controller 2	9	6	5	3
Controller 3	8	9	6	5

VECTORS IMPOSED

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	21	26	22	19
Controller 2	18	27	24	28
Controller 3	19	32	15	42

MESSAGE FREQUENCY

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	127	116	110	97
Controller 2	146	175	139	138
Controller 3	100	118	92	106

MESSAGE DURATION (SEC.)

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	387	420	395	404
Controller 2	401	642	582	436
Controller 3	417	445	394	445

CONTROL ACTIONS
(Vectors + Altitude Changes)

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	31	32	26	22
Controller 2	27	33	29	31
Controller 3	27	41	21	47

HOLDS

	VG		SRS	
	P_1	P_2	P_1	P_2
Controller 1	0	0	0	0
Controller 2	0	0	0	1
Controller 3	0	0	0	2

APPENDIX A

Basic Data Tables

Simulated VG vs SRS

		CONFLICTING A/C				A/C OFF AIRWAY			
		VG		SRS		VG		SRS	
		O_1	O_2	O_1	O_2	O_1	O_2	O_1	O_2
P_1	C_1	5	4	2	6	1	1	3	3
	C_2	2	2	5	5	0	1	3	2
	C_3	3	3	2	1	1	2	5	5
P_2	C_1	4	4	4	3	2	2	3	3
	C_2	3	2	3	2	2	2	5	3
	C_3	4	3	0	1	4	2	5	3

P = Problem

O = Observer

C = Controller

APPENDIX A

COMPARISON OF DATA BETWEEN RUNS 1, 2 AND RE-RUNS 1, 2

RUN SCOPE PROBLEM SUBJECT	RUN 1 SRS 2 1	RE-RUN 1 SRS 2 1	RUN 2 VG 2 2	RE-RUN 2 VG 2 2
A - CONFLICTING AIRCRAFT				
A - Observer 1	4	1	3	1
B - Observer 2	3	2	2	1
B - AIRCRAFT OFF AIRWAY				
A - Observer 1	3	3	2	1
B - Observer 2	3	3	2	1
C - HOLDS	0	0	0	1 - 2 turns
D - ALTITUDE CHANGES	3	7	6	6
E - VECTORS IMPOSED				
A - Re-idents	0	0	0	0
B - Separation	14	15	16	18
C - Return to airway	5	7	11	13
F - COMMUNICATIONS MEASURE				
A - Frequency	97	Not	175	152
B - Duration (Sec)	404	Measured	642	575
G - TRACKING CONFUSION	2	0	1	0

SECTION VI

A COMPARISON OF CIRCLES AND DOTS AS TRACKING SYMBOLS FOR THE SRS SYSTEM IN AIR TRAFFIC CONTROL

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A COMPARISON OF CIRCLES AND DOTS AS TRACKING SYMBOLS FOR THE SRS SYSTEM IN AIR TRAFFIC CONTROL

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PURPOSE

To compare circles and dots for effectiveness as tracking symbols. Statistical tests were run to compare circles and dots as tracking symbols with regard to two aspects of effectiveness:

a. Target initial capture

b. Velocity insertion.

TARGET INITIAL CAPTURE

Procedure

Ten targets were placed in the general form of a circle at various ranges about the scope face. Subjects were instructed to acquire these ten targets as rapidly as possible. Each of these subjects did three runs with circles and three runs with dots. The targets were acquired by placing the dots at the center of the targets; in the case of the circles, the targets were acquired by placing the symbols so that the circle surrounded the center of the target. The measure taken was the total time in seconds required to capture all ten targets.

Results

The following table presents the scores in seconds which were obtained.

	DOTS	CIRCLES
Operator 1	81 68 70	59 64 52
Operator 2	82 83 89	76 74 66
Operator 3	76 76 67	50 57 54
Mean	76.9	61.3

It can be seen from the table that a speed difference exists between circles and dots. This difference is very reliable statistically (.002 level, sign test), indicating the conclusion would be the same 998 times out of 1000.

In summary it is concluded that circles are significantly faster for initial acquisition of targets.

VELOCITY INSERTION

Procedure

Matching the target velocity with the tracking channel velocity is a very important aspect of tracking. The circle and dot symbols were checked to see if the symbol had any effect on the speed or accuracy of this velocity matching procedure. A test was set up which measured the time it took the subjects to adjust tracking channel speed to target speed. The channels were intially set at speeds different from the targets to be tracked. Four targets with associated tracking channels (or gates) were presented to the tracker at the beginning of each run. Each target was going in a different direction, i.e., one was going east to west, one west to east, one north to south, one south to north.

A total of 16 runs was made. Each of the two subjects did four runs with circles and four with dots; in two of these runs the tracking channels were initially set at 100 knots faster than the target, and in two of the runs the tracking channels were 100 knots slower than the targets. All targets were about 300 knots in speed. The subjects were not given any of this information.

The design of this experiment was as follows:

		CIRCLES		DOTS	
		Replication 1 Gates	Replication 2 Gates	Replication 1 Gates	Replication 2 Gates
0 kts eater Than rget	Subject 1	1 3 5 7	1 3 5 7	1 3 5 7	1 3 5 7
	Subject 2	1 3 5 7	1 3 5 7	1 3 5 7	1 3 5 7
0 kts Less Than rget	Subject 1	1 3 5 7	1 3 5 7	1 3 5 7	1 3 5 7
	Subject 2	1 3 5 7	1 3 5 7	1 3 5 7	1 3 5 7

16

The runs were performed in random order. Observers were assigned to record the time and speed each time the tracker made a correction to the tracking gate. The trackers were instructed to make corrections only when the target was completely outside the circle or when the target was not in contact with the dot. These instructions removed minor variations due to not centering the gate.

VELOCITY INSERTION (Continued)

Results

The basic data collected in the experiment are shown in Appendix A, Table 1. The figures shown are the times in minutes and decimal portions of minutes at which the trackers made adjustments in the speeds. It will be noted from the data that it was not possible to start all gates out at exactly the speed called for in the design. There was also some difficulty with the speed adjustment of the 15-J-1-C target generators.

These difficulties were overcome in the data analysis in the following manner. The assumption was made that in all cases the trackers had adjusted the tracking channels to within a very close agreement with the true speed of the targets. Since the same targets were always used with the same gates, the final gate speed readings were appropriately averaged to determine the true speeds of the targets. Then, the fact that the gates were not set out at exactly 100 knots greater than or less than the true target speed was overcome by expressing all of the difference between the gate speeds and target speeds in terms of a percentage of the true target speed:

$$\frac{\text{Target Speed} - - \text{Gate Speed}}{\text{Target Speed}} .$$

Further analyses were done in terms of these percentages rather than in absolute numbers. These percentages appear in Appendix A.

These percentage curves were averaged in various combinations, and average curves for the important conditions of the experiment appear in Figure 1 and Figure 2 in Appendix A. Since the speed changes with time were in steps, it was possible to determine the percentage deviation at all intervening times. For 2-second increments the percentage deviations were averaged for all sessions in which dots were used, and for all sessions in which circles were used. Since the variability within any given time interval was small, it was not necessary to transform the percentages for averaging. The median values were also plotted (Fig. 2, Appendix A).

An analysis of variance was performed to examine the effect of the major variables in the experiment. The performance measure chosen for analysis was the time at which the subject had been able to adjust and maintain the gate speed to within 10% of the target speed. These times are shown in Table 2. Table 2 was used in the analysis of variance, after use of a logarithmic transformation to normalize the data.

The variables studied in the analysis of variance were as follows:

1. Symbol types (circle vs dot)
2. Initial target - channel speed relationship (i.e., gate initially 100 knots faster than target vs gate initially 100 knots slower than target)
3. Trackers (subjects)
4. Channel-target combinations (i.e., the specific J-1-C targets and SRS-1 tracking channels used in combination out of those available).

The analysis of variance of the data on the times at which the subjects got and kept the gates within 10% of the true speed indicated that there was no difference between the circles and dots as tracking symbols. Similarly, there was no difference in the adjustment time depending on whether the gate was initially slower or faster than the target. Neither were any of the two variable interactions significant (e.g., initial speed X circles-dots).

There was a statistically significant difference among the channel-target combinations. The average times for the four channel-target combinations are as follows:

TARGET-GATE COMBINATIONS

	#1	#3	#5	#7
Time to adjust speed to within 10% of true target speed (minutes)	2.13	2.11	4.24	3.07

This may reflect some defect in 2 of the tracking channels used.

Two of the four 3-variable interactions were significant, i.e., subjects by target-channel combinations by symbol types, and, initial channel-target speed relationship by target-channel combination by symbol types. However, these higher order interactions have no practical significance.

It is concluded that there is no difference between circles and dots as tracking symbols as concerns the effectiveness of velocity insertion.

APPENDIX A

Table 1

BASIC DATA

Subject 1/Circles

Gate Speed 100 Knots Less Than Target Speed

Channel #1				Channel #3				Channel #5				Channel #7			
TS 286				TS 286				TS 252				TS 252			
Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS
0 00	190	96	33	0 00	200	86	30	0 00	190	62	.25	0 00	190	62	25
0 75	210	76	27	0 75	230	56	19	1 00	200	52	21	1 13	220	32	.13
1 50	300	14	05	2 25	260	26	09	1 75	220	32	13	2 58	230	22	09
4 00	280	6	02	4 00	260	26	09	2 33	230	22	09	3.42	400	148	59
7 75	290	4	01	5 00	290	4	01	3 08	240	12	05	3 75	240	12	05
8 00	290	4	01	6 25	300	14	05	4 28	250	2	01	5 13	260	8	03
				8 00	300	14	05	5 00	250	2	01	7 10	250	2	01
								6 25	260	8	03	8 00	250	2	.01
								7 50	260	8	03				
0 00	190	96	33	0 00	200	86	.30	0 00	190	62	25	0 00	190	62	.25
0 50	210	76	27	0 50	240	46	16	0 75	200	52	21	0 91	220	28	11
1 33	250	36	12	1 33	240	46	16	1 50	220	32	13	1 75	250	2	01
3 50	250	36	12	2 00	270	16	05	2 25	230	22	09	3 42	240	12	05
4 08	280	6	02	3 50	280	6	02	3 25	240	12	05	3 91	290	38	15
6 25	270	16	.05	5 16	280	6	02	4 50	250	2	01	4 58	230	22	09
7 50	290	4	01	6 50	300	14	05	5 50	260	8	03	5 55	250	2	01
8 00	290	4	01	7 50	250	36	12	6 75	260	8	03	6 91	270	18	07
				8 00	260	26	09	7 66	270	18	07				
								8 00	270	18	07	8 00	270	18	07

Gate Speed 100 Knots Greater Than Target Speed

Channel #1				Channel #3				Channel #5				Channel #7			
TS 286				TS 286				TS 286				TS 252			
Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS	Time	Gate Speed	TS-GS	TS-GS/TS
0 00	400	114	40	0 00	420	134	47	0 00	400	114	40	0 00	400	148	59
0 50	360	74	26	0 50	380	94	33	0 66	380	94	33	0 83	330	78	31
1 08	290	4	01	1 08	300	14	05	1 41	370	84	29	1 50	250	2	05
2 83	270	16	05					2 41	350	64	22	2 00	320	68	27
7 25	270	16	05					3 00	340	54	19	2 80	270	18	07
7 50	270	16	05	7 50	300	14	05	3 66	340	54	19	5 16	250	2	01
8 00	270	16	05	8 00	300	14	05	4 58	320	34	12	7 83	230	22	09
								5 75	310	24	08	8 00	230	22	09
								6 75	310	24	08				
								7 75	300	14	05				
								8 00	300	14	05				
0 00	400	114	40	0 00	420	134	47	0 00	400	114	40	0 00	400	148	59
0 58	350	64	22	0 58	340	54	19	0 83	390	104	36	0 92	340	88	35
1 41	300	14	05	1 41	310	24	08	1 41	370	84	29	1 50	250	2	01
2 58	270	16	05	3 50	290	4	01	2 25	360	74	.26	2 33	270	18	07
5 00	270	16	05	6 41	280	6	02	2 92	350	64	22	3 17	260	8	03
6 41	270	16	05	7 75	280	6	02	3 50	340	54	19	5.83	250	2	01
8 00	270	16	05	8 00	280	6	02	4 50	330	44	15	7 08	260	8	03
								5 41	320	34	12	8 00	260	8	03
								6 83	310	24	08				
								8 00	300	14	05				

NOTE: TS = true target speed
GS = gate speed

Table 1 (Continued)

BASIC DATA

Subject 2/Circles

	Channel #1				Channel #3				Channel #5				Channel #7			
	TS 286				TS 286				TS 252				TS 252			
	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS
Gate Speed 100 Knots Less Than Target Speed	0 00	190	96	.33	0 00	210	76	27	0 00	190	62	25	0 00	190	62	.25
	1 83	210	76	27	0 92	230	56	19	1 12	210	42	.17	1 42	210	42	.17
	3 75	220	66	.23	2 25	240	46	16	2.58	220	32	13	3 50	220	32	13
	4.92	260	26	09	4 25	260	26	09	4.54	240	12	.05	6 42	230	22	09
	6 16	240	46	16	6 25	270	16	05	6 33	250	2	01	8 00	230	22	.09
	7 25	290	4	01	8 00	270	16	.05	8 00	250	2	01				
	8.00	290														
	0 00	190	96	33	0 00	200	86	.30	0.00	190	62	25	0.00	190	62	25
	1 00	190	96	33	1 25	230	56	19	1 37	210	42	17	1 66	200	52	21
	2 00	250	36	12	3 58	260	26	09	2 83	220	32	13	3.13	220	32	13
	3 33	290	4	01	5 58	270	16	05	4 30	230	22	09	5 95	240	12	05
	5 50	270	16	05	8 00	270	16	.05	5.83	250	2	01	8 00	240	12	05
	8 00	270	16	05					8 00	250	2	01				

	Channel #1				Channel #3				Channel #5				Channel #7			
	TS 286				TS 286				TS 286				TS 252			
	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS	Time	Gate Speed	TS-GS	(TS-GS)/TS
Gate Speed 100 Knots Greater Than Target Speed	0 00	390	104	36	0 00	400	114	.40	0.00	390	104	36	0.00	400	148	59
	0.50	340	54	19	0 66	330	44	15	0 05	380	94	33	0 57	320	68	.27
	1 25	270	16	.05	2 42	330	44	15	1 15	360	74	26	1.25	330	78	31
	2 16	270	16	.05	3 58	320	34	12	2.32	340	54	.19	1.75	210	42	17
	5 10	270	16	05	5 58	320	34	.12	3.66	320	34	.12	3 97	220	32	.13
	8.00	270	16	05	7 66	300	14	05	3 80	300	14	05	6 08	240	12	.05
					8.00	300	14	.05	8 00	300	14	.05	8.00	240	12	.05
	0.00	400	114	40	0 00	390	104	36	0.00	390	104	.36	0.00	400	148	.59
	0.58	300	14	.05	0 75	320	34	12	0.87	370	84	.29	0.97	300	48	19
	4 17	280	6	02	2 00	300	14	05	2 20	340	54	.19	2.50	260	8	03
	8 00	280	6	02	8 00	300	14	.05	3.47	320	34	.12	4 93	250	2	01
									6.13	300	14	.05	7 20	250	2	01
									8.00	300	14	05	8.00	250	2	01

NOTE: TS - true target speed
GS - gate speed

Table 1 (Continued)

BASIC DATA

Subject 1/Dots

Gate Speed 100 Knots Less Than Target Speed

Channel #1				Channel #3				Channel #5				Channel #7			
TS 286				TS 286				TS 252				TS 252			
Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS
0 00	190	96	33	0 00	200	86	30	0 00	180	72	29	0 00	190	62	25
1 08	240	46	.16	1 08	260	26	09	1 25	210	42	17	1 36	210	42	17
2 42	410	124	13	2.50	270	16	05	2 60	230	22	09	1 78	230	22	.09
3.50	400	114	40	4 33	280	6	02	4 60	250	2	01	5 38	240	12	.05
4 33	290	4	01	6 08	290	4	01	6.25	260	8	03	7.42	240	12	05
7 00	290	4	01	8 00	290	4	01	8 00	260	8	03	8 00	250	2	01
8 00	290	4	01												
0 00	190	96	33	0 00	190	96	33	0 00	190	62	25	0 00	190	62	25
0 58	210	76	27	0 58	130	156	55	0 58	190	62	25	0 66	200	52	21
1 50	250	36	12	1 08	190	96	33	1 17	200	52	21	1 20	220	32	13
1 75	240	46	16	1 75	240	46	16	1 75	200	52	21	2 00	260	8	03
2 75	250	36	12	2 75	270	16	05	2 17	220	32	13	3 17	250	2	01
3 50	260	26	09	3 50	330	44	15	2 83	230	22	09	8 00	250	2	01
5 00	270	16	05	5 33	330	44	15	3 83	240	12	05				
7 17	270	16	05	6 08	290	4	01	4 75	240	12	05				
8 00	270	16	05	7 33	290	4	01	5 50	240	12	05				
				8 00	290	4	01	6 33	250	2	01				
								75	250	2	01				
								7 75	260	8	.03				
								8 00	260	8	03				

Gate Speed 100 Knots Greater Than Target Speed

Channel #1				Channel #3				Channel #5				Channel #7			
TS 286				TS 286				TS 286				TS 252			
Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS
0 00	400	114	40	0 00	420	134	47	0 00	400	114	40	0 00	400	148	59
2 50	350	64	22	1 00	370	84	29	1.08	380	94	.33	1 20	370	118	47
3.75	330	44	15	2 50	370	84	29	2 17	360	74	26	2.33	270	19	07
4 50	300	14	05	4.50	290	4	01	2.92	350	64	22	4.00	250	2	01
6 00	260	26	09	5 00	310	24	08	3 66	330	44	15	5 16	250	2	01
6 66	270	16	05	6 00	290	4	01	5 83	310	24	08	6 08	250	2	01
7 00	290	4	01	8.00	290	4	01	7 41	300	14	05	8.00	250	2	01
8 00	290	4	01					8 00	300	14	05				
0 00	390	104	.36	0 00	410	124	43	0 00	390	104	.36	0 00	400	148	59
0 50	320	34	12	0 50	370	84	29	0.58	390	104	36	0.75	370	119	47
2 00	300	14	05	1 25	350	64	22	1 42	380	94	33	1 50	300	48	19
2 42	250	36	12	2 00	310	24	08	2 66	360	74	26	2 50	270	18	07
3 42	270	16	05	3 42	310	24	08	3 66	350	64	22	3 75	250	2	01
6 25	270	16	.05	6.25	310	24	08	4 33	340	54	.19	4 66	250	2	01
8 00	270	16	05	7 00	310	24	08	5 25	320	34	12	5 33	270	18	07
				7 08	300	14	05	5 83	310	24	08				
				8 00	290	4	01	8 00	310	24	08	8 00	270	18	07

NOTE: TS = true target speed
GS = gate speed

Table 1 (Continued)

BASIC DATA

Subject 2/Dots

	Channel #1				Channel #3				Channel #5				Channel #7			
	TS 286				TS 286				TS 252				TS 252			
	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS
Gate Speed 100 Knots Less Than Target Speed	0 00	190	96	33	0 00	200	86	30	0 00	190	62	.25	0 00	190	62	25
	0 33	210	76	.27	0 50	220	66	23	1 05	200	52	21	1 07	220	32	13
	1 08	280	6	02	1 17	260	26	09	1 83	210	42	17	2.03	240	12	05
	4 42	240	46	16	4 67	260	26	09	3 42	230	22	09	3 65	240	12	05
	5 58	260	26	09	5 75	270	16	06	4 87	230	22	.09	6 72	250	2	01
	6 42	260	26	09	6 75	280	6	02	6 13	240	12	05	8 00	250	2	01
	8 00	260	26	09	8.00	280	6	02	8 00	250	2	01				
	0 00	200	86	30	0.00	200	86	30	0 00	190	62	25	0 00	200	52	21
	1 83	210	76	27	1 92	220	66	23	2 02	230	22	09	1 50	240	12	05
	3.16	260	26	09	3 33	260	26	09	4 83	250	2	01	3 67	240	12	.05
	6 15	260	26	09	6 33	290	4	01	6 15	250	2	01	8 00	240	12	05
	8 00	260	26	09	8 00	290	4	01	8 00	250	2	01				

	Channel #1				Channel #3				Channel #5				Channel #7			
	TS 286				TS 286				TS 286				TS 252			
	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS	Time	Gate Speed	TS-GS	TS-GS / TS
Gate Speed 100 Knots Greater Than Target Speed	0 00	400	114	40	0 00	390	104	36	0 00	390	104	36	0.00	390	138	.55
	1 16	360	74	26	0 67	270	16	06	0.97	300	14	05	1.07	290	38	15
	2 50	300	14	05	1 83	270	16	06	2 07	360	74	26	2 20	290	38	15
	5 42	290	4	01	4 00	280	6	02	3 33	330	44	15	3.75	250	2	01
	8.00	290	4	01	6 50	280	6	02	4 75	320	34	12	5 10	270	18	07
					8 00	280	6	02	6.75	300	14	.05	7 15	260	8	03
									8.00	300	14	05	8 00	260	8	.03
	0 00	390	104	36	0.00	420	134	47	0.00	390	104	.36	0.00	400	148	.59
	0 50	260	26	09	0 66	300	14	05	1 28	370	84	29	0.97	360	108	.43
	2.33	270	16	06	2 66	290	4	01	2 95	330	44	15	2 07	350	98	39
	8 00	270	16	.06	5 16	300	14	05	4 72	320	34	12	3.20	320	68	27
					8 00	300	14	05	6.53	300	14	.05	4.33	260	8	03
									8 00	300	14	.05	8.00	260	8	.03

NOTE: TS = true target speed
GS = gate speed

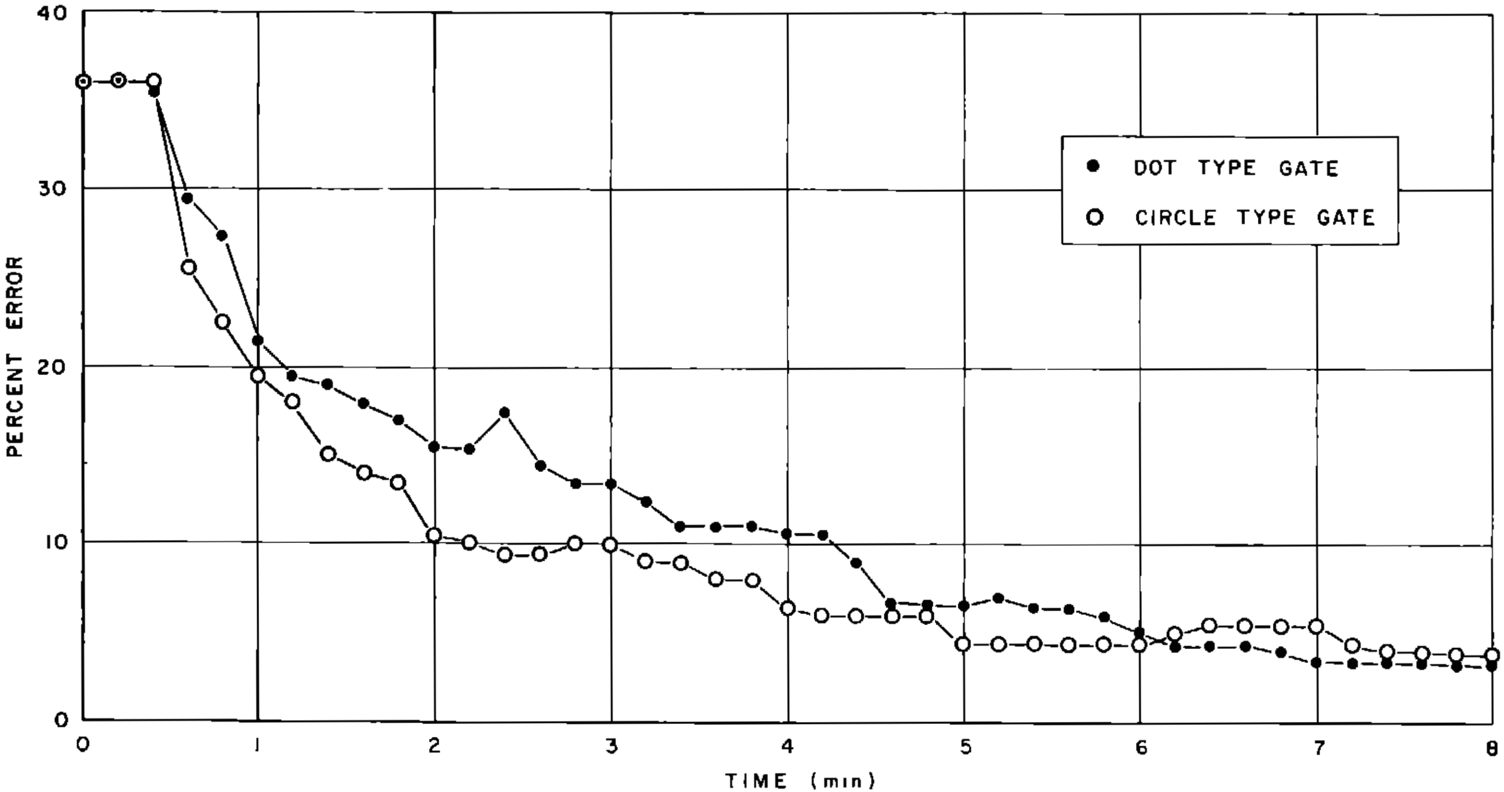

FIGURE 1 AVERAGE ERROR BETWEEN TARGET AND GATE

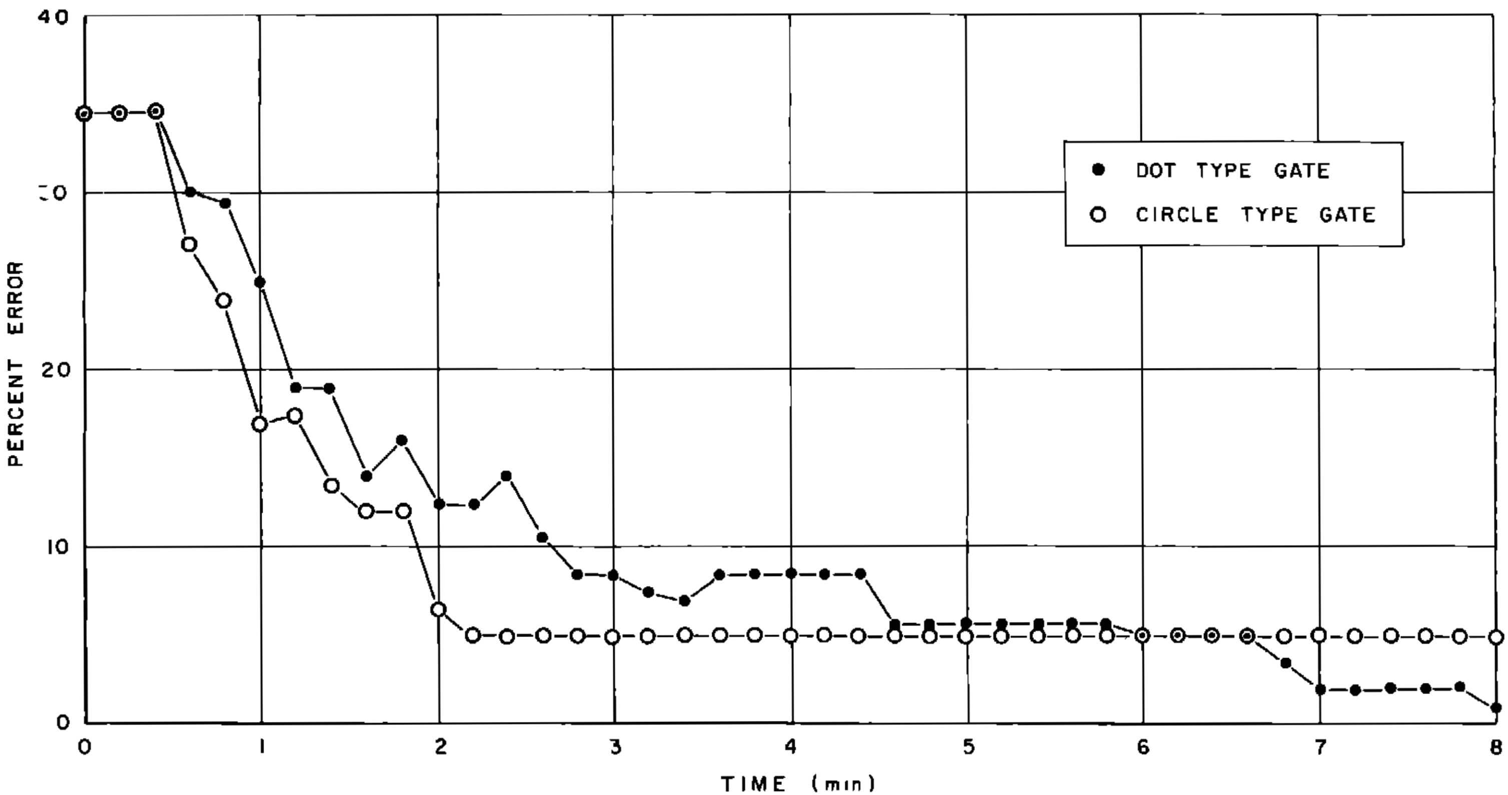

FIGURE 2 MEDIAN ERROR BETWEEN TARGET AND GATE

Table 2

DATA ON ARRIVAL TIME
AT 10% POINT

		CIRCLES				DOTS			
		R1		R2		R1		R2	
		Gates	Time	Gates	Time	Gates	Time	Gates	Time
Gates 100 kts Greater Than the Target Speed* (400)	S1	1	1.50	1	4.08	1	4.33	1	3.50
		3	2.25	3	2.00	3	1.08	3	6.08
		5	2.33	5	2.25	5	2.60	5	2.83
		7	3.75	7	4.58	7	1.78	7	2.00
	S2	1	7.25	1	3.33	1	5.58	1	3.16
		3	4.25	3	3.58	3	1.17	3	3.33
		5	4.54	5	4.30	5	3.42	5	2.02
		7	6.42	7	5.95	7	2.03	7	1.50

		R1		R2		R1		R2	
		Gates	Time	Gates	Time	Gates	Time	Gates	Time
Gates 100 kts Less Than the Target Speed* (200)	S1	1	1.08	1	1.41	1	4.50	1	3.42
		3	1.08	3	1.41	3	4.50	3	2.00
		5	5.75	5	6.83	5	5.83	5	5.83
		7	2.80	7	1.50	7	4.00	7	2.50
	S2	1	1.25	1	0.58	1	2.50	1	0.50
		3	7.66	3	2.00	3	0.67	3	0.66
		5	5.80	5	6.13	5	6.75	5	6.53
		7	6.08	7	2.05	7	3.75	7	4.33

*Target Speed Approximately 300 Kts