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EVALUATION OF A THREE-DIMENSIONAL PICTORIAL AIR TRAFFIC CONTROL DISPLAY

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by

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SUMMARY

This report describes the operational evaluation by simulation techniques of a pictorial-type air traffic control display in order to determine its application to the control of high-altitude aircraft in the present air traffic control system.

The use of transparent tapes in conjunction with transparent plates to represent aircraft vectors and altitudes, respectively, forms the basis of the display. Each transparent tape is imprinted with a longitudinal line and with arrows to represent a track and the direction of flight, and with transverse lines and numerals to represent consecutive increments of time at a selected ground speed. Aircraft vectors are depicted by affixing appropriate tapes to a plate. Routes of flight, estimated locations at any time along the routes, and locations and times at which the routes will intersect are portrayed pictorially for all aircraft represented by the tapes at the altitude represented by the plate. By placing similarly prepared plates, one behind the other, in a horizontal or vertical stack, a three-dimensional presentation of traffic in a selected block of airspace is formed.

A prototype display, utilizing the above procedure, was fabricated and tested. It was found to be unsatisfactory because all flight posting was performed with the plates positioned in the display, and all flights assigned the same altitude were posted on the same plate. These methods necessitated the sharing of both the plates and the working space by both the posting and the control operating positions.

A modified model was evolved which permitted each aircraft to be posted on an individual plate. The plates then were assembled by altitudes. The tests of the modified display confirmed the greater utility of these procedures, and indicated the possible application of the principles to an operational display as well as to the simulation of certain features of an electronically generated pictorial-type display.

INTRODUCTION

In March 1957, a preliminary study of the principles and display design representing a new concept in air traffic control (ATC) displays was begun by the CAA Technical Development Center (TDC). This concept, which originated as an employee suggestion submitted by Mr. L. C. Moore* of the Fort Worth Air Route Traffic Control (ARTC) Center, was forwarded by the CAA Office of Air Traffic Control to TDC for study and possible evaluation.

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The suggestion set forth the principles of a display designed to facilitate the exercise of control over all airspace from 24,000 feet upward, and to replace the tabular-type ATC display. In lieu of a tabular display, the suggestion proposed the use of tapes to form a pictorial-type display having the tracks, points of intersection, and positions of all aircraft being controlled depicted continuously in a three-dimensional (3-D) manner. It was suggested that the principles incorporated in such a display would

1. Display both the vertical and horizontal relationships of aircraft.

2. Display both the present and future relationships of aircraft.

3. Depict aircraft as vectors which would indicate the amount of existing separation between aircraft in terms of time, and the amount of separation which could be expected at any point along a route of flight

4. Depict the effective altitudes and boundaries of special areas to be taken into consideration in the control of air traffic.

5. Display off-airway traffic as effectively as airway traffic

6. Permit the posting of control data covering the entire route of flight in one rapid operation.

7. Permit newly posted traffic to be filtered immediately in order to ascertain the most nearly confliction-free altitude or route.

8. Be usable with any form of ground or airborne navigational system.

9. Complete the requirements of a radar ATC system for the control of high-altitude traffic.

The preliminary study indicated that an evaluation of the principles of the display would be useful, and the design of a prototype model was initiated in May 1957. Although the fabrication of a working model of the display was completed in December 1957, difficulties in obtaining a supply of vector tapes for flight posting delayed the evaluation tests until April 1958.

Examination of the prototype model of the pictorial display suggested the possibility of combining it with some form of bright or projected radar. Accordingly, provision was made in the tests for operation of the display in conjunction with the superimposed panoramic radar display (SPANRAD) developed at TDC and also for experimentation with projected radar

EVALUATION OBJECTIVES

The evaluation of the suggested 3-D display was conducted in order to:

1. Test the principles for the control of all airspace, especially for the control of high-speed aircraft operating at high altitudes.

2. Determine the desirability of modifying the prototype display for further evaluation.

3. Determine possible uses of a 3-D pictorial-type display in conjunction with direct-view, bright, or projected radar.

4. Determine, insofar as possible, operating procedures and the requirements, characteristics, and features of a display suitable for in-service evaluation.

5. Determine the feasibility of using the suggested principles to simulate a computer-generated, pictorial, electronic display.

EQUIPMENT DESCRIPTION

Prototype 3-D Pictorial Display.

The prototype display, shown in Fig. 1, consisted of a metal frame enclosing six glass plates, each 31 inches by 31 inches in size, the tracks upon which the plates were moved from one side of the display to the other, and the mechanism for moving the plates. The frame was 64 inches long, 39 inches high, and 4 1/2 inches deep, and was divided vertically into two areas or bays of equal size. Each of the glass plates represented one altitude or flight level, and could be positioned individually in either of the bays by means of the hand cranks at the bottom of the display, operating through a system of gears and drive chains.

The bay on the right was designated the posting bay, and a map depicting a control area 500 nautical miles square was situated on the back of the bay. The bay on the left was designated the control bay, and was back-lighted by a lighting device occupying the position corresponding to the map behind the posting bay.

Suitable interphone and air/ground/air communications equipments were terminated at the display for use at each bay, and a small flight progress board was situated adjacent to the posting bay.

Vector Tapes.

Flight posting was accomplished by means of preprinted, adhesive, transparent cellulose tapes shown in Fig 2. Each tape was printed with a longitudinal line and arrows indicating the route and direction of flight, with transverse lines representing consecutive 5-minute increments of time, and with numerals indicating the ground speed represented by each tape and the minutes represented by each transverse line. For test purposes, a supply of tapes was obtained in each of three speeds, 425, 500, and 550 knots, which were chosen as representative of the speeds of aircraft in use and which afforded a usable range.

Flight Progress Board Display.

As shown in Fig. 3, flight progress boards representing the controller and assistant controller positions for two sectors were equipped with the necessary communications equipment, and were operated in the conventional manner for comparison with the pictorial display.

Auxiliary Equipment.

In some modes of operation, the basic displays were augmented by the auxiliary equipment shown in Figs. 3, 4, and 5. The TDC dynamic ATC simulator was used in conjunction with all modes of operation of the flight progress boards and of the prototype pictorial display. As described elsewhere in this report, one or two SPANRAD's were used in various modes of operation of the prototype pictorial display and of the flight progress board display. In addition, a television camera was employed as a third input to a SPANRAD in superimposing handoff situations for the SPANRAD controller from the pictorial display.

TEST ENVIRONMENT

The prototype model of the pictorial display was situated in the en route laboratory adjacent to the dynamic ATC simulator, and was provided with key-box equipment capable of simulating air/ground/air voice communications, and long-line and local interphone communications. In order that a comparison could be made, a simulated ARTC Center, equipped with conventional flight progress strips and tabular-type flight progress boards, was located adjacent to the pictorial display.

A hypothetical control area was established, with Indianapolis at the center and with secondary radar coverage of 200 nautical miles' radius Appropriate maps were prepared, based on the High-Altitude Facility Charts published by the U. S. Department of the Air Force. Figure 6 shows one of the maps mounted in the display.

The principles of the prototype display being tested were suggested as making possible a three-dimensional, pictorial-type display, applicable to an area control concept (control of all airspace) at high altitudes (24,000 feet and above). The aircraft usually flying at such altitudes normally have a ground speed of 400 knots or more, and in order to test the capabilities of the display in the control of high-speed aircraft over a relatively large geographical area, a departure was made from the conventional sector pattern. The control area was not divided geographically into sectors but was divided by altitudes. In this test, the 29,000- to 39,000-foot altitudes, inclusive, represented a sector having lateral boundaries coincident with those of the control area. The adjacent sectors thus would begin at 40,000 feet and extend upward, and at 28,000 feet and extend downward, and would have the same lateral boundaries.

The tabular-type flight progress board display used for comparison controlled the same six altitudes, but was divided geographically into two sectors because the number of fix postings necessary was too great for effective operation by one controller The sector division line extended from north to south approximately through the center of the control area, as shown in Fig. 7.

It was anticipated that the comparison of the pictorial and tabular displays also would yield, as a by-product, an indication of any differences in the amount of traffic coordination required by altitude sectorization as opposed to geographic sectorization.

Four traffic samples were prepared, each providing a traffic density of approximately 35 aircraft per hour. Each sample had a running time of 1 hour 15 minutes, and began with approximately 10 aircraft already posted. It was designed so that the full 24-target capacity of the simulator was airborne within the area for approximately 75 per cent of the sample running time.

Four controllers and two assistant controllers familiar with most of the control area covered in the tests were furnished by the Indianapolis ARTC Center In order to minimize learning and memory factors, four lists of aircraft identifications and aircraft types were used, and these lists, the traffic samples, and the operating positions of the controller personnel were changed for each test run.

Two observers were assigned from the TDC staff to monitor the control exercised in the various runs. The observers noted the number and type of potential conflictions which occurred, the number of potential conflictions not noted or resolved by the controllers, and the number of potential conflictions which were resolved by the use of radar.

In order to present an operating situation as realistically as possible, all inbound flight data were transmitted by interphone from a "ghost" position to the appropriate operating positions, and all flight data on aircraft outbound from the control area were transmitted similarly from the operating positions to a second ghost position. All coordination between sectors, and between the display controllers and the radar controllers in those modes utilizing radar, was accomplished by means of interphone, and all controller/pilot communications took place over the simulated air/ground/air channels. The number and duration of all air/ground/air and interphone contacts were measured automatically and recorded electrically.

The tabular and the prototype pictorial displays each were operated in four different modes.

1. Mode 1 utilized the displays only, and employed Army-Navy-Air Force-CAA (ANC) procedures and separation standards

2. Mode 2 utilized a direct-view radar scope in conjunction with the display for each sector, and basically employed ANC procedures and separation standards. However, radar procedures and separation standards could be employed at the discretion of the display controller.

3. Mode 3 utilized a SPANRAD in conjunction with the display for each sector, and basically employed ANC procedures and separation standards. However, radar procedures and separation standards could be employed at the discretion of the display controller.

4. Mode 4 utilized a SPANRAD for all control of aircraft in each sector and the associated displays were used only for backup in the event of radar failure and to carry detailed flight information. In this mode, combinations of ANC and radar procedures and separation standards were used at the discretion of the display controller.

TEST PROCEDURES

Mode 1.

The tabular display was operated in Mode 1 as two sectors of an ARTC Center, with no radar, and staffed by two controllers and two assistant controllers. The display was operated in the conventional manner, using ANC procedures and separation standards.

In Mode 1, the prototype pictorial display also was operated without radar. However, it encompassed in one sector the same airspace represented by two sectors on the tabular display, and was staffed by two controllers and one assistant controller.

In the operation of the pictorial display, an estimate on each flight inbound into the control area, or on each departure from within the area, was forwarded by a ghost position by means of interphone to the assistant controller, who copied the information on a flight progress strip. The glass plate representing the appropriate altitude then was selected by the assistant controller and positioned in the right bay by means of the associated hand crank.

A vector tape representing the proper ground speed then was selected, and beginning at the time and fix indicated in the flight plan, the flight was posted in accordance with the authorized route. The aircraft identification, the appropriate hour or hours, and such supplemental information as climb and descent data were written on the tape by means of a china marking pencil.

In order to filter the traffic, the display controller then checked for potential conflictions with other aircraft posted previously at the same altitude and, if such conflictions existed, positioned the plate in the left bay in order to ascertain if a confliction-free altitude was available for the route requested. If an altitude change would avoid conflictions, such a change was coordinated with the facility under whose jurisdiction the flight then was operating. Because of communications equipment limitations, such coordination was assumed for purposes of the test. If a confliction-free altitude did not exist or if a change of altitude could not be effected, the points of potential confliction were indicated for the air/ground controller by affixing small adhesive tabs to the plate adjacent to the points where the conflictions would occur. There were two basic methods considered for indicating an aircraft climbing to, or descending from, an assigned altitude. The first method used was to affix a small adhesive tab, marked with either a climb or a descent arrow, to the plate adjacent to the point where the climb or descent was commenced. The second method was to mark, with red grease pencil, the portion of the vector tape corresponding to the portion of the flight path involved in the altitude change. Any deletions, additions, or corrections of posted data were accomplished in the right bay.

Following the completion of flight posting and confliction search, the plate was positioned in the left bay, and the display controller and the air/ground controller collaborated as necessary in determining whether any control instructions were to be issued.

All air/ground/air contacts were made by the air/ground controller, who also revised the posted vector tapes, removed the portions of tape representing completed segments of the flight, and performed any other operations necessary to maintain the current status of the posted flight data. The controller could accomplish these actions by positioning the plate bearing the posting of the aircraft with which he was in contact so that the appropriate vector tape was accessible to him.

The estimates and flight data on aircraft outbound from the area were forwarded by the assistant controller to a second ghost position at least 15 minutes prior to the time the aircraft was estimated to pass the last fix in the area. This estimated time was written on the flight progress strip at the time the posting was completed, and it was the responsibility of the display controller to keep this time, and any other flight data, current on the flight progress strip representing each flight.

Mode 2.

In Mode 2 the displays were operated as in Mode 1 and, in addition, a direct-view radar scope was available at each sector. These scopes were represented by SPANRAD's without the use of the tracking surface. Each SPANRAD was staffed by an additional controller, making a total of four controllers for the tabular display, and three controllers for the pictorial display. The display controllers could make use of radar through the radar controllers for identifying and separating aircraft in accordance with the Standard Manual of Radar Air Traffic Control Procedures, in addition to their own use of ANC procedures and separation standards. Inasmuch as all aircraft flying at the altitudes used in the test normally would be equipped with radar beacon, the radar controller was permitted to simulate beacon identification by requesting the simulator operators to blink their target lights.

Mode 3.

In Mode 3 the displays were operated as in Mode 1 and the SPANRAD's were operated as in Mode 2, with the addition of the tracking feature. Although coordination between the tabular display controllers and the radar controllers again was effected by means of interphone, in the case of the pictorial display, the plotted tracks of the aircraft were televised and mixed with the radar display on the SPANRAD tube, with the interphone used only to supplement this procedure as required.

Using the equipment shown in Fig. 4, it was possible for the pictorial display controller to indicate the estimated point of confliction, or the tracks of the aircraft concerned, by pointing to the appropriate location on the display, as shown in Fig. 8. The situation then could be reproduced pictorially by the radar controller through the use of SPANRAD.

Mode 4.

In Mode 4 the basic control was exercised from the SPANRAD's, utilizing a mixture of ANC standards and radar separation in accordance with the usual SPANRAD procedures. The tabular and pictorial displays were operated in this mode as backup displays in the event of radar failure. Such failure was simulated by capping the SPANRAD camera at an arbitrarily selected point during the test run. After the simulated failure, the control function was picked up at the displays in accordance with ANC procedures and separation standards.

Projected Radar.

In this mode of operation, illustrated in Fig. 9, the display was provided with radar by focusing a theater-type television projector on a translucent screen behind the left bay of the prototype display The projector and screen replaced the back-lighting device used in the other modes. The projected image, which was the same simulator video map and radar targets appearing on the SPANRAD's, was in register with the fixes and scale of the map of the control area. This mode was designed to be operated in a manner similar to Modes 2 and 3 by substituting a projected radar display for the direct-view radar and SPANRAD.

TEST RESULTS

Comparison Between Tabular and Prototype 3-D Displays.

Although an experimental phase had been planned to permit procedural and operational adjustments to be made, delay in the delivery of the vector tapes made it necessary to begin the tests of the prototype display without the benefit of a "debugging" period. The tests had been devised as a direct comparison of the pictorial display and the conventional tabular display, but it soon was apparent that the pictorial display could not be operated in its existing configuration as a single sector at the same traffic density as the tabular display comprising two sectors.

The capabilities of the prototype pictorial display were limited by the necessity of sharing the plates and the working space by the controller and the assistant controller. It was found that a plate needed by the assistant for posting a new flight often was being updated by the controller as a result of an air/ground contact in which he was currently engaged, or it was in use by the controller in resolving a traffic confliction. The time required for the posting of flight data was variable from approximately 1 minute up to 10 minutes due to the lack of plate availability. The result was a continual backlog of unposted flight data.

The reverse situation was more serious in nature. Frequently, the controller was in urgent need of a plate currently being used by the assistant. This resulted in partially posted flight data, the accumulation of "deadwood" or completed but unremoved flight segments, and the introduction of hazardous control situations caused by the inability of the controller to remain abreast of the traffic situation.

As only a limited amount of work could be performed on the same plate simultaneously by both the controller and assistant under the stated circumstances, additional difficulty was presented by the necessity for sharing the working space. Only two bays were available, if the assistant was engaged in posting a flight in the right bay, all of the plates, except the outer one in the left bay and the one in use by the assistant, were inaccessible to the controller for updating while in contact with a pilot. This necessitated the keeping of notes by the controller, since it was impracticable for him to make a temporary substitution of plates in the right bay. Conversely, if the controller had positioned a plate in the right bay for use in the course of an air/ground contact, all but two of the plates were inaccessible to the assistant.

Because the portion of the tests utilizing the tabular display had been completed first, due to the uncertainty of the delivery of the vector tapes, it was decided to reduce the traffic samples by one-third and proceed with the tests of the pictorial display. As the communications measurements and observers' reports had been completed for the tabular display runs, it also was decided to complete the corresponding measurements and observations of the pictorial display, even though they were of questionable validity, in order to obtain any information they might offer.

All of the VOR's depicted on the map originally were designated as compulsory reporting points. However, the plate- and space-sharing problems made it impossible for the air/ground controller to cope with this number of contacts. Accordingly, the compulsory reports for each flight were reduced to one report over the first VOR upon entering the area, one intermediate VOR report, and one report over the last VOR upon leaving the area.

One of the anticipated benefits of the pictorial display had been the capability of filtering traffic conflictions occurring at any point along the entire route and of selecting a confliction-free altitude or route for each flight. This procedure proved to be very difficult to apply in the case of the prototype display because of the plate- and space-sharing problems mentioned previously, and because of the difficulty encountered in reposting flights requiring adjustments of altitudes, routes, or times.

The plates in the prototype model were spaced approximately 1/2-inch apart. It was found by experimentation that a spacing of 1 to 1 1/2 inches provided a much better 3-D effect because of the increased parallax.

The tests demonstrated conclusively the feasibility of utilizing a manually prepared pictorial plotting display with either direct-view or scan-converted radar. It was particularly effective with scan-converted radar having a third input from the display mixed with the radar and tracking inputs, which permitted the plotted tracks and positions to be directly compared with the tracks and positions being made good by the radar targets. This procedure minimized the necessity for continuous tracking of all radar targets. The majority of the resolved potential conflictions depicted on the pictorial display were effected by radar, whereas the majority of such conflictions on the tabular display were resolved by the application of ANC procedures. The greatest difficulty encountered in the use of the display in conjunction with SPANRAD was related to the space-sharing problem. The plates were not always readily available for positioning before the television camera.

Although no categorical claim of superiority could be made for either display based solely upon the tests, it was the opinion of the participating personnel that the greatest deficiency of the pictorial display had been one of equipment rather than principle. It also was a generally expressed opinion that the effective operation of the tabular displays as a single sector would have been impossible because of the number of fix postings required, even at a reduced traffic density comparable to that of the pictorial display runs.

As a result of the operating experience gained in the tests, it was decided that an attempt should be made to eliminate the difficulties inherent in the prototype model of the pictorial display, and if a feasible solution could be found, to test the display in a modified configuration.

Considerable attention was given to the possibility of adding a third bay to the display. Although such an addition would have done much to alleviate the problems associated with space-sharing by providing more work area, it was rejected because of the increased travel required of the plates and because it would afford little or no relief from the necessity of plate-sharing. The concept of the modified display then was evolved.

Representatives of the Central Altitude Reservation Facility (CARF) visited TDC after the completion of the prototype tests, and expressed an interest in obtaining the display for experimentation. It subsequently was shipped to CARF for investigation of the possible application of the principles at that facility.

MODIFIED THREE-DIMENSIONAL PICTORIAL DISPLAY

The modified pictorial display, shown in Fig. 10, was designed to serve as a laboratory model to test the principle of posting flights on individual plates, rather than posting all flights at any one altitude on a single plate.

The most obvious physical changes from the prototype model were the absence of hand cranks and in the over-all dimensions, which now were 53 inches in length, 24 inches in height, and 16 inches in depth. The plates were 20 inches square, with a 2-inch-square tab on each side. The wooden frame was constructed in the form of a box, open on each side, and divided into six slots at each end. The dividers forming the slots continued along the top and bottom, making the slots continuous the full length of the frame.

The principal operational change was in the manner of posting. Instead of all flights at one altitude being posted on a single plate, each flight was posted on an individual Plexiglas plate at a plotting position adjacent to the display. All of the completed plates representing the same altitude then were assembled in the same slot, which could accept a maximum of six plates. A total of 24 plates were available for the tests. The equipment available for use at the plotting position made it necessary to reverse the operating positions for this display, placing the plotting position on the left and the control position on the right.

It was necessary to retain the same scale for the control area map as was used for the prototype model because the preprinted vector tapes had been designed for that scale. Since smaller plates were used, this resulted in a control area 375 nautical miles square instead of 500 nautical miles, as in the case of the prototype display

TEST PROCEDURES

The modified pictorial display was staffed with one controller and one assistant controller and was tested only in Mode 1, with 4 runs, inasmuch as the principles utilizing radar, which were examined in Modes 2, 3, and 4 of the tests of the prototype display, also were applicable to the modified display. Each flight was posted on an individual plate for use with the modified displays. Otherwise, the method of receiving, posting, and forwarding flight data essentially was the same as that used with the prototype display The major posting differences were that the aircraft identification was written on the tabs on each side of the plate, and the time an aircraft was estimated to cross each fix was indicated by the addition of a mark across the tape at the correct point.

After each flight was posted, the plate was placed in the left bay of the display by the assistant controller. This bay normally was empty except for the posted plates representing aircraft currently in contact with the controller It then was possible for the controller to move the new posting into the right bay for comparison with the other flights posted previously at the same altitude, in order to filter the traffic by adjusting altitudes or routes as necessary or to take any other control action required.

Although from this point the operation of the modified display corresponded to that of the prototype display, the basic difference existing between the two displays again should be noted. In the case of the prototype display, it was necessary for the controller to share both the plates and the operating space with the assistant controller, whereas in the modified display the controller had unrestricted access to both the operating space and to any of the plates upon which flights had been posted.

TEST RESULTS

The tests of the modified display were made utilizing a full traffic sample of 35 aircraft. Even though the display was staffed and operated with only one controller and one assistant controller, only two problems of any consequence were disclosed.

It was found that, at the traffic densities used in the test runs, the workload of the assistant controller was much too great if the flight data on all aircraft entering or departing the sector must be handled by interphone. During the tests he was able to keep the posted flights current, since the flight posting time was approximately 27 seconds. In order to maintain this current status, with respect to newly received inbound flight data, it was necessary to assume that another position was forwarding outbound flight data to the adjacent control facilities. Such conditions would require the staffing of another operating position, so that one position would receive and transmit via interphone the flight data on all inbound and outbound aircraft, while the other position posted the flights on the plates. The use of electronic computers for flight progress strip printing and flight data passing functions also would fulfill the additional operating position requirements.

The second difficulty was less serious. It was found that occasionally the assistant controller must delay inserting a newly posted flight in order to avoid interfering with the controller engaged in updating the flight data in the course of an air/ground contact. A simple solution would be the addition of a "suspense" slot on the front of the display into which all posted flight data would be inserted by the assistant controller. Solutions to both of these problems are indicated in an artist's concept of an operational-type display, which appears as Fig. 11.

The tests of the modified display confirmed the belief that the operating difficulties encountered in the tests of the prototype display were inherent in the design of the display and not in the principles. In one run of the modified display tests, an experienced air route controller, who was unfamiliar with the area and had not operated the display prev ously, was able to control traffic safely at the relatively high density used in the tests.

In order to maintain as great a workload as possible for the tests, all VOR's depicted on the map of the control area were designated as compulsory reporting points, as was the case initially in the tests of the prototype model. No undue difficulty was experienced by the controller personnel in completing all of the required air/ground contacts.

The 20-inch-square posting area provided by the plates of the modified display were more easily scanned by the controller than the larger plates of the prototype model. At the same time, they appeared to be sufficiently large to avoid an overcrowded appearance of the posted flights.

It was clearly evident that the capability of the pictorial display of enabling the controller to detect potential conflictions quickly at any point along a route of flight greatly meliorated his workload by enabling him to adjust flights before or at the time they entered his area of control. In the case of the modified display, the ease of reposting because of altitude, route, or time adjustments made the fullest application of the filtering process practicable.

A similar benefit of this type of display was the immediate availability of the times or locations certain control instructions should take effect or should be completed, without the necessity of calculating mileages or times.

Although it was not possible to explore the possibility fully during the tests, it appeared that intersector coordination and transfer of control might be feasible by means of a physical transfer of the posted plate representing the aircraft involved. Application of this procedure would be dependent upon the development of suitable procedures, design of equipment, and the juxtaposition of the sector operating positions.

Projected Radar.

Little difficulty was encountered in obtaining satisfactory resolution between the projected radar and the map of the control area represented by fixes depicted on the plates of the display.

Considerable technical difficulty was experienced with some of the electronic components of the projector, and although flights were posted in order to observe the effect, no active runs were attempted pending the availability of more suitable projection equipment.

Posting Plates.

Although all of the fixes were indicated on each plate of the prototype display, they were indicated only on the back of the modified display. In lieu of fix indications on the plates, the times when the aircraft were estimated over the fixes were designated by marking the tapes with a china pencil. This procedure appeared to be satisfactory for use with the control area configuration used in the tests. However, it may be desirable in most cases to have at least the major fixes indicated on each plate.

Some difficulty was encountered in maintaining the clarity of the plates in the modified display. The Plexiglas plates acquired strong charges of static electricity which attracted sufficient foreign matter to decrease the transparency progressively as the number of plates in the display was increased. Although the over-all transparency was reduced below desirable limits when all 24 plates were in place, the display still could be operated.

In an attempt to resolve the problem of plate clarity, investigations were made of several antistatic preparations which purport to reduce or eliminate static electricity from Vinylite phonograph records. One of these was subjected to limited testing on the Plexiglas plates. Four plates which were given an application of the material, together with four other untreated plates, were exposed for six weeks. The dust which had accumulated on the treated plates was wiped off easily, while the untreated plates were difficult to clean. The plates then were rubbed vigorously with cheesecloth in an attempt to induce static electricity. The small amount of static electricity thus induced on the treated plates dissipated completely after approximately 5 seconds. The untreated plates acquired a large amount of static electricity which dissipated very slowly.

Vector Tapes.

It was anticipated that the vector tapes obtained for the tests would not prove satisfactory in all respects, inasmuch as the time available and the developmental costs of the small quantity required prohibited exhaustive exploration of all sources The greatest problem encountered in the use of the tapes was the high degree of adhesiveness, which rendered removal from the plates very difficult. It also was difficult to apply the tape correctly and to dispose of used or severed excess portions. A great reduction in the adhesiveness, or spots, or a single narrow stripe of the same adhesive would be necessary to make the tape operationally usable.

A similar problem was found in the difficulty of tearing or cutting the tape at specific points. Several methods were used in an attempt to cope with this situation, including hand-held dispensers and various types of cutters to be worn on a finger, but none proved satisfactory. An associated problem was that of indicating a change of direction in a route of flight. Cutting, or tearing, and rejoining the tape at the point where the change of direction took place, was found to be the most satisfactory method from the standpoint of legibility, but it also was the most difficult to accomplish. A change of direction could be indicated much more easily by bending the tape, but this method resulted in folds, overlapping, and much reduced legibility of that portion of the tape.

In some cases, an objectionable amount of clutter was generated by the intersection of several tapes over the same point, but an illegible situation never was created. This probably could be alleviated to some extent by a reduction in the boldness of the print, particularly if the display would not be mixed with scan-converted radar. The line widths chosen were selected so as to ensure visibility on the SPANRAD

Wastage of the preprinted tapes amounted to approximately 30 per cent, which was occasioned by the necessity of beginning each flight posting at the correct minute. The excess tape preceding this minute had to be discarded, as no practicable method was found for conserving it for later use

If the tapes for ground speeds of 400 knots and above were printed in 25-knot intervals, six tapes would be required to represent speeds commonly in use at this time, and the possible error in ground speed would range from approximately 4 to 6 per cent. In order to have tapes available in 10-knot intervals, with errors from approximately 1 1/2 to 2 1/2 per cent, 16 tapes would be required, which would complicate to some extent the use of the tapes. Because cellulose tape and adhesives are subject to deterioration with age and at temperature extremes, it is probable that some difficulty could be expected in storing and using the type of tape utilized in the tests.

A possible solution to the tape problems might be the development of dispensers into which rolls of transparent tape could be inserted, the desired ground speed and time adjusted, which then would print the time and speed, and apply adhesive to the proper length of tape as needed.

ANALYSIS OF TEST DATA

Inasmuch as the alteration of the traffic samples negated a direct comparison of the two types of displays, a complete analysis of the measurements and observations is not included in this report. When all communications measurements recorded during the pictorial display runs were increased by one-third to compensate for the reduced traffic sample, a very close correlation was found between the number and duration of all air/ground/air measurements of the tabular display tests and of all interphone measurements with the exception of controller/controller coordination contacts. As had been expected, since the controlled airspace was encompassed by a single sector in the case of the pictorial display, a marked reduction in coordination contacts and time was indicated. This reduction ranged from 100 per cent in Mode 1, when no pictorial display coordination was required, to more than 50 per cent in Modes 2 and 3 which required coordination with the SPANRAD controller.

No attempt was made to correlate the reports of the observers, since increasing or decreasing the amount of traffic in a sample would have had an unpredictable effect on the number of potential conflictions and therefore, on the number of unresolved conflictions. A raw tabulation of the observers' reports indicated that a total of two conflictions were not detected or resolved in the pictorial display runs, and a total of five conflictions were not detected or resolved in the tabular display runs.

CONCLUSIONS

The basic principles of the 3-D pictorial ATC display make feasible the control of all airspace by means of a pictorial-type display. The incorporation of these principles in the two experimental displays demonstrated their applicability to the control of high-speed, high-altitude aircraft. Although operating limitations were present in varying degrees in both displays, they were, for the most part, inherent in the equipment design rather than theory. It may be concluded that a suitably designed display would provide.

1. Rapid posting of flight data.

2. Filtering of posted flights in order to determine altitudes or routes which are as nearly confliction-free as possible.

3. Immediate availability of information concerning the relationships at any time or any position of all aircraft posted on the display.

4. Ease of correlation of the posted flight data with a radar display, particularly with SPANRAD or projected-type radar.

5. Possibilities of reducing interfacility and intrafacility coordination.

Even though it may be presumed that a display based on the procedures employed in the prototype model would be improved by the addition of a third bay, the tests indicated the most satisfactory procedure to be the posting of each aircraft on an individual plate, rather than posting all aircraft assigned the same altitude on the same plate. Other specific operating procedures would be largely dependent upon equipment configuration and application.

Three major problems were encountered in the use of the vector tapes. The adhesive quality of the tapes obtained for the tests was too great to permit easy application and removal; it was difficult to tear or cut the tapes at desired points, and no satisfactory method was found for separating and rejoining, or for curving, the tapes to indicate changes of direction in routes of flight. It is possible that further investigation of tape materials, adhesives, and methods of application will alleviate these problems.

Two other factors also should be noted. The cost of 25 cents per 100 inches of the pilot run of tape could be reduced considerably by quantity production. A further monetary saving might be anticipated through the development of an economical means for reducing the present 30-per-cent tape wastage; however, should this not be possible, it is expected that the benefits to be derived from this display might compensate for this wastage. In addition, a reduction of the clutter produced by several intersecting tapes would be desirable if it can be achieved without unacceptable loss of tape legibility

Improvement also would be desirable in the transparent quality of the plates when the display is operated at full, or nearly full, capacity.

Although the mode of operation utilizing projected radar must be considered experimental because of the limitations imposed by the electronic difficulties mentioned previously, it appeared that correlation between the radar and pictorial displays would be particularly rapid and easy in this mode. Further evaluation should be carried out with more suitable projection equipment.

The artist's concept of a display, Fig. 11, depicts what may be a satisfactory arrangement of operating positions and duties. A portion of the functions performed by the assistant during the tests has been given to the display controller, and a second controller position has been added to provide for periods of continuous high-density operation.

The arrangement portrayed is based upon the use of electronic computers for the automatic forwarding of flight data and production of flight progress strips. However, the forwarding of flight data by means of interphone and the manual production of flight progress strips also could be utilized by adding another operating position adjacent to the display controller and flight posting positions. In the latter configuration, the new position would receive by interphone data on flights inbound to the sector where the flight progress strips would be prepared manually. The functions at the other positions would remain essentially the same, except that the display controller would forward data on flights outbound from the sector to the adjacent control facilities by means of interphone.

In the operation of the display, the assistant controller would post the flights from data available to him on flight progress strips or on a computer read-out. The display controller would filter newly posted flights to select the optimum altitudes or routes, maintain the current status of the flight progress strips or computer read-out, and update the computer by means of an input device. The radar controller would make all air/ground contacts, and effect radar separation as required, either by use of his own projected radar display or by a handoff to a SPANRAD unit by means of the upper bay.

It appeared from the tests that some of the principles incorporated in the displays are similar to certain proposed features of electronically generated pictorial-type displays.[1] This is particularly

[1]Fred S. McKnight, "Operational Requirements for ATC Displays," CAA Technical Development Report No. 308, September 1957.

applicable in the presentation of aircraft as vectors and in the selective or cumulative display of altitudes. The similarity would be increased by the use of computers as envisaged in the preceding paragraphs.

RECOMMENDATIONS

It is recommended that a comprehensive study be made of the technical design and human engineering factors required in a display for in-service evaluation, and of the possibility of developing suitable vector tape dispenser equipment. In this connection, a thorough investigation of tape materials, adhesives, and methods of application should be made. A further investigation should be made of means of reducing the static electrical charge accumulated by the plates, and of the possible use of other transparent material. A display should be designed and fabricated, incorporating the results of these studies and investigations, and subjected to a thorough simulated or in-service evaluation, as appropriate.

It also is recommended that the principles described in this report be investigated for possible use in the simulation of those features of electronically generated displays to which they may be found applicable

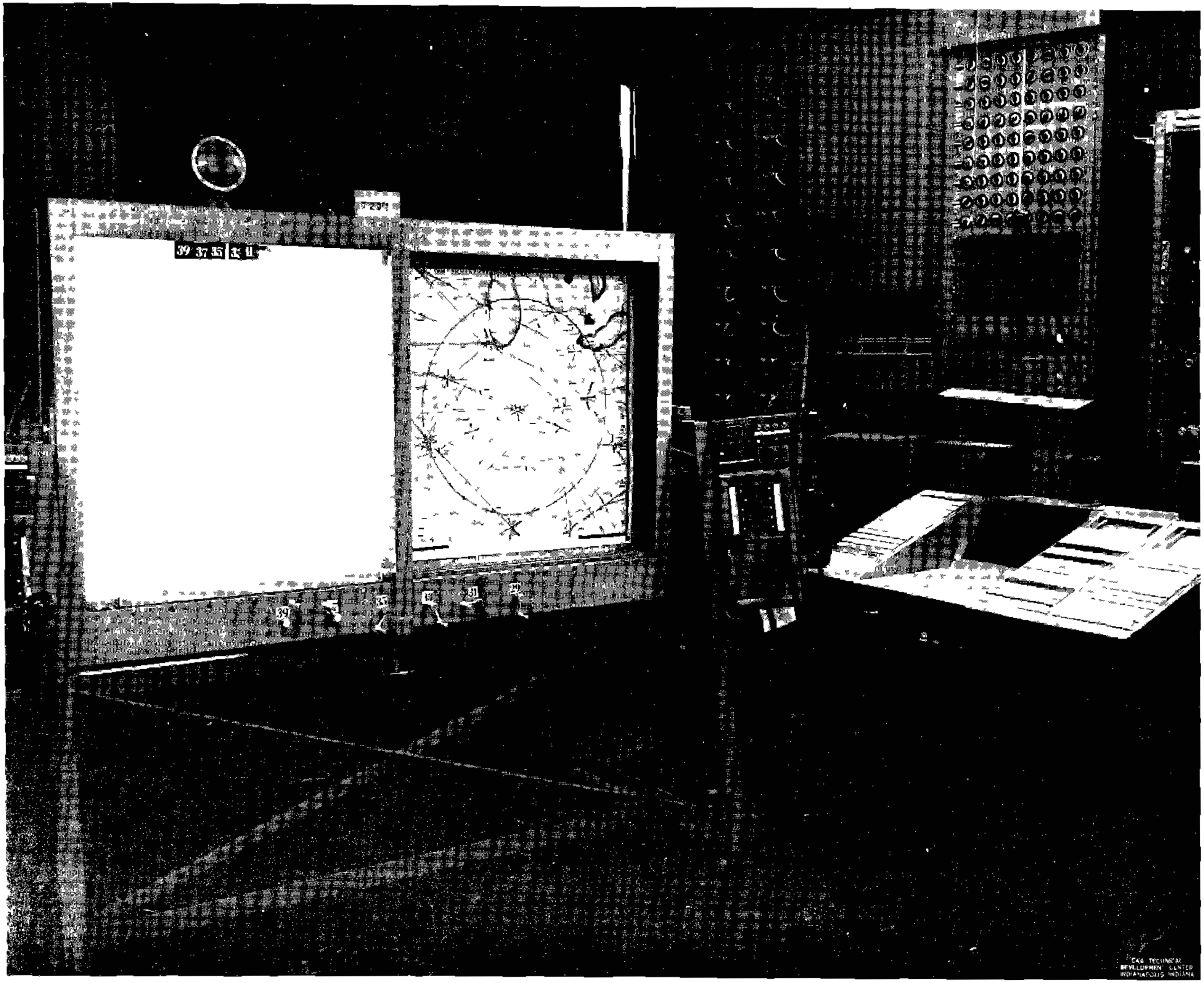

FIG. 1 PROTOTYPE THREE-DIMENSIONAL PICTORIAL DISPLAY

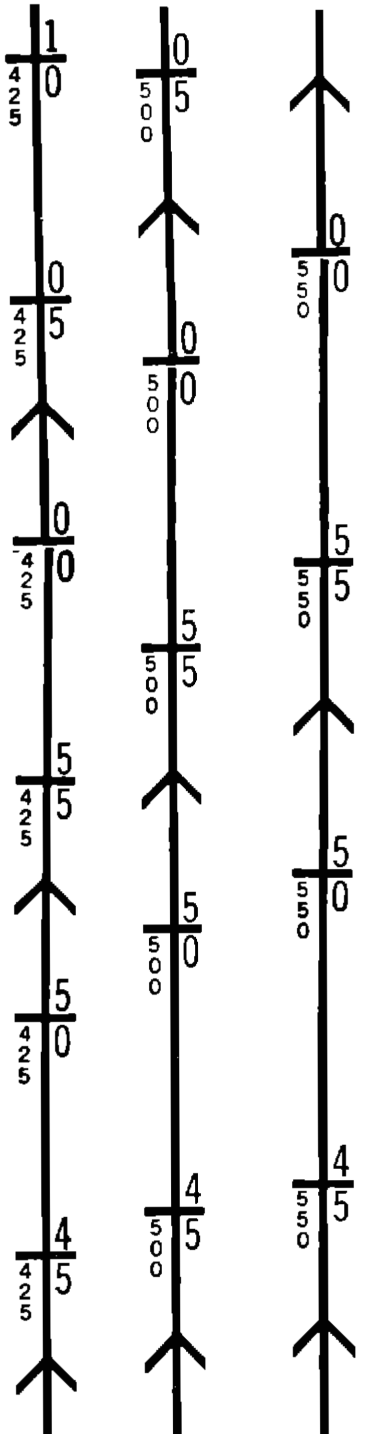

FIG. 2 VECTOR TAPES

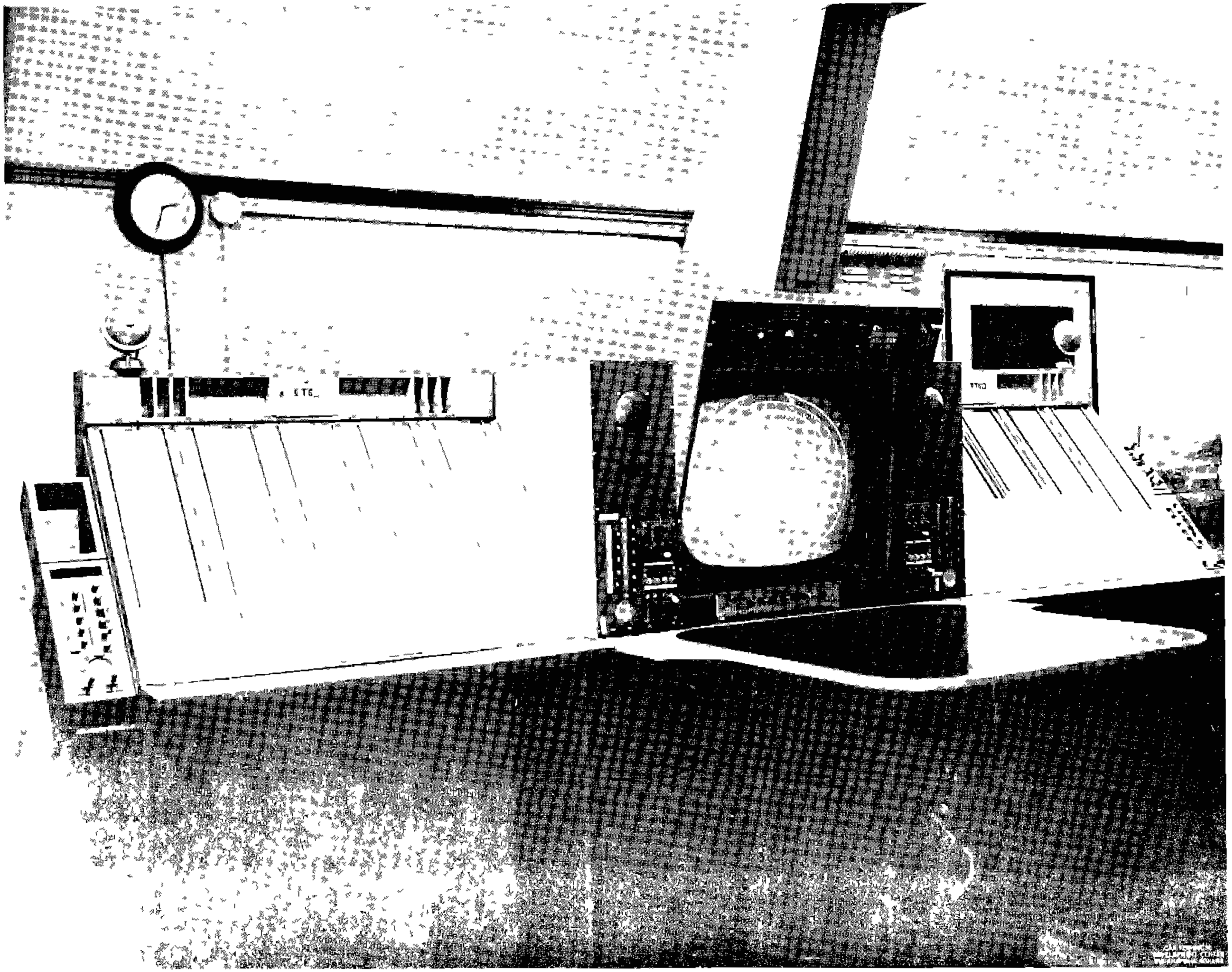

FIG. 3 FLIGHT PROGRESS BOARD DISPLAY

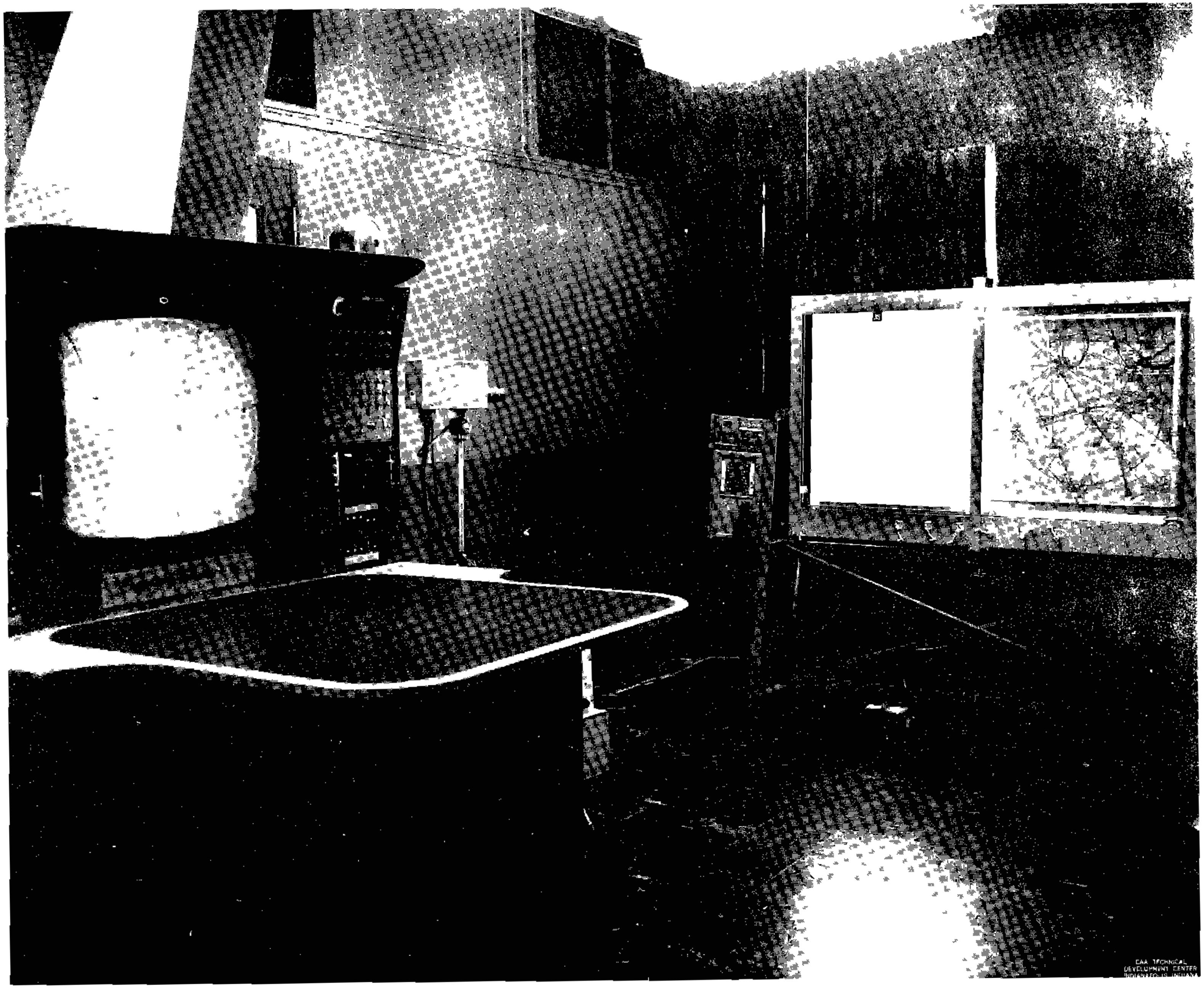

FIG. 4 AUXILIARY EQUIPMENT

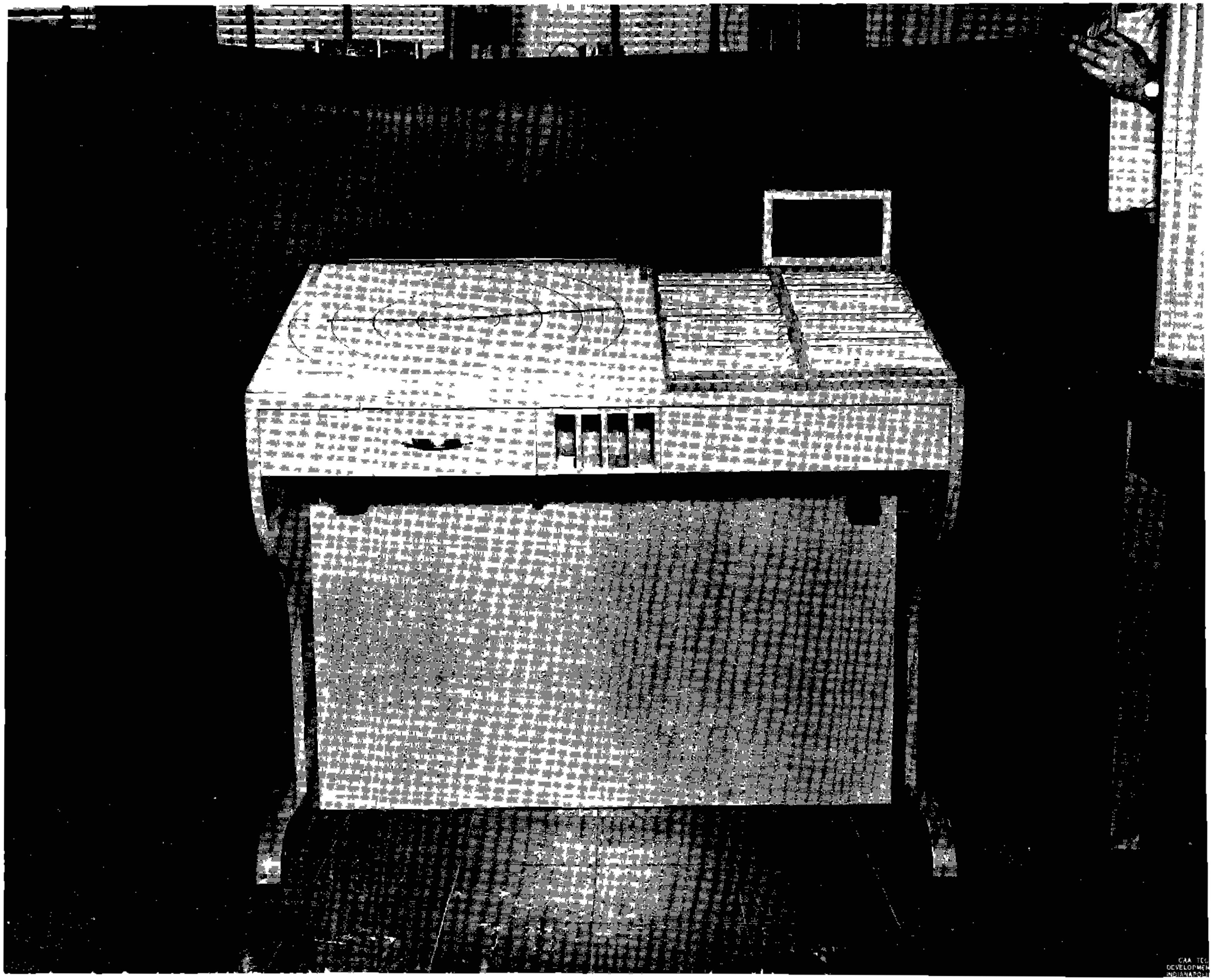

FIG. 5 AUXILIARY EQUIPMENT - ASSISTANT CONTROLLER'S POSITION

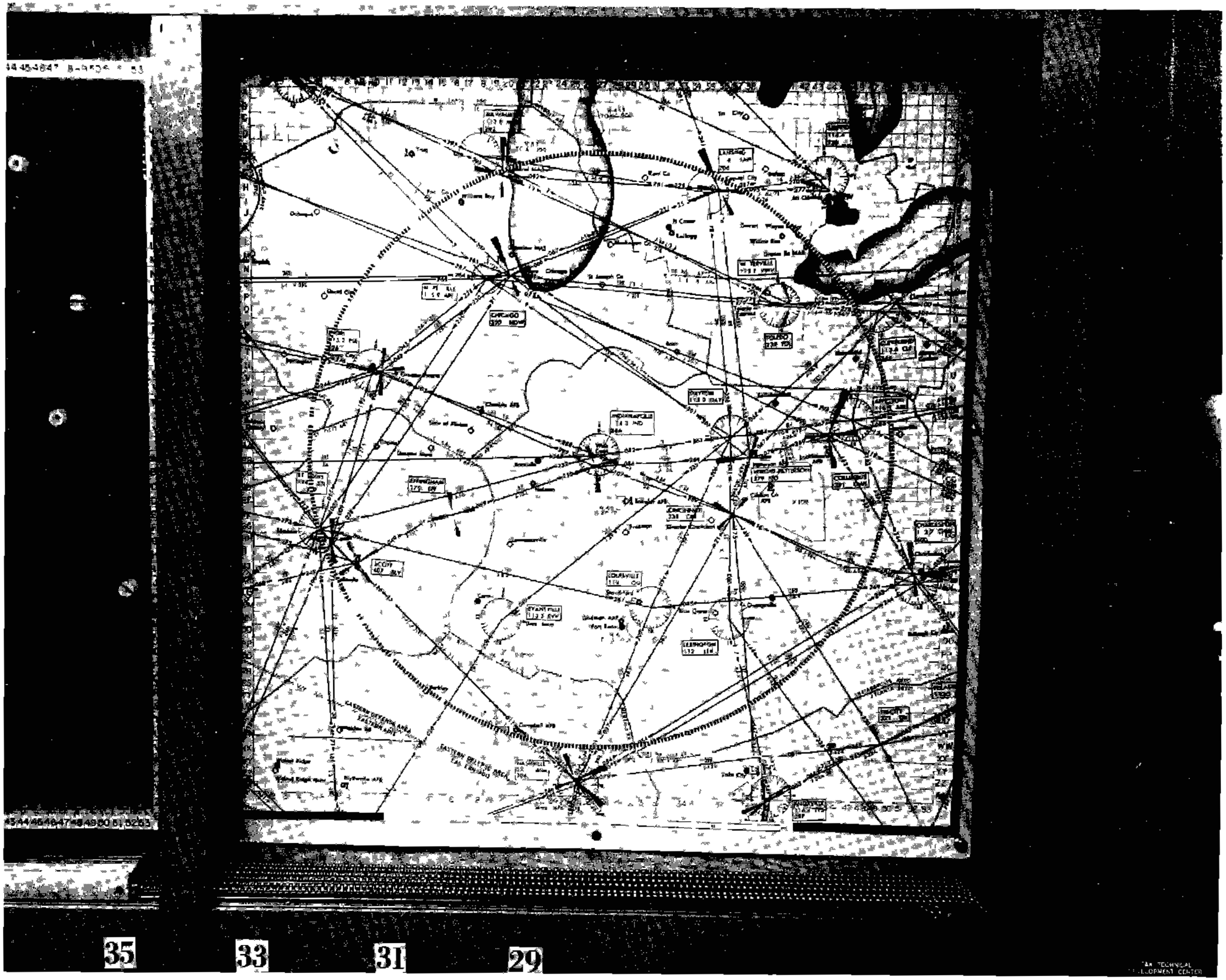

FIG. 6 HIGH-ALTITUDE PLOTTING MAP FOR CONTROL AREA

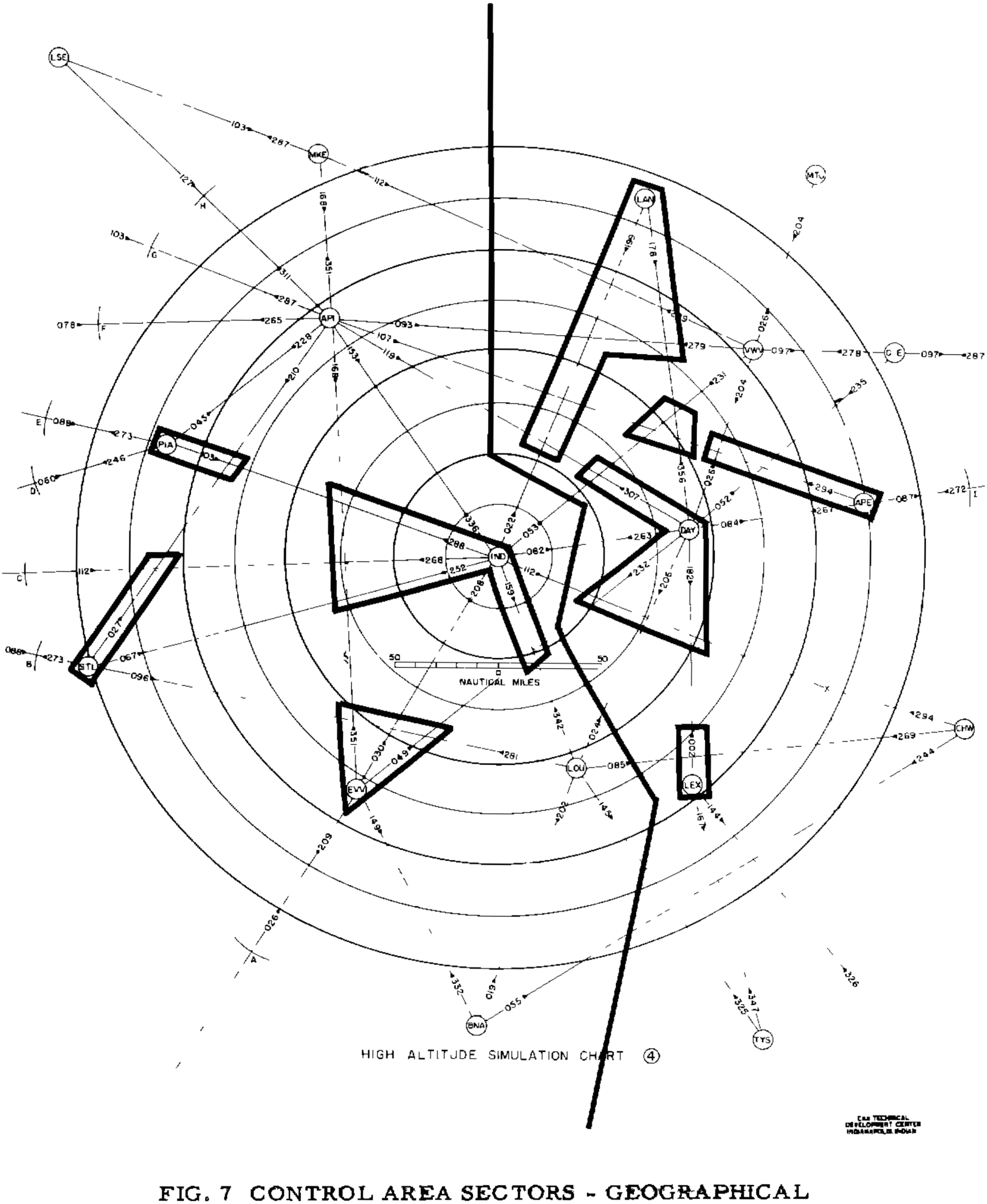

FIG. 7 CONTROL AREA SECTORS - GEOGRAPHICAL

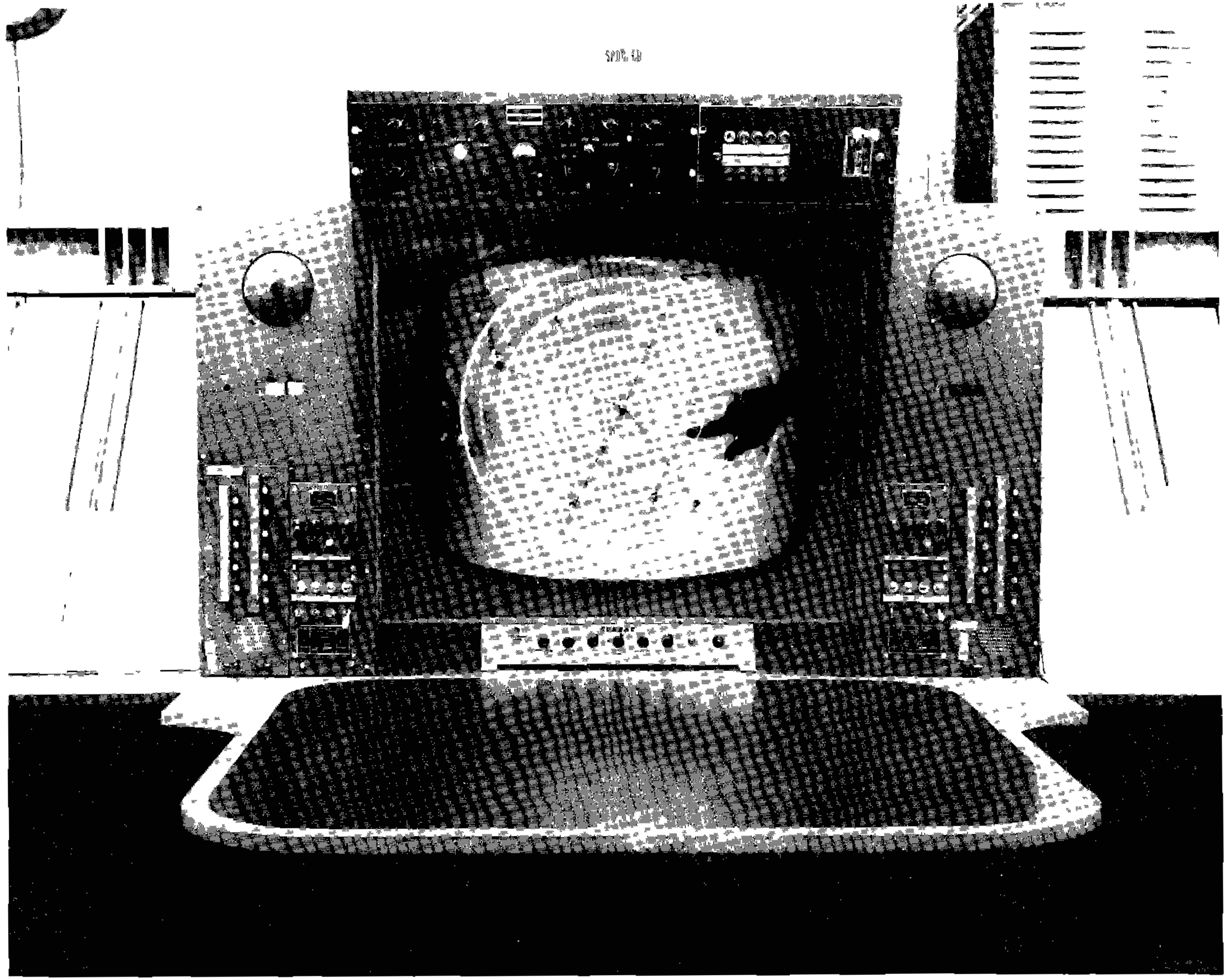

FIG. 8 CONFLICTION HANDOFF TO RADAR CONTROLLER

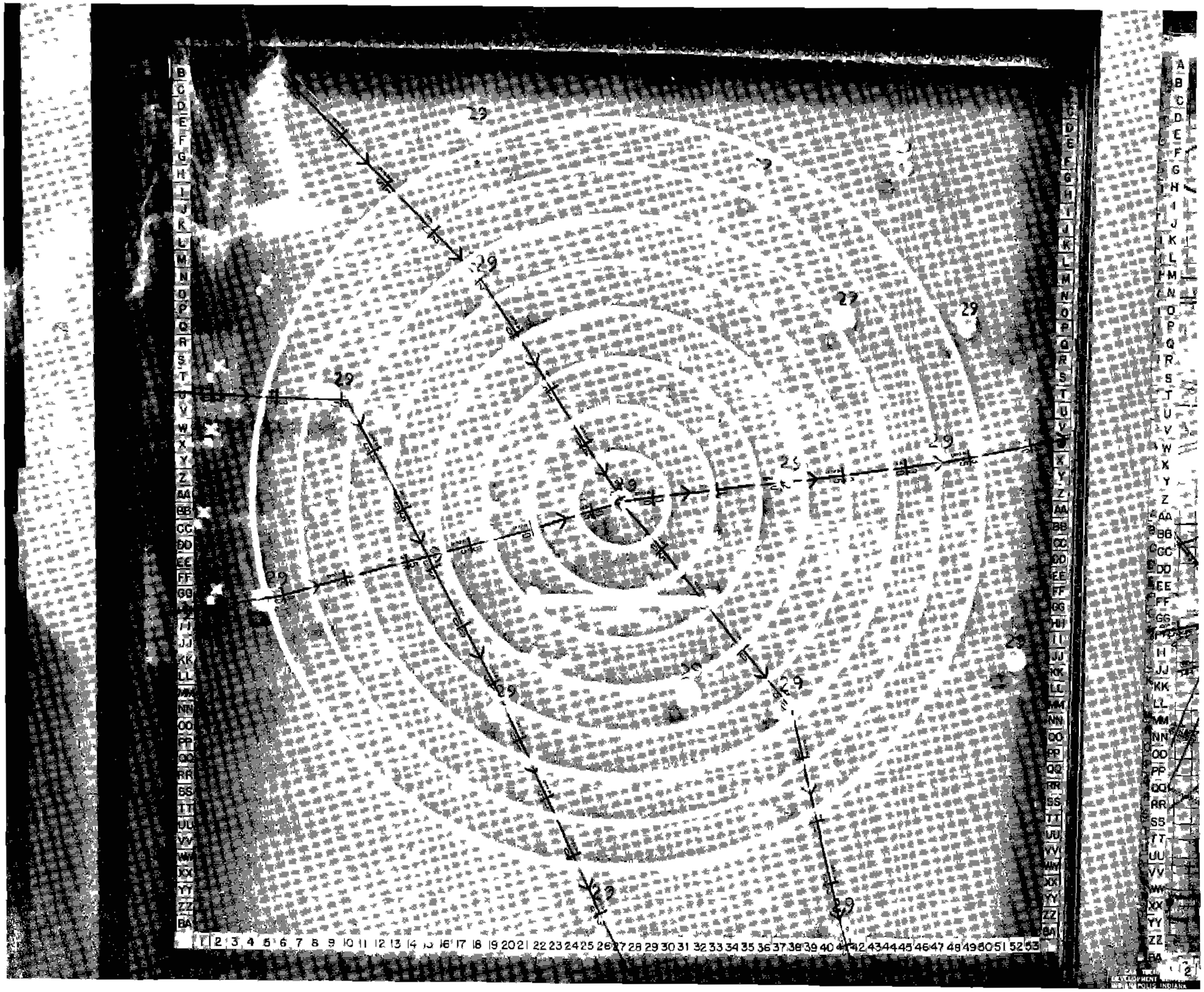

FIG. 9 INTEGRATED PROJECTED RADAR AND THREE-DIMENSIONAL DISPLAY

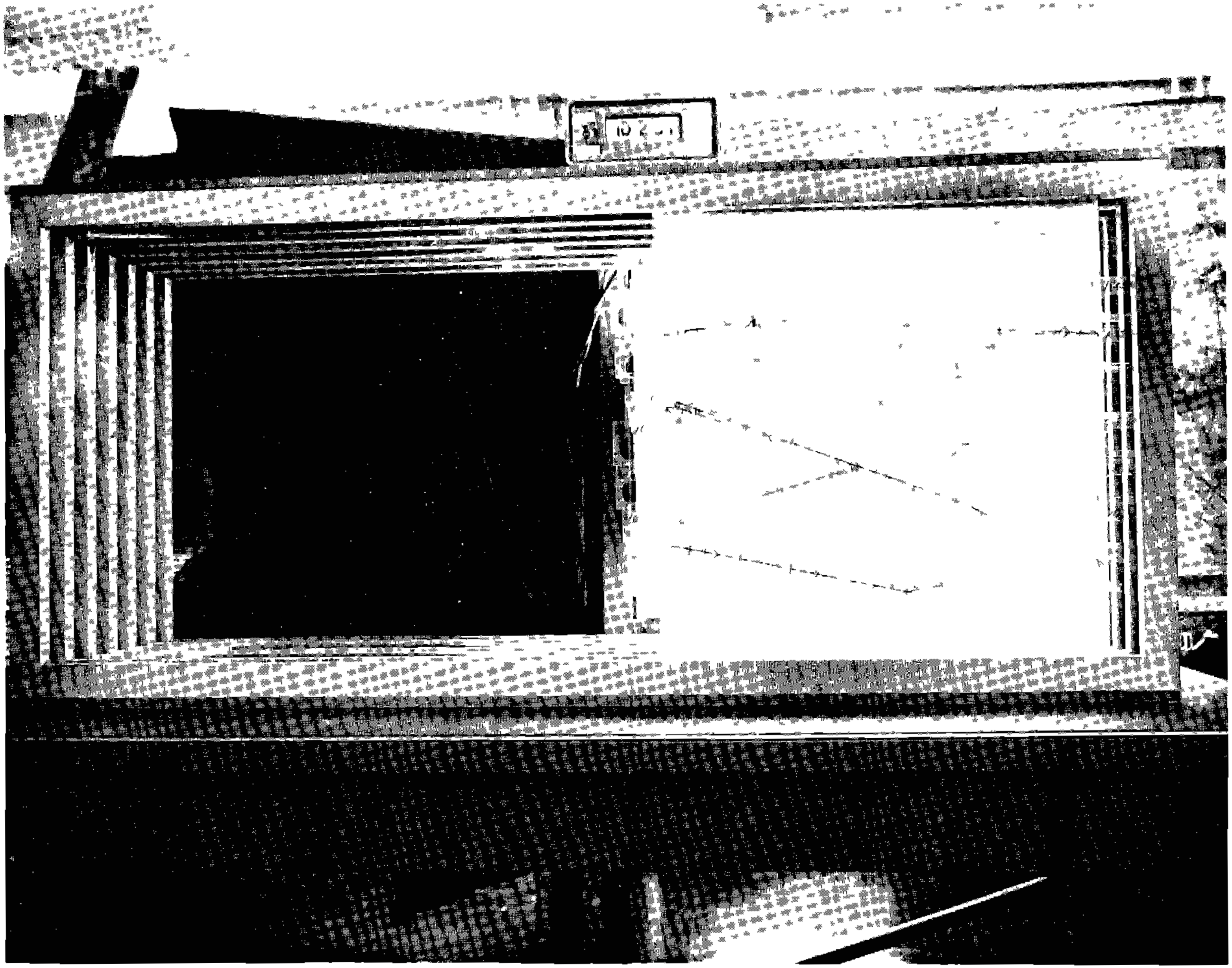

FIG. 10 MODIFIED THREE-DIMENSIONAL PICTORIAL DISPLAY

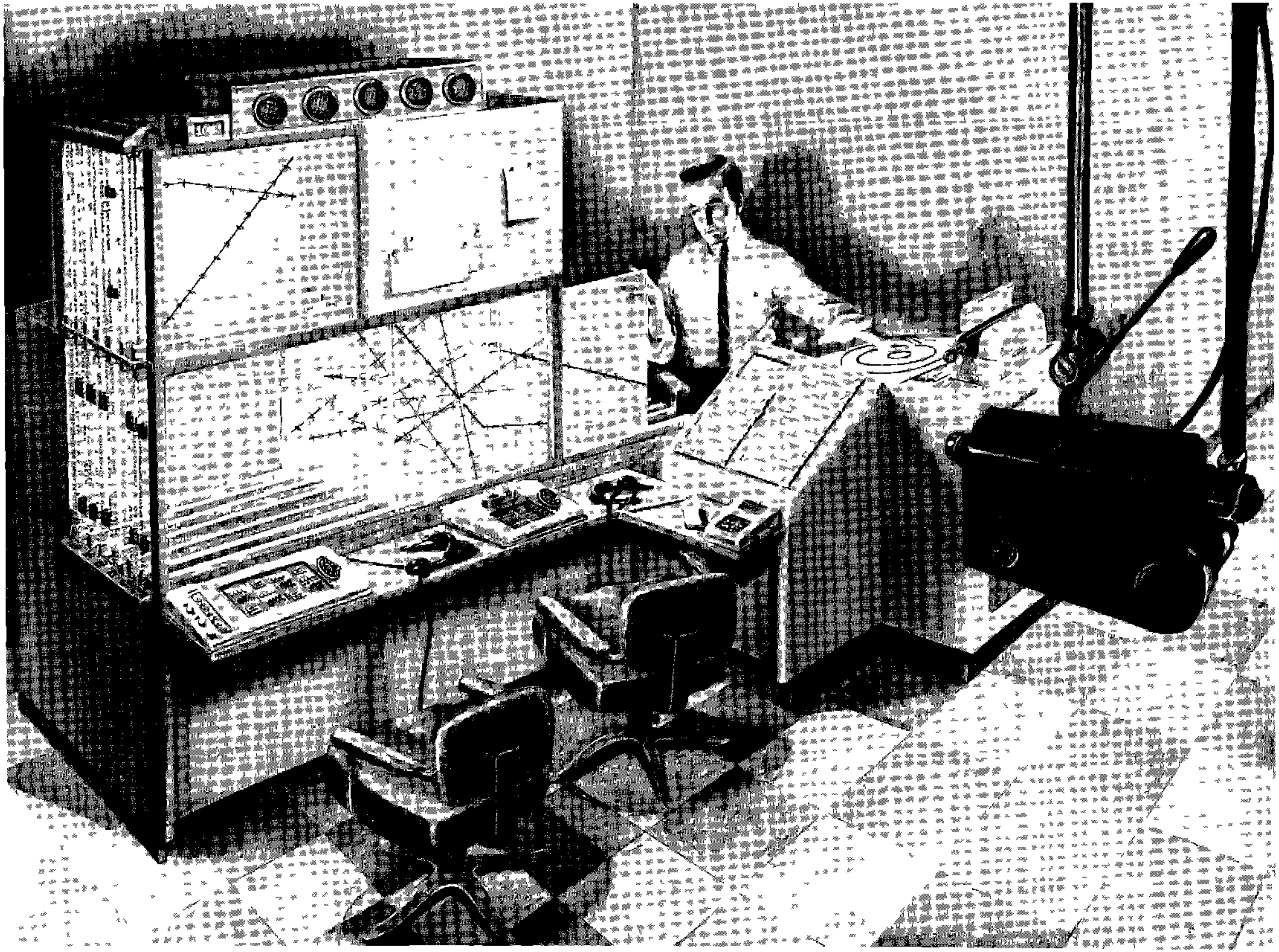

FIG. 11 ARTIST'S CONCEPT OF OPERATIONAL THREE-DIMENSIONAL DISPLAY WITH INTEGRATED RADAR