Operational Requirements for ATC Displays

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OPERATIONAL REQUIREMENTS FOR ATC DISPLAYS*

FOREWORD

This project was performed by the Civil Aeronautics Administration Technical Development Center under the sponsorship of the Air Navigation Development Board as a joint civil/military effort to meet stated operational requirements for a Common System of air navigation and traffic control.

INTRODUCTION

Requirements for air traffic control (ATC) displays have been enumerated in general terms by several groups These include reports by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 31, Air Coordinating Committee (ACC) Special Working Groups 5 and 13, and various other organizations See bibliography. This report has been prepared to furnish guidance to system and equipment designers on the display requirements which are considered essential for air traffic control.

Although it is recognized that some control functions may be handled automatically by machines in the future, all of the reports listed in the bibliography generally agree that the human controller will be needed in the system to serve either as the active control-decision element or as a monitor of the machine. Suitable displays will continue to be essential, therefore, to provide the human controller with information on the movement of all aircraft, and to permit him to determine the need for new or additional control instructions to provide for safe and expeditious movement of traffic.

Most of the reports indicate the need for both a pictorial-situation display showing current positions and relationships between aircraft and a planning display showing proposed occupancy of airspace to permit advance planning of control and flow regulation

The material in this report is based on (1) recommendations contained in the reports listed in the bibliography, (2) the results of experimental tests and evaluations conducted at the CAA Technical Development Center (TDC), and (3) analysis and recommendations of experienced air traffic controllers. The original manuscript was prepared in December, 1956, as part of an ANDB project for development of improved ATC displays after a series of conferences between personnel of the CAA Technical Development Center and the Air Force Traffic Control and Landing System group of Wright-Patterson Air Force Base.

GENERAL OPERATIONAL REQUIREMENTS

The following general operational requirements should be met by the display system

1. The display should indicate the present position of all aircraft in the control system.
2. The display should indicate the projected or future flight path of each controlled aircraft in flight and of those aircraft desiring to enter the control system.
3. The display should indicate airspace reserved for use and unassigned airspace available for use.
4. The display should indicate when and where control action is required.
5. The display should provide for insertion of information by the human controller.
6. The display must present information in the most efficient manner for maximum economy of personnel.
7. The display system must provide adequate reliability, fail-safeness, and protection against loss of data

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Systems Design and Display Inputs

The detailed specifications that follow are based on the concepts

1 The advanced type of display system is primarily for high-density traffic areas, that is, it may not be justifiable economically for low-density traffic areas

2 A high rate of accurate position data will be available from most of the aircraft being controlled These position data may be derived from primary radar, from secondary radar (beacons), from aircraft navigational systems with data transmitted automatically over air/ground data links, from special military tactical systems, or from other special position-reporting systems under development

3 A small percentage of aircraft may be handled on the basis of positions estimated from flight plans and voice position reports

4 Suitable computers and automatic data-processing equipment will be part of the ATC system environment

5 Air traffic control will be required on an area basis as well as on airways or heavily traveled routes

6 One-way airways, channeled altitude levels, and various procedures designed to reduce traffic problems will be used on the more heavily traveled routes

The display system should provide for the following informational inputs

1 Computer-developed tracks based on flight plans updated by the latest position data available

2 Primary radar returns

3 Secondary radar (beacon) returns

4 Track-while-scan (TWS) radar-tracking gates (automatic or human rate-aided)

5 Position, altitude, and identification information from aircraft via automatic air/ground data links or other automatic position-reporting devices

6 Other ATC facilities

7 Special military tactical systems

8 Control personnel using the display

Figure 1 illustrates one possible ATC system design providing for integrated use of these inputs In this suggested design, aircraft tracks on the pictorial display would be generated by a computer (flight position generator) from the flight plan data These computer-developed tracks would be corrected and updated by any position data available

Voice position reports from the aircraft would be inserted into the flight plan processor to update the flight plan, the flight plan processor in turn feeding these data to the flight position generator Insertion of the voice position reports may be done by the controller, his assistant, or in some cases, by a third-party communicator

Primary and secondary radar data would be available to the controller on his display by time-sharing the writing beam of the cathode ray tube (CRT) Provision should be made for the controller, his assistant, or a tracker to adjust the position, direction, and speed of the aircraft track generated by the flight position generator, based on actual observations of the radar returns from the aircraft In other words, after identifying a particular radar return, the controller would adjust the computer-generated track to follow the identified radar return TWS radar tracking gates may be a part of the system It is envisioned these gates would feed into the flight position generator, automatically correcting the generated track to follow the radar or beacon returns

Position data received over air/ground data links, or from other special position reporting systems, will probably require some processing before it is used to correct the flight position generator A link from special military tactical systems to the ATC system will permit requests for use of the airspace to be made and provide position information on special tactical vehicles which may not have normal communications capabilities with ATC

It is anticipated that all of the functions included within the dotted line might be accomplished by one computer or several smaller computers working together The latter arrangement is preferable, in some respects, for simplicity of design and reliability

Controller-Display Functions

Air traffic control is based on both long-term and short-term predictions of occupancy of airspace Long-term planning is necessary to provide an orderly and expeditious flow of traffic Flow control or flow regulation at "bottlenecks" in the airspace is included in this long-term prediction control In the short-term control category are included those control

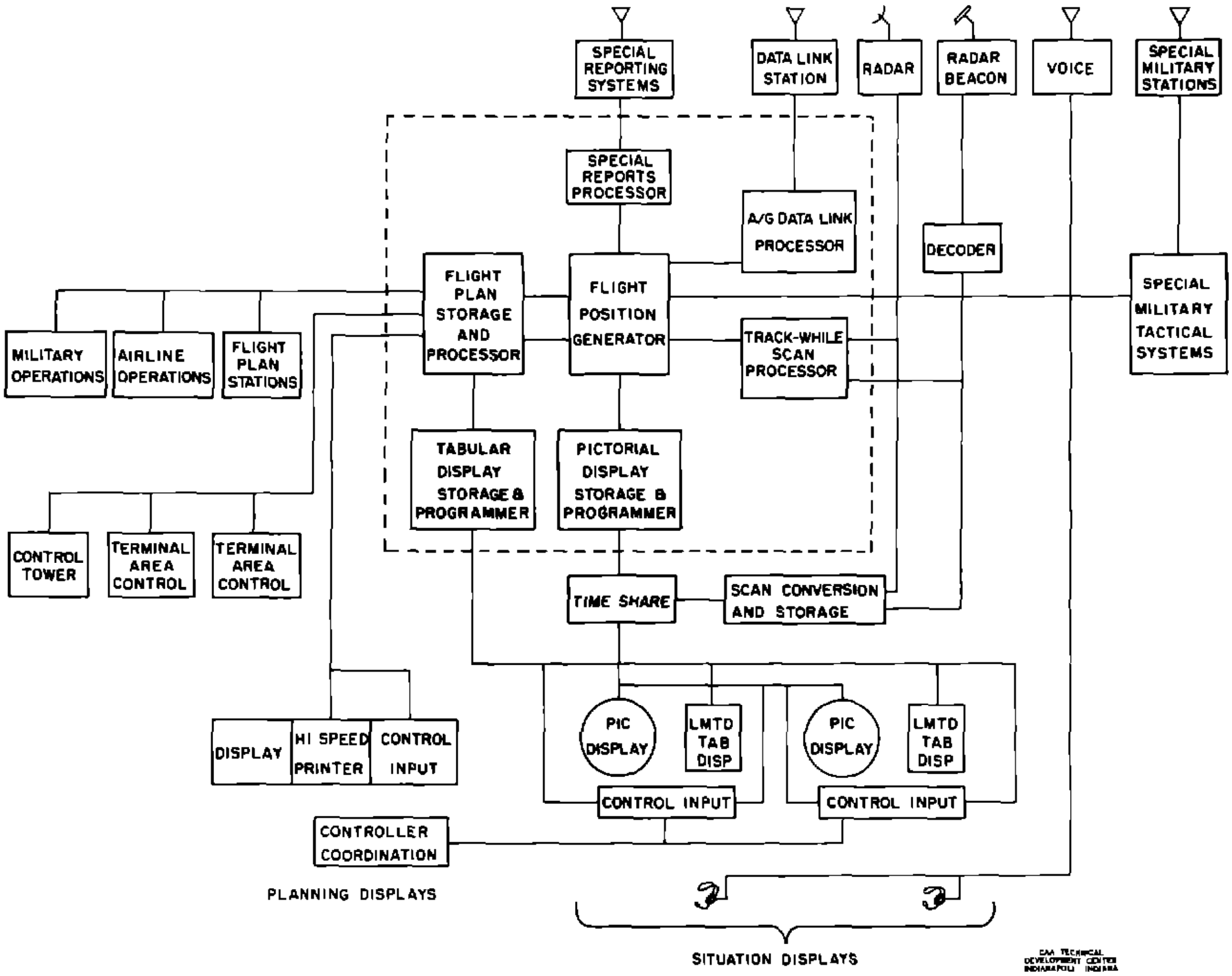

Fig 1 Proposed ATC System Design

actions based on the immediate situation such as radar vectoring and "altitude-laddering " Typical of these are the procedures used during climbs to cruising altitude or during descents from cruising altitude to destination

A third function which must be performed in the control system is continuous monitoring of the movements of all aircraft to insure that safe separation is being maintained As in any control-system loop, position data must be fed back at intervals to confirm that the aircraft is occupying the airspace reserved for its use

In the system described the advance planning control functions are based on the use of displays showing the future airspace-time relationships between aircraft The short-term control functions and the continuous monitoring of movements of aircraft are based on use of situation displays showing the current airspace use of each aircraft

Because it is difficult for one controller in a high-density traffic situation to be shifting his thinking constantly from the immediate control problems to those of long-time-ahead planning and control, it is believed that these two control functions should be handled by two different controllers This is done today to a limited extent, with some controllers handling the immediate situation and with flow controllers and sector coordinators taking a longer look ahead and coordinating use of the airspace between several sectors

In the proposed system, one group of controllers working with planning displays will regulate flow of traffic, reserve airspace for use, and eliminate as many potential conflicts as possible in advance A second group of controllers using situation displays will monitor the current movements of traffic continuously and provide the short-term control functions The controllers on the current-situation displays will be alerted to any potential conflicts which cannot be resolved in an optimum manner by the planning controllers.

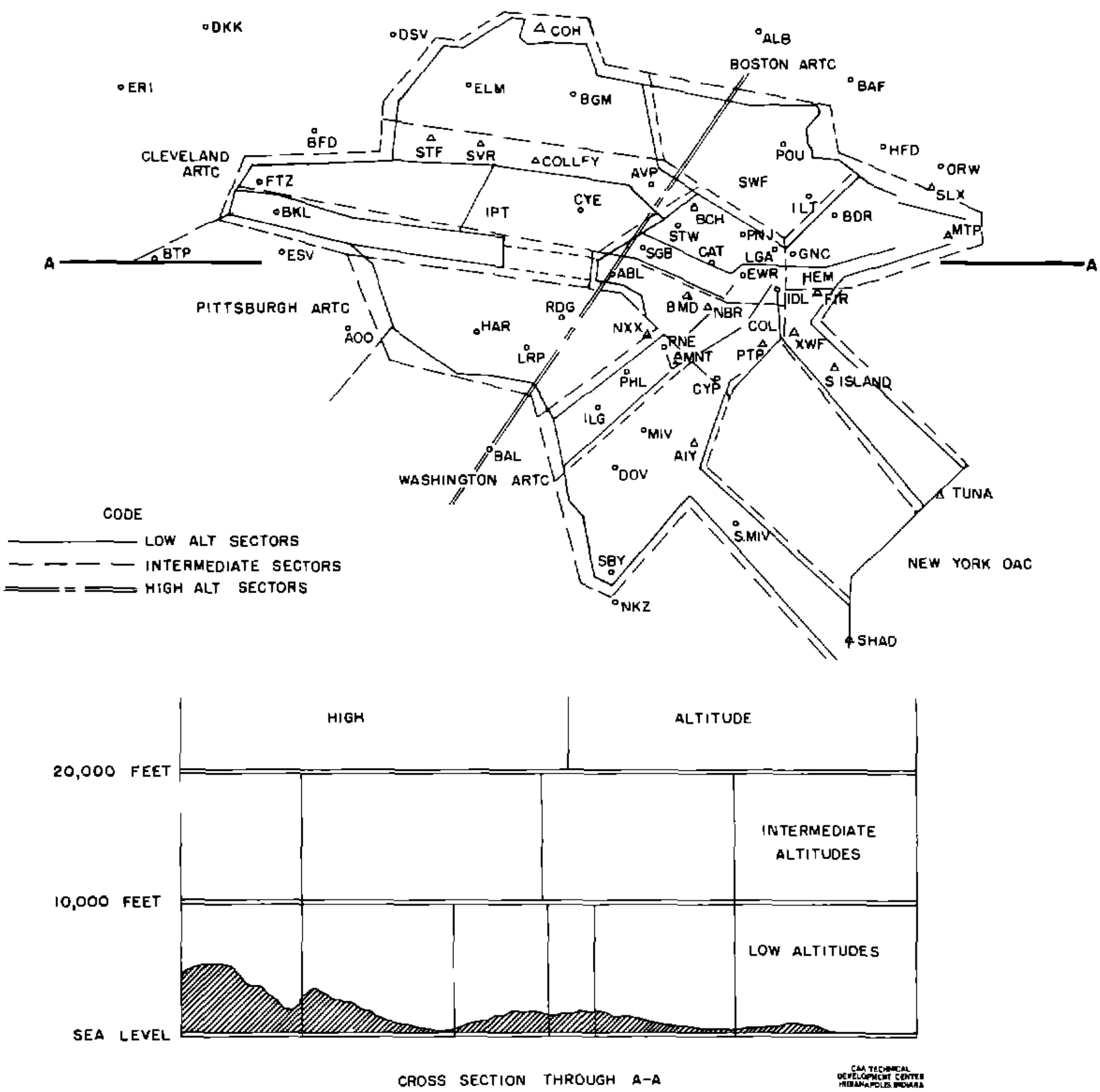

Fig 2 Possible Sector Arrangement

The planning-display controllers will provide flow regulation or flow control at bottlenecks in the system such as airports and their associated holding stacks and major route junctions or intersections They will not schedule more traffic during periods of time (such as 15- or 30-minute blocks) than the peak capacity of these bottlenecks will allow The current-situation controllers will resolve impending conflicts and provide separation between these aircraft as they arrive, but they will not be overloaded by peak demands which exceed the capacity of the system.

In high-density traffic areas the controlled airspace will be divided into sectors, both geographically and by altitude strata, with each controller being responsible for a defined volume of airspace See Fig 2. As traffic demands vary, the sectors may be combined or subsectors may be established The sectors for the planning controllers and current-situation controllers may or may not coincide During light traffic periods controllers may handle both planning displays and situation displays simultaneously if these displays can be made physically compatible

In general, it is envisioned that the current-situation display controllers will be handling traffic from the current time to 15 or 20 minutes ahead of current time and the

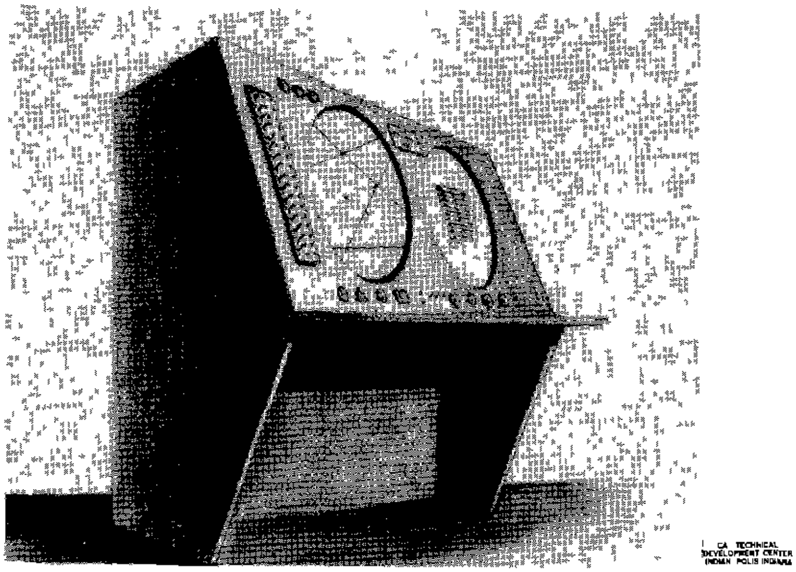

Fig. 3 Situation Display Console

planning-display controllers will be concerned with the flow of traffic from 15 to 20 minutes ahead of current time to two hours or more in advance.

CURRENT-SITUATION DISPLAYS

General Description.

The current-situation display consoles should provide a pictorial display showing the current geographic positions of all aircraft being controlled. They also should provide a limited tabular-display board. There should be input buttons or devices by which the controller can insert new information into the display and data-processing system and for selective read-out of desired data. Figures 3 and 4 are artists' concepts of individual current-situation displays.

In using the pictorial display the controller will compare present positions, altitudes, headings, and speeds of aircraft, and mentally, he will extrapolate future flight paths for relatively short distances ahead. When aircraft at the same altitude are observed to be on closing courses, the controller will provide lateral, longitudinal, or altitude separation through vectoring, assignment of short-delay patterns, or assignment of nonconflicting altitudes or routes.

Pictorial Display

The pictorial display should present the following information items directly on the display at the current geographic position of each aircraft

1 A position symbol indicating actual or estimated position of the aircraft and the quality of position data
2 A heading vector indicating heading and relative speed of the aircraft
3 The current altitude and the newly assigned altitude when an altitude change is taking place
4. The identity (radio call) of the aircraft
5. A minimum route indication for a short distance ahead, plus destination.
6. A potential conflict indication
7. An "aircraft-in-emergency" indication.
8. Maps of required geographic reference data

To reduce readability problems when targets overlap, suitable controls should be provided to permit the controller

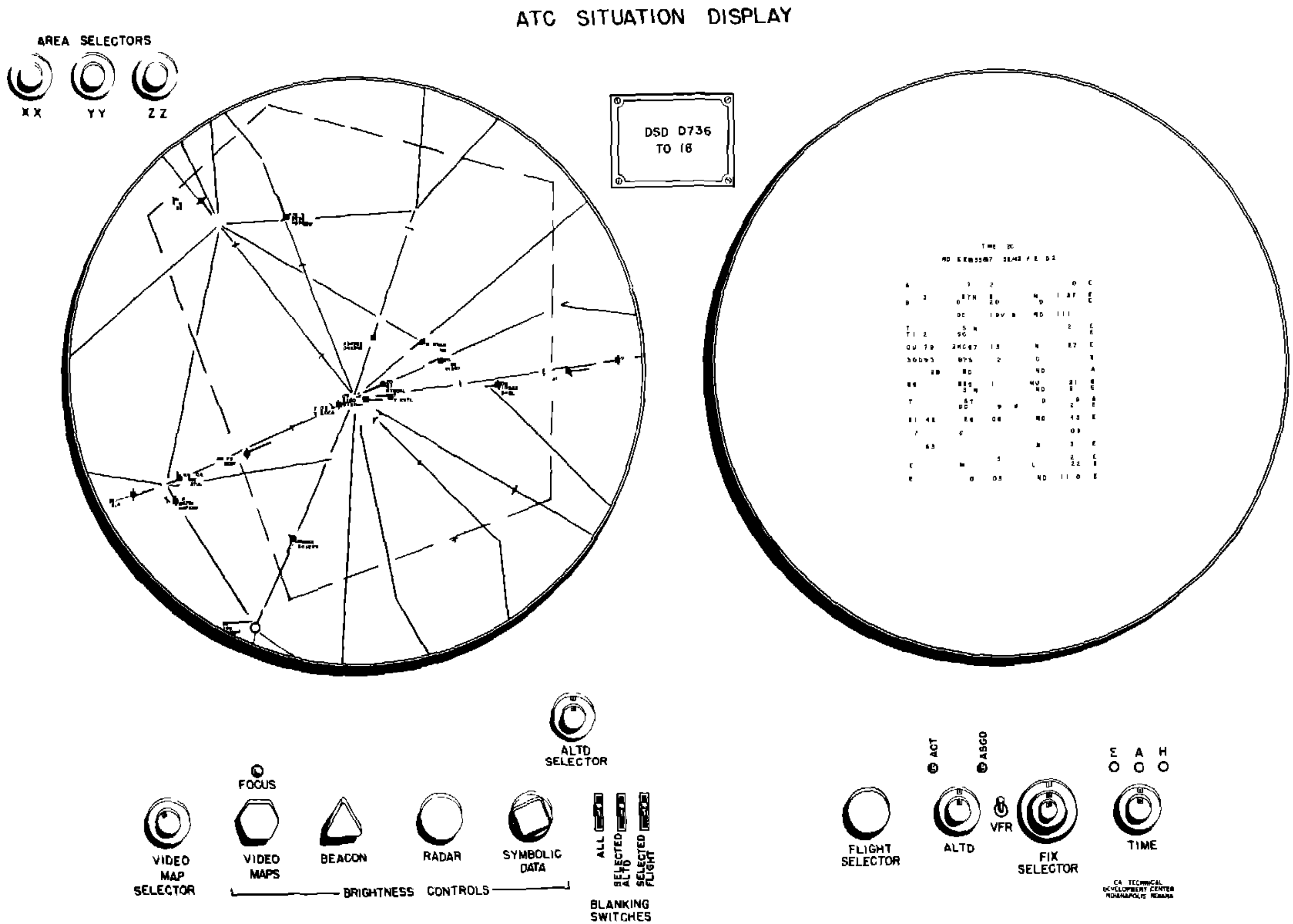

Fig 4 Situation Display

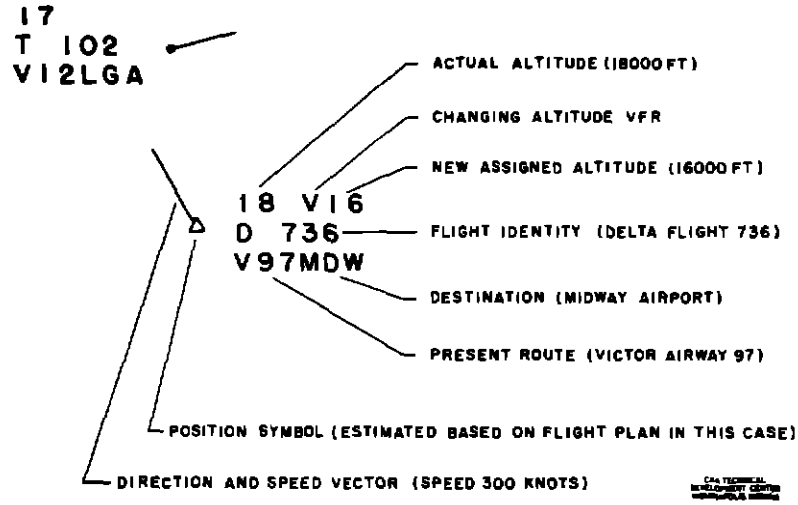

Fig 5 Examples of Data on Pictorial Display

1 To display traffic information at selected altitudes only
2 To cut off temporarily from the display all written data for individually selected aircraft

In addition to the processed data, the display should permit direct display of primary radar returns and secondary radar-beacon returns Presentation of beacon returns should include a means for limited identification such as a single-blip presentation for all selected-code, beacon-equipped aircraft, a double-blip presentation for discrete identity of individual aircraft on the selected code, and an extended range blip to present aircraft in emergency

The following symbology is suggested for the pictorial display Approximate sizes are for a 20-inch diameter display area Figure 5 illustrates the format desired

1 The current position symbol should be indicated as follows

Dot Size 0 030 inches	•	Indicates highly accurate position data with positive identification such as those derived from a radar beacon system with positive identification of targets, or from primary radar with a human-monitored TWS gate and positive identification
Small circle Diameter 0 150 inches, ± 0 050 inches	○	Indicates somewhat less accurate relative position data such as those derived from aircraft navigation systems and transmitted to the ground over automatic position-reporting devices
Small square Sides 0 150 inches, ± 0 050 inches	□	Indicates position data derived by primary radar with an automatic TWS gate (non-continuous monitoring)
Triangle Sides 0 150 inches, ± 0 050 inches	△	Indicates estimated position data based on the flight plan updated by available position reports such as voice reports, relatively infrequent air/ground data-link reports over fixes, or occasional radar checks
Diamond Sides 0 150 inches, ± 0 050 inches	◇	Indicates a departing aircraft ready for takeoff but not yet airborne

These indications of quality of position data will be used by the controller in determining the amount and type of separation required between various flights

2 The heading vector should be indicated by a line drawn from the current position symbol This line should be drawn in 5° increments The length of the vector should represent one minute of flying time at scale factors of 6 to 20 miles per inch and one-half minute of flying time at scale factors of 2 and 4 miles per inch

The following information should be written alongside the current position symbol and vector All letters and numbers shall be standard Arabic characters

1 The current altitude should be written in two numerals representing thousands of feet The current altitude should be followed on the same line by a blank space if the altitude is based on voice reports or on pilot-inserted data-link reports It should be followed by a dot if the altitude data are transduced directly from a suitable altimeter in the aircraft and transmitted over data-link, beacon, or other automatic devices to the ground The dot or blank in third space should be followed by a V if the aircraft is climbing or descending with visual flight rule (VFR) restrictions In the next two spaces, a newly assigned altitude to which the aircraft is climbing or descending can be indicated by numerals in thousands of feet

2 The identification of the aircraft should be written on a line below the altitude line It may consist of any combination of six letters or numbers This will be the actual radio call used by the controller to communicate with the aircraft

3 A minimum route indication should be provided on the line below the identification The airway route being flown currently or the next fix ahead will be indicated by the first three figures or letters, followed by the destination in three letters

4 Potential airspace conflicts determined by the automatic computers can be indicated by pulsating the brightness of the data for the aircraft in conflict

5 An aircraft-in-emergency indication should be provided by drawing a square around the entire symbology for the particular aircraft

6 Suitable maps of navigation facilities, route structure, airports, and similar facilities should be provided for selection by the controller

Letters and numerals should be as small as practical, but they should have adequate readability to permit rapid scanning of data by the controller For a 20-inch display surface, letters and figures approximately 1/8-inch to 3/16-inch are recommended

Information should be written at a rate high enough to eliminate flicker problems Any residual storage on the phosphor screen as targets move should not be bright enough to smear or make unreadable the new data being written

Limited Tabular Display

A small tabular display (electronic or electromechanical) is required next to the pictorial display to complete the current-situation display consoles It will serve several functions, including

1 Tabular posting of aircraft in holding stacks and of aircraft proposing departure from airports in the control sector where overlap of the target data on the pictorial display may make the information unreadable

2 Comparison of estimated times of aircraft over any fixes in the controller's sector, such as for sequencing aircraft properly in approach stacks or for determination of potential conflicts based time separation

3 A means of controller access to the display and automatic data-processing system for entry of new information, including

- a Newly assigned altitudes
- b Current altitudes as reported by voice to the controller
- c VFR restrictions in climb or descent
- d Position reports from aircraft not being tracked by radar or other means as received by the controller over air/ground voice channels
- e Modification of stored flight plans to reflect issuance of holding instructions and expected release times for updating of planning displays
- f Temporary cutoff of selected aircraft on the pictorial display to reduce reading problems of overlapping data

The following information for each aircraft displayed on the associated pictorial display should be posted on the limited tabular display

1 Identification

2 Number and type of aircraft
3 Current altitude
4 VFR restriction in climb or descent
5 Assigned altitude
6 Fix designator
7 Time, with a category indication

Identification should consist of any combination of six letters or numbers, the number and type of aircraft should be designated by five characters or numbers Current and assigned altitude should be expressed in thousands of feet The fix designator should represent any fix within the control sector of the controller The time should represent

1 The estimated time over the fix, when followed by an E
2 The actual time over the fix, when followed by an A
3 The proposed time of departure from an airport, when followed by a P
4. The estimated time of departure from a fix if an aircraft is held or delayed en route, when followed by an H

Information on each flight should be posted in horizontal rows, with flights sequenced vertically by altitude

An associated button by each horizontal row, or a movable electronic arrow, should be provided to permit selection of individual flights by the controller for modification of data in the system

A conflict-alarm lamp, or a special symbol if a cathode ray tube is used, should be associated with each horizontal row This alarm signal should be lighted by the computer to indicate less than standard predicted time separation between aircraft at the same altitude

A row of pushbuttons or other suitable selectors along the bottom of the limited tabular display should be provided to allow selection of individual vertical columns for modification of data by the controller A limited keyboard or other selectors should permit insertion of new data in the board This should be a block of information

Other Design Factors

Because of the problems caused by overlapping target data on large combined area displays in high-density areas where all altitudes are presented on a common display, individual situation-display consoles for each controller are desired Through suitable automatic data-processing systems, only the processed data needed by a controller for his assigned sector, plus limited overlap into adjacent sectors of airspace, should be presented Although the primary radar data for a geographic sector cannot be filtered by altitude layers, the raw radar data should be available to the controller for checking positions shown by the automatic processing equipment, for checking operation of the TWS gates, and for verification of position data received by automatic means or by voice Normally it is anticipated that assignment of TWS gates to new targets will be initiated by the situation-display controller after radar identification of the target Automatic or human-rate-aided tracking by the controller, his assistant, or tracking operators then will continue.

It is anticipated that each situation-display controller can monitor the movements and provide short-term control for approximately 20 aircraft simultaneously in a general en route traffic situation when many of the aircraft are at assigned cruising altitude and continuous issuance of new control instructions is not required When most of the aircraft are in climbs or descents or are changing routes, and when many control instructions must be issued, each controller may be able to handle up to ten aircraft only Design-wise, it is recommended that each situation-display console provide for a maximum capacity of up to 40 aircraft to permit display of data for the sector under control, with overlap into adjacent sectors The amount of traffic assigned to each controller will depend upon local area characteristics

The individual situation-display consoles should be provided with controls which will permit display of data for any portion of the control area geographically and between any selected altitude levels The following range scales are suggested for each pictorial display (Scale factors are shown for a circular display 20 inches in diameter)

Diameter of Area Covered (miles)	Range from Center of Display (miles)	Scale Factor (miles/inch)
400	200	20
280	140	14
200	100	10
160	80	8
120	60	6
80	40	4
40	20	2

The larger areas of coverage will be used for high-altitude sectors and high-speed aircraft where the airspace is stratified by altitude, and for combined display of several sectors during light traffic conditions The shorter ranges will be used for the higher density traffic areas

If a cathode ray tube is used for the pictorial display, a usable area 18 to 24 inches in diameter is desired The limited tabular display may use an electronic tube or electromechanical indicators Two bays of tabular data for 20 aircraft each may be provided, although one bay for all 40 aircraft is preferred

Good human engineering practice is required throughout The over-all console size should be approximately 52 inches in height and 42 to 50 inches in width so that the controller can reach all portions of the display while seated Space must be provided for air/ground and interphone communications key-selector equipment It is anticipated that suitably located standby consoles will be used to provide a safety backup in the event of equipment failure

PLANNING DISPLAY

General Description

The planning displays should provide information in tabular form on proposed occupancy of airspace for a future period of time The estimated arrival times of aircraft at certain critical points in the airspace, such as at major airway junctions and intersections and at approach fixes or airports, should be posted along with other pertinent data including identification, altitude, and route of flight A supplemental portion of the display should show predicted relationships of aircraft on the lesser traveled routes and the relationship of these aircraft with pertinent aircraft on major routes The associated automatic data-processing equipment and computer should compute estimates automatically, revising these as new position data are received It also should process flight-plan data for proper display and should include activation of alert or conflict-warning signals

The planning controllers will be concerned primarily with examination of new flights entering the control area (either taking off from within the area or entering from an adjacent control area), comparing proposed routes and cruising altitudes with those already assigned, and determining the best over-all organization of traffic flow to reduce the number of potential conflicts to a minimum and to provide a smooth traffic flow In using the planning displays, controllers can scan visually and compare the estimated times of arrival and relative speeds of aircraft at the same cruising altitudes over the posted fixes Where less than the minimum time separation is predicted, the controller can examine adjacent altitude levels or adjacent routes, and insofar as possible, he can reassign aircraft to nonconflicting routes or altitudes The planning controllers normally will not be concerned with problems of climb-out or descent or other short-term control actions, because these actions can be handled by the current-situation controllers

In addition to organizing traffic flow in advance to eliminate as many conflicts as possible, the planning controllers will provide flow-control service From knowledge of forecast weather, available navigation and control aids, airport capacity, and potential demand for service, they will estimate the acceptance rate at bottlenecks in the system and limit the peak flow of traffic at these points to prevent overloads By comparison of estimated arrival times at these critical points, the controller will determine when the peak capacity for blocks of time will be exceeded and will select appropriate aircraft to reduce speed or delay en route to reduce the arrival rate at the critical point to maximum system capacity Aircraft on tactical missions or aircraft in emergency conditions can be provided with priority-scheduled use of airspace as necessary

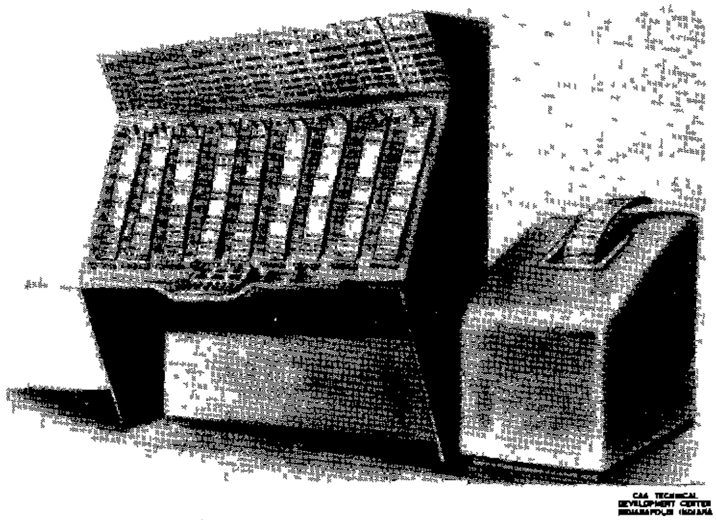

Fig 6 Planning Display Console

Normally the planning controllers will forward all control decisions to the appropriate situation-display controller who currently is controlling the aircraft or to the situation-display sector where the flight first will enter the control area

Detailed Design

The data to be displayed to the planning controllers may take several forms In whatever form used, however, it should include items of the basic flight plan and proposed occupancy of airspace by route, altitude, and time It should be noted that computers may be programmed to do many of the routine duties associated with the planning-control function if sufficient capacity and computing speed are available This is turn will affect the amount and kind of data to be displayed for the human controller The following description is one way in which data may be displayed, based on automatic computation and processing and on human controller decisions for all planning and flow-control functions Figure 6 is an artist's drawing of a possible design for the planning display console

The planning displays may include the following information at posted fixes

1 Identification of aircraft Six characters in any combination of letters or numbers representing the flight identity
2 Number and type of aircraft Six characters, letters and/or numbers
3 Equipment category Three characters, the first character representing navigation aids aboard the aircraft, the second character, the radio equipment for ATC communications, and the third character, whether radar beacon and/or air-ground data link is carried
4 Departure airport Three-letter identifier
5 Destination airport Three-letter identifier
6 Route to fix being posted Four characters, numbers and/or letters For direct-route flights the previous fix identifier followed by a dash can be used
7 Fix being posted Three-letter identifier This can be preceded by a four-character group indicating distance in miles and direction from the fix for direct-route flights not passing directly over the fix
8 Route from the fix posted Four characters, numbers and/or letters For direct-route flights a dash should be followed by the three-letter identifier for the next fix over which the flight will pass
9 Current situation display sector Two digits to designate the sector in which flight is operating or will enter first
10 Estimated time over the fix Four numbers in 24-hour clock time This group can be preceded by a P if the flight is not yet airborne and if time is based on a proposed departure time
11 Requested or current altitude Two numbers indicating altitude in thousands of feet
12 Assigned altitude Two numbers indicating altitude in thousands of feet
13 Conflicting traffic Two six-character groups indicating identification of conflicting flights

All of this information should be posted in tabular form for each major fix Flight data may be sequenced by altitude or by estimated time over the fix Normally flight data should be posted for a period of from 15 minutes to two hours prior to the estimated time over the fix Each line of new or modified information should carry a distinctive symbol such as an asterisk at the beginning of the line to identify it as entry of new data

At intersections of minor routes with major routes, and at intersections of minor routes, only the crossing aircraft and those aircraft within 10 minutes and 2,000 feet of the crossing aircraft need be posted

Access to the automatic data-processing system by pushbuttons or selector switches should be provided to permit the controller to modify information in Items 5 through 12 Provision should be made for traffic densities of up to 80 aircraft estimated over a fix

Because of the amount of data to be displayed, and because the data to be displayed are not as critical timewise as on the current-situation displays, it appears that a high-speed printed paper readout device will be suitable A new sheet of data updated approximately every ten minutes for all critical fixes posted can be produced by such a printer and associated computer

Provision should be made for the planning-display controller to transmit initial ATC clearances to the control tower for departing flights, including route and cruising-altitude assignment The approved cruising altitude and route will appear simultaneously at the proper current-situation display sector

When the planning controller wishes to change the altitude of an aircraft en route or to slow down or delay an aircraft en route, this information can be transmitted by telautograph-type devices or voice communications over interphone to the cognizant situation-display controller After effecting the requested change the situation-display controller will insert the new altitude or new fix estimate in the automatic data-processing system from the situation-display input keys

Planning displays may be provided as individual consoles or as one combined large display for all planning controllers If individual displays are provided it should be possible to select any fixes and any altitude strata within the control area as traffic conditions and available control personnel require

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