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# DEVELOPMENT OF A DYNAMIC AIR TRAFFIC CONTROL SIMULATOR


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Technical Development Report No. 191

Prepared for

The Air Navigation Development Board

Under

Project 6 7

by

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT AND

EVALUATION CENTER

INDIANAPOLIS, INDIANA



October 1953

U S DEPARTMENT OF COMMERCE

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CIVIL AERONAUTICS ADMINISTRATION

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# DEVELOPMENT OF A DYNAMIC AIR TRAFFIC CONTROL SIMULATOR

## FOREWORD

The Air Navigation Development Board (ANDB) was established by the Departments of Defense and Commerce in 1948 to carry out a unified development program aimed at meeting the stated operational requirements of the common military/civil air navigation and traffic control system This project, sponsored and financed by the ANDB, is a part of that program The ANDB is located within the administrative framework of the Civil Aeronautics Administration for housekeeping purposes only Persons desiring to communicate with ANDB should address the Executive Secretary, Air Navigation Development Board, Civil Aeronautics Administration, W-9, Washington 25, D C

## SUMMARY


This report outlines the desired performance characteristics of an air traffic control simulator and describes the construction and operation of a dynamic simulator which was designed to meet these requirements The dynamic simulator provides a means of studying the equipment, the system, and human elements of an air traffic control system in order to obtain a better understanding of the basic factors which affect the flow characteristics of the system

Results indicate that the simulator can serve as a valuable aid in the solution of present air traffic control problems and in research into future systems Also, it has proved to be a very effective training aid for air traffic control personnel

The report includes recommendations regarding the future design of simulator equipment and the application of simulation techniques


## INTRODUCTION

Air traffic control (ATC) is a highly complex subject which involves such interrelated factors as aircraft performance characteristics, airport design, navigational-system characteristics, and human reactions Prior to the implementation of suitable simulation techniques, ATC facilities and procedures had to be developed by cut-and-try methods There was no way of testing the performance of a new system except by the actual use of aircraft after the system was installed Because of the high cost of this method, it was not practical to conduct much actual scientific research into the various factors of the ATC problem Because of the lack of an opportunity to analyze, evaluate, and refine the various elements of the system while they were still in an early developmental state, it was seldom that optimum traffic capacity was obtained for the money spent on air navigation and traffic control facilities Over a period of years the traffic acceptance rate or the capacity of our airway and terminal-area traffic control systems for Instrument Flight Rule (IFR) operations has consistently lagged behind the potential traffic demand rate

For many years simulation has been used in other fields of research as a valuable aid in the investigation of basic characteristics of proposed systems, in the demonstration or development of proposed procedures, and in the training of personnel to handle such procedures In view of the particular difficulty in carrying out full-scale experiments in ATC, the use of simulation was recommended in the report by Special Committee 31 of the Radio Technical Commission for Aeronautics (RTCA) [1] A simulator suitable for experiments in ATC was built by the Division of Radiophysics of the Commonwealth Scientific and Industrial Research Organization in Australia, and the results which were obtained showed close correlation with the results of similar procedures performed by real aircraft [2] In a contract placed by the Air Navigation Development Board with the Franklin Institute, a study was made of the applicability of simulation to the investigation of ATC problems [3] From this study a slide rule and a graphical simulator were developed, both of which are proving their worth as useful tools in the investigation of these problems The value of a dynamic type of simulator which would include both the human and the machine elements was also recognized in this study

A simulator for studying human factors in ATC systems was constructed at the University of Illinois under the auspices of the National Research Council (NRC), Committee on Aviation Psychology, with the use of funds provided by the Department of the Navy [4] The simulator provides a promising method for the simultaneous study of variations in systems and procedures of ATC and of display problems in the presentation of navigation information, particularly with respect to changes in heading in the terminal area This type of simulator uses Link trainer crabs to represent aircraft It was designed primarily to study the interaction between instrument displays and traffic approach control systems A simulated radar indicator is provided to the ground controllers

As a result of work completed at the Technical Development and Evaluation Center of the Civil Aeronautics Administration on the evaluation of the Navascreen equipment, it appeared that this equipment, which was developed originally as a pictorial display for ATC, was particularly well-adapted for use in its simulation

It was believed from preliminary studies of this problem that a logical approach to the simulation of ATC would be to assume that the problem is evolutionary in nature Thus, a simulator was constructed from available components to meet the known requirements From this starting point, necessary improvements were made as operational experience was gained and as more knowledge of the basic characteristics of ATC was obtained

## DESIRED CHARACTERISTICS

Since means for studying the types and amounts of information which are required in the pilot's cockpit are already available, the design of an ATC simulator should give primary consideration to features for the study of the functions of the over-all system and for the study of the requirements of the control agencies However, simulation both of the aircraft and of the pilot must be included to the maximum

[1] "Air Traffic Control," Paper 27-48/DO12, RTCA Special Committee 31, Washington, D C, May 12, 1948

[2] T D Newnham, "An Air Traffic Simulator," Division of Radiophysics, Commonwealth Scientific and Industrial Research Organization, Commonwealth of Australia, October 1949

[3] S M Berkowitz, W W Felton, R S Grubmeyer, and R R Reid, "The Applicability of Simulation to the Investigation of Air Traffic Control Problems," Final Report No F-2130-1, Franklin Institute, Philadelphia, Pa, March 17, 1950

[4] B E Johnson, A C Williams, Jr, and S N Roscoe, "A Simulator for Studying Human Factors in Air Traffic Control Systems," with an appendix, "Diagrams and Technical Descriptions of the Components of the Air Traffic Control Simulator," by M J Schwetz, University of Illinois, NRC Committee on Aviation Psychology Report No 11, June 1951

extent practical in the system in order to avoid incomplete or unrealistic conclusions based on the simulation tests. The principal ATC system elements which must be considered in the design of a simulator can be listed as follows:

1. The required number of aircraft with their basic performance characteristics and variations. These factors include flight speeds, altitude changes, and turning characteristics. Although these characteristics vary widely under different conditions, it is possible to obtain enough actual flight data to determine the distribution of these variables. These distributions can be designed or injected into the simulator.

2. The communications systems between aircraft and ground agencies and between ground agencies.

3. The navigational information to the pilot of the aircraft.

4. The layout of the essential components of the en route and the terminal-area control agencies, including their information inputs, displays, and outputs.

5. Means for duplicating, insofar as possible, the human element in the ATC system. This is done by providing sufficient numbers of controllers and pilots to operate the various components of the simulator. It appears that the variables resulting from the behaviors of men can be approximated only by making the operating conditions closely similar to those which might exist in the system being tested. Although it is not possible to duplicate exactly all the stress and distractions which might exist under actual operating conditions, every effort is made to keep the conditions as realistic as possible. The validity of the test results can be no better than the approximations made and the extent to which these variables are represented.

6. Means for recording significant data regarding the performance of the various elements of the traffic control system during the simulation tests. Since a greater amount of time is required to analyze the results than to perform the tests, it is important that the data be in a form which is as close as possible to the required end result and which does not require an unreasonable amount of interpretation effort.

A fundamental factor in the design of a simulator is the number of aircraft which will have to be controlled simultaneously, since this quantity determines the complexity and the cost of the equipment as well as the operating costs of any simulation program. The required number of aircraft depends to some extent on the type of system being evaluated. Apparently there is no single, well-defined number which represents the maximum number of aircraft which will have to be controlled simultaneously. However, the problem may be approached on a statistical basis by finding the probability that a given number of aircraft will be at a given time in the control sectors or the terminal areas under study. If, for example, only arriving aircraft are considered and if it is assumed that departure and over traffic are handled in a manner that does not interfere with the arriving aircraft, the solution can be obtained from probability curves.

If it is assumed that the terminal area has a radius of 30 miles and that a maximum landing rate of 45 aircraft per hour is used, then the probability that more than 25 aircraft will be in the control zone at the same time is about 80 times in a million; and that 20 or more aircraft will be there is about three times in a thousand.

Another factor to be considered in the system being evaluated is the area in which variable control is used. For example, the system may require aircraft to follow standard courses, laid down by navigational aids, until 15 miles from the airport. During the last 15 miles to a landing, the aircraft are placed under variable control and are directed to different courses in order to arrive in the proper sequence on the final approach path. Thus, the variables in the system are in a smaller area, and this area is the principal one in which the data and the results are to be determined. In view of this fact, a smaller number of aircraft can be used in the simulation tests and can be required to enter the 15-mile sector at the proper time and location.

## EQUIPMENT DEVELOPMENT

### Basic Evolution.

The simulator is designed around a projection type of display in which small, controllable spots of light representing aircraft are superimposed on a map projected on a large screen to form the pictorial display of the ATC system under study. Ever since its inception early in 1951, the simulator has undergone an almost continuous evolution during which new features have been added from time to time and old equipment has gradually been replaced as better components were developed for the job.

The initial arrangement utilized the Navascreen projectors and control consoles in an arrangement wherein the display was projected in reverse on a translucent plastic screen 12 feet square and was viewed from the opposite side by controllers seated at an improvised control desk. Although the Navascreen projectors have a very accurate and stable system of speed control as well as the ability to display different aircraft identification numbers, they suffered from a very serious fault; namely, the inability to make curved transition courses when changing from one heading to another. The square-turn characteristic made the resulting flight paths unrealistic and presented an awkward problem to the operators whenever a change in heading was required. For this reason, the Navascreen projectors were soon replaced with a set of projectors originally developed for the Teleran demonstration equipment.[5] These projectors were not quite as accurate on straight-line flight speeds as the original Navascreen equipment, but their ability to make standard-rate left and right turns made the resulting display much more realistic from the standpoint of simulating the flight paths of actual aircraft.

In addition to these projectors, specialized terminal-control and en route-control desks were added. The initial model of a mechanical data-transfer equipment was developed and installed as a communications link between the terminal-control and en route-control positions.

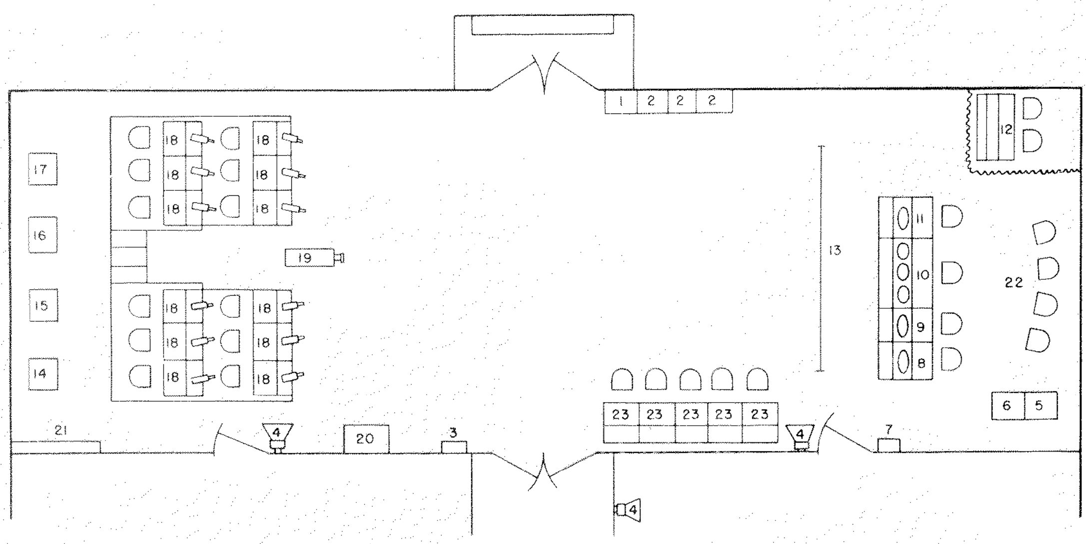
The resulting pictorial display was still unrealistic because it was presented on a large plastic screen rather than on a small scope simulating a radar display. For this reason, a television link was added. The television camera was mounted on the projection rack. The output of this camera went directly to three 12-inch cathode-ray tubes mounted on the control desks illustrated in Fig. 1. These displays were much more realistic from the standpoint of size and equipment layout, but they were presented on a solid television raster instead of being painted on the scope by means of a rotating polar beam. In order to make the displays more closely resemble the characteristics of a surveillance-radar presentation, an electro-mechanical linkage was developed to furnish the rotating-beam presentation.

The original optical projection system projected the picture on the screen in reverse, a system which required the console operators to observe the picture through mirrors. The operators were also a rather great distance from the projectors, so that an additional person was necessary to reposition each projector at the beginning of each flight. Also, the layout did not lend itself to further expansion.

For these reasons, a new arrangement of console and projector racks was built. This layout, which is shown in Fig. 2, placed the consoles in two tiers of six each, allowing expansion of the equipment to a

[5] Instruction Book for Television Radar Air Navigation Trainer, Radio Corporation of America, Publication IB-38461.


Fig. 1. Control Desks Showing the Simulated Radar Displays and the Data-Transfer Equipment



1. POWER SUPPLY, DATA-TRANSFER UNIT
2. RELAYS, DATA-TRANSFER UNIT
3. SIMULATOR MAIN-POWER SWITCH
4. PUBLIC-ADDRESS SPEAKERS
5. POWER SUPPLIES, TELEVISION-SYSTEM
6. FLYING-SPOT SCANNER
7. TELEVISION MAIN-POWER SWITCH
8. RADAR CONSOLE, DEPARTURES
9. RADAR CONSOLE, WEST SECTOR
10. SIMULATED WEATHER INSTRUMENTS AND DATA TRANSFER UNITS
11. RADAR CONSOLE, EAST SECTOR
12. DATA-TRANSFER UNITS AND ATC POSITIONS
13. SCREEN
14. ESTERLINE-ANGUS RECORDERS AND IMPULSE COUNTER
15. COMMUNICATIONS AND PUBLIC-ADDRESS AMPLIFIERS
16. POWER SUPPLIES, SIMULATOR
17. TEN-CHANNEL VOICE RECORDER
18. OPERATORS' CONSOLES AND PROJECTORS
19. TELEVISION CAMERA, MAP PROJECTOR, AND WIND-DRIFT MECHANISM
20. LOCAL TELEVISION MONITOR
21. ELAPSED-TIME INDICATORS
22. OBSERVERS' CHAIRS
23. EN ROUTE FLIGHT CONSOLES

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Fig. 2 Dynamic ATC Simulator Equipment Layout

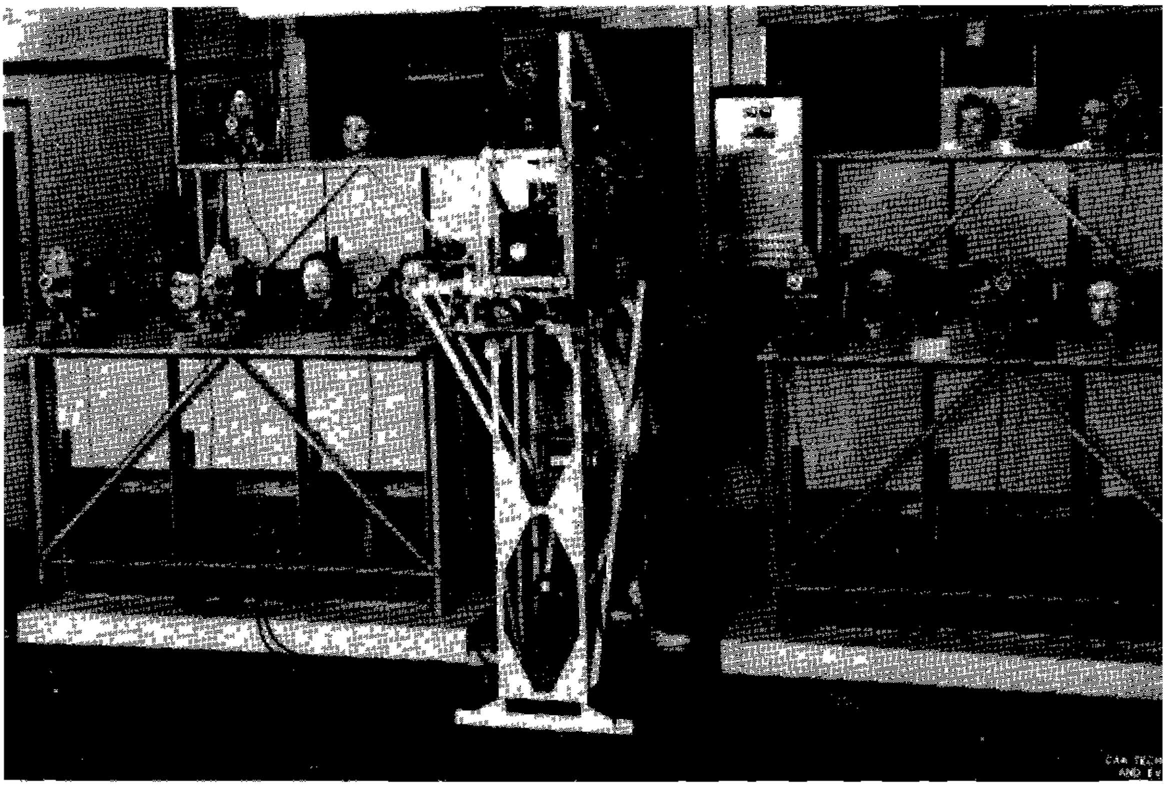


Fig 3 A View Of the Operating Consoles and of the Projector Systems Showing the Operators U
Simulate Aircraft Pilots

total capacity of twelve aircraft In addition, the layout placed the individual projectors within easy reach of the console operators and thus facilitated the repositioning operation The operating consoles and the projector systems are shown in Fig 3 Further realism was added by the development and installation of a device to inject wind drift into the control problem

## DESCRIPTION OF PRESENT COMPONENTS

### Map Projector

The map projector is the only surviving component from the original Navascreen layout It uses standard 4-inch by 5-inch lantern slides, which are made up as necessary to form the background of navigational systems being tested The scale of the slides determines the speed scale to be used by the individual spot projectors

### Spot Projector

Each spot projector, as shown in Fig 4, is a gimbal-ring-mounted light box driven from the rear by a friction drive unit The drive motor is a 27 5-volt d-c permanent magnet unit fed through slip rings from a regulated d-c power supply The motor is connected to a three-speed gear box which drives the friction wheel The drive motor, the gear box, and the friction wheel are all mounted in a rotatable drum which may be turned by a separate, geared drive unit in order to drive the light box in any desired direction Rotation of the friction-wheel assembly at a standard rate of 3° per second is effected by a reversible a-c torque motor

The spot-projector units were all modified from the original Teleran demonstrator projectors Each projection lamp is supplied from an individual 6-volt transformer and is controlled from a switch on the

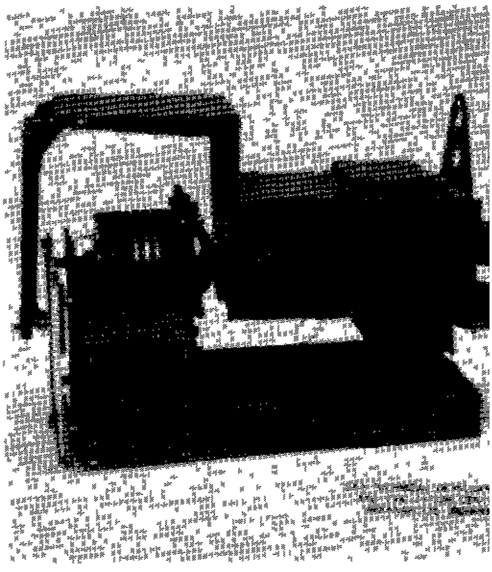

Fig 4 Spot Projector Which is Used to S
Positions of Aircraft on the Screen

Control of the a-c torque motor in orde
right or left turns is effected by the consol
through the use of a three-position switch
jector is equipped with a synchro geared to
able drum, so that continuous information

the projector heading is available to the console operator by reference to an azimuth indicator which is connected to a remote synchro on the control console

Speed control of the projector is accomplished by applying a variable d-c voltage to the drive motor Control is obtained from one-fourth to full speed By proper selection of gear ratio and of map scale, the projector can cover a speed range of approximately 100 to 1000 miles per hour (mph)

Operating Consoles

The control panel of a console is shown in Fig 5 The various instruments and controls with their functions are listed below

Fig 5 Operating Console Used to Control Spot Projector for Simulation of Aircraft Movements

TIMER The timer is adjustable from 0 to 120 seconds and is used to simulate runway-occupancy time and holding-pattern time

ALTIMETER The altimeter simulates a barometric altimeter and has provisions for controlling the rate of descent and ascent

HEADING INDICATOR The heading indicator is a selsyn repeater that is electrically coupled to the spot projector and thus indicates the flight course of the spot

TURN SWITCH The turn switch is a left-right switch that controls the motor which rotates the projector barrel to make standard-rate turns of 3° per second

MOTOR SWITCH The motor switch applies power to the projector drive motor

SPEED-CONTROL KNOB The speed-control knob is calibrated in mph and controls the speed of the spot

PROJECTOR-LIGHT SWITCH The projector-light switch applies power to the light for the spot

RECORD BUTTON The record button, when actuated, causes deflection of a pen on the recorder

VOLUME The volume control provides a means of adjustment for the headphone volume

CHANNEL-SELECTOR SWITCH The channel-selector switch can be used to select any one of six communications channels

TALK-BUSY SWITCH The talk-busy switch records busy time in the up position and talk time in the down position In the talk position, the microphone is connected to a communication channel

A Lumiline light fixture illuminates the various controls The panel and the control labeling are designed for good visibility under poor lighting conditions Jacks are provided beneath the console for headphones and breastsets

Television System

The television system, which is diagrammed in Fig 6, converts the optically projected display on the screen into a simulated plan-position-indicator (PPI) radar presentation for the traffic controllers The synchronizing generator generates the timing pulses necessary for a 735-line interlaced television picture with a field rate of 30 cps and a frame rate of 15 cps The timing pulses from the synchronizing generator operate the deflection and blanking circuits of the television camera The picture displayed on the projection screen is optically imaged on the photocathode of a sensitive-image orthicon tube in the television camera The target of the image orthicon is scanned by the electron beam in square co-ordinates The video output of the tube is amplified and mixed with blanking and synchronizing signals in the camera

The composite video-signal output of the television camera is fed to the operator's monitor and to the flying-spot scanner The operator's monitor presents the information from the television camera in square co-ordinates on its kinescope tube This monitor is located close to the television camera in order to facilitate camera adjustments The flying-spot, cathode-ray tube in the flying-spot scanner projects the pictorial information from the camera in the form of a square television raster on a rotating disk A slot extending from the center of the disk to the outer edge of it is used to simulate a PPI type of sweep The disk is driven by a variable-speed motor to simulate various antenna rotational speeds A multiplier phototube on the other side of the disk is illuminated by light that passes through the slot The signal output from the phototube is amplified by a video amplifier, and the synchronization signals are mixed with the video signals

The video output of the flying-spot scanner is presented on the screens of the 12-inch, cathode-ray tubes located in the two approach consoles and in the departure-control console An amber filter is used over the faces of the cathode-ray tubes to eliminate the blue flash that is emitted by a P7-type phosphor

Wind-Drift Simulator

The wind-drift simulator is shown in Fig 7 This device is a motor-driven mounting rack for the map projector and for the television camera This rack operates to move the projector in such a fashion that the map on the screen travels at a velocity and direction corresponding to the desired wind drift For example, in order to simulate a north wind of 20 mph, the map on the screen is moved toward the north at a velocity scaled to 20 mph The projected spots representing aircraft on the screen thus appear to be subject to a drift component of 20 mph toward the south Because the television camera is moved simultaneously with the map projector and because it is always aimed at the center of the map on the screen, no movement of the map is apparent on the television display at the control desks The wind-drift mechanism is actuated by two motors One motor supplies the north-south component, and the other the east-west

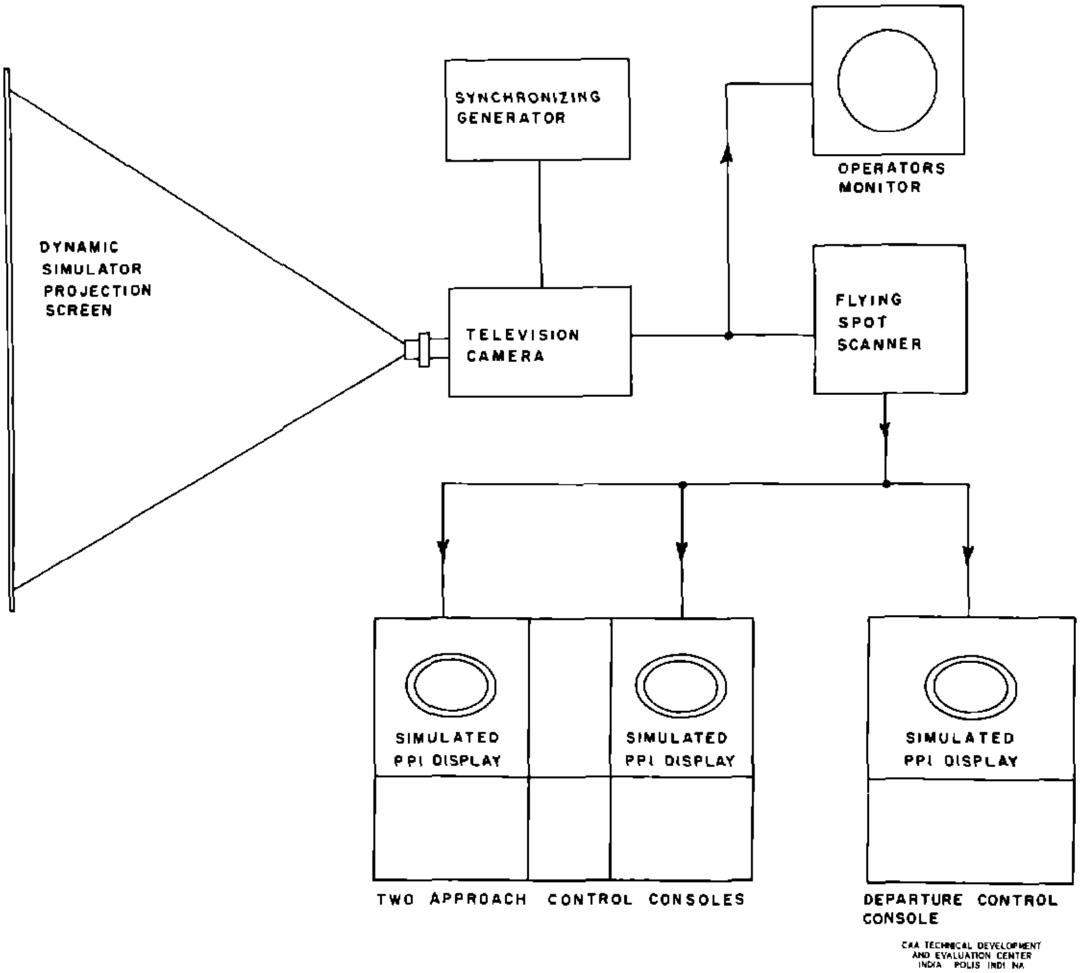


Fig 6 Block Diagram of Television System for Radar PPI Simulation

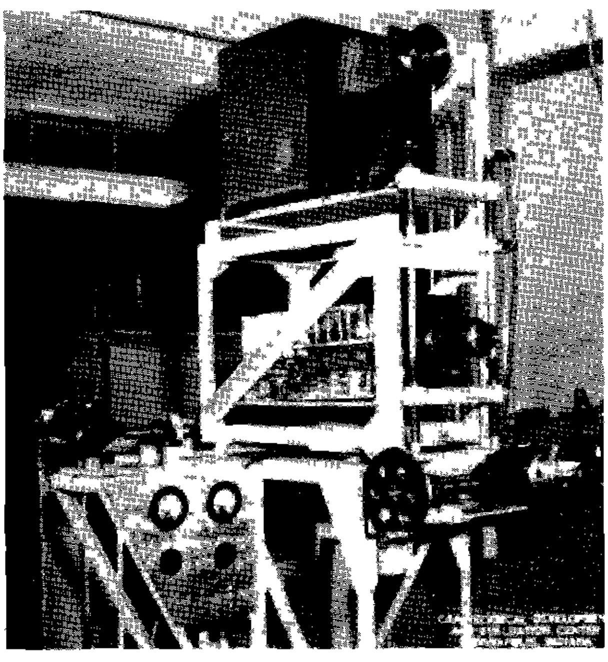

Fig 7 Map Projector and Television Camera Mounted on Wind-Drift Simulator

component of the desired wind drift The motors operate the rack through a worm-drive linkage Each motor is geared to a d-c generator which supplies a voltage to a tachometer which thus can be used for adjusting each motor to the desired operating speed Winds up to 300 mph in any direction can be simulated by this device The linkages are equipped with automatic alarms to advise operating personnel when the map is nearing the limit of its travel in a certain direction It is then necessary to stop the simulator and to reset the map position

Projection Screen

The original, translucent-plastic screen on the Navascreen system was intended for direct viewing from the opposite side, therefore, less than 40 per cent of its light was reflected back toward the projection side When the television system was installed, a much brighter reflection became necessary For this reason, the translucent-plastic screen was replaced by an opaque, beaded-glass screen, 12 feet square

Communications System

The communications system is diagrammed in Fig 8 There are six communications channels in the simulator Each channel is connected to all of the operator's consoles and to the three radar-controller positions Channel 6 is reserved for air/ground Air Route Traffic Control (ARTC) communications The ARTC position is connected to channel 6 only, and it is not provided with a channel-selector switch as the others are Therefore, the pilot may select channel 6 for communication with ARTC, or he may select

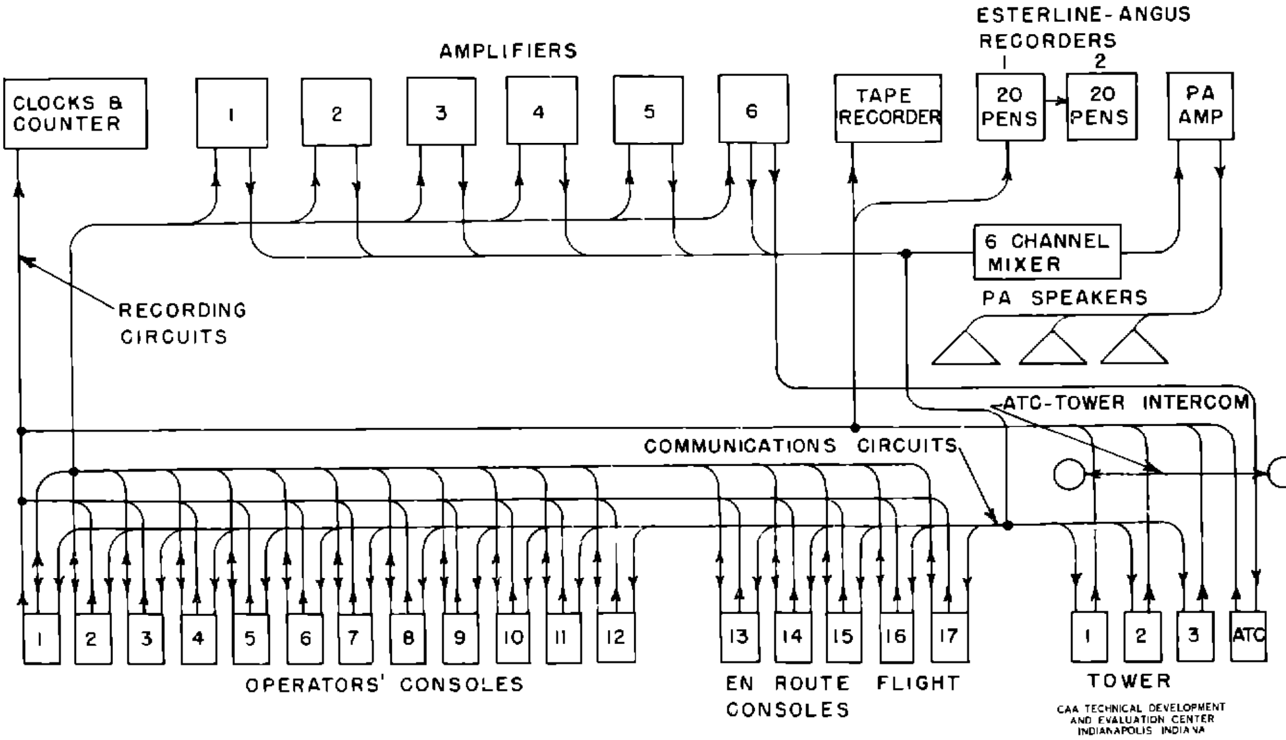


Fig 8 Diagram of Communications and Recording System (Data-Transfer System Not Included)

any other channel which might be in use at the tower positions for communication with the tower The radar controllers may select any channel including the ARTC channel, but interlocking circuits prevent direct tower-to-ATC communications by this fashion A separate interphone circuit is used for radar-to-ARTC communications

Console operators, in addition to being provided with a channel-selector switch, are provided with headsets, breastsets (microphones), and a volume control They may talk by depressing a switch, or they may indicate that they wish to talk and cannot by pressing this switch up The switch is a momentary-contact, spring-loaded one The operation is of a simplex type with side tone provided

The radar positions and the ARTC position have loud speakers instead of earphones and have hand-held microphones with momentary-contact switches instead of having breastsets These positions are also provided with volume controls The major difference between these positions and the console ones is that there is no side tone provided, a relay muting the speaker when the controller talks

A public-address system is installed for use in lectures and demonstrations It consists of a separate amplifier connected to the communications system and having three loud-speakers located in the simulation room Each speaker and each channel have separate volume controls This system can be used to present a composite picture of the entire traffic operation to spectators

## Data-Recording Equipment

A block diagram of the recording system is also shown in Fig 8 Two Esterline-Angus 20-pen recorders are installed One of these devices records communications data, at present recording the live time and the congestion time on each communications channel The data are segregated according to channel and initiating agency The other Esterline-Angus recorder is used to record flight data such as the time of take-off or landing or the time of passage over designated radio fixes A separate pen on this recorder is connected to a push button on each of the control consoles Console operators utilize a code in designating the type of flight information being recorded

A battery of electric clocks is utilized to record total pilot-communications time and total controller-communications time on each of three selected air/ground channels Electric-impulse counters are also used to record the total number of message segments on each of these circuits Activation of any press-to-talk switch or of any microphone switch rings up another number on the appropriate counter Each of the air/ground channels is connected to a ten-channel, magnetic, tape recorder, and all channels may be recorded simultaneously Any individual channel or any combination of channels may be played back

An automatic, single-frame, 35-mm camera is mounted on the projector rack in order to photograph the air traffic flow on the screen Time exposures are used in most instances The resulting films form a time-lapse sequence to show the actual paths covered by the simulated aircraft in the problem and to show the location of aircraft at specific times during the test run

## Time Synchronization

Because all aircraft must enter the problem on an exact schedule and because delays must be measured to very close limits, it is necessary to establish and maintain a definite time basis for all simulation runs All clocks and recording equipment must be synchronized on this time basis A master switch at the ARTC position supplies power to the clocks and to the recorders The Esterline-Angus recorders are driven by synchronous motors for instant starts and stops In running a long traffic problem, it is desirable to keep the number of interruptions at a minimum

## Power Supplies

Power for the activation of the Esterline-Angus recording pens is furnished by a 16-volt d-c power supply The spot-projector motors and the wind-drift-simulator motors receive power from a 28-volt d-c regulated power supply Microphone circuits receive power from a 6-volt d-c, battery-charger power supply The data-transfer unit receives power from a 110-volt

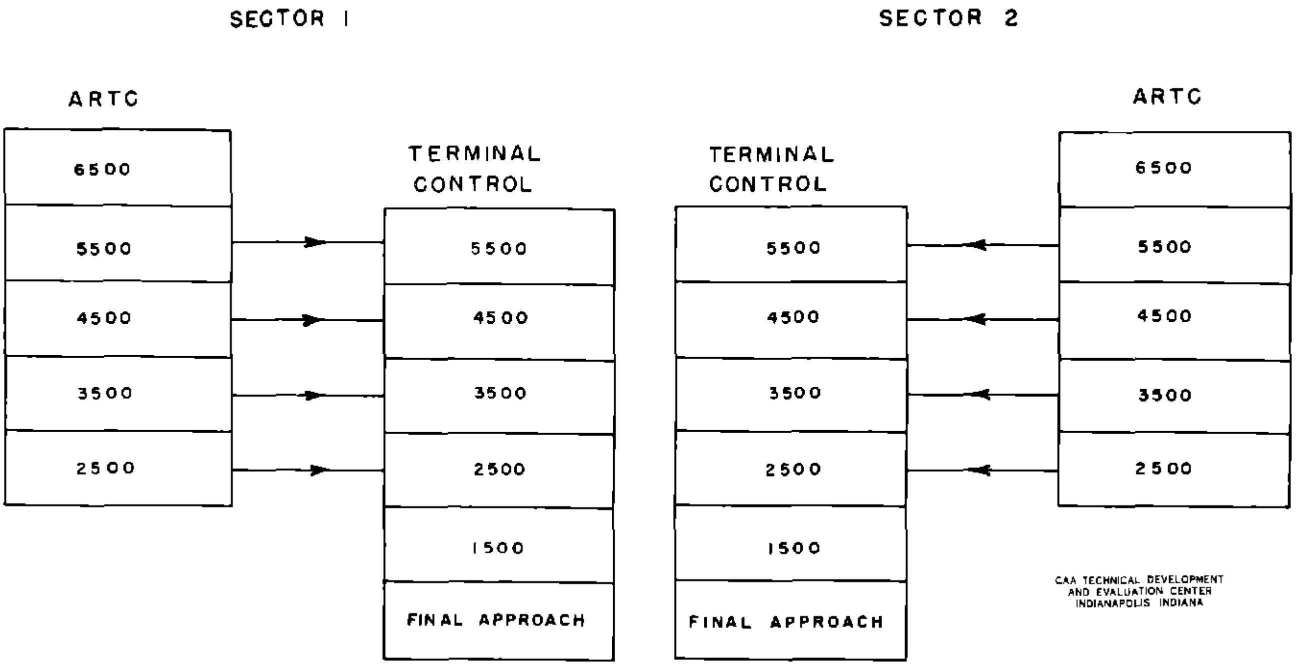


Fig 9 Altitude Blocks of Experimental Data-Transfer System

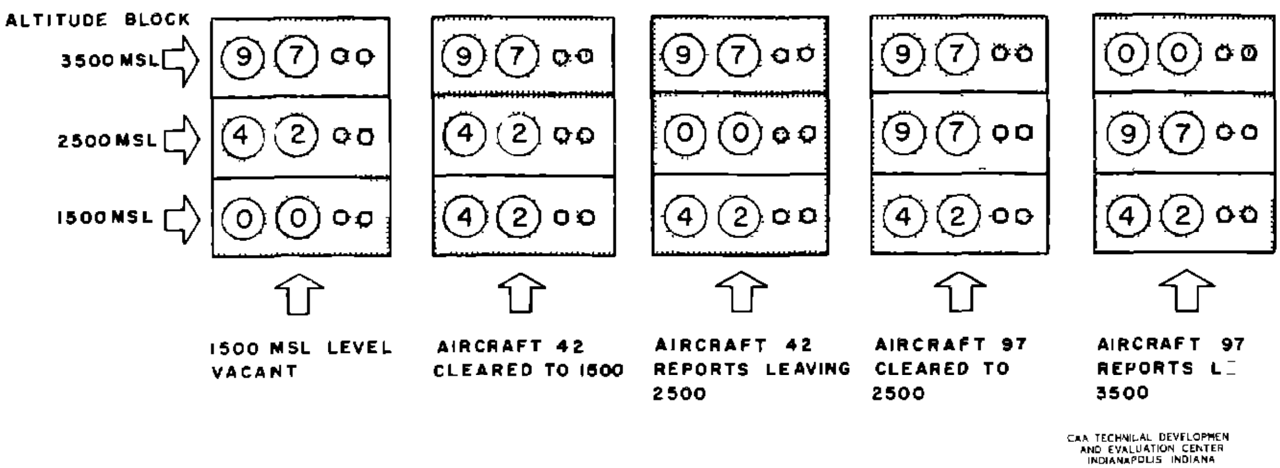


Fig 10 Section of Data-Transfer Board Showing Typical Descent Sequence

d-c power supply All other equipment is supplied from the main a-c power source of 110 volts at 60 cps

Data-Transfer Equipment

Early in the simulation program, an elementary type of mechanical data-transfer equipment was installed in order to determine the basic requirements of symbolic information displays for terminal-area traffic control and in order to compare the operation of automatic data-transfer equipment with the old manual flight-data-posting system

The data-transfer equipment consists of four display boards which are interchangeable with flight-progress boards Two boards are mounted at the ARTC control position and two at the radar control position The latter installation is shown in Fig 1 The boards are connected as shown in Fig 9, in order to provide an interlocking display of symbolic flight data for two terminal-area holding fixes The equipment is powered by a 28-volt d-c power supply It includes a pulser unit, several banks of relays, and a telephone-type dial unit which is used to initiate flight information from the ARTC position

Flight information consists of an arbitrary two-digit identification number for each aircraft entering the problem The information regarding the type of aircraft is coded into the first digit of the identification number As the aircraft enters the simulation problem, it is cleared by the ARTC controller to one of two holding fixes to maintain a specific altitude At this time, the ARTC controller dials the identification number into the specified altitude level of the appropriate display board Because the corresponding boards in the ARTC and the radar control positions are connected in parallel, the identification number dialed into the ARTC board appears simultaneously at the same altitude-display block of the corresponding radar control board As aircraft are cleared to different altitudes by either the ARTC or the radar controller, the information is transferred from block to block in accordance with the sequence shown in Fig 10

Basically, the equipment provides the following flight information about each aircraft at the ARTC and radar positions simultaneously

a Identification
b Type
c Clearance limit
d Altitude

Tests showed that this information is sufficient for routine terminal-area arrival-control operations, provided that it is supplemented by a pictorial display of the traffic situation All transfers of data are handled through the use of push buttons The equipment is interlocked so that only one aircraft can be cleared into any block of the system

Because the equipment saved so much ARTC-controller time during the test runs and because it also eliminated the need for a data-transfer man at the radar-control desk, it was retained for use in all subsequent simulation tests of single-airport terminal areas Although it is too elementary for actual operational use, the original data-transfer system has proved quite adequate for its purpose in the operation of simulation tests The lessons and the basic concepts developed from this equipment have gone into the design of the more complex limited-data-transfer equipment now on order for terminal-area traffic operations

## IMPROVEMENTS UNDER DEVELOPMENT

### Television System

A television synchronizing generator, a flying-spot scanner, and a monitor console from the experimental Pictorial Situation-Display equipment are being modified for use with the simulator[6] The present simulator television system will be modified for use with standard commercial-television scanning rates so that standard commercial-television components may be added to the system Use of the higher commercial scanning rates will reduce the stroboscopic effects resulting from simulating high radar-antenna rotational rates

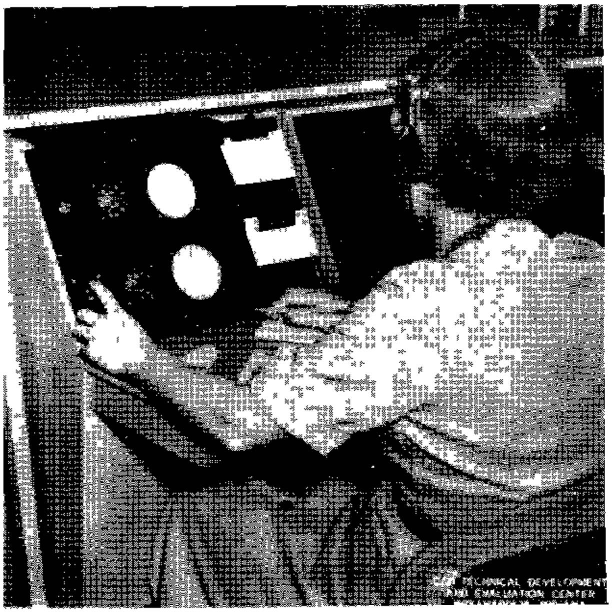

Fig 11 En Route Flight Console

[6]Instruction Manual for Experimental Pictorial Situation Display, Radio Corporation of America, Publication IB-39581

The addition of a second flying-spot scanner to the television system will provide means for the addition of radar clutter to the final picture

### Spot Projectors

The present spot-type projectors are driven by d-c motors of poor regulation characteristics and by gears of poor quality As a result, the accuracy of the spot speeds is not satisfactory Development has been started on a new spot-projector drive mechanism which will use motor-driven induction generators and precision gear trains A servo type of system for speed control is expected to insure accuracies of a high order

### En Route Flight Consoles

A new type of console is shown in Fig 11 This console is used to simulate aircraft flying outside of the radar area It has no associated spot projector Each en route console has equipment for simulating two aircraft It has communications facilities identical to those of the other type of consoles Its navigational instruments consist of a Grimes Navigator and a 60-minute timer for each simulated aircraft The Grimes Navigator is a clock-driven device which simulates a distance measuring equipment (DME) receiver Ground-speed information which indicates mileage flown (to a maximum of 100 miles) is set into the device The 60-minute timer can be used for longer periods

Normally, the operator of this console contacts ATC only, although the terminal-area communication channels are also available The operator is under control of ATC until his aircraft enters the terminal area, at which point a console having an associated spot projector is used for further flight

## OPERATION OF THE DYNAMIC SIMULATOR

### Types of Research Problems

As explained previously in this report, there is a relationship between the required number of simulated aircraft and the size of the control area under study Because of the relatively small number of control consoles which have been available for simultaneous use, this factor has thus far limited the dynamic-simulation program to the study of terminal-area operations Additional operating consoles will have to be available before the equipment can be used for tests of extensive en route control areas under heavy traffic conditions

One of the most extensive simulation programs which has been conducted so far has been an investigation of the various factors which affect the acceptance rate or the capacity of a terminal area The Washington terminal area has been used as the basic area for most of these tests Many hypothetical arrangements of radar facilities were tried out in order to determine the effects of different facility layouts on the flow characteristics of the traffic system Many different control procedures were tested in order to determine methods of reducing controller work load and of increasing traffic efficiency and safety The results of this program are described in a forthcoming report[7]

At the request of the Office of Federal Airways, the simulator has been used for studies of specific terminal areas The object of these studies has been to determine the best arrangement of navigational facilities and the most suitable control procedures for the areas under study Up to the present time, the Norfolk, Washington, and New York terminal areas have been the subjects of these traffic studies

[7]C M Anderson and T K Vickers, "Application of Simulation Techniques in the Study of Terminal-Area Traffic-Control Problems," CAA Technical Development Report No 192, October 1953

The New York metropolitan area was the subject of an extensive simulation study. Embracing four major civil airports and two large military air bases, the area handles more than 12 per cent of the total air-carrier traffic in the United States. Preliminary tests indicated that the traffic flow in this area could be improved if the present system of arrival and departure routes could be rearranged to segregate the arrival and departure paths for different airports. Accordingly, the problem was attacked from the air-route standpoint, as well as from the terminal-area standpoint, and routes within a radius of 50 miles were modified progressively to secure the necessary clear flight channels to and from the various airports. The terminal-area approach procedures and facilities were modified to provide a twin-stack system at La Guardia Airport, one twin-stack system serving the Newark and Teterboro airports, and a single-stack system serving Idlewild, Mitchell, and Floyd Bennett airports. The results of these tests will be published in a forthcoming report.

In order to accelerate the development program for new types of control equipment and thus to reduce the time lag between the initial concept and the final commissioning of such aids, simulation tests have proved valuable in pointing out weaknesses in the proposed equipment and in facilitating the development of better aids and procedures for their use. Extensive tests have been conducted on automatic data-transfer and approach-computer equipment. Some of the results of this phase of the simulation program will be published in a forthcoming report.[8]

Construction of Traffic Samples

In order to run simulation tests which compare one set of conditions against another, it is necessary to have a standard input of aircraft into the problem. This input takes the form of one or more traffic samples which are made up to simulate the operation of a number of aircraft with specific speed, climb, and descent characteristics. These aircraft are carefully scheduled to enter the problem at predetermined times and locations and to fly specific routes to specific destinations.

The validity of any simulation test depends a great deal on the traffic sample used. This sample must be formulated with care in order to insure that the test results will indicate the results which could be expected in actual operation. For example, the speed, climb, and descent programs for the various aircraft should be as realistic as possible. The proportion of various types of aircraft using the terminal area should approximate the proportion expected in actual operation. The proportion of traffic desiring to use the various routes should also be consistent with the route distributions expected in actual use. In addition, the traffic sample must be large enough to insure a good degree of statistical equilibrium. This implies that it should be large enough to take in sufficient combinations of situations so that the result will indicate the over-all operating characteristics of the traffic control system, rather than merely its performance in handling one specific sample of aircraft.

Most traffic controllers have noted that air traffic tends to enter the terminal area in bunches rather than in a smooth, steady flow. Another way to express this fact is to say that there are many more short intervals than there are long intervals between successive entries. This trait, which is a characteristic of all types of random flow, is reproduced in simulator traffic samples through use of Poisson's formula, or the law of small numbers. A detailed description of the application of this formula in the construction of traffic samples appears in an air-traffic-simulation report prepared by Franklin Institute Laboratories.[9]

For tests of existing airports, actual flight-progress strips from a typical day's IFR operations are used to furnish a typical sequence of the following data for the traffic sample.

1. Aircraft identification and types
2. Departure airports, routes, and destinations
3. Entry altitudes

One consideration in setting up a simulation test program is to obtain a maximum amount of significant information about the system flow characteristics in a minimum number of working hours. Since potential bottlenecks are not as apparent during light traffic conditions, it is usually necessary to accelerate the

[8] Ibid

[9] S. M. Berkowitz, "Analytical and Simulation Studies of Several Radar-Vectoring Procedures in the Washington, D. C., Terminal Area," CAA Technical Development Report No. 222, not yet published.

TABLE I

SPEED AND DESCENT PROGRAMS

| Classification | Typical Representative Type | Speed Program Cruise (mph) | *Intermediate (mph) | **Approach (mph) | Descent Rate (fpm) |
|---|---|---|---|---|---|
| Slow | DC-3 | 180 | 150 | 120 | 500 |
| Medium | Convair 240 | 240 | 190 | 140 | 500 |
| Fast | Constellation | 290 | 220 | 150 | 1000 |
| Jet | F-84 | 400 | 300 | 180 | 3000 |

* In zone extending from 10 miles to 5 miles (approximately) from the approach gate.
** In zone extending from 5 miles (approximately) from the approach gate to touchdown.

Exception: Jet aircraft continue at cruising speed until reaching the holding fix at 20,000 feet, then conduct letdown at intermediate speed until approximately 5 miles from the approach gate.

flow rate, as shown by actual flight-progress strips, to a rate more suitable for test purposes This is done by adopting a set of random-entry intervals determined through use of Poisson's formula

When it is not possible to secure actual flight-progress strips from past typical operations, traffic samples are compiled from available statistics regarding the percentages of different types of aircraft using the terminal area and the percentages of traffic utilizing different routes in the area Appropriate aircraft identifications, flight characteristics, and routes are then assigned to the various aircraft in the sample through use of a throw-down technique Entry times are assigned through use of intervals determined by Poisson's formula Recent analysis by the Franklin Institute indicates that traffic samples about two hours in length are satisfactory from the standpoint of statistical stability

In the interests of convenience, aircraft utilized in past simulation tests have been divided into four arbitrary classifications Speed and descent programs are listed in Table I

System Measurements

One of the most important advantages of traffic simulation is that it furnishes a means of obtaining actual measurements of various operating characteristics of a control system These measurements can show the relative superiority of one system or procedure over another When interpreted judiciously, they can furnish the justification for the procurement of desirable changes or modifications in control facilities or procedures

Several different criteria are used in scoring one traffic control system against another The actual selection of the various factors to be measured in simulation tests depends somewhat on the objective of the tests themselves Certain measurements are basic to practically all tests One of these is the measurement of aircraft delay This factor is indicative of the efficiency of the system in handling a specific traffic demand rate, since the function of any system is to provide a smooth, orderly flow of traffic with minimum delay to any one aircraft and with an equitable distribution of any necessary delays

The concept of aircraft delay, as used in simulation tests, differs somewhat from the concept presently used in the field in tabulating delays for the CAA Monthly Traffic Summary In actual traffic operations, it is not possible to determine delays due to path stretching and to velocity control The only delays which can be measured are those which are accrued by aircraft in holding patterns This has given rise to the fallacy that traffic delays occur only when holding patterns are used However, in simulation tests it is possible to measure the total delay due to holding, path-stretching, and velocity control This is done by comparing the actual arrival time of the aircraft in the problem with the theoretical arrival time shown on the basic schedule of the traffic sample This total delay is known as the "absolute delay" The term is defined as any excess of flying time over that which would be required to complete an approach on the shortest practicable path and with no other traffic Most evaluation studies include tabulations of average and maximum absolute delays encountered

An important criterion in the evaluation of new or modified traffic control systems, procedures, or equipment is the work-load factor In the interests of safety and efficiency, it is essential that the amount of controller work load required per aircraft be kept as low as possible Communications measurements are significant indices of controller work load

In simulation tests, the following communications factors are measured

1 Total live time on each air/ground channel

2 Total number of separate messages on each channel

3 Total time communications channels are congested (when two or more pilots desire to use a channel simultaneously)

4 Total intercontroller co-ordination time

These measurements are used to determine the average amount of communications required per aircraft and to determine the relative loading of the various channels

In systems which utilize radar vectoring, another index of controller work load is obtained through the measurement of the average number of aircraft under simultaneous guidance by the radar controllers

Significance of Measurements

The validity of the simulation test results depends on the accuracy of the equipment, the performance of the personnel involved, and the degree of simulation of the important characteristics of the system

Comparison of previous tests with the results attained in actual operations indicates that the speed and course errors in the simulation equipment produce deviations roughly equivalent to the deviations of actual aircraft in terminal-area operations

In running a simulation program relating to a specific terminal area, one factor which has given concern in the past is the possibility that the control personnel may actually become too expert in handling the specific situations presented by the traffic problem In such a case, the simulation results would appear to be much better than the results which could be expected from actual operations by control personnel who did not get the opportunity to handle hundreds of traffic operations of this type in a short period of time

This symptom was detected in early simulation operations, particularly in repeated runs of a short traffic sample In this case, control personnel soon memorized the problem and anticipated perfectly what was going to happen next To correct this condition, which tended to bias the results, the following procedures were found desirable

1 Use of longer traffic samples

2 Use of more than one sample, if possible

3 Rotation of personnel between control positions to minimize the possibility of unconscious memorizing of traffic situations

4 Use of additional personnel, preferably from the location which is being tested

This latter procedure has been found advantageous for several reasons

a It decreases the effect of the human factor by utilizing a larger sample of representative controllers

b It furnishes additional manpower for running the simulation tests

c Field personnel are often able to furnish detailed information regarding local problems, rules, or restrictions, which information tends to make the tests more realistic

d It serves as a training aid for field personnel by giving them concentrated experience in handling heavy traffic through use of the procedures being developed

e Field personnel participating in the tests can gain a better understanding of the reasons why certain procedures are more efficient than certain other procedures

Every effort is made to keep the simulation tests as realistic and consistent as possible However, it is not practical to reproduce in the laboratory all the complications and distractions which might exist under actual operating conditions Therefore, in studying reports of the simulation tests, it should be realized that the quantitative test results may not be duplicated exactly in actual practice However, since the same equipment, personnel, and traffic samples are used in all phases of comparative tests, the results are indicative of the relative performance of each system and can be safely regarded as qualitative information

## CONCLUSIONS

1 The present method of utilizing an electromechanically driven optical projector to simulate aircraft movement and of utilizing a television linkage to display the traffic situation to the controllers is satisfactory from the simulation standpoint This design is preferable to the all-electronic methods which have been developed to date because it is much simpler to construct and to maintain

2 The dynamic simulator furnishes a valuable method of testing proposed ATC equipment while such equipment is still in the developmental stage

3 The simulator is a very useful laboratory device for determining the basic laws which affect traffic flow Much of this knowledge can be utilized to place the planning of air-navigation and traffic-control aids on a more scientific basis than has been possible heretofore In addition, such knowledge can be used to develop more efficient control methods and thereby to reduce the amount of controller work load per aircraft

4 The simulator provides a very effective means of quickly pointing out potential bottlenecks in specific ATC systems and thus facilitates the development of better combinations of facilities and procedures to achieve maximum traffic capacity for the money spent on system modifications It has proved to be a valuable aid for training ATC personnel in the finer points of radar traffic control

5 The total number of projectors has an important effect on the size and complexity of the simulator Since size and complexity have a direct effect on equipment and operation costs, a practical maximum desirable number of projectors probably exists To investigate all phases of en route and terminal-area traffic control, it probably would not require complete simulation of more than two en route sectors and two terminal areas simultaneously It is believed, therefore, that the ultimate practical simulation design need never exceed a capacity of 50 controllable aircraft targets

## RECOMMENDATIONS

1 If it is assumed that it will soon be possible to apply many of the basic principles which have been learned during the simulation program to the improvement of present terminal-area traffic systems, the greatest opportunity for useful investigation of traffic-flow procedures and characteristics lies in the study of en route traffic problems It is highly important, then, that the facilities for the present simulation program be augmented in order that they might be available for use in the en route phase of the ATC problem

2 In drawing up specifications for a new simulator, the requirements listed in this report should be considered In modifying the present simulator, the most important needs are

a Additional projectors and associated control consoles

b Increased accuracy in projector-speed control

c Improved means of simulating certain facilities, such as radars, pictorial and symbolic displays, co-ordinating devices, and other equipment

From time to time, additional types of navigational and control equipment will have to be simulated For example, considerable work is planned on tests and on the development of various types of displays, including horizontal plotting scopes It is important that the over-all simulator design be sufficiently versatile and flexible that such equipment can be accommodated

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