TECHNICAL DEVELOPMENT REPORT NO. 410

THE USE OF SIMULATION IN ATC SYSTEMS ENGINEERING

by

Tirey K. Vickers

NAVIGATION AIDS EVALUATION DIVISION

APRIL 1959

FEDERAL AVIATION AGENCY
TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

FEDERAL AVIATION AGENCY

E. R. Quesada, Administrator

D. M. Stuart, Director, Technical Development Center

This is a technical information report and does not necessarily represent FAA policy in all respects.

THE USE OF SIMULATION IN ATC SYSTEMS ENGINEERING

TABLE OF CONTENT

TABLE OF CONTENT (Continued)

THE USE OF SIMULATION IN ATC SYSTEMS ENGINEERING

SUMMARY

Since 1950, simulation has been used as a primary tool for research and development in the complex field of air traffic control This report traces the development of simulation techniques and facilities at the CAA Technical Development Center, from its inception in October 1950, to March 1959, when the program was transferred to the FAA National Aviation Facilities Experimental Center After describing the application of simulation techniques to various types of air traffic control problems, the report summarizes the most significant accomplishments of the simulation program in the fields of human engineering, equipment development, and the formulation of design philosophy and procedures for the air traffic control system

INTRODUCTION

Problem Areas

The function of an air traffic control (ATC) system is to maintain a safe, orderly, and expeditious flow of air traffic However, the requirements for performing this function gradually are changing During the past decade, the ATC system of the United States has been forced each year to handle approximately 15 percent more traffic than it did during the previous year Meanwhile, technological advances have steadily widened the performance regimes of speed and altitude for the air vehicles which the ATC system must accommodate

To anticipate and cope with these changes, the Civil Aeronautics Administration and its successor, the Federal Aviation Agency, have conducted since 1950 a continous program of research and development for the ATC system Simulation has been an indispensable tool in the following applications of this program

1 Study of factors which influence flow characteristics and capacity of ATC Systems

2 Human engineering, workload simplifications

3 Design and development of control displays and computers

4 Study and formulation of control procedures for new types of navigation systems and various types of aircraft

5 Improvement of air traffic flow in specific problem areas, such as New York, Washington, Chicago, and many others

Advantages of Simulation

From the systems engineering standpoint, air traffic control basically is a closed-loop process involving a number of elements linked together as shown in Figure 1 Because of interaction between these elements, a change in one variable can affect the behavior of other portions of the system, sometimes in devious ways Thus, direct observation of the system in operation does not necessarily lead to an adequate comprehension of what actually is affecting the results

Prior to the introduction of simulation techniques, the difficulty of testing and analyzing air traffic control systems was a critical handicap to the development of system improvements This difficulty was caused not only by the inherent complexity of the system, but by the fact that any system tests required the use of actual aircraft flying in the actual system environment In terms of results, such tests were extremely slow, awkard and expensive

Because actual equipment installations were involved, system modifications required an inordinate amount of time Much time was wasted in waiting for suitable weather conditions Comparative performance measurements were almost impossible to obtain, due to the difficulty of replicating the initial traffic input and flight conditions during any subsequent test Because manned aircraft were involved, and it often was difficult to isolate test operations from other air traffic, cost and safety considerations usually precluded the conduct of extensive tests under high traffic loads

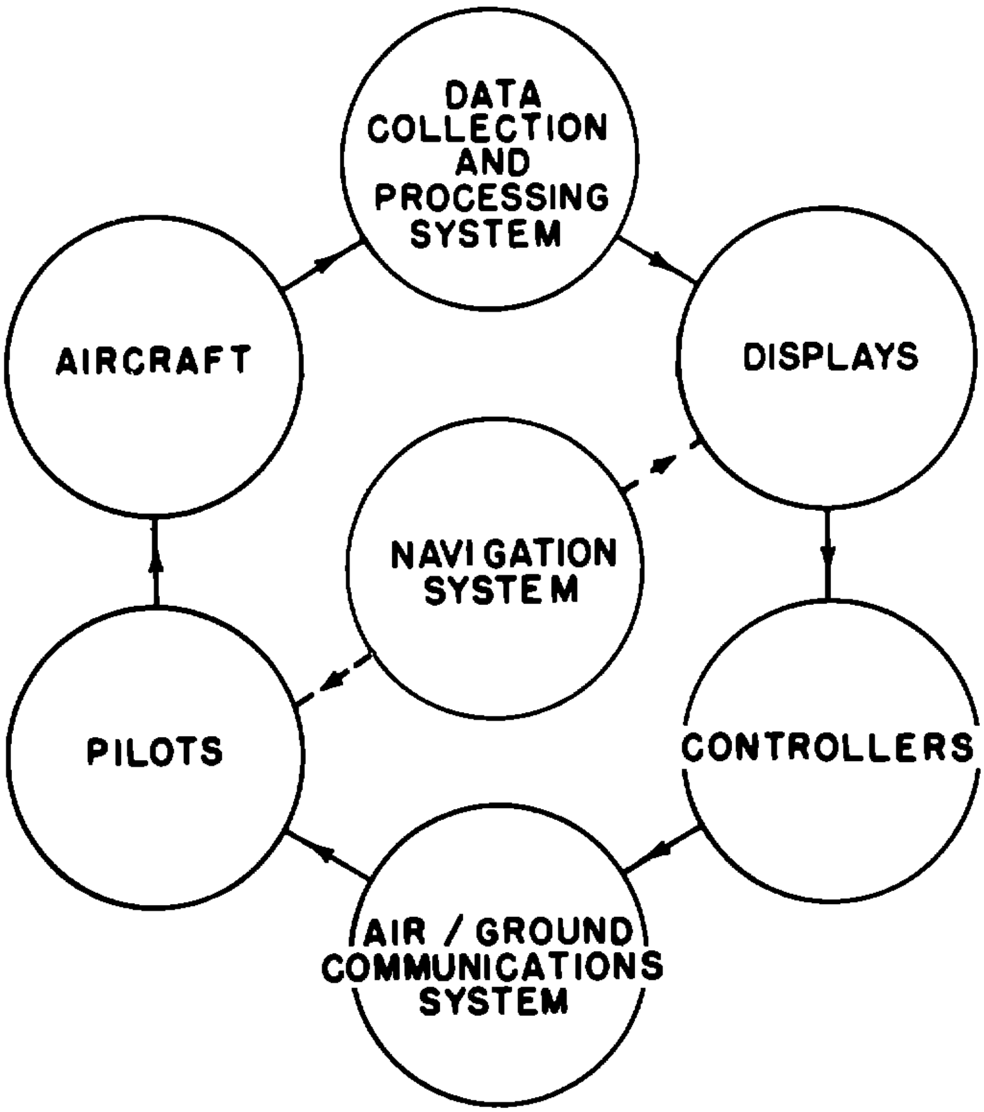


FIG 1 - FUNCTIONAL DIAGRAM OF ATC SYSTEM

The development of simulation techniques has provided a practical means of testing and analyzing the characteristics of ATC systems under controlled laboratory conditions Depending upon the objective of the specific project, simulation may include various phases, from the manipulation of mathematical or graphical models, to real-time dynamic system tests with the simulator providing a highly realistic environment and workload for the human controllers

Although live (flight) testing is useful as a final proof that the system actually operates satisfactorily as installed, an increasingly large portion of the operational testing can now be handled through the use of simulation techniques, at a considerable savings in cost and time

DEVELOPMENT OF SIMULATION TECHNIQUES

Graphical Simulation

Uses

Graphical simulation is a form of mathematical analysis accomplished with paper and pencil Fast and cheap, this method is useful in determining the effect of varying certain system parameters Also, it is used to determine the ideal performance of system, for comparison with data obtained from dynamic simulation or actual live operations Various types of graphical plots, including altitude/time, distance/time, and queueing charts, are used Typical applications will be discussed in this report

Altitude/Time (A-T) Plots

The first known use of graphical simulation in air traffic operations research was in 1949 Up to that time, the Washington approach control system exhibited a peculiar cyclic characteristic Even when a continuous supply of aircraft were being fed into the system, a large gap in the approach sequence always occurred after every fourth approach In studying this problem, a graphical plot of altitude versus time was developed to determine, minute by minute, the location of each aircraft in a typical approach sequence Communications data were correlated with this plot in the manner illustrated in Fig 2 This simple technique solved the problem by showing that a steady flow of traffic could be achieved if the secondary holding fix were moved closer to the primary fix, or if additional holding altitudes were used at the primary fix In addition, by pointing out the critical effects of communications delays on the operation of the system, this study[1] led to the adoption of direct air/ground communications facilities for Air Route Traffic Control (ARTC) Centers

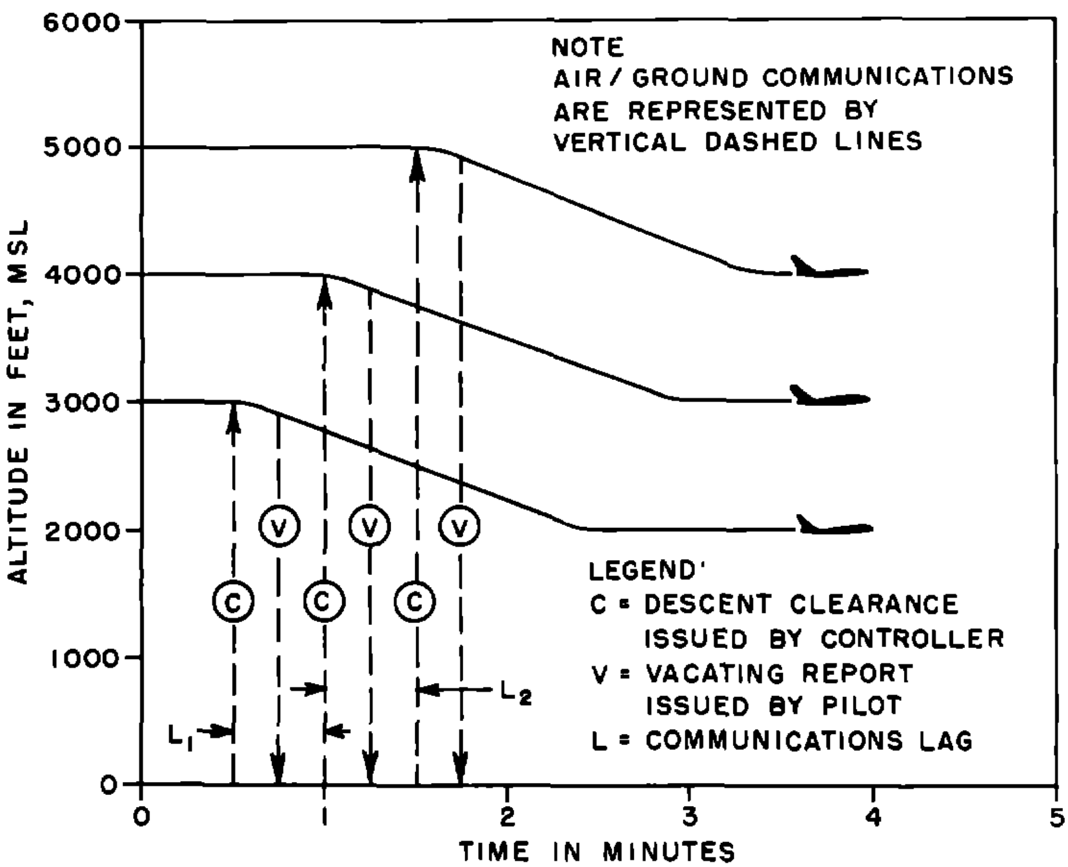


FIG 2 - SECTION OF ALTITUDE/TIME PLOT SHOWING TYPICAL LADDERING - DOWN PROCEDURE FOR THREE AIRCRAFT

---

[1] John H Hilton and Tirey K Vickers, "Terminal Area Time Study", CAA Office of Federal Airways, July 22, 1959

Space/Time (S-T) Plots

In 1950, the Franklin Institute Laboratories for Research and Development (FIL) investigated the feasibility of applying simulation techniques to the study of air traffic problems [2] During the next few years, graphical simulation techniques, especially plots of flight distance or space versus time (S-T plots) were developed to a high degree by personnel of FIL[3] and the CAA Technical Development Center (TDC) The S-T (Space-Time) curve is a graphical plot of space versus time Space in this case refers to the projected distance from some fixed point such as an approach gate or a runway threshold If desired, altitude data may be entered at the appropriate points on the curve in order to show the progress of each aircraft in the third dimension S-T curves are especially useful in analyzing the operation of approach systems and airport runways, as shown in Fig 3 and 4 In connection with human engineering studies, S-T curves are drawn to show the hypothetical or ideal output of a specific traffic control system The idealized data then are compared with the results of the dynamic simulation tests to determine the efficiency of the controller or the effects of human factors on the operation of the system

Queueing Charts

Although queueing theory is an important tool in operations research, the level of mathematics involved in its presentation is often beyond the comprehension of personnel engaged in the control of air traffic During a study of approach procedures for civil jet aircraft[4] in 1958, a

---

[2] 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", Franklin Institute Final Report No F-2130-1, Philadelphia, Pennsylvania, March 17, 1950

[3] S M Berkowitz and Ruth R Doering, "Analytical and Simulation Studies of Several Radar Vectoring Procedures in the Washington, D C Terminal Area", CAA Technical Development Report No 222, April 1954

[4] Paul T Astholz and Tirey K Vickers, "A Preliminary Report on the Simulation of Proposed ATC Procedures for Civil Jet Aircraft" CAA Technical Development Report No 352, December 1958

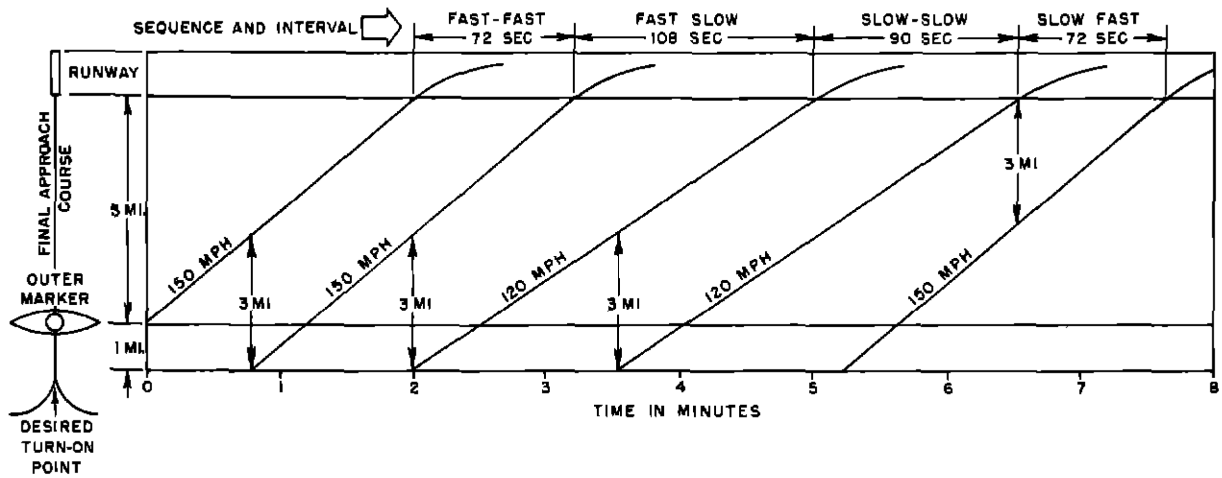


FIG. 3 - SPACE/TIME PLOT SHOWING EFFECT OF DIFFERENT APPROACH SPEEDS ON THE THEORETICAL APPROACH INTERVAL

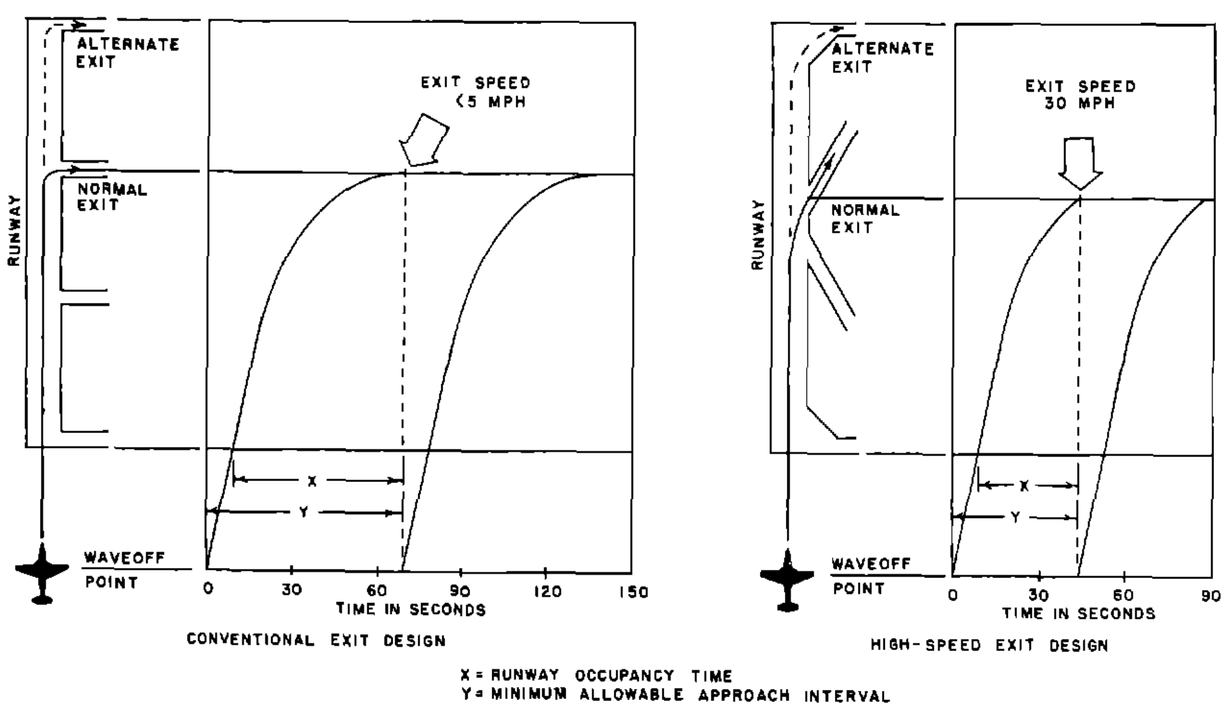


FIG. 4 - SPACE/TIME PLOT SHOWING FUNCTIONAL ADVANTAGE OF HIGH-SPEED RUNWAY EXITS

method was developed for presenting queueing phenomena in a simple, easily understandable form. This presentation, known as a queueing chart, is an adaptation of the Gantt or time-sequence chart which is used in business or project administration.

In the example shown in Fig. 5, the theoretical arrival times of a random sequence of 30 aircraft are plotted on successive horizontal

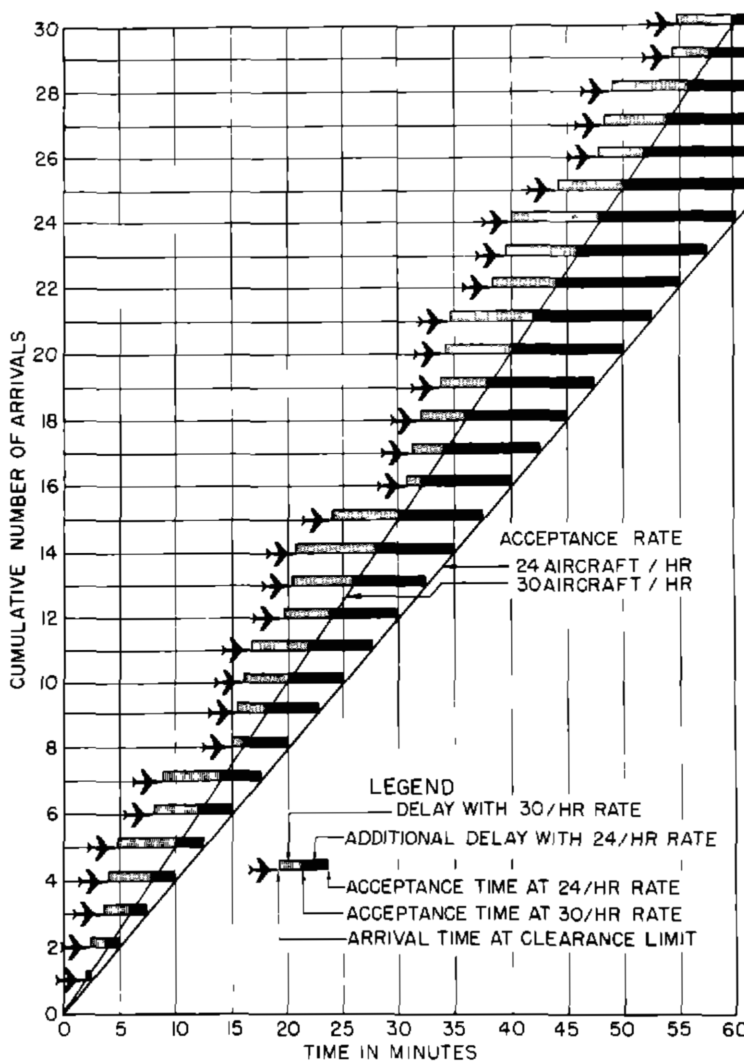


FIG. 5 - QUEUEING CHART SHOWING BUILDUP OF DELAYS UNDER SATURATED TRAFFIC CONDITIONS

lines Theoretical arrival time in this case is defined as the time an aircraft would arrive if it encountered no traffic delay Diagonal lines intersect the horizontal lines on the chart to show the approximate acceptance time of each aircraft, if the acceptance rate of the approach system were either 24 or 30 aircraft per hour The horizontal bars show the delays which each aircraft would encounter in either case

Queue length (the number of aircraft which are being delayed) at any given time can be determined by counting the number of delay bars which are crossed by a vertical line at the time in question This graph emphasizes the important effect of a relatively small change in airport acceptance rate, on the length of aircraft delays and the size of the queue

Dynamic Simulation

Early Efforts

Dynamic simulation is a real-time simulation technique which enables certain portions of the ATC system to be tested in a realistic control environment using human controllers who are confronted with the same workloads and decisions that they would have to face in the actual operation of the system under study The use of this type of simulation was proposed by the Radio Technical Committee for Aeronautics in 1948[5] Some work in this field was sponsored by the Australian Government at this time[6]

The first recorded use of a dynamic simulator for ATC research in the United States was in 1950, when the operation of a small one-target radar trainer led to the discovery and developments of the tangential approach concept[7] This simple trainer, which is shown in Figures 6 and 7, integrated

---

[5] "Air Traffic Control", Radio Technical Committee for Aeronautics, Special Committee 31, Paper 27-48/DO-112, May 12, 1948

[6] R B Coulson and V D Burgmann, "An investigation into Air Traffic Control by a Simulation Method , Division of Radio Physics, Commonwealth Scientific and Industrial Research Organization, Commonwealth of Australia, October, 1949

[7] C M Anderson, N R Smith, T K Vickers, and M H Yost, "A Preliminary Investigation of the Application of the Tangential Approach Principle to Air Traffic Control", Technical Development Report No 149, October, 1951

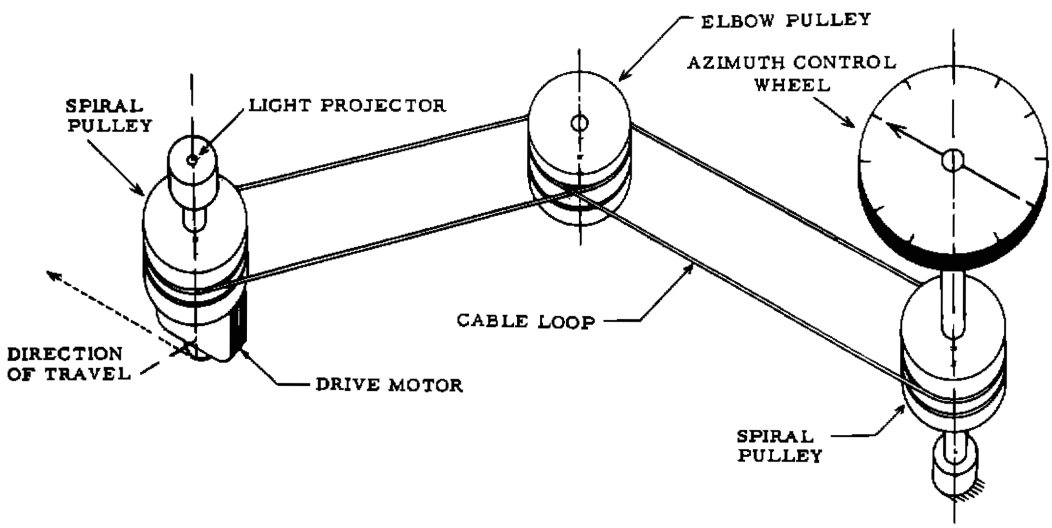


FIG. 6 - MECHANICAL HOOKUP OF RADAR TRAINER

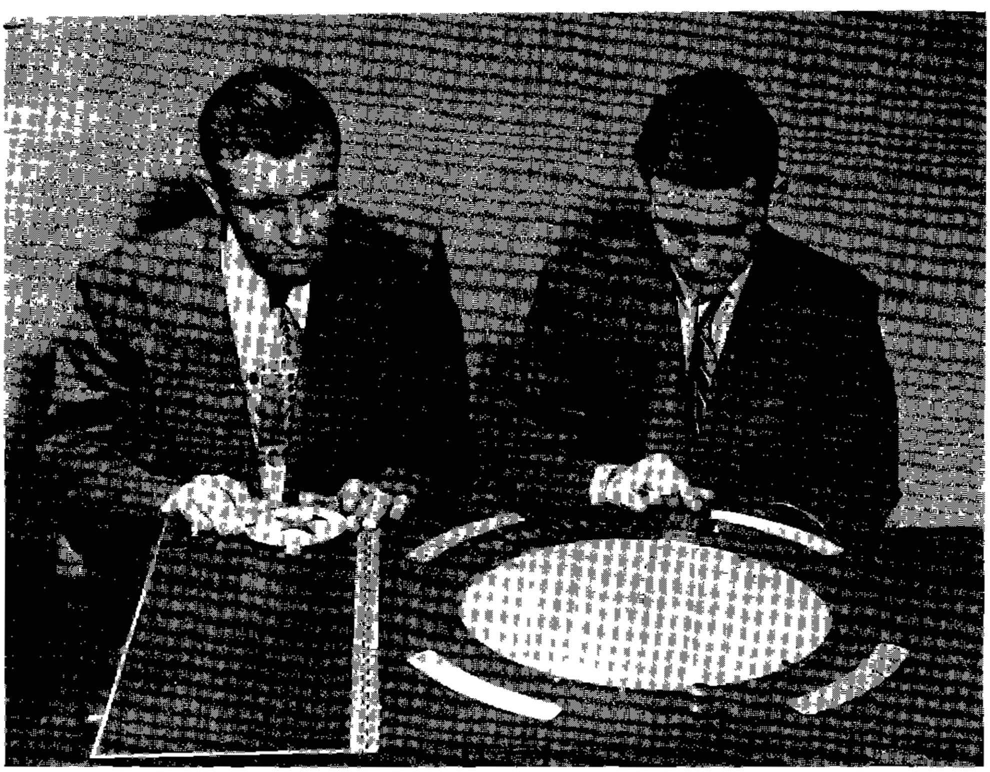


FIG. 7 - RADAR TRAINER IN USE

distance and heading to produce a realistic approach path, in the form of a small spot of light which traveled across the surface of a simulated radar scope

The tangential approach concept was a simple geometrical principle for guiding an aircraft to a desired point and heading in space In the radar approach application shown in Figure 8, the desired point was an approach gate to an airport runway Heading instructions were obtained from a simple grid overlay on the face of a radar indicator, to enable even unskilled controllers to guide an aircraft accurately to the desired point, from which the pilot could take over and complete a visual approach to the runway Subsequent flight tests, using various types of radars, verified the usefulness of this principle and the results of these early simulation tests[8]

Evolution of the TDC Simulator

In 1950, an air traffic control display device known as Navascreen[9] was tested at the Technical Development Center This device included equipment for projecting six controllable targets on a large translucent screen, as shown in Fig 9 The movement of each target was effected by two servo-driven mirrors, one turning on the X-axis and one on the Y-axis The initial position, speed, and heading of each target was controlled from a single operator's console which is shown at the right of Figure 9 Although the device did not offer much promise for use as an actual ATC display, an immediate application was seen for its use as an air traffic simulator

---

[8] Tirey K Vickers, "Development of Traffic Control Procedures for Tactical Airlift Operations", Technical Development Report No 235, April, 1954

[9] W A Amstutz, Jr , J E Herrmann, N R Smith, T K Vickers, "Evaluation of Navascreen", Technical Development Report No 145, May, 1951

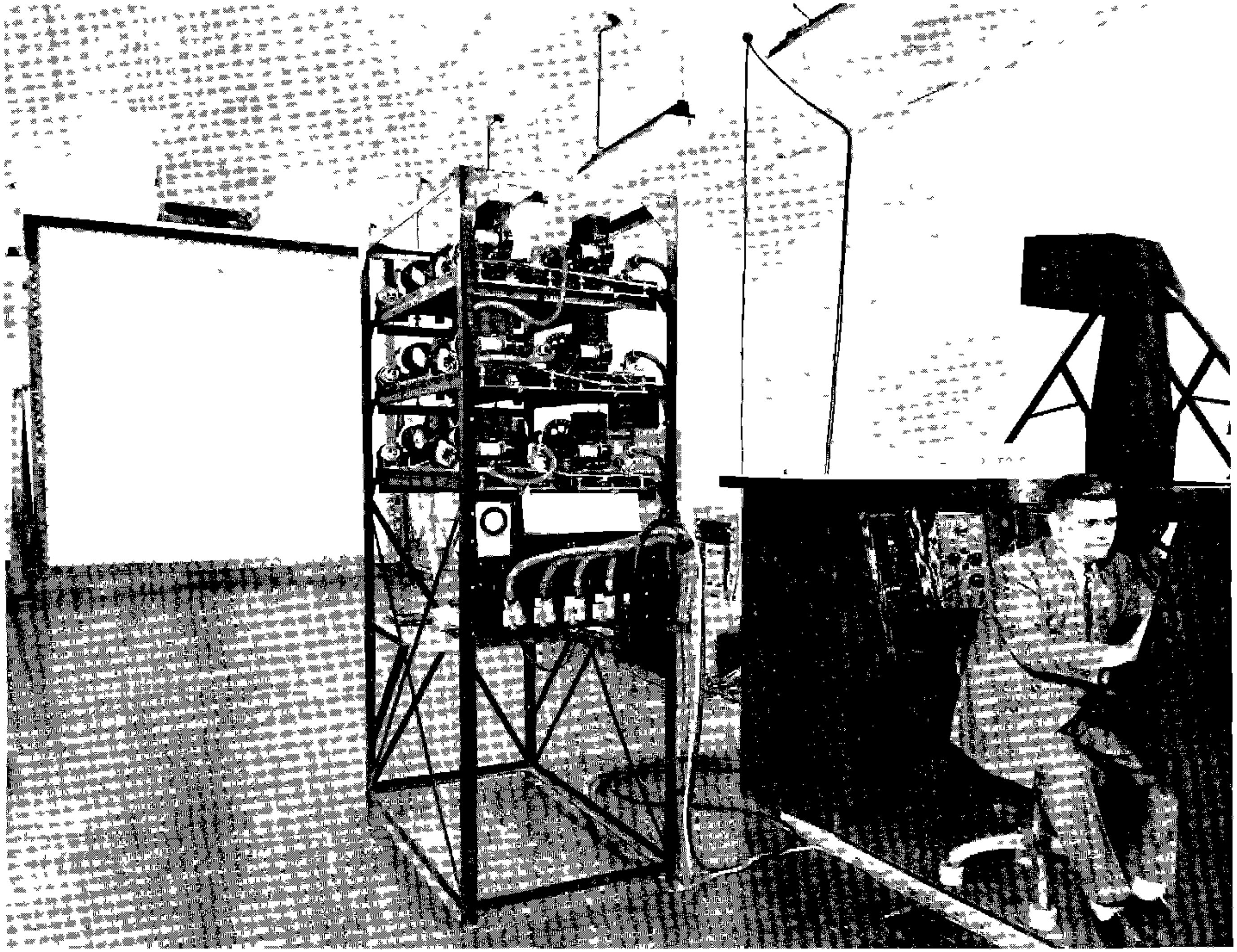
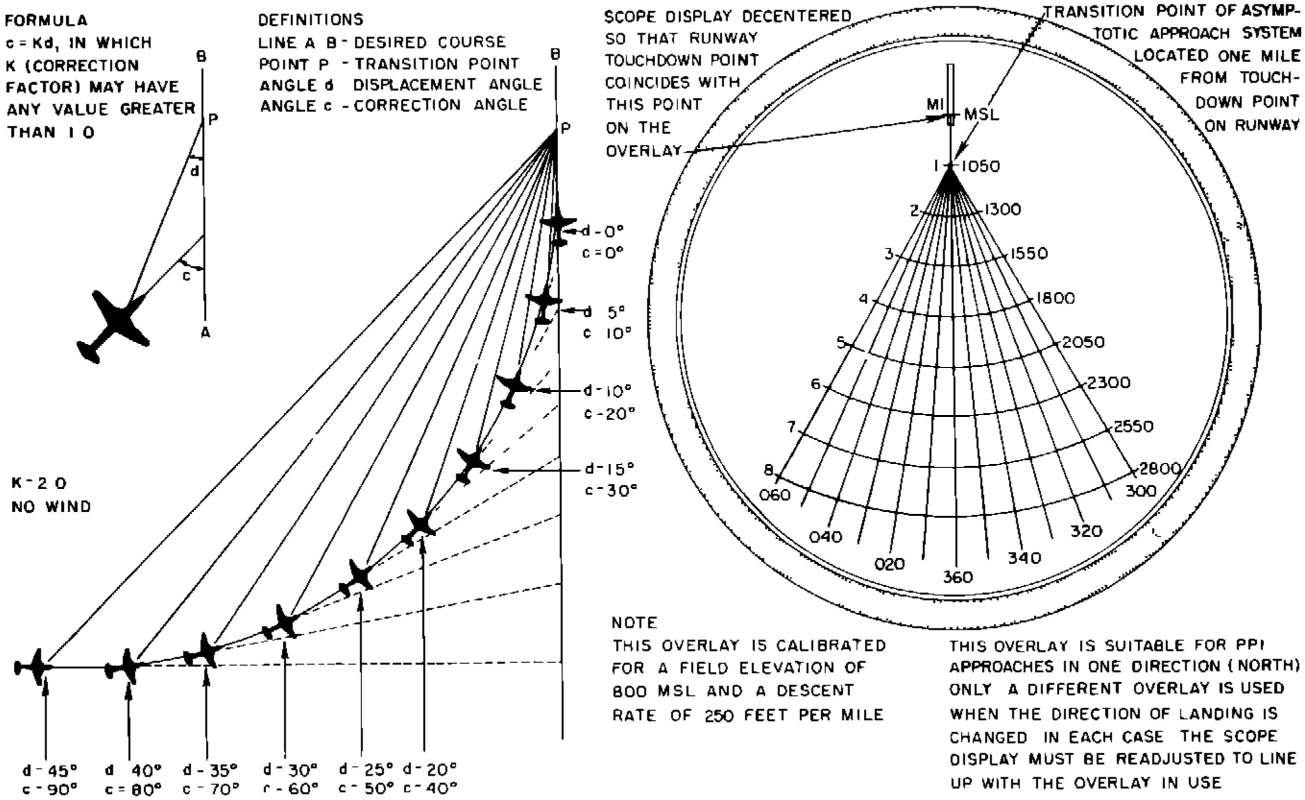


FIG 8 - TANGENTIAL APPROACH



(A) PRINCIPLE OF OPERATION

(B) TANGENTIAL OVERLAY FOR ASR SCOPE

FIG 9 - ORIGINAL NAVASCREEN EQUIPMENT

Initial tests of the Navascreen as a dynamic simulator for terminal area operations showed that the human workload in navigating a single aircraft target and handling the necessary ATC communications, was large enough to justify the use of one pilot per simulated aircraft Accordingly, the control panels for the six targets were taken out of their common console and reinstalled in individual consoles so that each unit could be operated by a separate person who assumed the role of pilot for one aircraft

The targets and the background map were projected in reverse The pilot consoles faced away from the viewing screen, and each pilot could look at the projected picture through a mirror, as shown in Fig 10 The

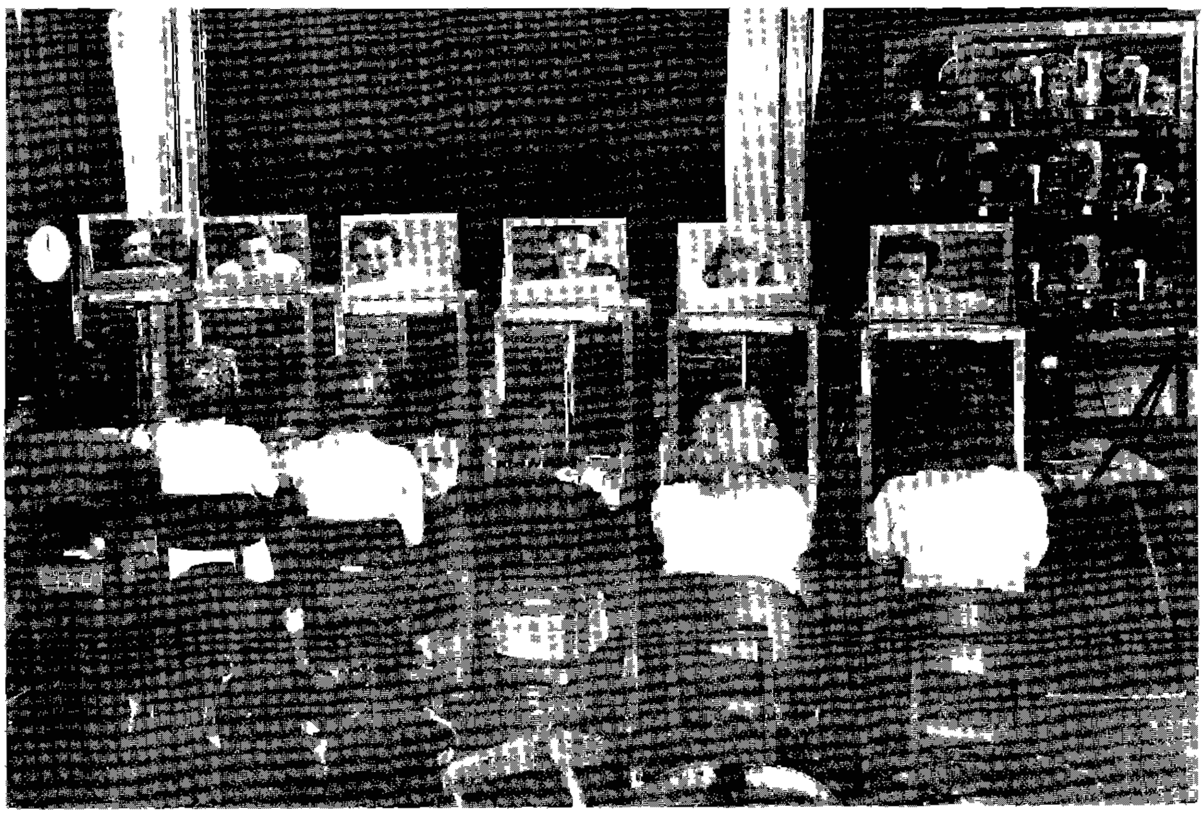


FIG 10 - NAVASCREEN SIMULATOR PILOT CONSOLES translucent viewing screen was designed for viewing from the opposite side Here the controllers were located, as shown in Fig 11 They observed the traffic display on the screen and communicated with the pilots by means of interphone channels which simulated air/ground radio channels Because only six targets were available, the early simulation projects were confined to small terminal area studies This layout was quite useful, however, in working out the basic procedures for the use of terminal area radar in multistack approach systems[10]

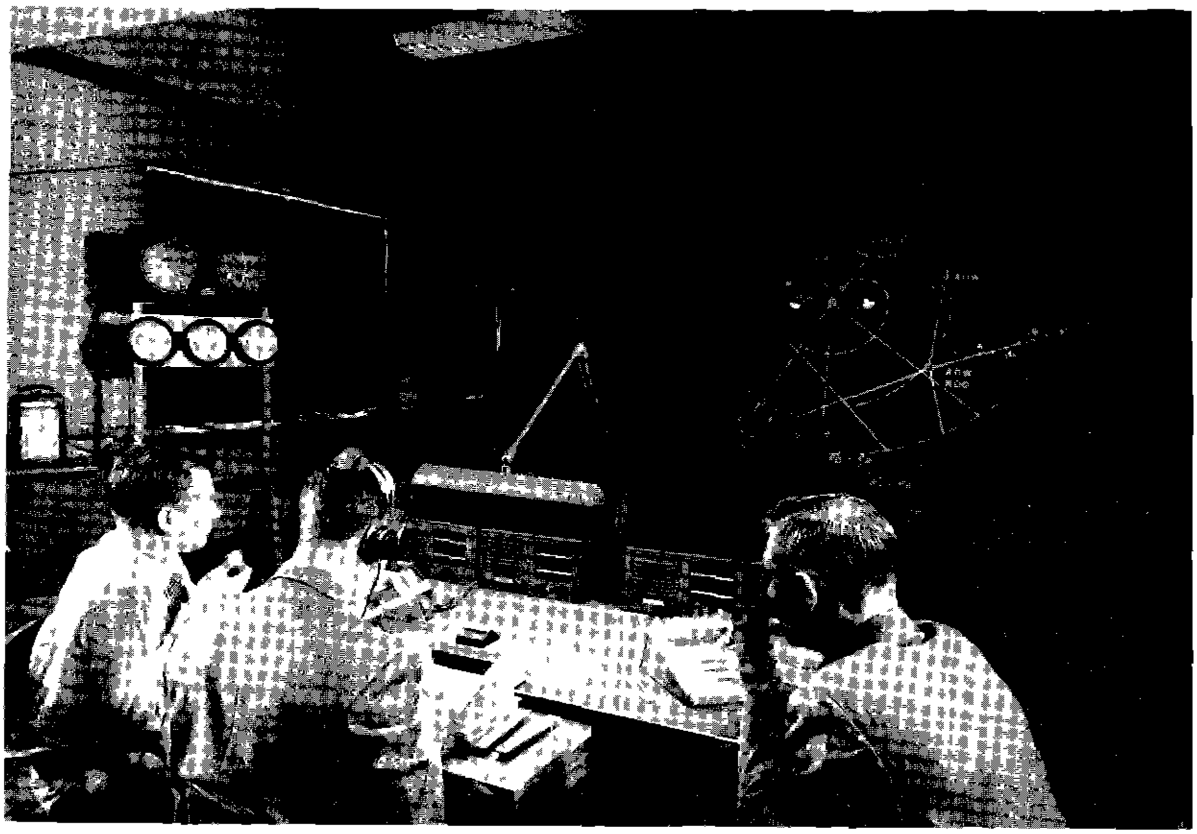


FIG. 11 - NAVASCREEN CONTROLLER POSITIONS USING PROJECTED ATC DISPLAY

[10] C M Anderson, N R Smith, T K Vickers, M H Yost, "Evaluation of Proposed Air Traffic Control Procedures in the Washington Terminal Area by Simulation Technics", Technical Development Report No 149, July, 1951

The main disadvantage of the Navascreen target generating equipment was that its targets could fly straight courses only To change heading, a target had to be stopped momentarily, then restarted on the new heading This produced an unrealistic, angular flight path

Early in 1952, Air Force experimental equipment, known as the Teleran demonstrator, became available This equipment included a television camera and eight target projectors of a type similar to that shown in Fig 12 Each target projector was equipped with a turning motor for standard-rate (3° per second) turns Forward speed was controllable Each projector continuously integrated forward speed and heading to produce a realistic curved path when the heading was changed Additional projectors of the same type were constructed in the TDC machine shops Soon the Navascreen projectors were phased out of the system, to be supplanted by the Teleran-type projector equipment

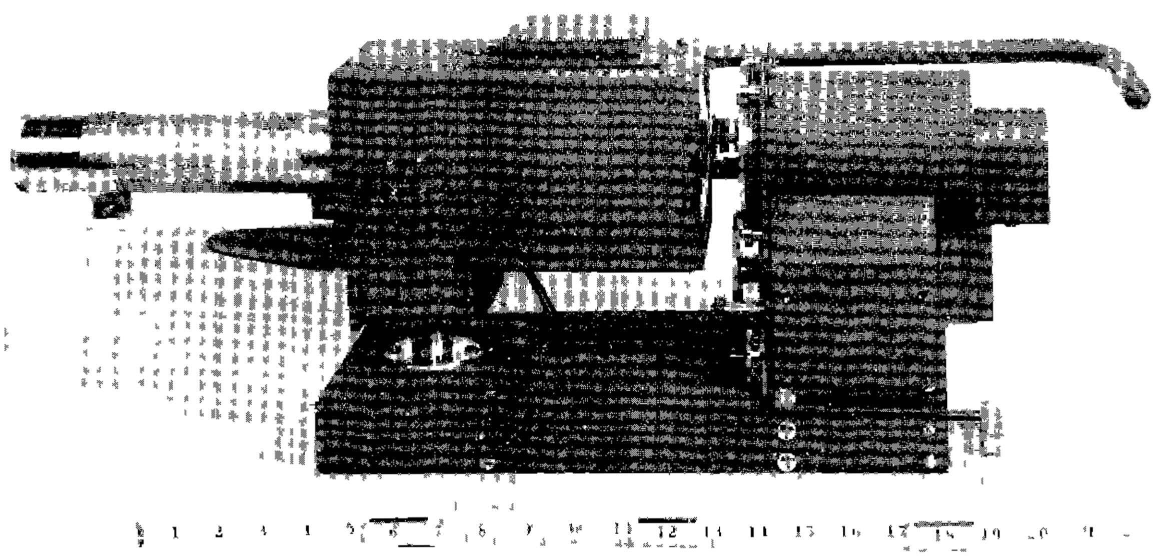


FIG 12 - TELERAN-TYPE PROJECTOR

To provide radar-type displays for the controllers, the television camera was used to scan the large viewing screen The TV video was filtered through a specially designed flying spot scanner which modified it for presentation in the form of a rotating sweep on long-persistence radar indicators, closely simulating the presentation of a Plan Position Indicator (PPI) radar

Air traffic control equipment at this time consisted of three radar consoles for terminal area operation, as shown in Fig 13 A rudimentary

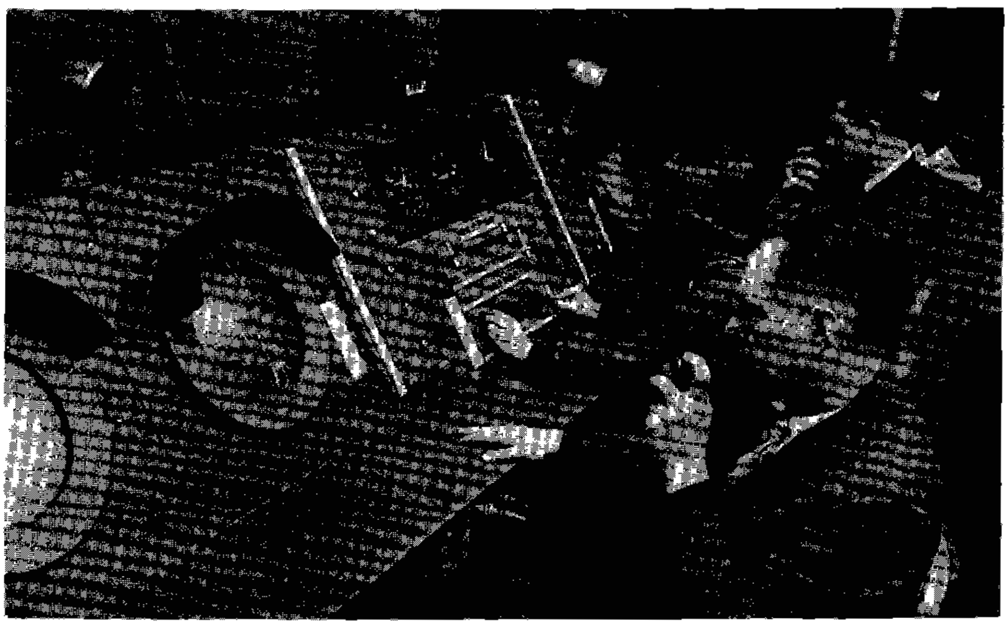


FIG 13 - SIMULATED RADAR SCOPES IN USE

ARTC position was installed to supply a realistic input of flight data to the terminal area controllers The initial model of a mechanical data transfer device was developed and installed as a communications link between the terminal area and ARTC control positions

No longer was it necessary for the controllers to view the traffic situation on the large translucent screen, so this was replaced soon by an opaque screen for better TV resolution Elimination of the translucent screen obviated the requirement for the pilots to look at the screen through a mirror A number of new pilot consoles were constructed, and placed in tiers so that each pilot could view the screen directly The communications system was expanded to six channels, and equipped with automatic recording equipment to record the number of messages and the total communications time on each channel

A wind-drift generator was added This device utilized the principle of relativity to simulate wind drift, by moving the projected background map in a direction opposite to the wind Thus, to simulate a wind blowing from the north, the background map was moved slowly toward the north This relative component of motion produced the effect of drifting all the aircraft targets toward the south

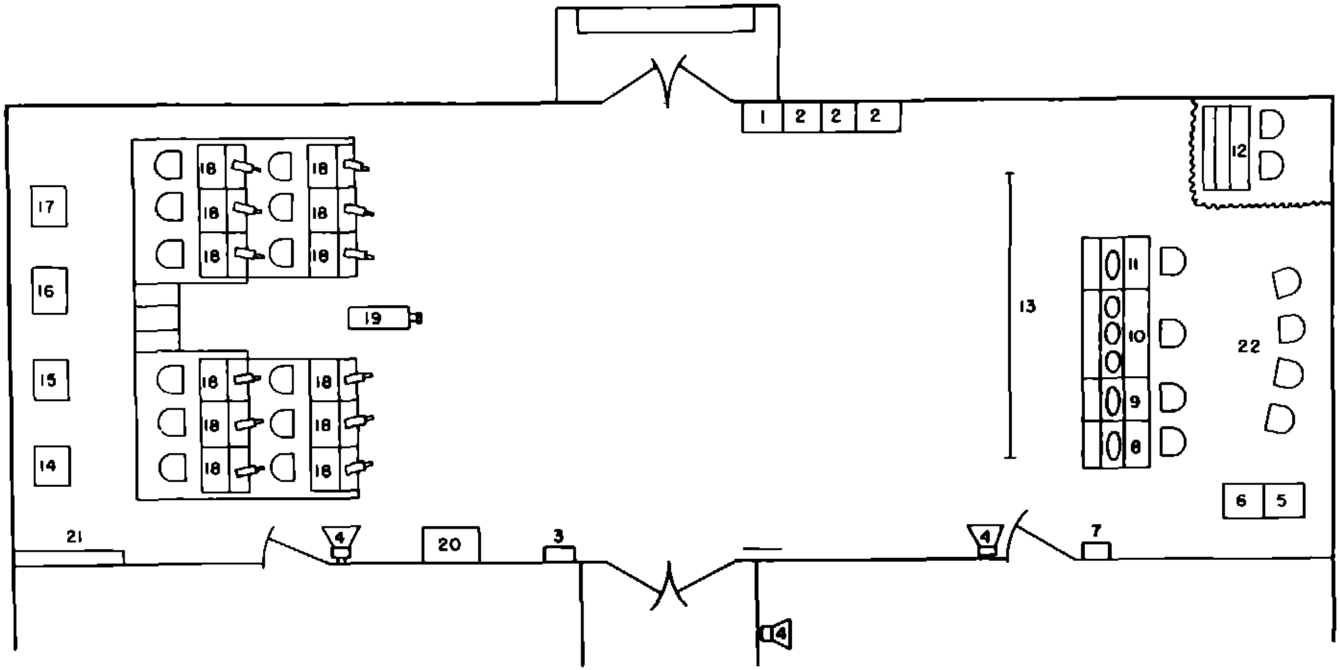
The wind-drift mechanism included two reversable controllable-speed, electric motors and associated gearing One motor served to move the map projector on the X-axis and the other on the Y-axis The television camera was mounted to move simultaneously with the map projector so that it always scanned the same portion of the background map After a period of an hour or so the wind mechanism reached the end of its travel At this time the simulation problem had to be stopped temporarily while the map projector was cranked back to its starting position

The equipment layout for the dynamic simulator, as it existed in 1953, is shown in Fig 14 During the next few years, the simulator remained in almost continual evolution, for increased accuracy, capacity, and versatility Target projectors were retrofitted with an improved servo-motor drive, and a gearshift was added to provide the added capability of using a 1 /1/2^{o} per second turn rate for simulating high-performance jet aircraft

A simulated six-code radar beacon system was added by installing a system of selective dimming switches for the target projector lights In operation, any target went from dim to bright whenever the pilot selected the same code switch position as the controller This set-up yielded much useful experience in determining the functional advantages of various procedures for using beacon codes in the ATC system [11]

---

[11] Tirey K Vickers, "Coding Requirements for the ATC Radar Beacon System," IRE Transactions on Aeronautical and Navigational Electronics, Volume ANE-4, Number 3, September, 1957



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

FIG 14 - EQUIPMENT LAYOUT FOR PROJECTOR ROOM

In order to expand the capabilities of the simulator for studying air route traffic control areas as well as terminal areas, a number of additional target projectors were manufactured in the TDC shops and added to the simulator An ARTC control room was added, and the communications system was expanded in order to provide adequate communications between the terminal area and ARTC control positions This layout was used in simulation tests of procedures and displays for ARTC use It also was used in many studies to improve air traffic flow in specific problem areas An electronic approach computer was built and installed for terminal area tests An improved type of electro-mechanical data transfer equipment was installed for evaluation in ARTC and terminal areas, as shown in Fig 15 Fig 16 shows a view of the ARTC room

The need for simulation studies of more complex multi airport terminal areas forced a further expansion of the simulator In 1958 a total of 42 targets was in use The expansion outgrew the original target projector room, which is shown in Fig 17 Although all 42 target projectors were installed in this room, 24 of them were operated remotely from pilot consoles installed in an adjacent room, as shown in Fig 18 This photograph also shows the large television monitors which supplied each pilot with a view of the projector screen, for navigation purposes

The need to simulate multiple radar sites in simultaneous operation was provided by four television cameras, focussed on different portions of the projector screen An improved communications system was installed to furnish complete interphone hookups between two ARTC rooms and two terminal area control rooms, as well as 20 simulated air/ground radio channels The simulation building was expanded in 1958 in order to accommodate the extra control rooms, as well as space for pilot training, briefing, data processing, and maintenance

Design Considerations The unique function of a dynamic ATC simulator, and the basic justification for its establishment, is to furnish a means of testing critical portions of the ATC system with human controllers To accomplish this function, the simulator must incorporate the significant effects of all the system elements shown in Fig 1 As shown in Fig 19, humans are retained in the controller and pilot positions, while analogues are employed for the other system elements The resulting flow of significant information around the loop is equivalent to the flow in the actual system The principal considerations which must be incorporated in the design of a dynamic ATC simulator include provision for

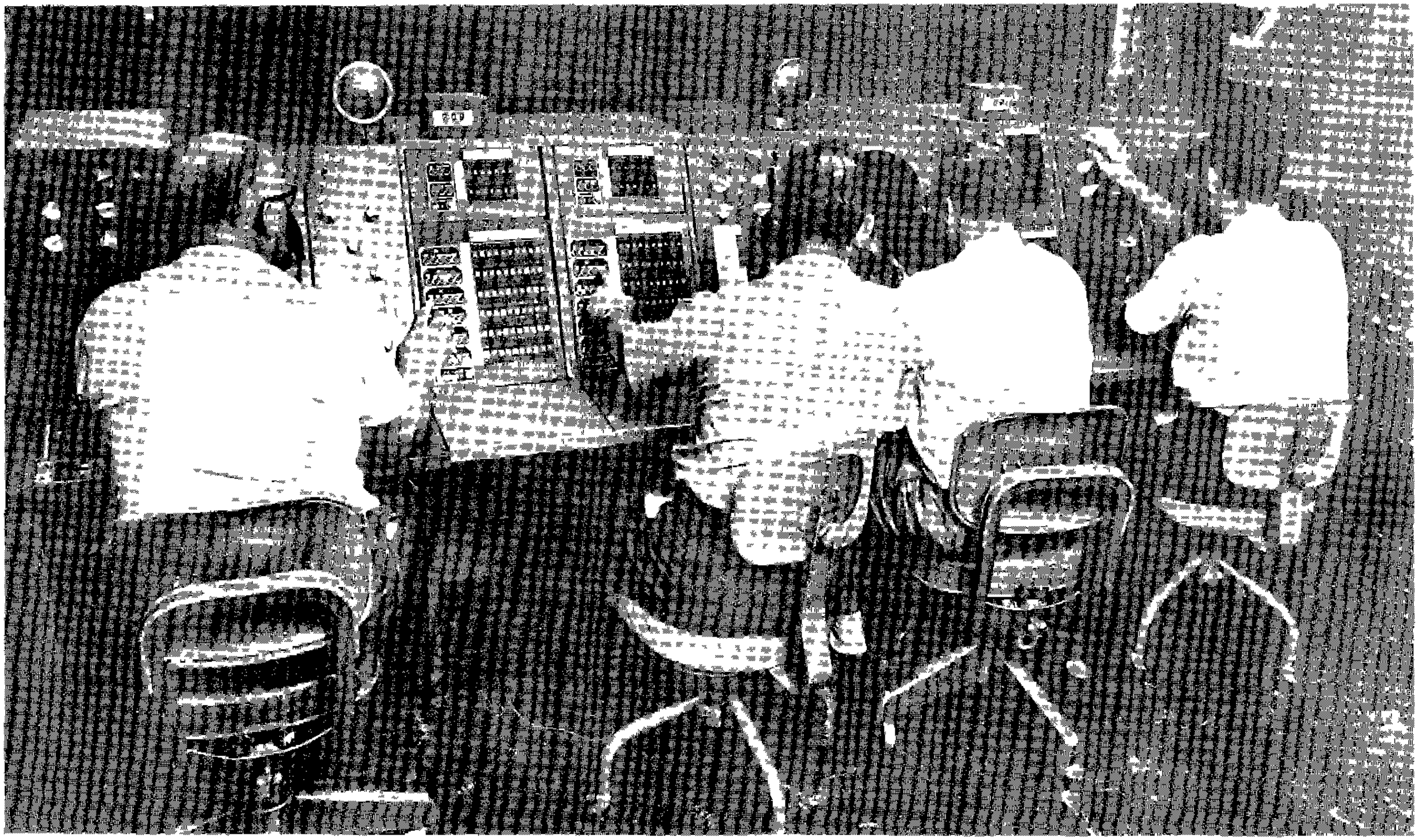


FIG 15 - ELECTRO-MECHANICAL DATA TRANSFER EQUIPMENT IN USE IN TERMINAL AREA CONTROL ROOM

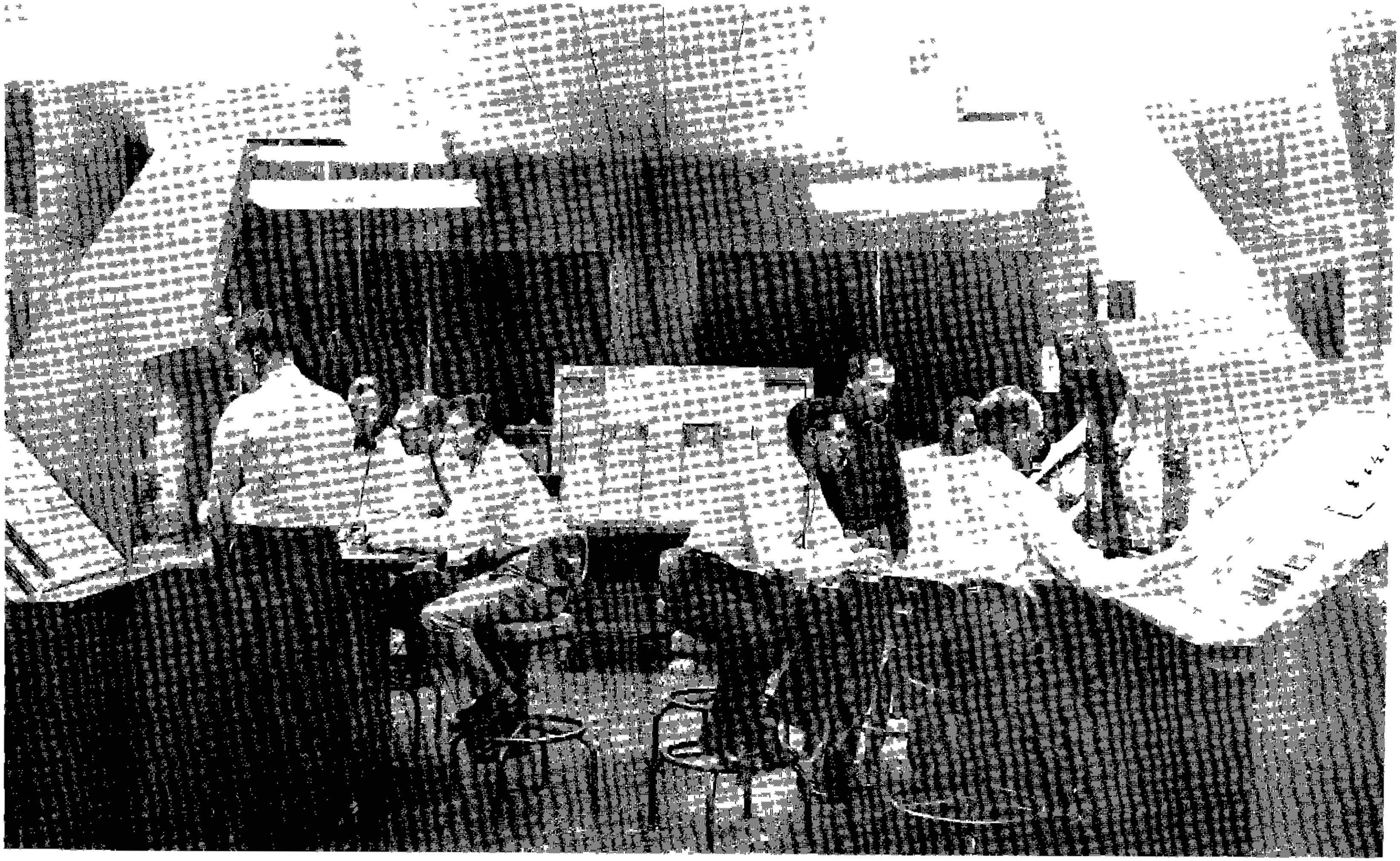


FIG 16 - SPANRAD UNITS IN USE IN ARTC CONTROL ROOM

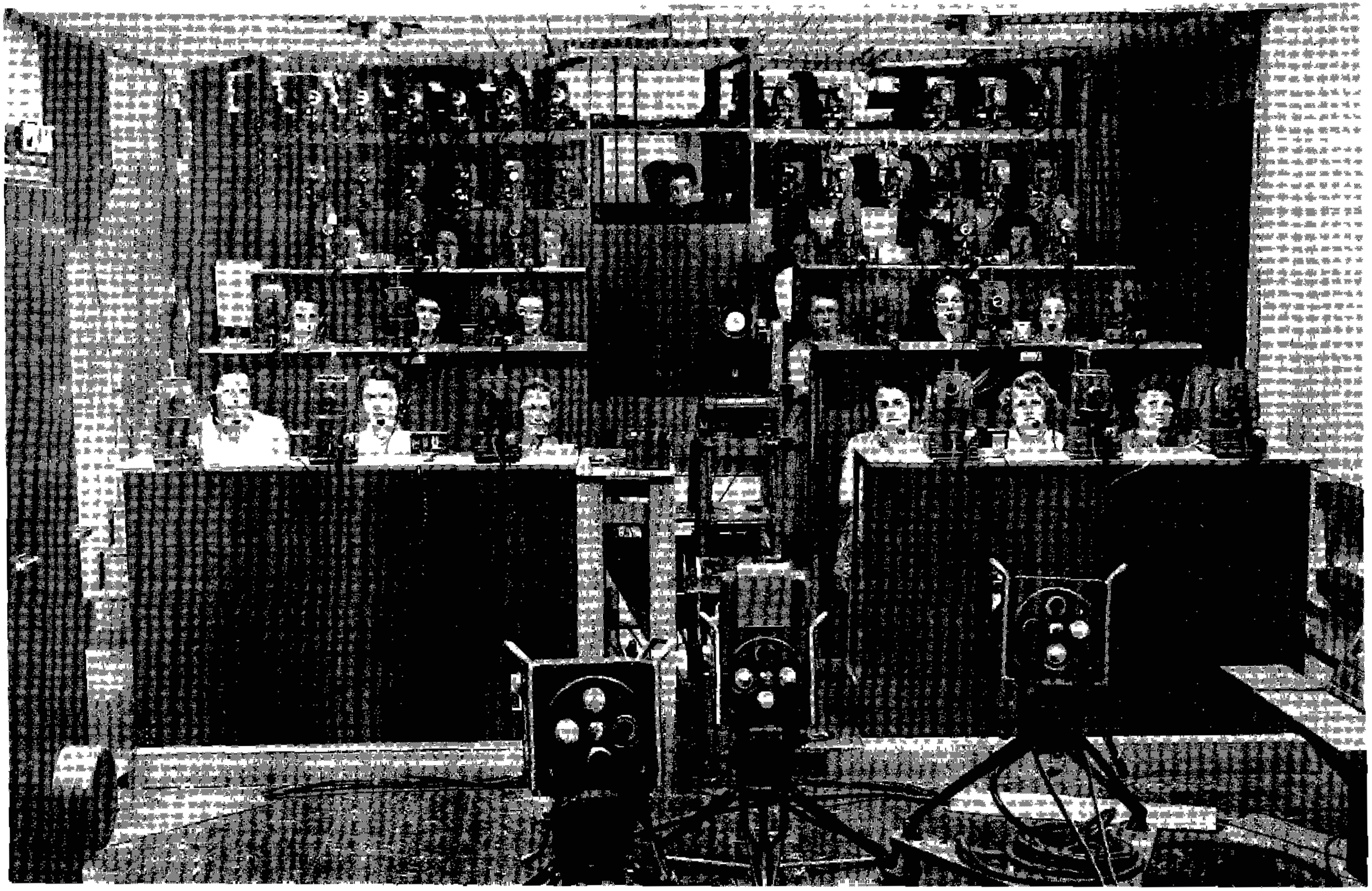


FIG 17 - PILOT CONSOLES AND T V CAMERAS IN PROJECTOR ROOM

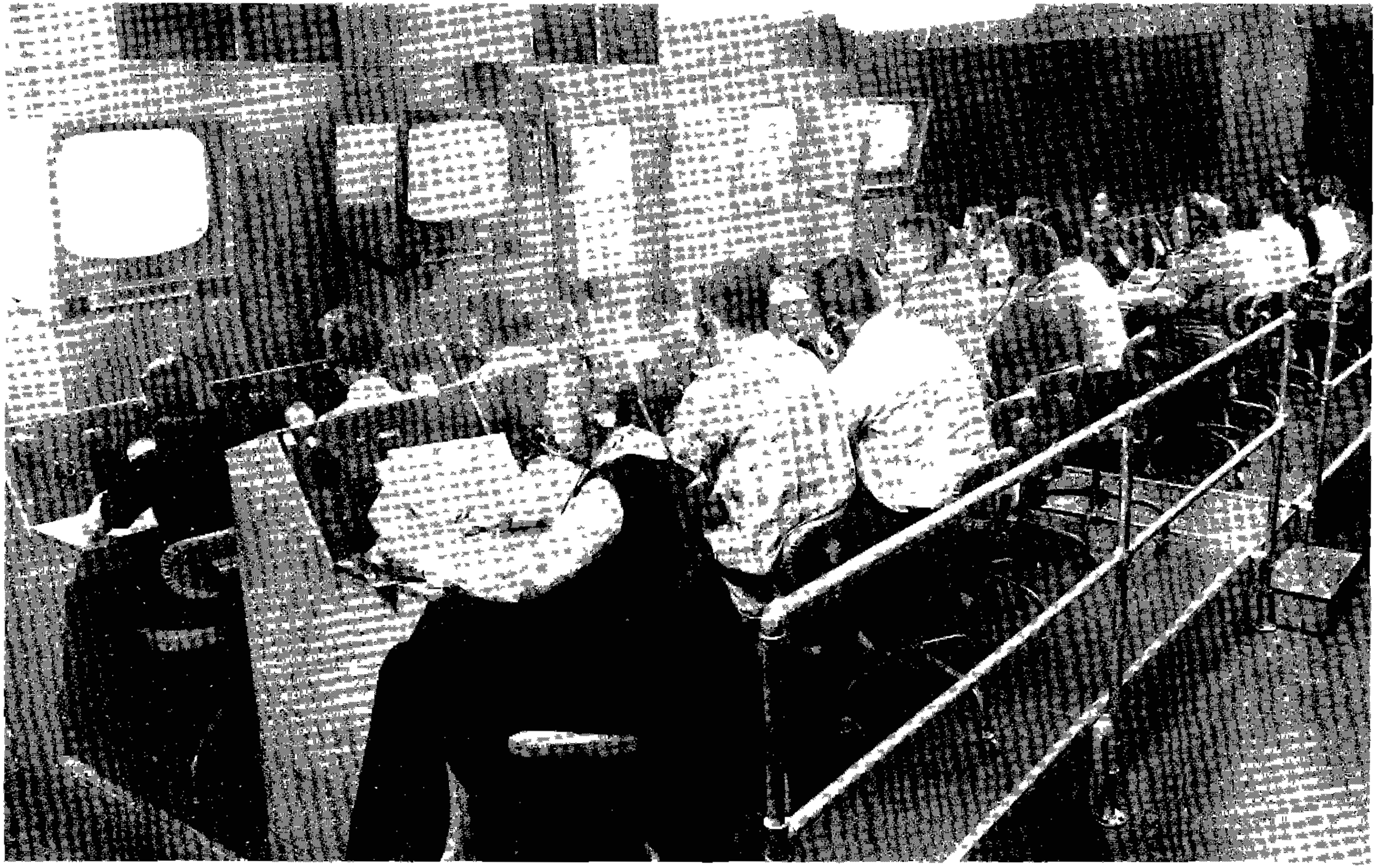


FIG 18 - PILOT CONSOLES IN REMOTE CONTROL ROOM, USING TV MONITORS FOR NAVIGATIONAL DISPLAYS

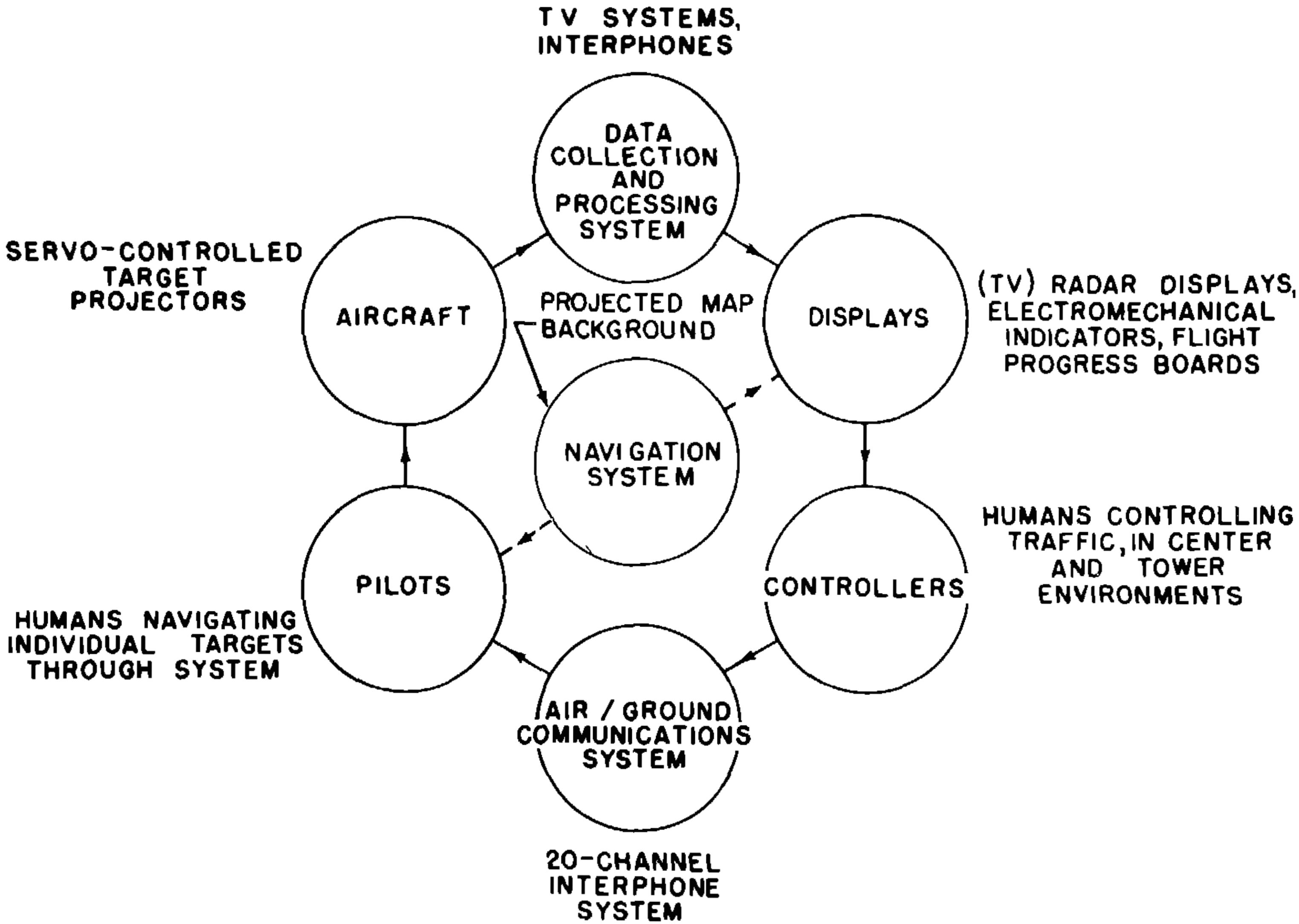


FIG 19 - FUNCTIONAL DIAGRAM OF ATC SYSTEM WITH ANALOGUES EMPLOYED IN DYNAMIC SIMULATION

1 The required number of aircraft with their basic performance characteristics, including flight speeds, acceleration rates, deceleration rates, and turn rates

These effects must be reproduced realistically It is not necessary that the pilot console duplicate the arrangement of an airplane cockpit or, that the simulated aircraft be as difficult to fly as the aircraft it represents To the contrary, it is extremely desirable that the equipment be easy to operate, so that personnel of normal capabilities can be trained to handle its operation quickly and in a satisfactory manner Simplicity also pays off in greater equipment reliability, which is a very important factor in any activity where a single breakdown could idle a large number of people

A fundamental factor in the design of a simulator installation is the number of aircraft which will have to be controlled simultaneously, since this quantity determines the complexity, personnel staffing, and operating costs of the simulation program The number of targets required is a function of the size of the area under study, as well as the traffic density which is desired for the tests For a given area, the number required is inversely proportional to the average operating speed of the aircraft in the traffic sample, since a faster target can traverse the area more quickly, and thus be available for reassignment in a shorter time It also is important to note that the higher the delays encountered during a particular test, the more targets will be required for simultaneous operation

Due to these variables, there is no definite number which can be recommended as necessary It should be noted that much useful work was accomplished with the TDC simulator, in studying terminal area operations, when only six targets were available With 42 targets, it was possible to simulate all the arrivals or all the departures within a radius of 70 miles of the Washington Airport, or arrivals and departures simultaneously within a 50 mile radius In this case, the additional capability made it possible to do a realistic job of simulating the transfer functions between the ARTC center and the terminal area control rooms, a very critical portion of the entire control work load The job could have been done piecemeal, with a smaller number of targets, but with a loss of realism and a considerable increase in testing time

Probably there is an upper limit to the number of targets which is practical for such an installation, due to the sheer magnitude of the administrative problems involved in directing, training, and coordinating the work of so many people After having reached a capacity of 42 targets with the TDC simulator, a point of diminishing returns was being approached, because the entire operation became more unwieldy and the accumulated delays from so many causes reduced the amount of time available for the test runs

2 The communication systems between aircraft and ground agencies, and between the ground agencies

3 The navigational information to the pilot of the aircraft

In the TDC simulator a single background map is projected on the screen to provide a pictorial navigation display for all pilots The entire navigation system can be changed quickly by substituting a new slide in the slide projector

4 The layout of the essential components of the ARTC and 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 behaviour of men can be approximated only by making the operating conditions very 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

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

The limitations of the techniques used in the existing dynamic simulator were recognized and studies [12] were conducted in cooperation with the Franklin Institute Laboratories, and the Canadian Department of Transport and Computing Devices of Canada, Limited to determine technical approaches and specification requirements for a new, improved and more flexible dynamic ATC simulator From this work it was concluded that digital techniques used in the design of a large dynamic simulator offered certain advantages over those provided by analog techniques in terms of high accuracy, large capacity, great flexibility, and data processing The digital approach, where the basic parameters throughout the simulator can be altered by relatively simple means, appears to be more desirable for a research tool. However, for the study of specific present problem areas where cost, availability, and interchangeability with existing simulation equipments is of utmost importance, the analog approach has certain major advantages

In 1958, the Airways Modernization Board placed an order for a 68-target dynamic air traffic control simulator system using analog techniques In addition, to simulating relationships between aircraft and fixed ground installations, such as radars, and ground display systems, the equipment is to provide a more automatic means of data collection and reduction using digital techniques.

Fast-Time Simulation

Fast-time simulation is a relatively new technique which utilizes a digital computer in non-real time operation Unfortunately the title presently applies only to the problem running time, and not to the time required to set up the original computer program Pioneering work in the field of fast-time simulation has been done by the Armour Research Foundation [13] and the IBM Corporation[14]

---

12 "An Air Traffic Simulator Study", Computing Devices of Canada, Limited, FR 1905M-58-1, S2, S3, S4, April 1958

13 G. W Bond, K S. Gale, and C J Moore, "Digital Simulation of Air Traffic Control", Proceedings of the National Conference on Aeronautical Electronics, Institute of Radio Engineers, May 1958

14 "IBM Fast-Time Simulation Summary Report," International Business Machines Corporation, October 20, 1958

Once the decision logic and airway route structure have been incorporated into the computer program, fast-time simulation offers the ability to "fly" extremely large numbers of simulated aircraft through the system in a short time Meanwhile, the computer is recording and processing the test data automatically Extremely large traffic inputs are desirable, if Monte Carlo techniques are to be used for analysis To generate and process such amounts of traffic by any other method would be a slow and tedious job

Besides the complex programming operation, a disadvantage of fast-time simulation is its inability to incorporate human factors directly Thus, the capabilities of this method relate it more closely to graphical than to dynamic simulation Actually the three methods complement each other, so it is probable that a complete simulation facility of the future will utilize all three methods in a coordinated and cooperative manner

When detailed data on human behavior become available from dynamic simulation tests or actual ATC operations, it may be possible to program these human characteristics (mainly in the form of random time delays and a certain unpredictability in making decisions) into the computer, to produce results more in keeping with the characteristics of the present human-operated ATC system

As the ATC system gradually becomes more automatic, it is probable that simulation by digital computers will become more appropriate to the synthesis and analysis of the ATC function

SIMULATION AT WORK

Design of Program

Figure 20 shows the sequence of stages for a complete ATC development cycle Although some of these stages are not always necessary, it is desirable that those which are used should follow this general sequence, which is arranged in the order of ascending cost, with the less expensive processes used first This procedure tends to minimize research costs by providing the opportunity to learn as much as possible about system behavior, and to weed out or revise impractical solutions, before the system reaches a more expensive stage or evaluation or implementation

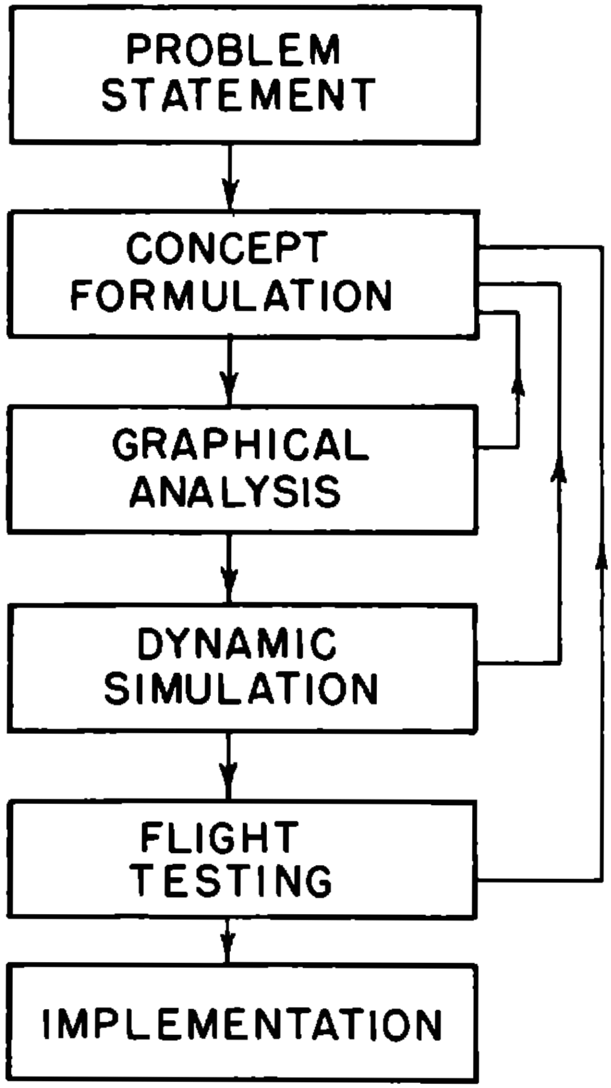


FIG 20 - NORMAL DEVELOPMENT CYCLE FOR ATC SYSTEM IMPROVEMENTS

The essential first step in any simulation program is to define the problem, as clearly and completely as possible It is preferable that this definition be in writing This step leads directly to a determination of the program objectives It also serves to pinpoint the areas in which additional information will be needed

The next step is for the research personnel to become as familiar with the problem as possible For example, if the problem relates to congestion in a specific local area, it is desirable for the research team to make an orientation trip to the area in question, to observe these problems first-hand and to discuss the various details with the personnel of the local control agencies. This familiarization further clarifies the program objectives and provides an insight into the scope of the effort which will be required to complete the study

Then, it is time to develop a plan of approach From the standpoint of research costs and efficiency, this can be the most critical step in the entire program, for it is here that the fundamental decisions will be made as to the significant factors which must be included, the concepts and techniques which will be tried, and the time facilities, and personnel which will be required

Because any simulation program can deal directly with only a relatively small segment of the vast ATC system (to which the segment usually is linked very closely), a basic question in the design of any simulation study is to determine how much of the system operation has to be simulated in order to secure meaningful answers to the problem under study

Here, much depends on the judgment and experience of the planner He must be able to analyze the problem in detail, and determine the relative importance of every factor which may be relevant to the functions under study Based on the limitations of personnel, techniques, facilities, time, and cost, as well as the objectives of the program, he must incorporate as many as possible of the most significant factors into the test program, and try to make intelligent allowance for any other factors which conceivably could affect the validity of the results

In the design of simulation experiments, an important objective is to obtain a maximum amount of significant information about the subject under study, with a minimum expenditure of money and time Significance in this sense implies that the accuracy of the results is adequate and commensurate with the program objectives Here, accuracy is interchangeable with cost, so a reasonable compromise must be reached It is possible to carry the scope and extent of the program far beyond the level necessary to achieve the de red objectives Over-elaborate programs tend to produce diminishing returns per unit cost In addition, their sheer complexity can bog down the studies in a morass of test data, masking the effects that were being looked for in the first place

In air traffic control, as in other fields of operations research, certain problems recur in many ways, over a long period of time Although they assume many different forms, their similarities make it possible to categorize and name them As research experience is accumulated, the various solutions can be associated with their particular categories, and thus provide starting points for possible solutions when similar problems appear later Some of these applications are discussed later in this report

In dealing with problems of an unprescedented nature, it is helpful to start by considering the various unknown factors in broad functional terms, rather than by concluding immediately that a certain function will have to be performed in a certain way In these cases, it is wise to allow additional time in the simulation schedule, for the exploration of more than one approach

One of the most useful products of any research program can be the generation of new ideas, as a direct result of the insights provided by the tests themselves Because the simulation process usually provides the first look at the operation of a new system or concept, it has proved to be an unusually potent stimulus for new ideas Excellent use often can be made of these potentially valuable by-products, by feeding them back into the program, as diagrammed by the loops at the right of Fig 20 In laying out the test schedule, it is very important to provide enough flexibility to take advantage of the new ideas which are generated during the test program

In the early years of dynamic simulation, the TDC test schedule was relaxed enough to permit this flexibility By 1958, however, the demand for simulation studies had reached a point where three simulation projects were being run concurrently on one shift, and personnel were being trained to staff a second shift The extremely tight and rigid schedule which had to be maintained on each project allowed insufficient time for creative thinking and almost no time at all to explore and test any ideas or concepts which originated during the course of a particular study As a result, the project tasks which were completed during this period were lacking noticably in new ideas and fresh approaches; and the solutions which were advanced, as a result of this work, were considerably below the optimums which might have been attained if sufficient time had been available for the study

Construction of Traffic Samples

In order to run simulation tests which compare one set of conditions against another, it is necessary to have a repeatable 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 performance characteristics These aircraft are scheduled carefully to enter the problem at predetermined times and locations and to fly specific routes to specific destinations What happens to these aircraft after they get into the problem depends on the dynamics of the system under study

The traffic 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 system should approximate the proportion expected in actual operation The proportion of traffic desiring to use the various routes and airports also should be consistent with the distributions expected in actual use

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 sequence of aircraft

In setting up a dynamic simulation program, one factor which must be considered is the possibility that the control personnel may actually become too expert in handling the specific situations presented by the traffic problem If this should occur, the simulation results would appear to be much better than the results which could be expected under actual operation

This symptom was detected in early simulation operations, during repeated runs of a short traffic sample In this case, control personnel soon memorized the problem and anticipated what was going to happen next To compensate for this learning factor, 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 intentional 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 averages the effects of human performance by utilizing a larger sample of representative controllers

b It furnishes additional manpower for running the simulation tests

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

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

In common with other forms of traffic air traffic has an inherently random characteristic, normally, aircraft tend to arrive in bunches, rather than at equally spaced intervals Relatively, there are many short intervals and few long intervals This characteristic is reproduced in simulator traffic samples through the use of the Poisson equation, or the law of small numbers A detailed description of the procedure for applying this equation to the construction of traffic samples appears in an ATC simulation report prepared by Franklin Institute Laboratories [3]

For tests of existing terminal areas, it often is convenient to utilize the records for an actual operating period to furnish a typical sequence of the following flight data for the traffic sample

---

[3] S M Berkowitz and Ruth R Doering, "Analytical and Simulation Studies of Several Radar Vectoring Procedures in the Washington D C Terminal Area", C A A Technical Development Report No 222, April, 1954

1 Aircraft identifications and types

2 Departure airports, routes, and destinations

3 Entry altitudes

Since potential restrictions to traffic flow are not as apparent during light traffic conditions, it often is necessary to increase the traffic density from that shown by the actual records, to a density which will provide more revealing test data and more efficient use of simulation time This can be done by assigning new entry times to each aircraft, through use of a "throw-down" technique, using a set of random intervals established by the Poisson equation Because of the recorded entry times and routes for any given hour of actual operations essentially are random, it also is possible to increase the original density by superimposing one hour's entries on the entries of another hour This serves to condense the original traffic sample and still retain its random characteristics

When it is not possible to secure detailed records of past operations, traffic samples can be compiled from available statistics relating to the percentages of different types of aircraft using the terminal area and the percentages of traffic utilizing different routes in the area Appropriate aircraft indenfications, flight characteristics, and routes are assigned then to the various aircraft in the sample through use of the throw-down technique Entry times are assigned through use of intervals determined by the Poisson equation Analysis by Franklin Institute Laboratories indicates that traffic samples about two hours in length are satisfactory from the standpoint of statistical stability

Measurements of Systems Performance

ATC system design involves the optimization of four partially conflicting criteria

1 Maximum capacity in aircraft operations per hour

2 Maximum safety (minimum probability of collision)

3 Minimum cost per aircraft operation

4 Maximum operational freedom (minimum restraint, and minimum required deviation from the flight routes and aircraft performance characteristics desired by aircraft operators)

The evaluation of system performance thus requires the measurement of significant data relating to one or more of these criteria

Capacity can be measured by saturating the system with an overload of traffic and then observing the rate of traffic flow in operations per hour This procedure is not always possible, due to limitations of the simulation facilities Actually, it is not even necessary, if the object of the tests is to compare only the relative capacity of two different systems This can be done by measuring the aircraft delays encountered, when feeding the same input of traffic through both systems Since delays are a result of flow restrictions (or in other words, a lack of capacity) delay forms an inverse index of system capacity

The concept of aircraft delay, as measured in simulation tests, differs from the concept presently used in the field in tabulating delays In actual traffic operations, the only arrival 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 from all causes, including holding, path-stretching, slowdown, descent, and communications lag 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, known as the "absolute delay", is the 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

Normally, safety cannot be measured directly, as the collision rate between simulated aircraft is infinitesimally low It is possible, however, to measure the relative exposure to hazard by measuring the number of times that a specific separation standard (such as three miles separation between aircraft flying on instruments at the same altitude) is violated during the course of a simulation run

From the standpoint of safety the human element is the most important element in the entire system For safety, as well as capacity, it is essential that the amount of controller workload be kept as low as possible Thus, measurements of controller workload have a significant bearing on the first two criteria

Communications measurements are some of the most tangible indices of controller workload They include the following types of data

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 as well as the relative loading of the various channels ATC communications usually are comprised of very short verbal messages and a definite break is required at the end of a message before any other party knows that he can start the next message In general, ATC communication channel is considered to be saturated when the channel loading ratio (talk time/total time) rises to a level of 65 percent over an extended period

In connection with the evaluation of displays, analyses of controller activity include the measurement of each items as the time required to operate the display inputs, and the time required to perceive and resolve potentially hazardous traffic situations

The most important factor in the workload of the controller is the workload of making decisions However, this is probably the one factor which is least amenable to analysis One approach which has been suggested for establishing a relative measurement of the decision workload is to analyze the entire decision process and compute the number of steps which a digital computer would require, to process the relevent data corresponding to the significant factors, and choose the proper responses from the list of available alternates This approach has not been followed, however, partly because of the sheer magnitude of the task In addition, some psychologists feel that such a digital micro-analysis would not resemble the thinking processes of a human controller, as it appears that a human brain can take tremendous short cuts by associating implicit bits of information and dealing with them in parallel, rather than in the series fashion of a digital computer

In lieu of the suggested quantitative analysis of the decision process, a qualitative analysis has been used with considerable success in the simulation program This is a method of obtaining the subjective opinions of the controllers themselves, as to the relative difficulty or magnitude of the decision workload, in controlling a standard sample of traffic This information is recorded on questionnaires which are completed by the controllers at the end of one or more runs on a given system From this relatively rough data have come a number of significant methods of reducing the decisions workload, as described later in this report

In connection with the criterion of operating costs, the simulation tests can be used to determine the number and types of personnel, communications channels, navigation aids, radars, and other operating equipment that will be required to perform the required control functions in the portion of the system under study

The criterion of operational freedom can be evaluated by comparing the length of the flight routes which are necessary to serve the various systems under study Other restraints, such as altitude restrictions, can be tabulated in a comparative manner The length of the unrestricted climb and descent routes serving a specific locality is usually a good index of operational freedom

SIGNIFICANT RESULTS

For a number of years, the simulation program has provided a unique opportunity to test many different ATC concepts, procedures, equipments, and route configurations, under traffic loads much higher than those presently encountered in the field As a result, it has been possible to analyze the effects on many operational factors, and to determine many of the basic principles which govern the performance characteristics of the ATC system A number of these principles, along with their applications, are discussed in the following sections

Dynamics of Air Traffic Flow

The Convergence Problem

The fundamental purpose of the ATC system is to prevent collisions between aircraft Since such collisions occur only when aircraft converge, the basic objective of the ATC system is the prevention of convergence At present, this is accomplished by the intentional establishment of definite amounts of spatial separation between the intended path or locus of each aircraft and that of every other aircraft in the system Present standards for longitudinal, lateral, and vertical separation are specified in another publication [15]

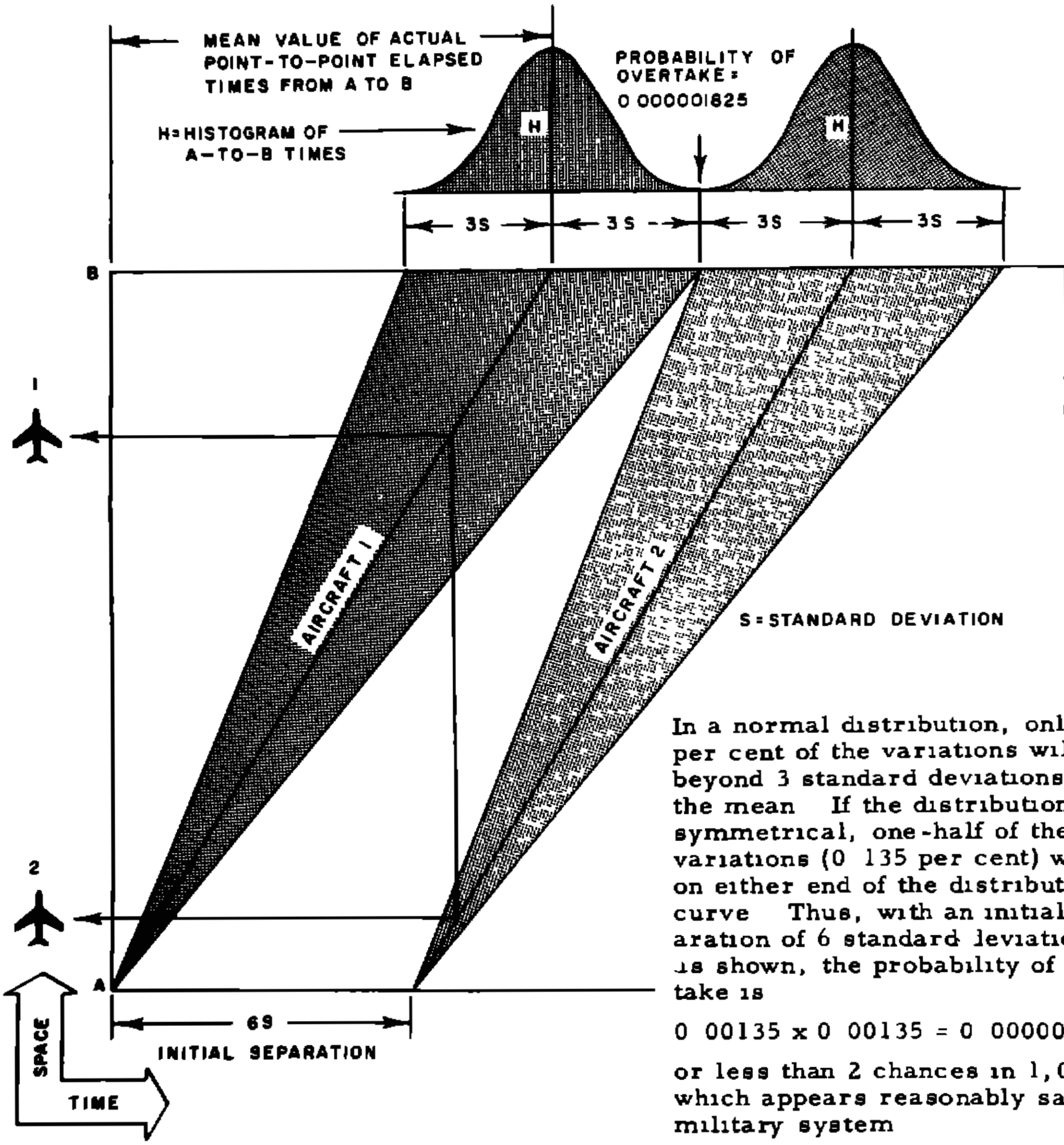
Fundamentally, the amount of separation established must always exceed the total variation, or prediction error, which could conceivably occur between the intended positions and the actual positions of the various aircraft, during whatever period of time will elapse before the situation can be rechecked and corrected In statistical terms, the amount of initial separation must always be at least six times the (expected) standard deviation of this error, for the period in question An application of this principle is graphed in Fig 21

Where control is based on the aircraft position reports received from pilots, as in procedural (ANC) control, the separation established must exceed the sum of the possible errors in the initial reported positions, plus the variations which might accrue before the next position reports can be received and acted upon

The amount of separation required has an inverse effect on the capacity of a traffic lane, as shown by the formula $N = V/S$, where N = number of aircraft per hour, V = average velocity of the aircraft in knots, and S = average separation between aircraft, in nautical miles Thus a significant reduction in the amount of position error would tend to reduce the amount of separation required which in turn would tend to increase the capacity of the traffic lane Horizontal and lateral position errors may be reduced by the use of more precise navigation and piloting techniques, or through the use of more frequent and accurate feedback of

---

[15] "ANC Procedures for the Control of Air Traffic", US Government Printing Office, Third Edition, September, 1957



In a normal distribution, only 0 27 per cent of the variations will lie beyond 3 standard deviations from the mean If the distribution is symmetrical, one-half of these variations (0 135 per cent) will lie on either end of the distribution curve Thus, with an initial separation of 6 standard deviations, as shown, the probability of overtake is

0 00135 x 0 00135 = 0 0000018225,

or less than 2 chances in 1,000,000, which appears reasonably safe for a military system

FIG 21 - SPACE-TIME CURVE ILLUSTRATING POSSIBLE STATISTICAL APPROACH TO DETERMINATION OF LONGITUDINAL SEPARATION STANDARDS aircraft positions (as through the use of radar) Vertical errors may also be reduced by more precise piloting techniques and, particularly at high altitudes, through the use of improved altimetry

The N= V/S formula shows that the capacity of a traffic lane can be increased if either the velocity is increased or the separation is reduced If these two quantities are fixed, the total capacity of the system can be increased by the operation of additional traffic lanes

Simulation tests have shown that the design of route systems for multiple-lane operation is one of the most important methods for attaining a significant increase in system capacity [16, 17]

However, as shown in Fig 1, the ATC system is literally built around the navigation system, so the ability to establish additional lanes (other than in the vertical plane) depends entirely on the flexibility and the flyable accuracy of the navigation system in use From the ATC standpoint, the ideal navigation system would provide complete area coverage with the freedom to establish defined lanes between any selected points in the airspace covered

The present practice of basing the route structure entirely on radial courses places an unfortunate restriction on the development of a high capacity multi-lane traffic system, since it requires an additional row of navigation facilities to implement a parallel traffic lane In view of the fact that the technical means have been available for years, to establish offset course on an area-coverage basis, the present practice is extremely wasteful of facilities and frequencies [17, 18, 19]

- -

[16] Clair M Anderson, Thomas E Armour, Donald S Schlots "Dynamic Simulation Tests of Several Traffic-Control Systems for the San Francisco-Oakland Area", Technical Development Report 293, September 1956

[17] Tirey K Vickers "Simulation Tests for Army Air Traffic Control," Technical Development Report No 298, May 1957

[18] Hugh Kay, "Development and Flight Tests of the CAA Type VI Course Line Computer", Technical Development Report No 143, May 1951

[19] E Blount, C E Dowling, H Kay, R E McCormack, E R Sellers "Technical and Operational Evaluation of the Type IV Pictorial-Display Equipment" Technical Development Report No 242 June, 1954

The mere provision of additional lanes is not the complete answer The design objective is simultaneous operation, a qualification which requires either that the lanes be non-convergent, or that the ATC system be able to integrate traffic flow at each point of convergence This is a key point in controller workload and system capacity Unless altitude separation can be used, doubling the number of traffic lanes increases the number of potential points of convergence four times

In designing a route system for heavy traffic flow, a primary objective is to minimize the number of convergence points Typical solutions for the four main types of convergence problems are listed below.

Convergence	Solution
1. Head-on	Establish one-way traffic lanes, preferably displaced laterally from each other in order to simplify altitude-change problems
2 Crossing Courses	Use of altitude separation at crossing points
3 Overtaking	Segregate aircraft by speed category, assign different categories to different lanes
4 Altitude Change	Establish climb and descent lanes latterally displaced from each other and from lanes being used by aircraft in level flight

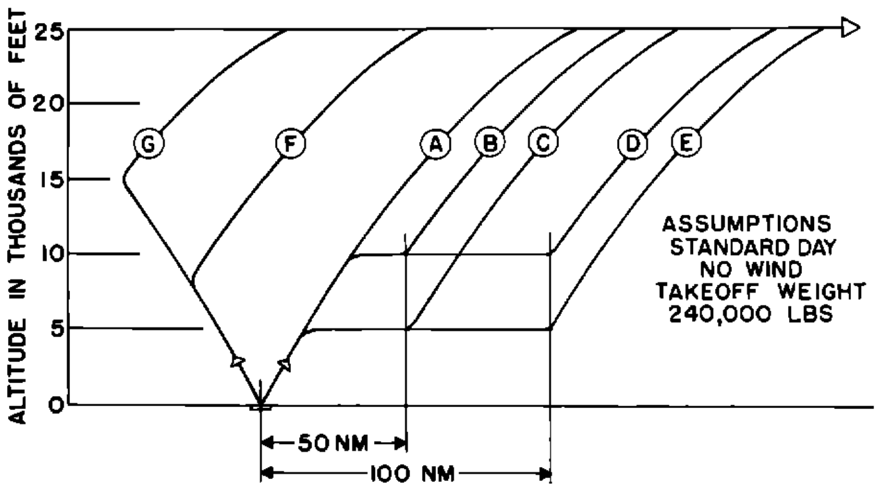
One of the most troublesome types of convergence problems occurs when a climbing or descending aircraft crosses another traffic lane The basic difficulty is due to the uncertainty of predicting the altitude of the climbing or descending aircraft at the point of crossing Unless radar can be used to monitor this situation closely, it usually is necessary for the controller to block a wide range of altitudes on the crossing airway The alternative to this waste of usable airspace is to interrupt the climb or descent and require that the aircraft maintain a constant specified altitude while crossing This procedure can be highly restrictive when the aircraft has to cross a series of airways This is a characteristic problem around high-density terminal areas

A very complex distribution problem exists in terminal areas having two or more major airports Traffic converging on the inbound routes from various directions has to be sorted out and distributed to the proper airports, and traffic from the various airports has to be distributed to the proper departure routes. Geometrically, it is impossible to eliminate all the points of route convergence However, it is often possible to improve terminal area traffic flow through the use of three basic steps

1. Careful redesign of the route structure to reduce the number of convergence points, with particular emphasis on making the traffic patterns of adjacent airports as independent of each other as possible This step involves a number of considerations for the optimum layout of approach systems, as detailed later in this report In addition, many other restrictions (such as terrain obstructions, noise factors, restricted areas, radar coverage, etc) have to be taken into consideration In many cases, it has been found helpful to by-pass the flow of over (non-landing) traffic around the terminal area to free more airspace for terminal area operations.

2 Judicious assignment of altitude reservations to separate the streams of high-density traffic at crossing points Care must be taken to insure that departures will not have to climb at an excessively high rate to cross the specified point at the assigned level, and to insure that arrivals will not have to cross a close-in fix at an excessively high altitude and then incur a delay because of the time required for descent beyond that point

   On the other hand, tunneling (restricting arrivals or departures to a low altitude) for excessively long distances can be undesirable This is particularly true for jet aircraft, because of their very high fuel consumption per mile, at low altitudes Figure 22 shows the effects of several departure restrictions on the flight time and fuel requirements of a typical civil jet transport Results indicate that where a choice can be made between a certain length of tunnel on course, versus a detour



FLIGHT PATH	DEPARTURE CLEARANCE	PENALTY	
		MINUTES	FUEL LBS
A	UNRESTRICTED CLIMB ON COURSE	0	0
B	TUNNEL TO 50 MILES AT 10,000 FEET	0 5	190
C	TUNNEL TO 50 MILES AT 5,000 FEET	1 3	520
D	TUNNEL TO 100 MILES AT 10,000 FEET	1 6	660
E	TUNNEL TO 100 MILES AT 5,000 FEET	3 4	1280
F	UNRESTRICTED CLIMB 50 MILE DETOUR	6 1	1540
G	UNRESTRICTED CLIMB 100 MILE DETOUR	10 3	3050

FIG 22 - EFFECT OF CERTAIN ATC RESTRICTIONS ON A TYPICAL CIVIL JET DEPARTURE

of comparative length to obtain an unrestricted climb, the tunnel should be less expensive in terms of flight time and fuel Obviously, the tunnel altitude should be as high as possible and the tunnel length as short as possible Detours represent wasted mileage, with relatively higher penalties in flight time and fuel

3 Simplification of control procedures to reduce the workload involved in integrating converging traffic streams This subject is detailed in a later section

In terminal area design studies, it has been found desirable to lay out the lanes for the routes of heaviest traffic flow first, providing them with climb and descent paths as free of restirictions as possible The less important routes are then fitted into the layout By facilitating traffic flow for the majority of aircraft using the system, this procedure tends to reduce the total control workload Since a terminal area is part of a much larger system, care must be taken to secure a balanced capacity for arrivals and departures Sub-optimization, the excessive improvement of either type of flow at the expense of the other, tends to reduce the over-all capacity of the area in handling sustained traffic loads

Approach Systems

In most instances, the control of departure traffic requires less workload than the control of arrivals This is because departure traffic is inherently divergent, schematically, the flow pattern goes from series (single file on the runway) to parallel (various departure lanes) On the other hand, arrival traffic is inherently convergent Getting the flow pattern from parallel (various arrival lanes) back into series (single file on the final approach path) is one of the most critical operations in traffic control, as far as system capacity, safety, and cost are concerned It is here that the traffic density reaches the highest level of the entire system Therefore, the study of approach systems has been one of the most important phases of the entire simulation program

The function of an approach system is to accept the input of various types of aircraft, from various routes and altitudes, at random times, and accomplish the following

1 Meter or regulate the flow of traffic to avoid overloading the approach path

2 Establish an optimum arrival sequence, arranging the landing order in such a fashion that each aircraft in the group will have a landing time as close as possible to the time at which it would have been able to land had it been the only aircraft in the air

3 Descend each aircraft from its entry altitude to an altitude at which it can intercept the glide slope for an approach

4 Space each aircraft properly behind the one ahead on the common path to the runway

5 Guide each aircraft to a point where it can intercept the approach course and proceed inbound toward the runway

6 Separate every aircraft properly from every other aircraft during this entire operation This implies the use of at least 3 miles' horizontal or 1,000 feet vertical separation at all times

The ultimate objective of the approach system is to adjust the arrival time of each aircraft so that it meshes smoothly into the stream of arriving traffic in an orderly landing sequence There are four basic techniques for adjusting the arrival time of aircraft

1 Holding
2 Path-stretching
3 Velocity control
4 Preassigned departure time

Present approach systems utilize holding techniques for the metering function and radar path stretching techniques for spacing and guidance to the final approach course

Approach systems can be classified in accordance with the number of holding stacks which they employ Single-stack systems are sometimes used at locations where traffic demand is low or where airspace restrictions prevent the establishment of a dual-stack layout Because altitude separation is employed between aircraft in a holding stack, the capacity of a single-stack approach system is limited by the descent characteristics of the aircraft in the laddering-down operation, as shown by the formula

$$A = \frac{60}{\frac{S}{D} + L}$$

where A = acceptance rate, in aircraft per hour, S = altitude separation (normally 1000 feet), D = average descent rate, in feet per minute, and L = communications lag (average time interval between issuance of descent clearances to successive aircraft, as illustrated in Fig 2) Where different types of aircraft are operating in the system, the average descent rate tends to revert to the slowest rate of an aircraft in the stack Extensive simulation tests have shown that it is very difficult to exceed an acceptance rate of 20 aircraft per hour with a single-stack approach system [20] The

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

use of a twin-stack system permits a considerable increase in acceptance rate, by reducing the restrictive effects of descent time and communications lag It also allows the radar workload to be shared conveniently by two controllers

Figure 23 shows a few of the approach system configurations which have been tested during the jet simulation study The overhead patterns shown on the left is an improvement over the conventional military jet teardrop penetration pattern Although the teardrop pattern works satisfactorily for isolated aircraft, it is poorly adapted to high-density approach operations, since it provides no room for adjusting the spacing of a jet aircraft behind a preceding aircraft Simulation tests show conclusively that the provision of a base leg (a segment of the approach path approximately 90° from the final approach) is essential for the attainment of precision in manual radar approach-spacing operations

The double overhead pattern shown in Figure 23 permits the segregation of jet and piston-engine approaches on opposite sides of the final approach course This feature simplifies control operations somewhat by minimizing overtaking problems in the maneuvering area However, the double-L and the trombone patterns have been developed to a higher degree of refinement during the past several years of simulation, and have been found to be well adapted for the control of jet aircraft

In general, simulation tests have shown that holding fixes and approach paths should be arranged as to permit easy transition to the final approach course, adequate room for descent, and space for a base leg for precise path-stretching operations To reduce the effects of speed differences between successive aircraft, the final approach path should be as short as possible, consistent with the ease of obtaining proper alignment of the aircraft on the final approach course

Comparative tests of symmetrical and asymmetrical twin-stack feeding systems show that the symmetrical system with one holding fix located on either side of the final-approach course provides far more efficient traffic-flow characteristics, by permitting direct access to the final-approach course by aircraft coming in from either stack Flight patterns are short, simple, and relatively easy to follow on the radar display By using the final-approach course as the boundary line of demarcation between the dual approach-control sectors, opportunities for conflicts between aircraft or for confusion regarding sector jurisdiction

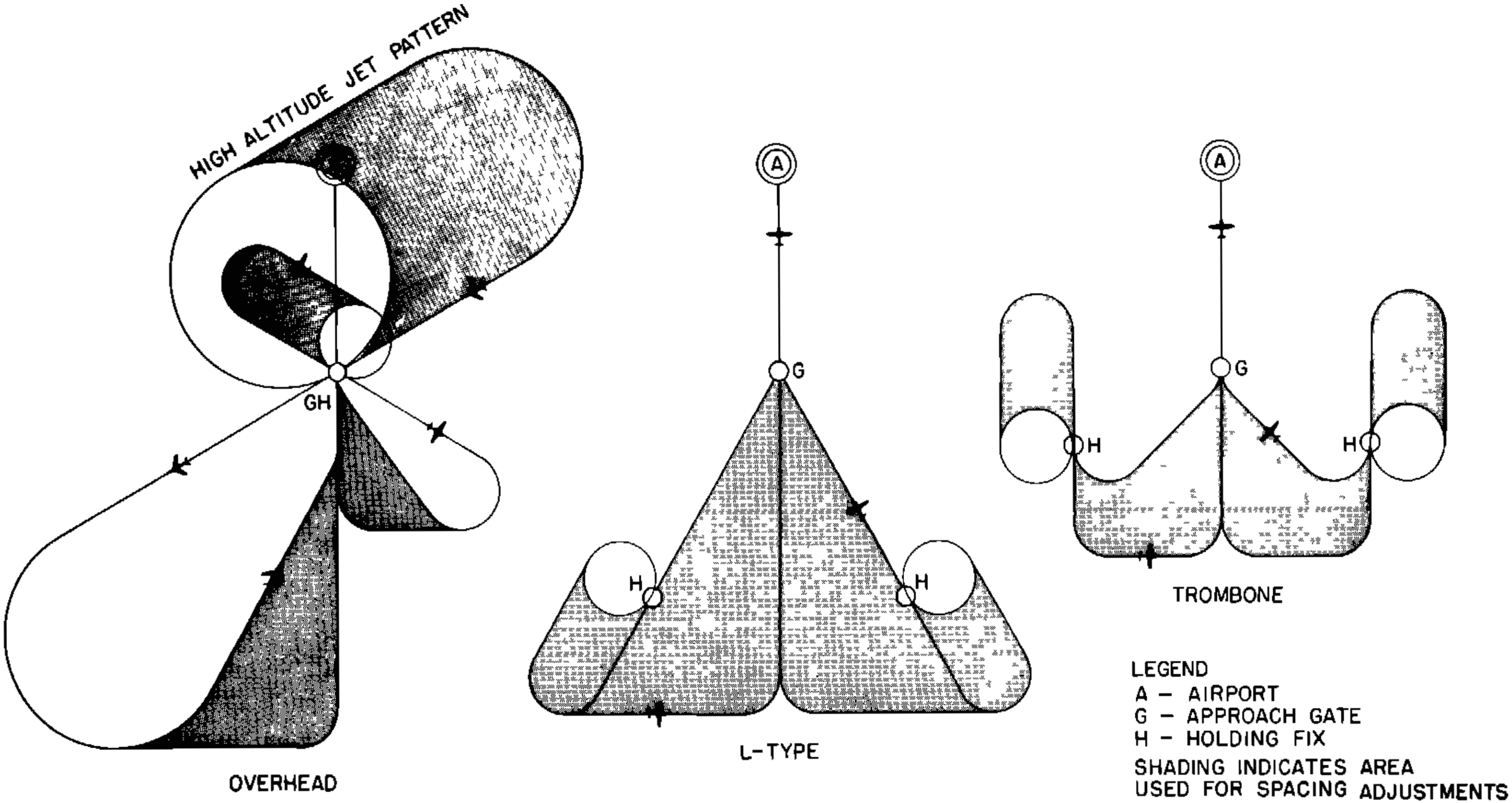


FIG 23 - TYPICAL TWIN-STACK APPROACH SYSTEMS are reduced to a minimum Consequently, traffic can be fed smoothly from either holding fix to the approach gate with minimum delay, minimum air/ground communications, and minimum co-ordination between controllers

As a possible means of minimizing low-altitude holding in congested terminal areas, considerable simulation work has been devoted to an approach system incorporating preassigned landing reservations, and utilizing velocity control during the last 100 miles or so of the flight to absorb most of the delay

A special slide-rule computer known as ASCON (arrival scheduling control) is used in the simulation of this system Starting with the optimum speed and deceleration program for each aircraft, ASCON computes the time the aircraft would arrive if it were the only aircraft in the area In determining this theoretical arrival time, the computer also takes into consideration the altitude and allowable descent rate of the aircraft, in order to insure that it will have adequate time to descend to the airports Using the theoretical arrival time, the controller then checks the list of landing reservations and reserves the first available time slot The computer then indicates what ground speed should be made good by the aircraft in order to arrive on its assigned schedule, taking into consideration the normal speed and descent capabilities of the aircraft

Further progress reports can be inserted into the computer to provide speed adjustments for greater precision In cases where the aircraft cannot fly slowly enough to absorb all the delay en route, the computer indicates the need for an en route delay maneuver, or determines the time at which the aircraft should leave any holding fix on the way in order to meet the assigned delivery time.

Simulation tests show that the establishment of a definite landing reservation for each aircraft does not, in itself, increase the airport acceptance rate However, it is apparent that the "derandomization" of arriving traffic simplifies the approach control operation immensely by metering the flow of arrivals to a steady rate which can be accommodated easily by the radar approach system

Tests indicate that the precision possible with velocity control alone is not as high as the attainable by path-stretching This is because the effectiveness of velocity control decreases progressively as the aircraft approaches the destination, while the usefulness of path-stretching is maintained right up to the approach gate For this reason, it appears that the use of offset approach courses with the ability to make last-minute path-stretching adjustments if necessary, still will be desirable even in a system which utilizes velocity control as a primary concept

Airport Design

During terminal area simulation programs, it has been noted that an increase in traffic flow which is gained through the elimination of one bottleneck often serves to uncover the existence of another at some other point in the system If this process is carried far enough, the final limiting factor in the capacity of the terminal area often turns out to be the airport itself

Two methods are available for increasing the capacity of a runway system, these are the reduction in runway-occupancy times and the provision of additional independent traffic lanes A very effective means of reducing the runway-occupancy times of arriving aircraft is the provision of adequate high-speed turnoffs, so designed and located that they can be used by arriving aircraft to vacate the landing runway while the craft is still rolling at a speed of 20 to 30 mph [21, 22] The effect of this facility on runway-occupancy times is shown in Figure 4. In order to retain the advantages of high-speed turn-offs during the hours of darkness, it is essential that such exits be well marked and well lighted.

Runway-occupancy times of departing aircraft may be minimized through the provision of adequate taxi strips with engine run-up areas located near the ends of the runways as shown in Fig 24. Because of traffic restrictions and because of delays in completing cockpit checks, aircraft cannot always take off in the same order in which they taxi away from the ramp To provide better utilization of airspace as well as to avoid airport congestion and long departure delays it is essential that adequate pavement width be provided in the run up area so that any aircraft can proceed directly from this point to take off position without having to wait for preceding aircraft to take off first

[21] "Preliminary Report on Airport Configuration Studies " CAA Airport Engineering Bulletin No 1 CAA Office of Airports June 1951

[22] Robert Horonjeff Dan M Finch, Daniel M Belmont, Gale Ahlhorn "Exit Taxiway and Design" University of California August, 1958

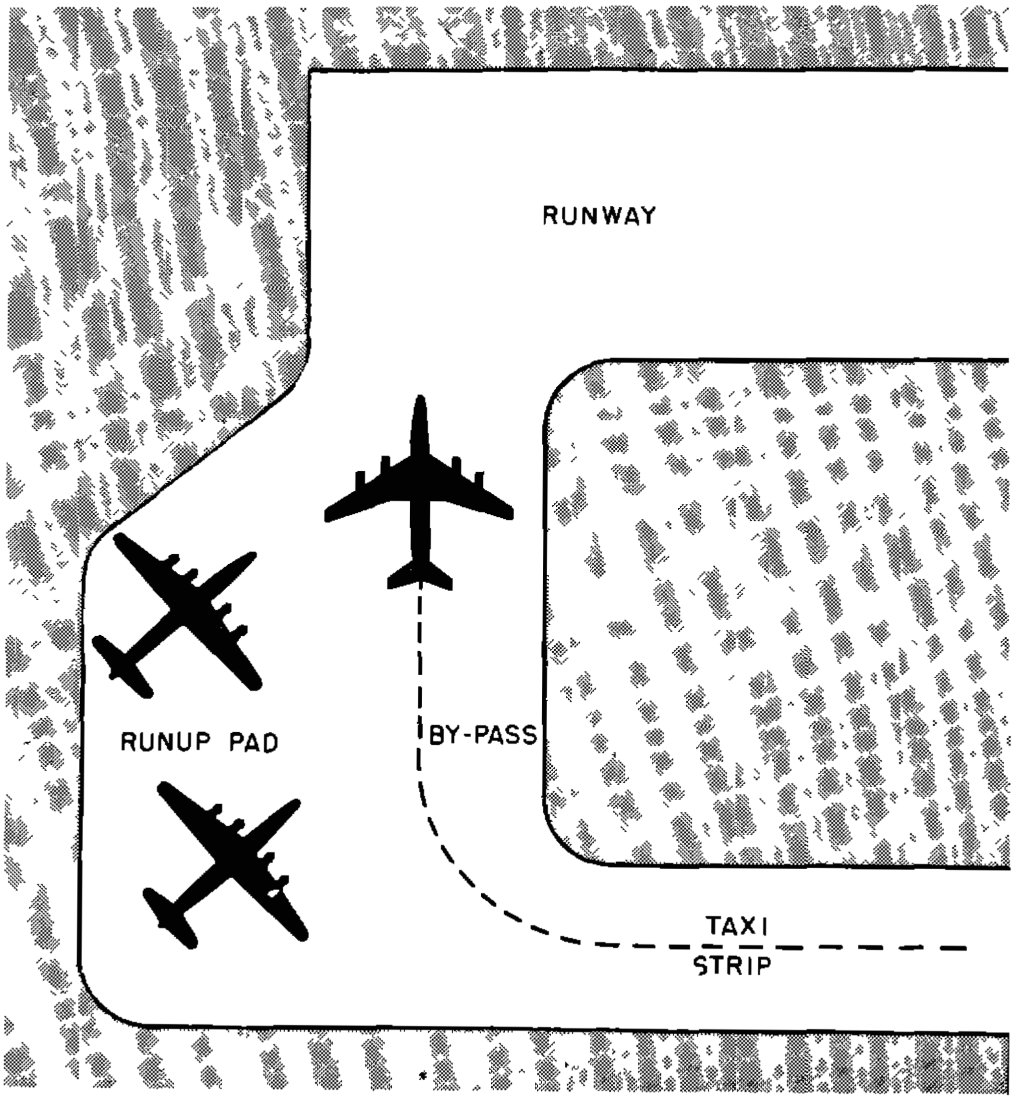


FIG. 24 - RUN-UP AREA WITH BY-PASS TAXIWAY

A great amount of simulation work has been conducted on the problem of increasing runway capacity through the use of additional traffic lanes Basically, any gain over the capacity of a single-lane system must be due to the fact that more than one operation can be conducted simultaneously Therefore, it is essential that various lanes be as independent of each other as possible Figure 25 shows one of the most promising of the

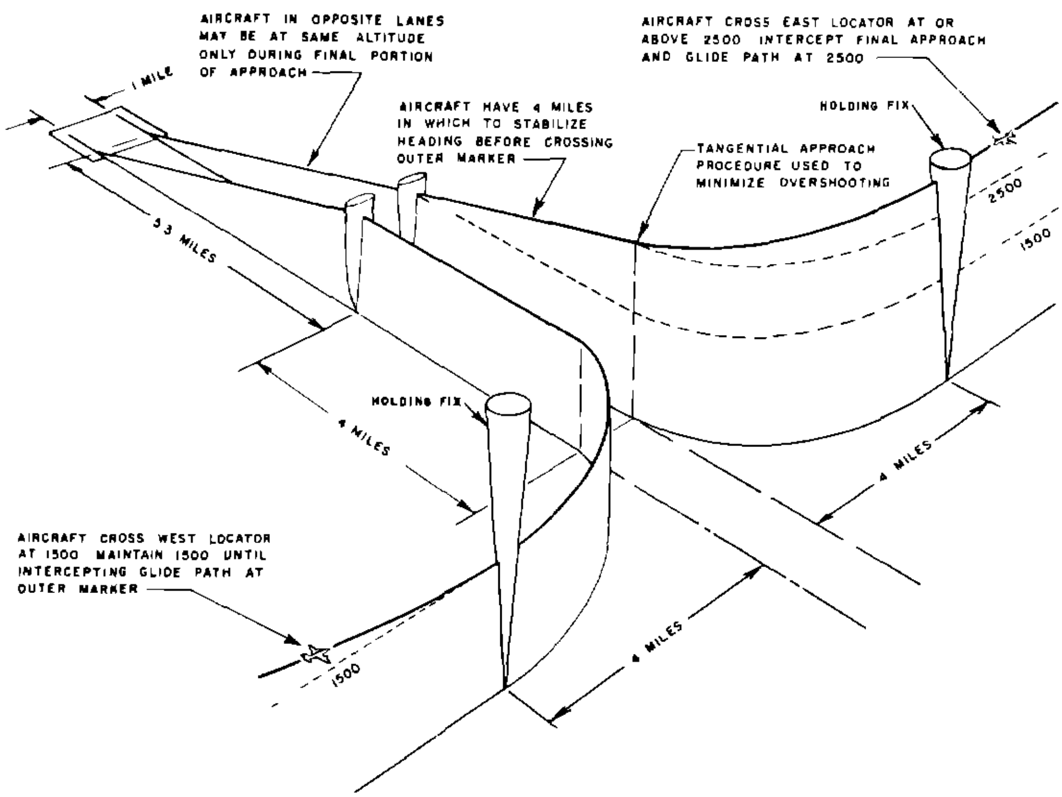


FIG 25 - DUAL-LANE APPROACH SYSTEM

high-capacity dual lane approach systems which has been developed in the simulation program Such a system would probably be justified only for airports having a demand rate exceeding 40 landings per hour

Figure 26 points up the large increases in spacing accuracy which are required to increase the acceptance rate of an approach system This implies that the design of high-capacity systems can be simplified by the use of multiple approach lanes with relatively low spacing accuracy, rather than by the use of a single approach lane with extremely high accuracy

To achieve an acceptance rate of 60 landings per hour using one runway and a reduced separation standard of 2 miles a system accuracy of plus or minus 4 seconds at the delivery point would be necessary. Such accuracy is far beyond the capability of present manual approach systems, and probably would be extremely difficult to achieve in automatic or semi-automatic systems as it must embrace the errors of all the elements of the control loop shown in Figure 1

The addition of a second approach lane would enable the system to handle the total demand rate by landing 30 aircraft per hour on each runway With the same separation standard the system accuracy could be relaxed to plus or minus 33 seconds, a value well within the capability of human controllers By increasing the spacing between aircraft in the same approach lane, it also would tend to reduce the effects of turbulence behind large jet aircraft Although these effects are not clearly defined at the present time recent studies in England indicate that such turbulence persists over a period of at least 2 minutes and, under certain conditions, can form a hazard to the operation of smaller aircraft following closely in the same lane

It is true that a dual approach system would require relatively high navigational accuracy to prevent interference between aircraft in opposite approach lanes However extensive simulation tests of dual-approach systems backed by flight tests of approaches into parallel lanes about 6,000 feet apart at Chicago O'Hare Airport, indicate that the turn-on is potentially the most hazardous part of the procedure, that once the aircraft are established on their respective ILS courses, with adequate monitoring by radar, there is little possibility of interference between aircraft in opposite lanes Tests indicated that any hazard due to over-shooting

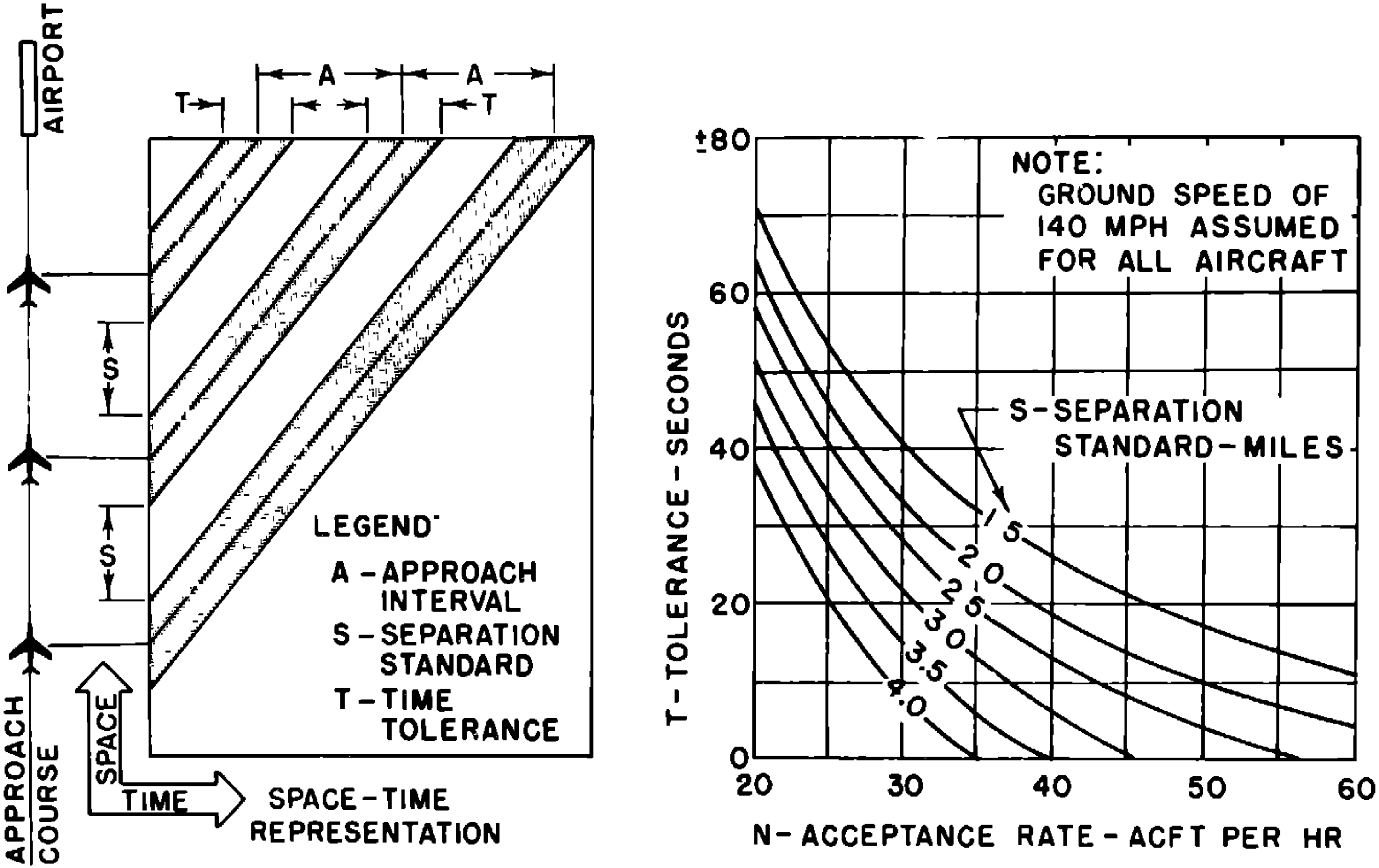


FIG 26 - RELATIONSHIPS BETWEEN ACCEPTANCES RATES, SEPARATION STANDARDS, AND TIME TOLERANCES REQUIRED FOR APPROACH SYSTEM the turn-on can be eliminated by placing the turn-on points opposite to each other, and far enough away from the approach gate so that aircraft turning into opposite lanes can have altitude separation from each other until they are established on their respective ILS courses

Table I summarizes the effect of various factors on airport acceptance rate as determined from hundreds of hours of dynamic simulation runs, utilizing present separation standards (with the exception of reduced separation between aircraft in parallel lanes of dual-approach systems) Capacity figures are based on the internal restrictions of the airport only, without regard to the restrictive effects of the airway system or of adjacent airports

TABLE I

AIRPORT CAPACITIES

Radar	No of Feeder Fixes	No of Landing Runways	No of Independent Takeoff Runways	Landings Or Takeoffs Per Hour	Total Operations Per Hour
No	1	1	0 - 1	15	30
Yes	1	1	0 - 1	20	40
Yes	2	1	0	23	46
Yes	2	1	1	31	62
Yes	2 - 4	2	0	40	80
Yes	2 - 4	2	1 - 2	46	92

Human Factors

Need For Workload Simplification

The present control system depends on the ability of human controllers to make satisfactory decisions regarding the disposition of individual aircraft in the traffic situation These decisions are made on the basis of flight information supplied by other humans Control instructions based on these decisions must be formulated and transmitted to human pilots, who must comprehend and apply these instructions in the subsequent control of the individual aircraft

Because of the critical importance of the human element in air traffic control, much work in the dynamic-simulation program has been devoted to a study of the controller's job One point brought out in this study is that certain mental and physical limitations exist, an individual controller can be expected to see and do only so much during a specified increment of time Where the system requires that this capacity be exceeded, two alternatives are open One is to add additional control personnel The other is to find ways of simplifying the job of the controller to the point where he can control a higher traffic load

The addition of control personnel is a solution which has often been used in the past to meet increased traffic loads However, this procedure has two disadvantages First, the provision of additional control positions represents a large increase in operating costs In addition, each subdivision of the total work load by a greater number of control positions brings with it an increased amount of intercontroller co-ordination At some point, the co-ordination work load becomes so complex that it becomes a barrier to any further increase in the capacity of the system

For these reasons, the simplification of controller workload has been one of the most important objectives of ATC research This problem has been approached from its three main aspects, the functions of data acquisition, decision making, and communications

Data Acquisition

The essence of this problem is the presentation of flight data Thus it embraces all aspects of display design, a subject which has been given constant attention during the entire simulation program

The controller is involved in an almost continuous sequence of decisions regarding the disposition of the individual aircraft in the traffic situation The function of the ATC display is to present to the controller, in an orderly, comprehensive form, the data needed for making these decisions The display also serves as a feed-back loop to keep the controller informed of the results of his decisions and control actions Radar

ATC systems require a display which incorporates the following elements of flight data for each aircraft

1) Identity
2) Flight plan (type, speed, route, destination)
3) ATC clearance status (assigned altitude, clearance limit)
4) Actual altitude
5) Actual plan position (with some indication of heading)

In present systems, 5) is shown as a target on a pictorial display Usually the other elements are shown symbolically One of the primary problems in the operation of any pictorial display is to secure, when needed, the positive association of all five elements for each aircraft There are two general methods of keeping the elements associated.

1) Displaying the symbolic elements directly on the pictorial display and moving them as necessary to coincide with the plan position of the aircraft target

2) Posting the symbolic elements on an adjacent tabular display and tying certain key items to the associated target on the pictorial display

Although it would be desirable, theoretically, to be able to secure all the control data for one aircraft by looking at one place on the display, tests using the first method show that such displays tend to become very congested and disorderly, in appearance, in high-density traffic operations This is due to the sheer volume of symbolic data necessary for control If all of it is posted on the pictorial display on a scale large enough to be read by the controller, it soon grows to occupy a relatively large portion of the display surface

The congestion of this data is abetted by an inherent limitation of all pictorial displays - the fact that the display surface can present only a two-dimensional representation of a traffic situation that is actually taking place in three dimensions This often causes the targets of aircraft at different altitudes to be superimposed on each other on the display In such cases, the symbolic elements cannot remain associated with their respective targets without overlapping or masking each other Thus, the use of a supplementary tabular display for the symbolic data becomes necessary in high-density traffic operations

The magnitude of these basic problems can be appreciated from a look at Figure 27, which shows how the forecasted New York traffic density for 1975 might appear on a radar plan-position indicator

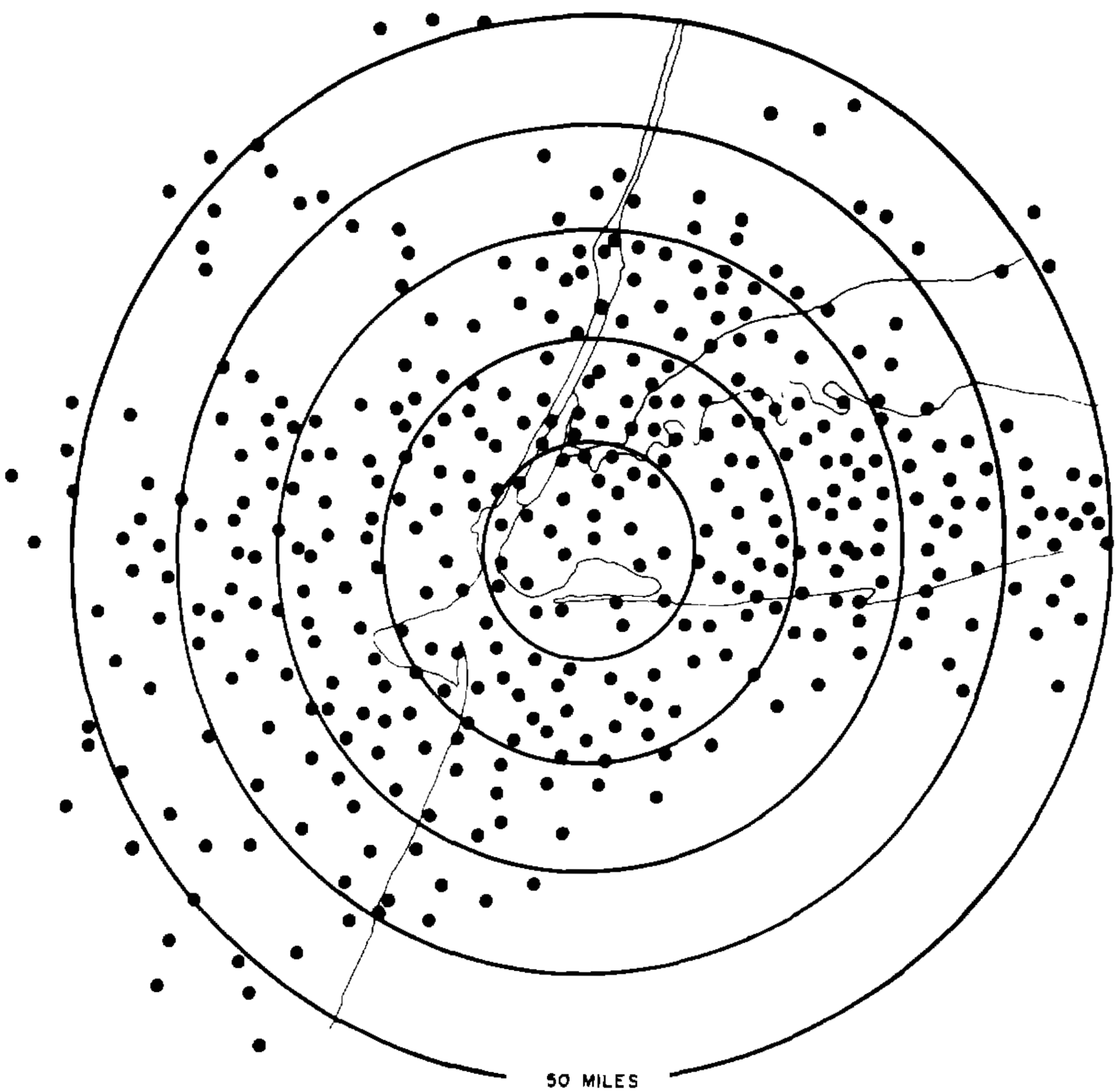


FIG 27 - SIMULATED PPI PLOT OF PEAK 1975 TRAFFIC IN NEW YORK (FROM CURTIS COMMITTEE REPORT TO THE PRESIDENT)

In one sense, this display gives the controller for much information, in that one man could not possibly be expected to keep track of more than a relatively few aircraft, in a relatively thin stratum of altitudes However, the radar display presents all the targets at all altitudes, in a moving mass of confusion.

In the other sense, this display does not give the controller enough information, in that there is nothing intrinsic in the radar presentation to tie any particular target to its associated data elements of identity, flight plan, clearance, and altitude Without this hookup, the presentation is practically worthless for control purposes

Four basic principles can be applied to simplify workload in situations where a man is confronted with too much information

1 Eliminate non-pertinent information

2 Condense or summarize information

3 Place it in categories so that it may be called up when needed, but not otherwise

4 Divide responsibility so that one man does not need all the information

Thus the ability to sectorize the airspace and filter the display so that the controller sees only those targets which are pertinent to his control situation is an important design objective for future ATC systems

Much simulation work has been accomplished in the exploration of this problem, particularly in connection with the use of secondary radar, which should provide this capability[11] As a result, it has been determined that the ultimate need is for a filtered display with a very rapid and flexible cross-reference between aircraft identification, altitude, and position, and a positive hookup between the target position and the four other associated data elements

---

[11] Tirey K Vickers, "Coding Requirements for the ATC Radar Beacon System," IRE Transactions on Aeronautical and Navigational Electronics, Volume ANE-4, Number 3, Spetember, 1957

Over the years of the simulation program, much work was accomplished on displays for the interim period One of the first was PANOP (Panoranic Presentation) a pictorial display for procedural (non-radar) control This was a large XY display using a horizontal table-top as a plotting surface Pertinent flight data for each aircraft was printed on a small boat-shaped marker, known as a "shrimp boat" The marker was positioned manually on the map surface to coincide with the approximate position of the aircraft in the system, as determined from position reports received from the pilots

The main advantage of this system was its saving in paperwork, since all pertinent information about the flight was carried on a single target marker, instead of being tabulated on a large number of flight progress strips Although this display worked very well at low traffic densities, it was not well suited to high-density operations due to the clutter problem and to the difficulty of checking the required data from so many points on the map surface, for the preplanning operation which is so necessary for procedural control

In an army airlift project[23] the "shrimp boat" marker was adapted for an XZ (route versus altitude) display which functioned very well in the highly regimented operation for which it was designed The airlift system had a very small number of routes These were represented schematically by tracks on the inclined display surface which is shown in Figure 28 The representation was repeated for each useable altitude level Flight information was carried on "shrimp boat" markers, which were manually positioned on the appropriate track segments, to show schematically a profile of the entire airway traffic situation This type of display may have future application in future interurban helicopter ATC operations

The "shrimp boat" concept was also applied to projected radar displays as shown in Figure 29 However, the characteristic difficulty of projected radar displays was the lighting problem The display was of no value unless the symbolic target data could be read Getting enough light in the room to read the data usually tended to obliterate the radar picture

---

23 Tirey K Vickers "Simulation Tests of a Tactical Airlift System," Technical Development Report No 279, October, 1955

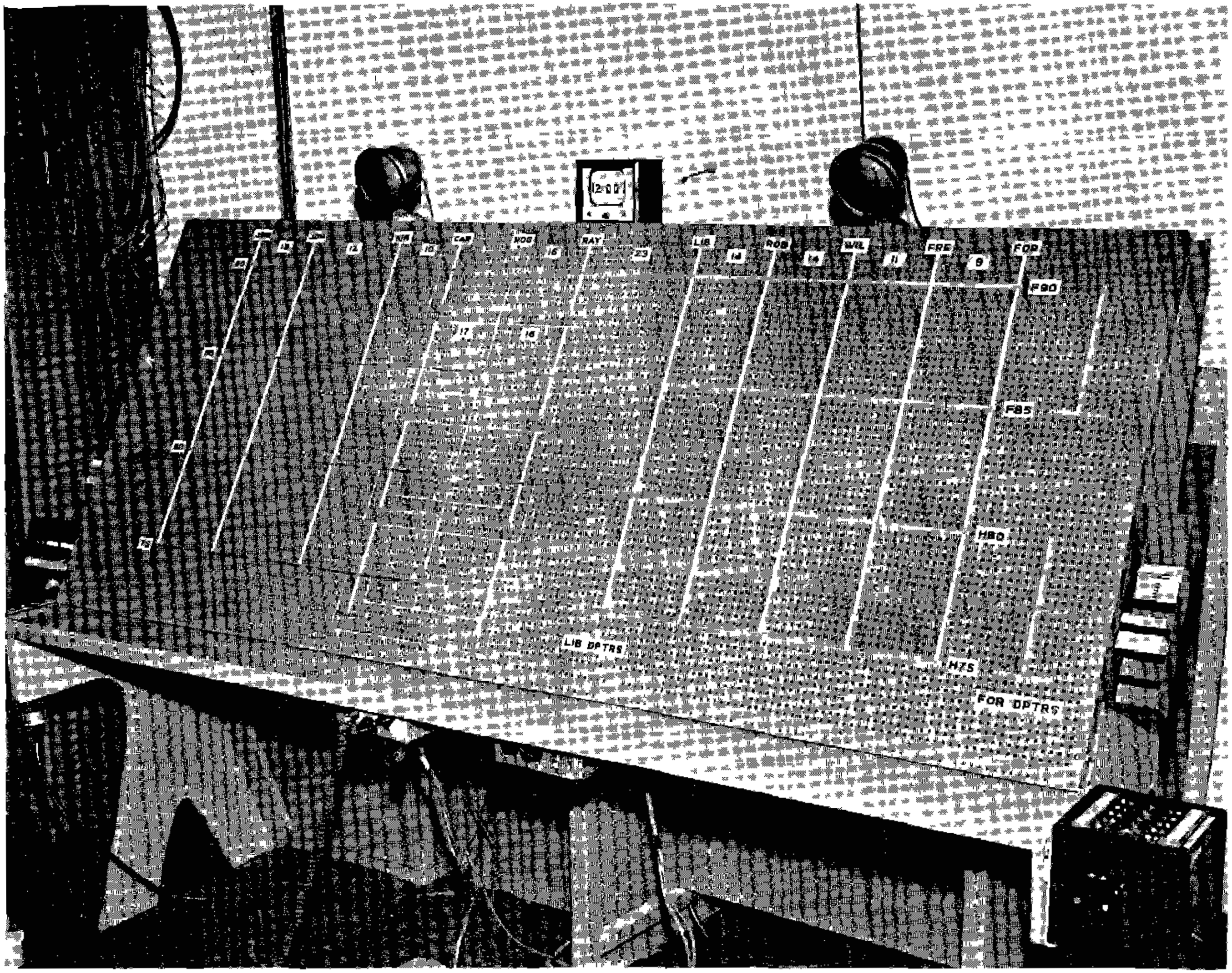


FIG 28 - TRACK LAYOUT OF SCHEMATIC DISPLAY

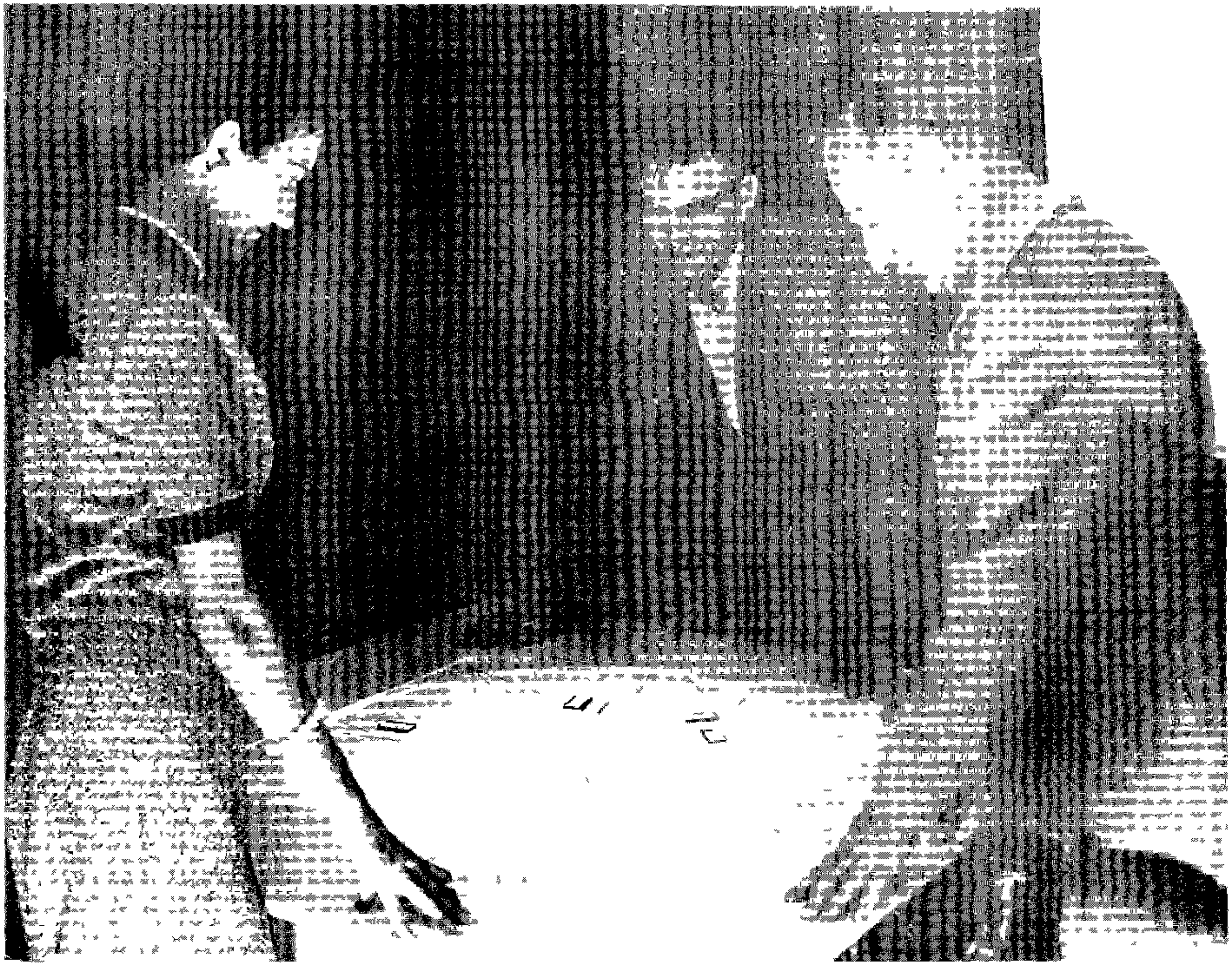


FIG 29 - PROJECTED RADAR DISPLAY USING "SHRIMP BOAT" MARKERS

By passing the lighting problems which had plagued ATC radar operations for years, French radar-to-television scan conversion techniques were used to develop the Spanrad (Superimposed Panoramic Radar) display Spanrad is a manual-tracking device which superimposes a television picture of manually-positioned target markers, with their associated radar targets, on a large bright-tube display

For ATC use, this device was integrated with standard communications equipment and flight progress boards, as shown in Fig 16, with each sector manned by two controllers One handled the interphone communications and data posting functions The other handled the air/ground communications and control decision functions He also maintained target identities by re-positioning the target markers to coincide with their associated radar targets The target markers carried only aircraft identification, altitude and destination data All supplementary data was tabulated on the flight progress boards This procedure functioned very well in a large number of simulation tests

Two types of electro-mechanical data transfer equipments were tested during the simulation program The first, which was quite elementary, was installed to determine the basic requirements for such equipment The second type was a more elaborate model which handled the display and transfer of symbolic data from the ARTC Center to two approach control sectors, thence to a final appraoch (PAR) controller, thence, to a ground-control position which normally would be located in a control tower cab Provision was also made to handle missed approaches Part of the equipment is shown in Fig 15 Although this system functioned very well in the installation for which it was designed, it was relatively inflexible for adaptation to other system layouts[24]

Decision Making

The decision-making function is the most important job of the entire control operation Observations made during high-density simulation tests indicate that controller judgement is a residual element after the mental energy utilized in thinking about other things has been deducted For example, if the attention of an approach controller is concerned with

---

[24] "Operational Evaluation of the Union Switch and Signal Limited Data Display and Transfer System", Technical Development Report No 373, October, 1958

establishing and maintaining identification of a large number of targets, he will have less time for making critical decisions regarding aircraft spacing, with the result that his spacing will become less accurate [20]

Six general principles have been developed, during the simulation program, for reducing the workload of making control decisions

1 Design the route layout and control procedures to reduce the number of decisions required Usually, this is accomplished by reducing the number of possibilities for convergence, as previously detailed

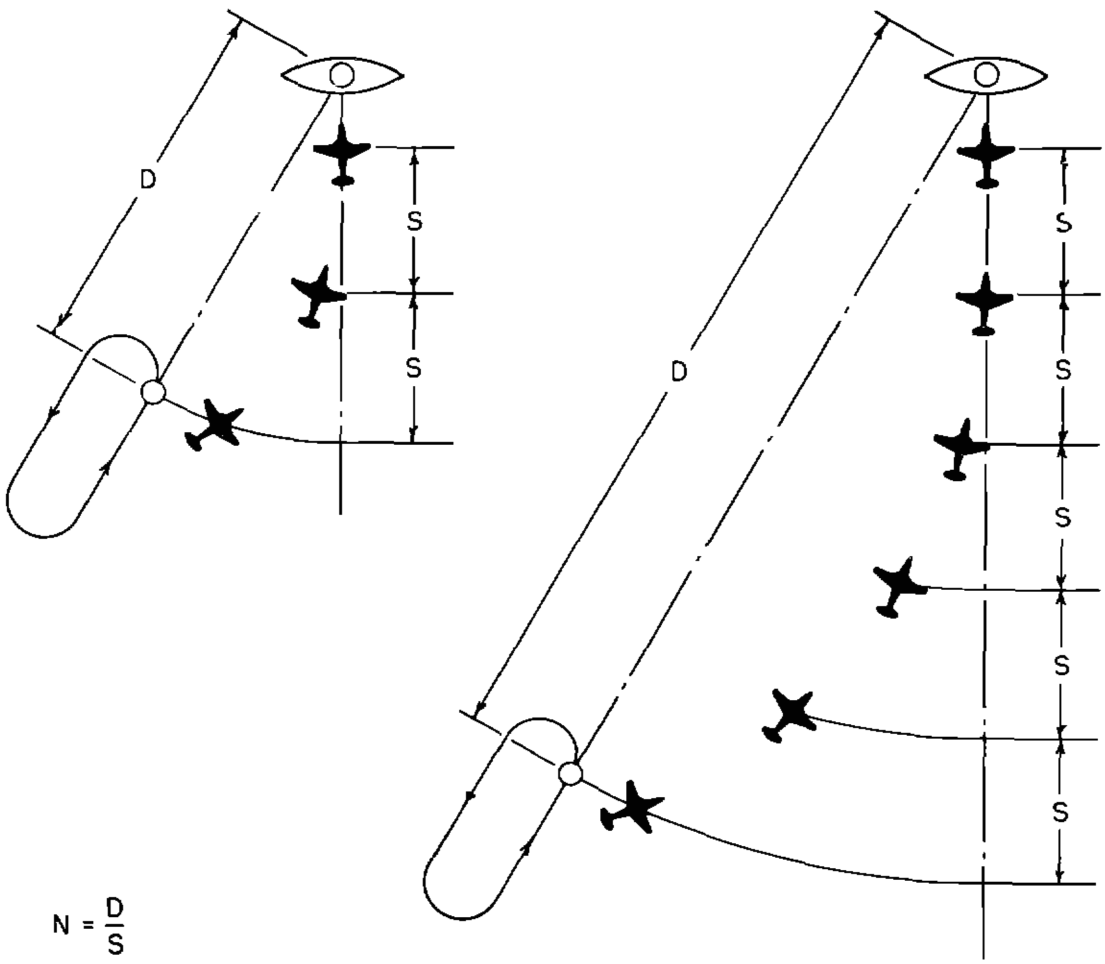
2 Reduce the number of variables which must be considered in making a decision This simplification not only reduces the time required for the decision, but also tends to increase safety by decreasing the possibility of overlooking an important factor Metering the traffic flow to the final approach path is an important means of reducing the number of simultaneous variables and thus keeping the control operation within manageable limits

   Avoiding the use of excessively long approach paths is another method of simplifying the control workload, as shown in Figure 30 In this example, the use of a long approach path requires the simultaneous control of a large number of aircraft in order to keep the approach path full This increases the communications workload and the radar identification problem, further dividing the controller's attention

   Worst of all, it sets the stage for a possible chain reaction If one of the aircraft slows down unexpectedly, the controller must be prepared to take immediate action to correct the spacing of all the aircraft behind it With a short approach path, the possibility of such an incident is lower, and the workload involved in correcting the situation is much less To protect himself against these effects, the controller will tend to utilize additional separation between aircraft on a long common path This in turn decreases the acceptance rate in accordance with the N = V/S formula

---

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



$$N = \frac{D}{S}$$

N = NUMBER OF AIRCRAFT REQUIRED TO BE ENROUTE SIMULTANEOUSLY BETWEEN HOLDING FIXES AND APPROACH GATE
D = DISTANCE BETWEEN HOLDING FIXES AND APPROACH GATE
S = DESIRED SPACING BETWEEN AIRCRAFT

FIG. 30 - EFFECT OF DISTANCE BETWEEN APPROACH GATE AND HOLDING FIXES

These effects are graphed in Figure 31, which shows the results of a series of simulation tests in which a steady supply of jet aircraft was fed into an airport from holding altitudes of 20,000, 10,000, and 4,000 feet [4] Here the communications decreased and the acceptance rate increased, as the length of

[4] Paul T Astholz and Tiery K Vickers, "A Preliminary Report on the Simulation of Proposed ATC Procedures for Civil Jet Aircraft" CAA Technical Development Report No 352, December, 1958

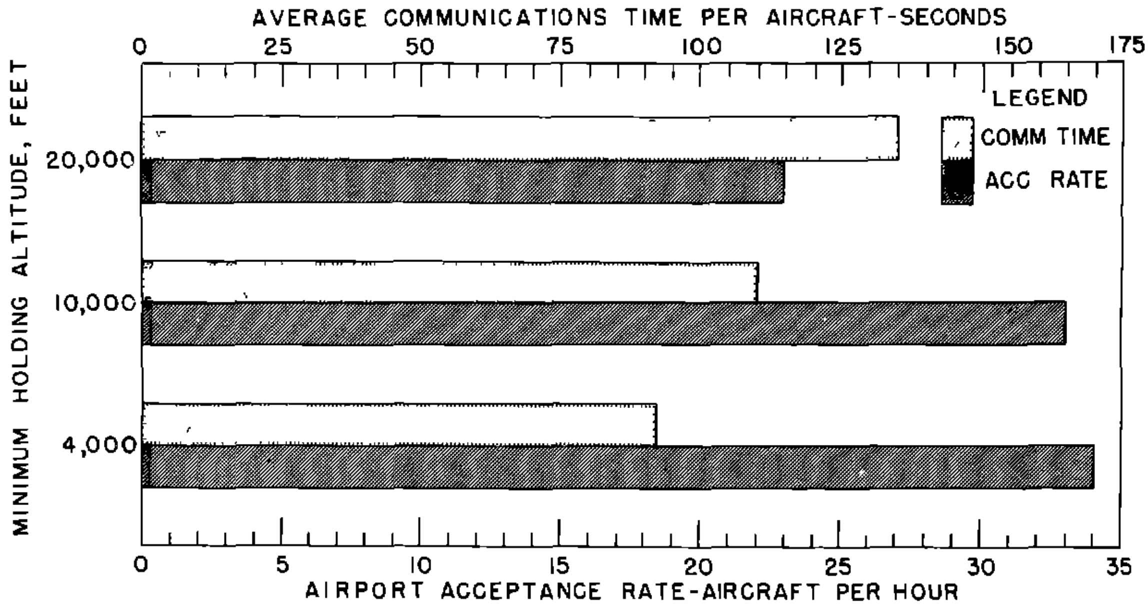


FIG 31 - EFFECT OF JET HOLDING ALTITUDE ON COMMUNICATIONS AND ACCEPTANCE RATE

the approach path decreased from about 45 miles (with the 20,000 foot pattern) to about 15 miles (with the 4,000 foot pattern)

3 Increase the controller's perception of relevent data Here, the design of filtered displays, in accordance with the principles previously described, is an important factor Getting the radar controllers out of the dark room, through the use of bright-tube displays, is a further step in this direction Selectivity of perception, in discrimmating quickly between relevant and irrelevant bits of information, is the mark of an experienced controller The quality can be improved by proper training

4 Relieve the controller of extraneous duties, to provide more time for decision making

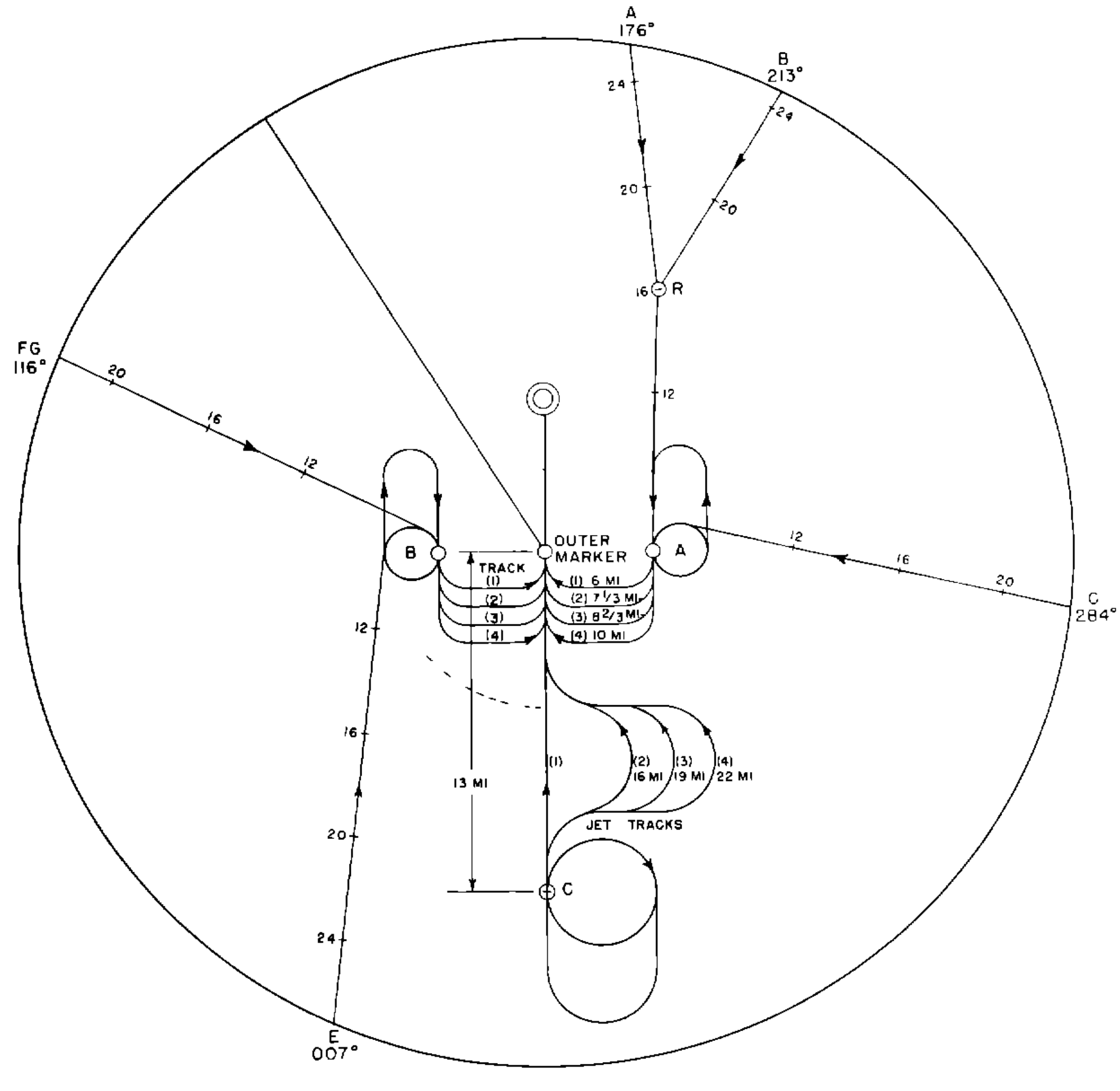
5 Provide feedback so the controller can observe immediately the effects of his decision From the standpoint of controller work load, it is very desirable that the radar display be able to maintain continuity in the display of each target track Comparative simulation tests made with and without radar trails showed that the presence of trails is a distinct advantage to the controller as an aid in the identification of specific targets when these targets have been assigned different headings Trails give a very good indication of speed, wind drift, and relative motion In addition, they maintain continuity in the traffic picture, under conditions where targets cannot be observed continuously, and provide the controller with an early indication as to whether or not certain instructions are being followed by the pilot

Simulation tests showed the superiority of large-scale displays over small-scale displays, in the approach spacing operation With the large-scale display, small changes in aircraft headings or separations could be detected sooner, thus resulting in more precise spacing and higher acceptance rates

6 Provide the controller with aids to judgment In radar approach operations, the proper spacing of aircraft on the final approach path is a decisively important function For safety, the spacing must be enough to maintain adequate separation all the way down to the runway, taking into account the expected approach speeds of the successive aircraft and the possible deviations from these speeds that could concernably occur However, too much spacing will reduce the acceptance rate of the approach system

Using a series of pre-computed paths, an electronic computer was developed to handle the metering and spacing operation Details of this system, known as EMTAC (Electronic Multi Track Approach Computer) are shown in Figs 32, and 33 The system functioned very well in simulation tests

However, during the time the computer was being built, an improved manual spacing procedure was developed, utilizing the spacing table shown in Fig 34, and a series of concentric reference lines marked on the radar scope, as shown in Fig 35



NOTE
THE NUMBERS ON ENTRY ROUTES AND TRACKS ARE APPROXIMATE FLYING MILES TO THE OUTER MARKER
THE NUMBERS IN PARENTHESIS ARE TRACK NUMBERS ASSOCIATED WITH THE INNER FIXES, A, B, AND C

FIG. 32 - TRACK LAYOUT FOR EMTAC SYSTEM

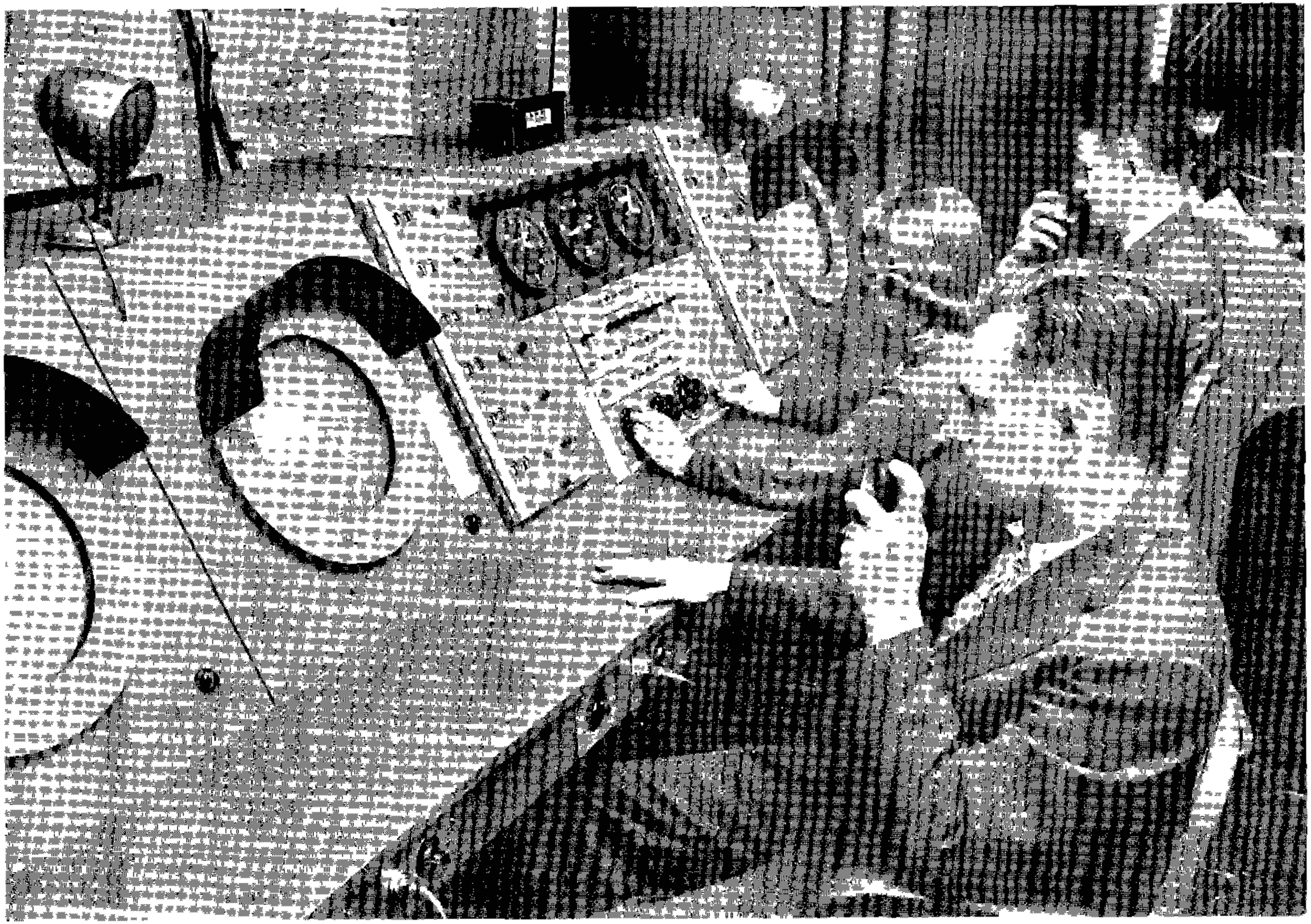
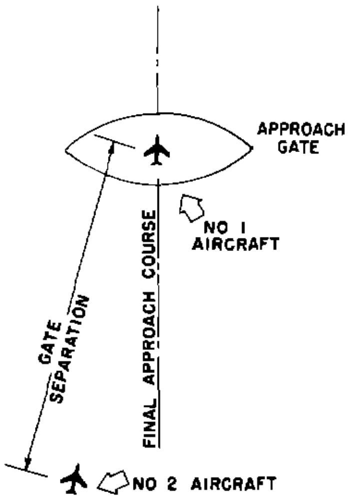


FIG 33 - CONTROL PANEL FOR EMTAC SYSTEM



OPTIMUM AIRCRAFT SPACING

DISTANCE, APPROACH GATE TO TOUCHDOWN, 5 MILES

AIRCRAFT SEQUENCE		GATE SEPARATION (MILES)
NO I	NO 2	
S	M	51
S	F	55
S	J	66
M	S	31
M	F	45
M	J	58
F	S	30
F	M	35
F	J	52
J	SMF	30
SAME TYPE		40

AIRCRAFT CATEGORY		APPROX APPROACH SPEED	
		MPH	KT
S	SLOW	120	104
M	MEDIUM	140	122
F	FAST	150	130
J	JET	180	156

FIG 34 - APPROACH SPACING TABLE

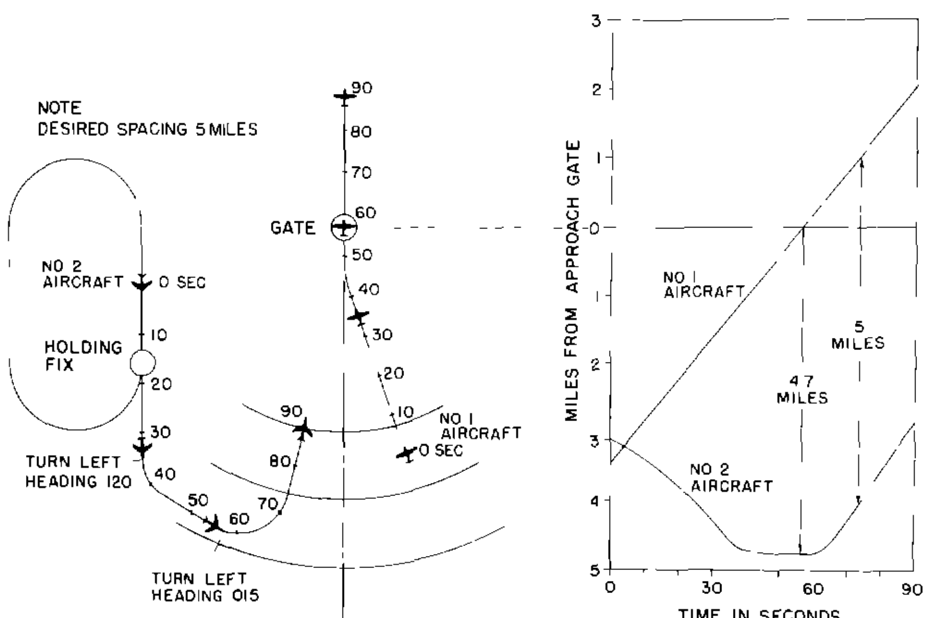


FIG 35 - EXAMPLE OF APPROACH SPACING PROCEDURE, USING CONCENTRIC REFERENCE LINES MARKED ON SCOPE.

It was found that controllers using these simple aids could attain a slightly higher precision in spacing approaches, and thus a slightly higher acceptance rate, than the electronic computer[3, 25]

In the operation of complex terminal areas, the demarcation of definite boundary lines and buffer zones between adjacent radar vector areas has been found very helpful in allowing controllers to make better use of available airspace in their radar vectoring operations

Communications

As previously indicated, the time spent in communications reduces the time available for decision making It can also limit the number of aircraft which a controller can handle simultaneously, and can form a limiting factor to system capacity, particularly in activities such as the laddering-down function shown in Figure 2, where the start of one operation must wait for the completion of the proceeding operation Therefore the reduction of communications workload per aircraft is an important objective of ATC systems design

Since communications is so essential in the data acquisition, decision making, and command (clearnace) functions, any simplification which can be made in these other fields tends to reduce the amount of communications workload For example, the elimination of convergence points and restrictions to secure a long uninterrupted climb area on a busy departure route will tend to reduce the amount of communications required for departing aircraft, by reducing the opportunities for such aircraft to affect any other aircraft in the area.

Similarly, the design of better displays tends to reduce the amount of coordination required by the controller in assembling the various bits of information he needs for the decision making function

Simulation tests show that the establishment of clean-cut lines of jurisdiction between adjacent sectors greatly reduces the amount of co-ordination required

---

[3] S M Berkowitz and Ruth R Doering, "Analytical and Simulation Studies of Several Radar Vectoring Procedures in the Washington, D C Terminal Area", CAA Technical Development Report No 222, April, 1954

[25] Samuel M Berkowitz and Edward L Fritz "Analytical and Simulation Studies of Terminal-Area Air Traffic Control" Technical Development Report No 251, May, 1955

In the operation of high-capacity twin-stack approach system, feeding into a common approach path, coordination can be reduced under saturated traffic conditions, when controllers feed two aircraft from one stack, followed by two aircraft from the other This reduces the amount of coordination by 50 per cent, and also sets up a very convenient work cycle, less fatiguing to operate over long periods than a first-come, first-served system

Where a large number of interdependent decisions by two controllers must be made, it has been found desirable to place these controllers adjacent to each other, to speed the transfer of pertinent data and come to faster agreement This principle has been used with considerable success in simulation tests of common IFR rooms

CONCLUSION

It is concluded that

1. ATC simulation has grown from a mere idea into a highly specialized and useful field during the eight years covered by the report. Approximately 50 Technical Development Reports have been prepared on the various tasks handled by simulation studies, and the conclusions and recommendations in these reports can be considered as part of this report

2 The expansion of the ATC simulation program, using graphic, dynamic, and fast-time techniques, should be a major effort in the establishment of new facilities in the FAA's Bureau of Research and Development

3 This report, and the listed references and reports, can be used to acquaint the new organization with the work completed on previous programs and help ease the transition of these programs from the Technical Development Center to the new facilites of the Bureau of Research and Development

ADDITIONAL TDC SIMULATION REPORTS

NO	TITLE	DATE
147	Evaluation of Proposed Air Traffic Control Procedures in the Washington Terminal Area by Simulation Technics	July 1951
187	Preliminary Study of Traffic Control Systems for the Proposed Washington Supplemental Airport Using Simulation Techniques	November 1952
191	Development of a Dynamic Air Traffic Control Simulator	October 1953
235	Development of Traffic Control Procedures for Tactical Airlift Operations	April 1954
237	Dynamic-Simulation Tests of Several Proposed Dual-Airport Traffic Control Systems for Washington Terminal Area	May 1954
239	Dynamic-Simulation Tests of Several Traffic Control Systems for the Fort Worth-Dallas Terminal Area	August 1954
245	Evaluation by Simulation Techniques of a Proposed Traffic Control Procedure for the New York Metropolitan Area	August 1954
270	Dynamic Simulation Tests of Several Traffic Control Systems for the Chicago Metropolitan Area	April 1955
289	Development of a Portable Radar Simulator	September 1956
297	Summary of Joint FIL-TDC Simulation Activities in Air Traffic Control	March 1957
315	Simulation Tests of IFR Operations at the Proposed Davidsonville Naval Air Station	June 1957

316	Dynamic Simulation Tests of Baltimore Friendship Airport at Increased Traffic Densities	July 1957
318	Simulation Tests of the Northrop Sky Screen as an Air Traffic Control Display	July 1957
332	Air Traffic Simulation Tests of Three Proposed Sites for the Washington Supplemental Airport	November 1957
341	Simulation Tests of the Factors Affecting IFR Traffic Capacity at Chicago O'Hare Airport	February 1958
356	Dynamic Tests of Several Traffic Control Systems for the Los Angeles Area	June 1958
372	Simulation Tests of Instrument Flight Rule Operations in the Detroit Metropolitan Area	October 1958
375	Evaluation of a Three-Dimensional Pictorial Air Traffic Control Display	November 1958
385	Dynamic Simulation Tests of Several Traffic Control Systems for the Jacksonville Area	February 1959
386	Simulation Tests of Air Traffic Operations in the Seattle-Tacoma Area	February 1959
398	Dynamic Simulation Tests of Several Air Traffic Control Systems for the Kansas City Area	March 1959
405	Simulation Tests of Proposed ATC Procedures Applicable to Future Operations in Washington Terminal Area	April 1959

401	Simulation Tests of Air Traffic Control Operations in the Tampa Terminal Area	April 1959
411	Simulation Tests of Air Traffic Control Operations in the Denver-Colorado Springs Area	May 1959