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A plan by the Systems Engineering Team of the Office of Aviation Facilities Planning, The White House

MAY, 1957

LETTER OF TRANSMITTAL

May 6, 1957.

Dear Mr. Curtis:

This report presents our plan for meeting aviation facilities needs in the United States for the next two decades.

Respectfully,

Preston R. Bassett,
Chairman,
Systems Engineering Team.

UNITED STATES

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CONTENTS

PREFACE

This report is in two parts. The first part is a condensation of our findings and recommendations. The second part consists of six appendices that treat various aspects of the problem in greater detail.

In the condensed report, the reader will find the information that we believe is essential for a basic understanding of what we propose.

Those who wish to examine in greater detail the thinking behind our plan will find it useful to read the first three appendices, System Engineering, Principles of Air Traffic Control, and System Design Concepts. The reader interested in how we propose to modernize the system will find the next two appendices useful. Appendix D is a catalog of techniques potentially useful in the modernization of our national system of aviation facilities. The techniques that we believe show greatest promise, together with a proposed initial configuration based on these techniques, form the subject of appendix E.

Of all elements in our national system of aviation facilities, airports have been the most neglected. Unless airport development is given the attention it deserves, airport capacity may well become the factor that limits capacity in the whole system. For this reason, we have devoted our final appendix to a detailed analysis of airports.

GLOSSARY

Access Lane—A 3-mile wide, 1,000-feet-thick ribbon of airspace reserved for passage from initial to the final path-stretching zone in multi-airport terminals.

AI Radar—Airborne radars used for interception of enemy aircraft.

Air Situation—The geometric and velocity relationships of aircraft flying in a particular segment of airspace.

Area Navigation—Navigational guidance over an area. A system of area navigation offers guidance over an infinite number of paths between any two points in the area. By contrast, a point-to-point navigation system offers guidance over only a finite selection of paths between a limited number of points in the area.

ATC—Air traffic control.

Aviation Facilities—A combination of equipment, procedures, regulations, airports, and weather service into a working system of air traffic control for the support of military and civil aviation operations in the United States.

CAA—Civil Aeronautics Administration.

Clearance—Permission from an air traffic controller for an aircraft to proceed along a prearranged path.

Close Control—*See* vectoring.

Controlled Separation—A method of avoiding conflicts between aircraft by relying on traffic supervision by a control agency.

Data Processing—Reception, correlation, computation, display, and exchange of information upon which the exercise of traffic control is based.

Dynamic Simulation—Testing of a dynamic system by introduction of data derived from the simulated tracks of predicted aircraft movements.

Fan Out—A procedure used for separating aircraft laterally so that they can be identified by the use of two-dimensional radar.

Field Measurement—Measurement of the actual performance of systems of control under actual operating conditions.

Fix—A geographical reference point defined by an electronic or visual device.

Flow Control—Limitations applied to the flow of traffic to keep elements of the system, such as airports or airways, from becoming overloaded.

General Aviation—That segment of aviation operating for private purposes, either for individual pleasure or transportation of business personnel, crop dusting, etc.

Holding—An orbitting maneuver by aircraft unable to proceed along a particular flight path.

Hyperbolic Navigation Reference—An electronic method of defining a horizontal grid structure in the airspace. The structure is formed by the intersections of two families of hyperbolæ.

IFR—Instrument flight rules—the rules prescribing weather conditions that require flight by reference to instruments.

IFR Weather Conditions—Weather conditions that require flight to be conducted under instrument flight rules. When IFR weather conditions exist, instrument flight rules supersede visual flight rules.

Instrument Weather—*See* IFR weather conditions.

Mechanized Communications—High-speed coded exchange of intelligence.

Monte Carlo Analysis—The analysis of system performance by subjecting random samples of predicted traffic to either real or simulated control facilities.

National Aviation Policy—Broad fundamental objectives representing the national interest in aviation operations.

Operations Analysis—The scientific observation and analysis of the operation of an existing system.

Operations Research—The scientific, quantitative analysis of system requirements and synthesis of proposed systems.

Path Stretching—Modification of an aircraft path so as to change its time of arrival at a particular point.

Pictorial Display—A pictorial representation of the air situation.

Pogo Operations—Simplified air traffic control procedures used by the CAA for low-altitude, short-haul operations. Aircraft are dispatched directly from one tower controller at the airport of origin to the tower controller of the airport of destination.

Real-Time Dynamic Simulation—Testing, by simulation, of segments of an air traffic control system, using real equipment and human operators. This is in contrast to mathematical analysis, which might be done in speeded-up time, approximating the characteristics of human operators.

Safe Lateral Separation—The minimum distance designated for aircraft passing each other at the same altitude.

See-and-Be-Seen Separation—A method of avoiding conflicts between aircraft by relying on their pilots to observe the presence of other aircraft, and to take any avoiding maneuvers needed to prevent collision.

Self-Contained Navigation—Navigation through information obtained by means completely independent of external sources.

Station-Keeping—Maintaining position relative to another aircraft.

STOL—Short takeoff and landing aircraft.

System Development—Development of procedures, equipment, regulations, and other elements of a complex system to meet the functional requirements defined by system research, and the environmental requirements of particular users.

System Engineering—A scientific process that applies method and logic to the design, development, and continuing improvement of a complex system.

System Experimentation—Investigation of complete segments of a traffic control system using actual aircraft.

System Laboratory—An environment in which system concepts are generated, analyzed, and tested.

System Research—The research effort necessary to apply the system engineering process. System research consists of operations research, system experimentation, and exploratory equipment development.

Technical Breakthrough—A major advance in science based on an unpredictable discovery.

Users—The various groups of aviation that use the services of the Nation's aviation facilities. This includes the Army, Navy, Air Force, commercial transport, and general aviation.

Vectoring—Controlling the flight path of an aircraft by the issuance of a relatively rapid sequence of instructions giving the directional changes needed to make good the desired path.

VFR—Visual flight rules—the rules prescribing the weather conditions necessary for flight by visual reference to the ground.

VFR Weather Conditions—Weather conditions prescribed for flight under visual-flight rules.

VOLSCAN—The original VOLSCAN was a three-dimensional radar developed at the Air Force Cambridge Research Center. AN/GSN-3 computing equipment associated with this radar has come to be known as VOLSCAN, even though the specific radar is no longer part of the system. The function of the computer is automatic scheduling of aircraft approaching for landing.

I. INTRODUCTION

For some years the present system of aviation facilities has not been capable of meeting the requirements of its users. This has resulted in delays in instrument weather, the saturation of traffic-controller capabilities, and midair collisions that could have been prevented if the capacity to provide separation for a larger number of aircraft had existed in the system. Meanwhile high-performance aircraft, operating too high or too fast to avert collision by visual means, are entering the airspace and many more are on their way.

This report deals with the modernization of our national system of aviation facilities over the next two decades. It begins with an examination of the traffic expected over this period. Then follows an analysis of the operational desires of the users and a discussion of system-design concepts that allow these desires to be satisfied. The report concludes with a suggested initial configuration of a modern aviation facilities system and a plan of action to insure the continued modernization of this system.

II. THE AIR TRAFFIC, 1957–75

By 1975, the total air traffic will be approximately two times what it is today. The major proportion of aircraft flying in 1975 will be under air traffic control. To serve these users, a tenfold increase in the capacity of the system will be needed.

The major portion of the overall demand for air traffic control will stem from the expected 400-percent increase in general aviation. Airline movements are expected to increase about 50 percent, while military traffic will decrease slightly. By 1975, helicopter and STOL flights, mostly over and around large cities, will represent about 5 percent of the total movements.

Passenger movements will increase more than aircraft movements, because transports flying in 1975 will have greater passenger-carrying capacity than those flying today.

Average aircraft speeds will go up. Some types of military aircraft will fly regularly at supersonic speeds. Most airline aircraft, and some types of general aviation, will fly at near-sonic speeds.

With the increased use of jets, average altitudes used will be higher than those in use today. And, for jet operations, choice of proper cruising altitude and elimination of enroute delays will be even more critical than they are today.

III. NATIONAL AVIATION POLICY

Our national system of aviation facilities includes airports, navigation aids, communications service, and a system for the controlled separation of air traffic. In modernizing this system, three objectives must be met. First, overall safety of the system must be increased. Second, the capacity of the system must be expanded. (A tenfold increase in system capacity will be needed by 1975.) Finally, the system should cause a minimum of interference with users' operations.

As a matter of national policy, we believe that the system must be based on the following concepts:

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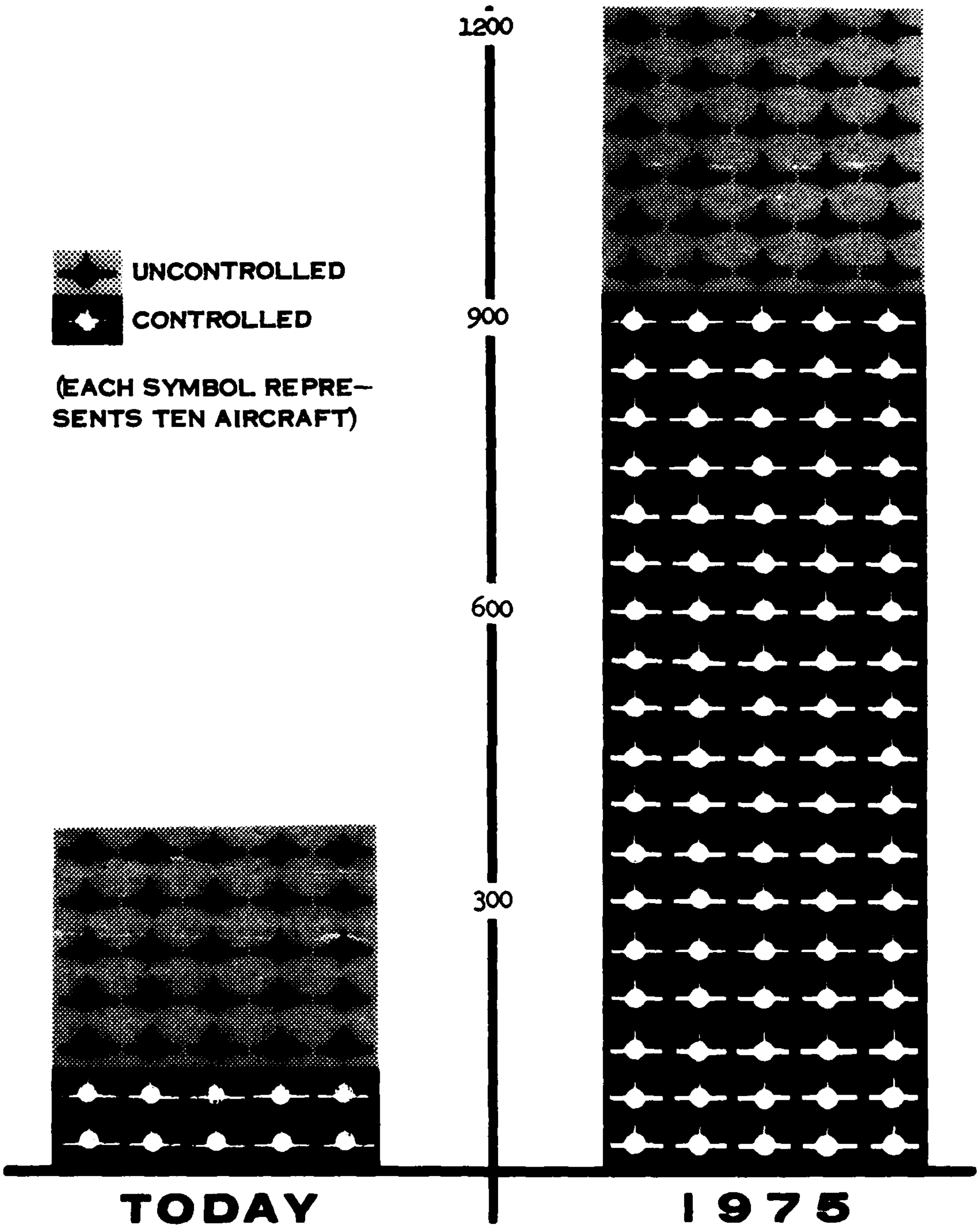


PEAK-HOUR TRAFFIC in the New York area. Total traffic, both controlled and uncontrolled, will increase about three and a half times. Traffic desiring to use the control system (black area) will increase far more rapidly than will the total traffic. This is why our aviation facilities must have a tenfold increase in capacity by 1975.

- Controlled separation of all air traffic—both civil and military—in the United States must be provided by a single, integrated system of personnel, regulations, procedures, and facilities.
- The system must support the air defense of the United States against enemy attack by providing information on friendly aircraft that is inherent in the system, and by serving as the common Army, Navy, and Air Force system of aviation facilities in time of war.
- Conversely, the air defense system should provide the national system of aviation facilities with information which it possesses, which is useful for safe and expeditious flow of air traffic.
- The facilities, procedures, and regulations should be designed to insure a fair priority of service for all users. This priority must give way to military necessity in times of military emergency.
- Improvements to the system must be compatible with current procedures and equipment. Changes in system design should be evolutionary, not revolutionary.
- The system must be flexible. It should be capable of expansion to meet unanticipated demand without major redesign and without interrupting flight operations. Similarly, it should be flexible enough to permit procedural changes to keep pace with changing conditions.
- The cost of the system to the Nation must be reasonable—compared to the overall value of national aviation operations. For the user, the cost must be reasonable in comparison to the cost of the aircraft flown and the quality of the service desired. The system must serve the lightly equipped user effectively and without seriously increasing his operating costs.

IV. PRINCIPLES OF AIR TRAFFIC CONTROL*

We are convinced that aircraft using see-and-be-seen separation cannot share the same airspace with aircraft separated by air traffic control. We realize controlled and uncontrolled aircraft cannot be segregated from one another overnight. But we feel safety demands that immediate steps be taken to carry out such segregation as quickly as possible.

A. DIVISION OF AIRSPACE

This segregation should be carried out by reserving zones of airspace for each type of separation. First, all airspace above a designated altitude should be set aside for controlled separation. Flight in this airspace takes place under conditions that make see-and-be-seen separation unsafe.

Below this upper zone, a further division of airspace should be made. Funnels and cylinders of airspace should be reserved for controlled separation of aircraft traveling from the upper zone to airports on the ground.

*For a more detailed discussion of the philosophy of traffic separation, see app. B.

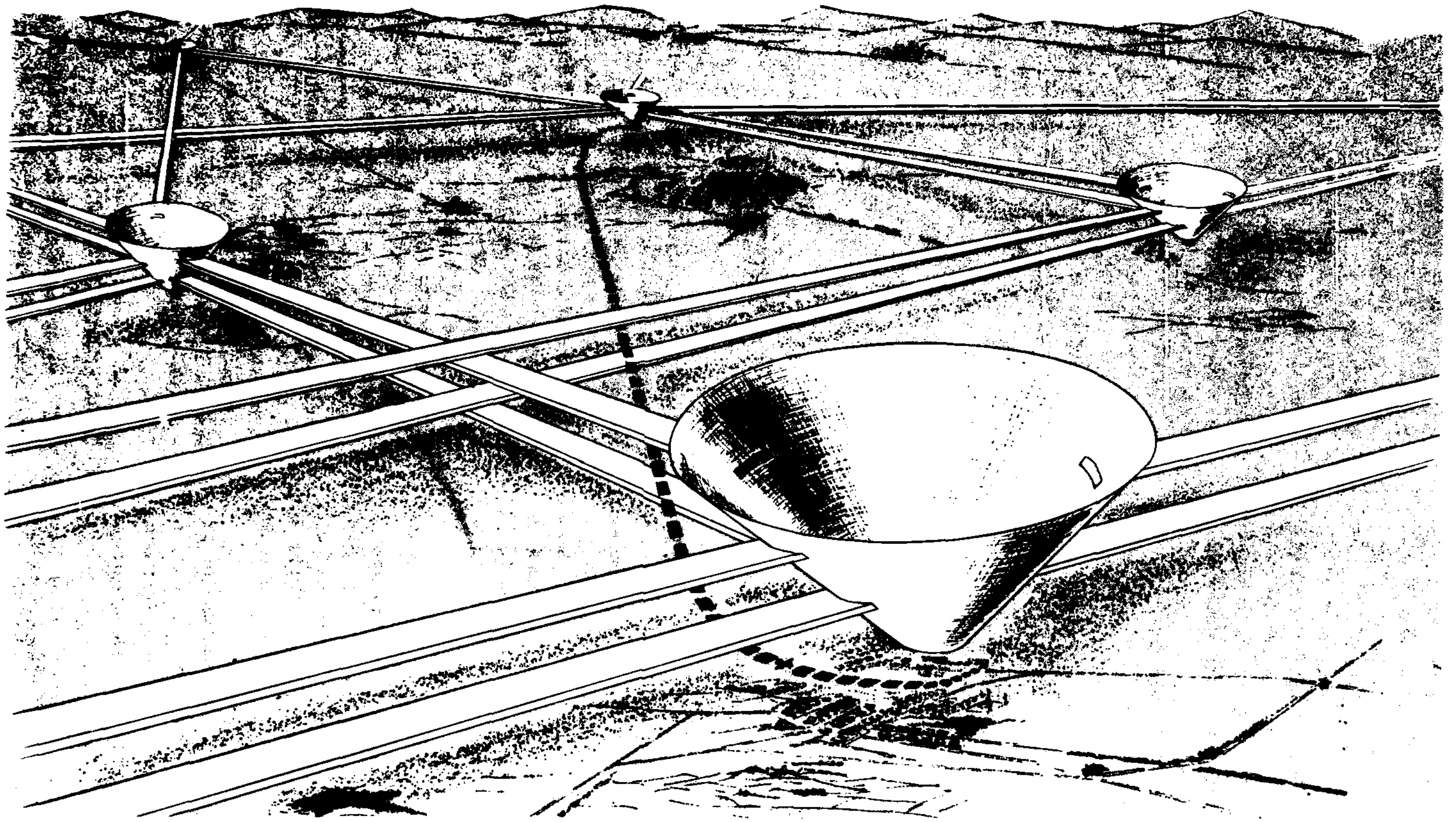
Ribbons of controlled airspace connecting the funnels and cylinders should be set up for controlled *separation of low-flying traffic.*

Airspace outside of the ribbons, funnels, and cylinders should be reserved for aircraft capable of see-and-be-seen flight. In VFR weather conditions, these aircraft are separated by individual see-and-be-seen action. When these aircraft encounter IFR weather, the pilots can apply for, and obtain, controlled separation from ATC. Once the aircraft reenters VFR weather conditions, it will automatically revert to see-and-be-seen separation. It is apparent, therefore, that aircraft operating in this airspace must always meet the minimum criteria for see-and-be-seen flight, even though they may operate intermittently under control.

In controlled airspace, diminishing blocks of airspace will need to be set aside as restricted areas, as controlled separation goes into effect.

B. MINIMUM REQUIREMENTS

For flight in see-and-be-seen airspace, an aircraft must meet accepted minimum cockpit visibility



DIVISION OF AIRSPACE below the upper, all-weather control zone. Cones of controlled airspace funnel traffic between the upper controlled zone and airports on the ground. Slant. airways (not shown) lead from the bottom of these cones down to the airport surface. Ribbons of controlled airspace link the cones with each other. Dashed line shows separate, nonconflicting path of see-and-be-seen aircraft.

requirements. It must be flown at speeds less than the maximum prescribed for see-and-be-seen flight and it must be equipped with a standard sensitive barometric altimeter. In addition, if electronic methods are needed to mark the sides of ribbons, funnels, and cylinders, then see-and-be-seen aircraft will have to carry a device to detect these boundaries of controlled airspace.

To fly in controlled airspace above the designated altitude, pilot and aircraft must meet the following standards:

- The aircraft must be equipped with a standard sensitive barometric altimeter and a two-way radio with the appropriate frequencies.
- Both pilot and plane must be capable of instrument flight and navigation of a designated accuracy.
- The pilot must be able to make required position reports and carry out simple holding and path-stretching maneuvers.

For flight below the designated altitude, a pilot who meets all these requirements, save that of instrument flight capability, may still be cleared by ATC to fly in the controlled ribbons, funnels, and cylinders as long as VFR weather conditions prevail.

C. FLIGHT PATHS

With a proper division of airspace, it should be possible for a plane to travel from one point to another using either controlled or see-and-be-seen separation. To do this requires the setting up of *separate, nonconflicting* paths for see-and-be-seen and controlled air traffic. These paths should begin and end on an airport. Depending on the local situation, separate airports can be provided for see-and-be-seen aircraft, or this type of traffic can have a separate landing area at airports handling both kinds of operation.

Controlled airspace should provide paths arranged to serve the needs of its users in the most efficient and equitable manner. These needs vary with type of aircraft, length of flight, and weather and wind conditions. For short-distance flights between population centers, fixed paths (like today's airways) are desirable. Aircraft would follow very nearly these same paths even if no control were exercised.

Transcontinental flights, on the other hand, should have flexible paths to take advantage of pressure patterns and to avoid adverse weather conditions. These flights commonly take place at high altitudes, where the aircraft operate more efficiently. At these altitudes, they do not conflict with the short-haul traffic in fixed paths.

Direct flights between minor population centers also need to be accommodated. This kind of traffic is a small percentage of the total and tends to be spread out over the whole country. Thus, in any particular area, the density of this type of traffic will be very low. As long as the traffic density is low, safe separation along the arbitrary paths needed for this type of random flight can be provided by the system.

For flights inbound in a terminal area, descending paths that converge on the terminal are required. Also, inbound aircraft must maneuver so that they will be lined up and ready for final approach, at the correct altitude and airspeed. The path an aircraft follows during this maneuvering process must combine descent with horizontal path stretching in such a way that aircraft reaches the approach gate in the proper configuration and at the time it is expected. For outbound flights, ascending paths are needed.

Helicopters, with their low speed and high maneuverability, can use airspace that is not available to many conventional aircraft. This natural separation can be used to advantage in selecting helicopter paths that are compatible with those used by fixed-wing aircraft.

Some present military aircraft must carry out high-performance flight to get adequate range, speed, or economy. Ordinarily, the critical element is flight in the vertical plane, with a need for very rapid climb and descent. A case in point is the problem of interceptors. These aircraft have the difficult job of seeking out enemy aircraft through airspace that may contain friendly aircraft. The present method of roundabout vectoring of interceptors for traffic safety purposes prevents high-performance flight, and is, therefore, inadequate from the standpoint of military security. Steep, nearly vertical fixed paths are needed for this kind of operation.

V. SYSTEM DESIGN CONCEPTS*

We believe that the control of air traffic should be carried out by a central ground authority, separating traffic by constant prearrangement of airspace reservation. Controller and pilot should agree beforehand on a clearance limit and a track, altitude, and time that the flight will make good. Before issuing a clearance, the controller should examine the air situation to see if the flight will be safely separated from all other aircraft. If not, controller and pilot should work out an alternative flight plan. The other method of separating traffic would be to allow aircraft to fly random paths, with ATC intervening occasionally to resolve potential conflicts. We have examined the possibility of using this method, but rejected it as impractical. (For a discussion of prearrangement vs. occasional intervention, as a means of controlling traffic, see app. B.)

A. BLOCKS

For the control of enroute traffic, the airspace should be divided into blocks that are fixed with reference to the ground. Separation can be achieved by making sure that only one aircraft occupies a particular block at any given time. Aircraft can progress from block to block, with the controller clearing them into each block far enough ahead of time to assure uninterrupted flight. These blocks must be large enough to permit an aircraft to hold within the block when so required by unscheduled interruptions in the traffic flow. (For a discussion of block structure, see app. B.)

In terminal areas, there is not enough airspace to use separate blocks for individual aircraft throughout. Where necessary, closer spacing will be used, taking care that safe holding space is available beyond.

B. AIRCRAFT POSITION INFORMATION

Aircraft position information is an essential part of the control system. Routine position reports will be required from aircraft enroute a maximum of once for every block occupied. In the terminal area, more frequent reports are necessary because of higher densities. Similarly, the accuracy required increases for terminal area operations.

We believe air-derived position reports should be supplemented by ground surveillance. For high-density operations, this surveillance must be three-dimensional. (For details of surveillance techniques, see apps. D and E.)

C. NAVIGATION

The navigation element of the system has a triple role. First, it must provide a reference for pilots to find their way to their destination. Second, this reference must be precise and reliable enough to permit safe lateral separation between aircraft on nonconflicting paths at the same altitude. And, third, the navigation element must provide a reference that defines the block structure.

Each of these requirements calls for area navigational coverage from the ground up to the highest altitude used. As with the requirement for position information, the accuracy of navigational coverage needed is greater in the terminal area than enroute.

It should be a design goal to provide a single navigation reference usable throughout the system. This would permit the use of a single, simple receiver for enroute, terminal, and surface navigation.

D. COMMUNICATIONS

Rapid communication is essential to the effectiveness of any system where control is exercised remotely. For this reason, communications between controllers and between controllers and pilots should be mechanized. Voice communications should be kept for emergency use and for those aircraft not equipped with mechanized communications. Improved techniques of voice communication are needed to make this service more effective than it is today. (See apps. D and E for specific suggestions to make voice communications more effective.)

*For a more detailed discussion of system design, see app. C.

E. EQUIPMENT STANDARDIZATION

Both the navigation and the communications functions require airborne equipment as a part of the system. Proposed common systems of air traffic control have often been based on standardization of equipment for all users of the system. We believe this is unnecessary. The common requirement for system use should be a level of performance adequate to insure efficient use of the system. As long as the equipment used meets the specified level of performance, a user should be free to carry the equipment of his choice.

F. DATA PROCESSING

Control should be decentralized, with each controller having a display of the airspace under his jurisdiction, tailored to fit the geometry of his airspace. Data should be concentrated and organized to suit the needs of each controller. The human controller can—and should—retain his vital role as the decision-making element of the system. But the processing, storage, communication, and display of data used to make the decisions should be mechanized. Additionally, automatic computing devices should be used to carry out calculations to facilitate scheduling, and flow control decisions.

G. AIRPORTS

Airports are an integral part of the system of aviation facilities. However, unlike other elements of the system, airports are designed, built, financed, and operated by local authorities. This imposes the necessity for coordinated national and local effort to insure that airports do not become the neglected element of the overall system. We believe the Federal Government should exercise the leadership necessary to assure that this coordination takes place by providing airport authorities with—

- Forecasts of expected traffic demands for airport use.
- Criteria for determining the location of new airports.
- Criteria for the design and layout of facilities at both existing and proposed airports.

(A more detailed analysis of the role of the airport as an essential element of the aviation facilities system will be found in app. F.)

H. AIR DEFENSE AND AIR TRAFFIC CONTROL

We have examined the possibility of integrating the SAGE and air traffic control systems. Obviously, some integration will be mutually beneficial. However, we have been unable to determine the exact degree of integration that is desirable or possible.

While SAGE is highly mechanized, the present air traffic control system depends heavily on human data processing. More complete mutual assistance between the two will be possible when the air traffic control system reaches a comparable degree of sophistication.

Rather than design an ATC system based on full sharing of facilities with the air defense system, it seems more reasonable to modernize the air traffic control system, keeping in mind the advantages of exchange and correlation of air situation data with the air defense system.

In terminal areas, the air traffic control system needs precise three-dimensional data at rates not within the capability of SAGE as it is presently programed. We believe that the usefulness of SAGE radar information is limited to enroute areas—particularly areas of low traffic density, such as transcontinental high altitude operations. We believe, further, that the radar requirements of air traffic control and air defense over the next two decades warrant the development of a radar meeting the requirements of both systems.

The areas where integration of the two systems appears practical are—

- Transmission of air defense radar data to air traffic control centers.
- Joint use of the communications system.
- High data rate transmission of the friendly air situation from air traffic control centers to air defense sectors.
- A more sophisticated correlation of air situation information that is available within the ATC complex with that available in the air defense system.

These areas should be investigated by a comprehensive program of experimentation designed to determine the extent to which integration can, and should, take place. The ANDB has already started a joint civil-military experimental program in Boston, to develop data on which to base such integration. This project should be accelerated.

VI. TECHNIQUES

The techniques used to satisfy the operational and design concepts fall into two classes—those capable of early implementation and those requiring research and development. Short-term improvements that can be made within the next year or two involve procedures rather than new equipment. Known operational techniques which have been used successfully in a limited number of cases should be applied more generally. Wherever possible, the techniques so used should be compatible with, and capable of evolving into, the long-term modernization program. We are convinced, therefore, that both the immediate short-term improvements and the continuing modernization effort should be coordinated by the same agency.

Our survey of the existing state of the art has disclosed a number of developments that have potential applications for air traffic control. (See app. D.) We believe this existing technology can furnish the basis for most of the improvements needed for modernization of the system over the next two decades. However, a comprehensive experimentation program is needed to select the proper techniques, modify them for use in the system, and develop methods for so using them.

VII. SYSTEM DESCRIPTION

Out of the wealth of existing technology, we believe it is possible to build a system of aviation facilities that will fulfill the system design concepts we have set down. In appendix C, we have outlined in detail how such a system should be set up, and what techniques should be used to make the system work. A great deal of experimental work remains to be done before it will be possible to spell out in detail just what the system will finally look like, and how it will operate. However, we visualize the system working generally in the manner described below.

Consider first the case of a flight on high-density fixed airways, say from Washington to New York. Before departure, the flight plan will be fed into the system automatically. Machines for this purpose will be located in airline dispatch offices, and at other key spots on the airport. The flight plan will be stored in the system, available to any of the responsible control units on demand. Pertinent parts of the flight plan will be displayed before the controller responsible for issuing the first clearance. And, the entire flight plan will be confirmed, in principle, to the pilot.

When the pilot is ready to leave the ramp, he will push a button on his instrument panel to request taxi clearance. This clearance will be given to him by visual display on the instrument panel. The controller will monitor his progress with ASDE radar. As he taxis out to the end of the runway, he will follow the proper taxiway by using the guidance signals, supplemented by electronic taxiway centerline guidance.

When the pilot comes to the end of the runway, he will see a billboard-type display giving him his takeoff clearance and other pertinent information. For example, the billboard might show him any last-minute changes in flight plan, or altimeter setting.

Climbing out, the pilot will take the prescribed inclined airway for his direction of flight. For each direction, there will be a single, fixed slant airway. For navigation up this slant path, he will use a precision slant-beam navigation aid—possibly like a steeply slanting ILS. When the pilot reaches his cruising altitude, he will push the "REPORT" button on his instrument panel. This will feed his position and altitude into both the controller's display and the control system's memory.

The New York-Washington airway system will consist of 6 airways, each with 8 altitude-spaced, one-way lanes. Each one-way lane airway will have 2 blocks. In the middle of each block will be a compulsory reporting point. As the pilot passes over this point he will push his "REPORT" button. Back from the controller will come his clearance to the fix in the second block, together with an estimated time that he will be over that fix. (If for some emergency reason, the next block is not clear, the pilot will be told to hold inside the first block.)

The controller responsible for the first block at the altitude this pilot is flying will have been following the plane's progress on his display. Before the pilot reaches the first block's reporting fix, the controller will have automatically queried the controller responsible for the next block to get a clearance for the plane to continue into that second block. This query will be done in such a way that both controllers see and identify the same airplane on their displays.

As the first controller clears the plane to leave the first block, he will automatically transfer control to the controller responsible for the second block. With this transfer of control, the plane and its flight information will automatically appear on the second controller's display. Shortly after the plane reports over the compulsory reporting point in the second block, the pilot will be cleared to descend to the initial altitude.

Once he reaches this initial approach altitude, he will enter the first "buffer" or path-stretching zone. Here, his path will be stretched to the extent needed to position him properly in the approach sequence *behind aircraft arriving from other quadrants.* These aircraft will have separate buffering zones for each quadrant necessary, and a computer will be used to precalculate the final approach sequence and the path stretching needed to position random arrivals in his sequence.

Usually, the different paths used for path stretching will be precomputed and marked with a published designation. So, when the terminal area controller clears the pilot into the initial path-stretching zone, he will merely have to tell him the designation of the path to follow. The pilot will then be able to set this path into his pictorial display. When precomputed paths are not suitable, the controller will exercise close control.

Path stretching in this first buffer zone is, in effect, a coarse sort of positioning of aircraft in their proper approach sequence. From this zone, the aircraft will enter the access lane reserved for approach to the runway it will use at the destination airport. This access lane will be a slant path, and the pilot will navigate on it with an ILS-type beam—just as he did outbound from his departure airport. At the other end of the access lane, the plane will enter the final approach buffer zone over the airport. In this buffer zone, path stretching will be used to make any fine corrections necessary to assure precise positioning of landing aircraft in the sequence already established.

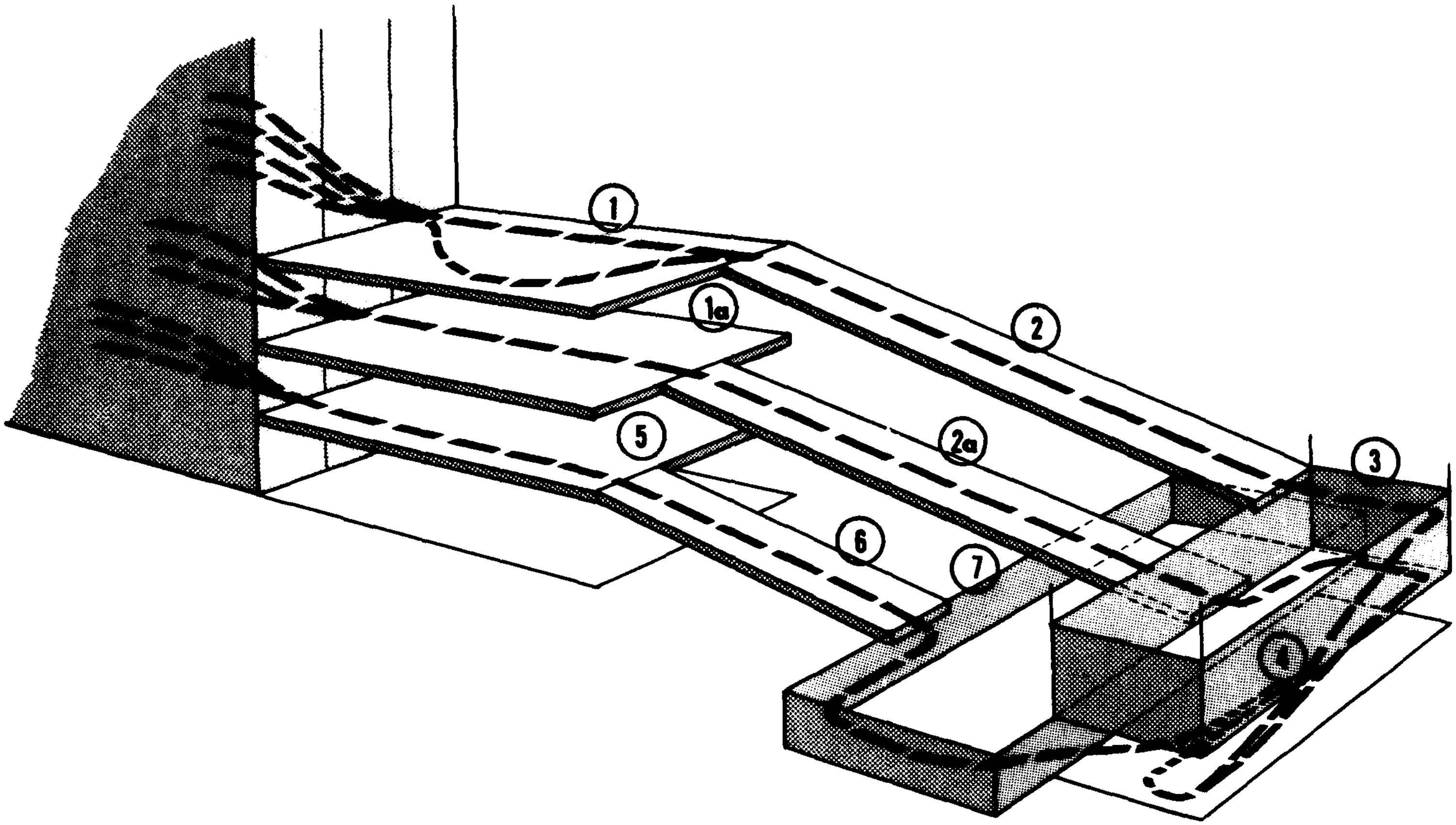
For landing, the pilot will use a precision approach and landing aid and his path will be monitored from the ground with three-dimensional surveillance. He will land on a runway reserved for aircraft with performance and equipment capabilities comparable to his. Shortly after touchdown, he will leave the runway via a high-speed turnoff. The place to turn off and the taxi route to follow to the ramp will be shown on a billboard-type display. For guidance on the turnoff and along the taxi path, he will use the same type of electronic system as he did when taxiing out for departure.

An aircraft can use this system without having all of the pushbutton automatic devices described. For example, a pilot could ask for his clearance by voice radio. Since so many of the paths are fixed and prearranged, his clearance could be returned to him by "canned" voice messages—even in cases where close control was being carried out. The controller would not need to talk to the pilot directly, save in emergency.

Consider next an aircraft making a see-and-be-*seen flight*—also from Washington to New York. This aircraft may operate out of the same airport as did the first one. But it will use a separate runway and separate airspace reserved especially for see-and-be-seen flight. Enough airspace will be set aside for this type of flight to permit the pilot to make the trip without entering controlled airspace.

In this airspace, the pilot will use his altimeter to stay clear of controlled ribbons. In fact, he can fly at one of the altitudes reserved for see-and-be-seen flight. Visual markings on his map will be used to show him the sides of controlled ribbons, funnels, or cylinders. In addition, ground surveillance of this controlled airspace will be used to monitor and detect any inadvertent flight into controlled airspace by see-and-be-seen aircraft. Since this particular route is a high-density route, surveillance will cover all three dimensions.

On arrival in the New York area, the see-and-be-seen aircraft will follow a path that avoids all of the controlled airspace down to a runway reserved for see-and-be-seen aircraft. If possible, this will be a parallel runway on the same airport used by controlled aircraft. In this case, the see-and-be-seen



AIRWAYS STRUCTURE in a multiple airport terminal complex. High-altitude flights descend from cruise to initial buffer zone (1) thence along initial approach access lane (2) to final buffer zone (3) over airport (4). High-performance aircraft coming into area at lower altitudes use middle buffer zone (1a) and access lane (2a) to final buffer zone (3). Low-performance aircraft use lower buffer zone (5) and access lane (6) to separate final buffer zone (7). Both types of aircraft have their own separate runways.

aircraft will have its own ramp facilities on the airport, separate from those used by the other aircraft. If local conditions do not permit the use of parallel runways at the same airport, a separate airport, reserved for see-and-be-seen aircraft, will be used.

Next, take the case of a controlled Washington-Los Angeles flight. This flight will climb out of the Washington terminal area on a steep path, guided by an ILS-type device. This flight will be cleared on up through altitudes until it reaches cruising altitude. In cruise, the flight will follow the appropriate flexible airway, reporting position routinely to the controller—possibly every half an hour. At the west-coast end of the flight, the plane will be cleared to descend and enter the funnel of controlled airspace above the terminal area. During descent, he will be monitored by surveillance radar and will not be required to report passing through altitudes as a routine. In the terminal area, the pilot will be controlled in the same manner as the flight on fixed airways described earlier.

A special case of high-altitude flight is the need of certain military aircraft to climb as gross weight is reduced by fuel consumption. These flights will be given a sequence of routine altitude changes that are close enough together to permit a smooth climb path.

Helicopter and STOL flights will follow prescribed controlled airways at altitudes below those reserved for fixed-wing aircraft. Enough space will be left between controlled helicopter airways and the lowest fixed-wing airway to allow at least one altitude for see-and-be-seen flight.

An interceptor taking off from an air defense base will climb out at the steep-angle that gives optimum performance. A special steep-angle attack beam will be used by the pilot to make sure he follows a precise path through airspace reserved for interceptor climb and descent. This airspace will be under ground surveillance at all times to be sure that no aircraft stray into it by mistake. Rapid, automatic intercommunication between the control and defense systems will let the air defense sector controller be sure this airspace is clear before he sends an interceptor through it.

VIII. ORGANIZATION

Our study of the problem of modernizing the Nation's aviation facilities has convinced us that the system can be modernized to meet the demand of the traffic of the next two decades. Moreover, this can be done largely with the technical knowledge that exists today. No major technical breakthroughs are required to insure success of the effort.

Instead, a major organizational breakthrough is needed. Organizational matters are not within the terms of reference of the Systems Engineering Team. However, we feel that an effective organization is so essential to the success of the proposed modernization that we would be remiss if we failed to point out the organizational changes needed.

There are many ways in which an effective organization can be set up. However this is done, we believe that certain basic characteristics must be built in. The organization should be capable of—

- Making continuing forecast of user needs.
- Developing and analyzing systems and subsystems.
- Establishing component requirements.
- Promoting the development of techniques, procedures, equipment and facilities.
- Introducing timely improvements into the national system.

In order to accomplish this, we believe that the modernization of the Nation's aviation facilities should be consolidated under a single, permanent high-level Government agency. This agency should have the sole responsibility for modernizing and operating the system. It must have the competence and authority to carry out these responsibilities. Modernization should come through the use of sound system engineering principles to provide the necessary improvements to the system. How to apply these system engineering principles to the modernization of the Nation's aviation facilities is discussed in appendix A. And the organizational changes which we believe to be necessary are contained in Section IX, Plan of Action.

IX. PLAN OF ACTION

The program that we recommend is a three-pronged attack on the problem of improving and modernizing our national system of aviation facilities. First, immediate steps are needed to improve the CAA's current implementation plans. Second, existing technology must be put to work in the system. And finally, a permanent continuing modernization program must be established.

The current CAA implementation effort can improve the operation of the national facilities, but the program must be speeded up. And, at the same time, doctrines must be developed for the use of equipment installed as part of this accelerated program.

The following steps are needed to develop such a doctrine:

- Analyze the bottlenecks in air traffic control throughout the Nation.
- Through operations research, determine the best way to use improved operational procedures to relieve these bottlenecks.
- Apply these improved operational procedures to eliminate the ATC bottlenecks.

The CAA should apply these steps thoroughly and continuously to its current implementation program. We recommend the CAA set up a full-time high-level operations group for this purpose.

As examples of the type of work that should be done, we cite the following:

- Modification of the airways structure, particularly around high-density areas. Among the procedures to be examined are greater use of one-way airways, speed segregation of enroute traffic by altitude, bidirectional instrument approaches at busy airports, and greater use of twin-stack feed procedures at high-density airports.
- Development and evaluation of a doctrine for the use of long-range radar—especially for en route control.
- Increased use of "Pogo" operations.
- Service test of the ATC radar beacon.
- Service test of VOLSCAN (AN/GSN–3).

Improvements planned as a part of the CAA's implementation program should follow the concepts that are used as the basis for long-term modernization.

The CAA's staff and facilities for training air traffic controllers should be expanded to allow more training in new procedures. An expanded program of training in radar procedures—including the use of enroute radar—is especially needed. Dynamic simulation should be used as a primary training tool in this program. Until simulator equipment can be made available for this training, the simulation facilities at the CAA's Technical Development Center, Indianapolis, Ind., should be used for training on a part-time basis.

These simulation facilities at TDC should also be used to support the operations group, by testing the application of operational procedures to particular areas. We recommend that TDC simulation facilities be improved and enlarged to meet both of these requirements.

A significant increase in the capacity and performance of the present air traffic control system will result from more widespread use of known procedures and the installation of more facilities. But this capacity will not be enough to meet the growing demand predicted for the next two decades. To be able to meet this demand, the system must be modernized. This modernization must extend to all elements of the system: traffic control doctrine, regulations and procedures, data processing, navigation, airports, and communications.

Modernizing our complex system of aviation facilities must be done in a systematic and logical manner, viewing the system as a whole. In other words, we must use the systems engineering approach. The essential elements of this approach are: (1) defining the problem, (2) preparing proposed solutions, (3) testing these proposed solutions, (4) developing the components needed to carry out a proposed solution, (5) testing the system using these components, (6) setting up the system, (7) operating the system, and (8) analyzing the system's performance. (A more detailed explanation of the system engineering process and a discussion of its application to air traffic control will be found in app. A.)

The task of applying this system engineering process to the modernization of our system of aviation facilities should be entrusted to the permanent, high-level Government agency recommended in part VIII. This agency should have the authority to determine national aviation policy, as a part of the process of defining the problem. To carry out its responsibilities for system engineering, this agency should have a system laboratory, equipment development laboratories, a joint civil-military system experimental facility, the necessary facilities for service testing the system and its equipment, and facilities for carrying out comprehensive operations analysis of the system in actual use.

We imagine that the organizational changes required to unify the Government activity supporting civil and military aviation will take some time to plan, and more time to establish and put into operation. The need for modernization of the system is urgent. Therefore, we recommend an interim organization be set up to start the modernization. This organization would be responsible for selecting improvements to be made in the system. The CAA would still be responsible for implementing these improvements and operating the ground environment. And user organizations would still develop and install cooperating airborne equipment.

In our study of the system modernization problem, we have approximated the first two steps in the system engineering process—defining the problem and synthesizing the solutions. Our recommended initial configurations are, in effect, tentative solutions. The interim agency should set up a comprehensive program of system research, involving operations research, system experimentation and equipment development.

The operations research program should—

- Continue the examination of concepts and the synthesis of improved solutions.
- Initiate "Monte Carlo" analyses of proposed systems to provide a coarse estimate of their feasibility.
- Continue forecasting aviation traffic and study forecasting methods.
- Initiate a comprehensive operations analysis program to measure the performance of the current system.
- Determine criteria for selecting airport locations and designing the airport facilities that form a part of the system.

There is a great storehouse of techniques which appear to be applicable to this modernization. However, these techniques cannot be applied immediately because equipment modification is required, procedures must be worked out, and the equipment and procedures must be integrated into working systems.

This requires extensive system experimentation. To do this, we recommend the interim agency establish a national experimental activity. This activity should be staffed jointly by civil and military operations and research personnel and assisted by outside contractors.

We recommend this experimentation include the following areas of activity:

Terminals.—Single airport terminals, such as Washington National; and multiple airport complexes, such as the New York area.

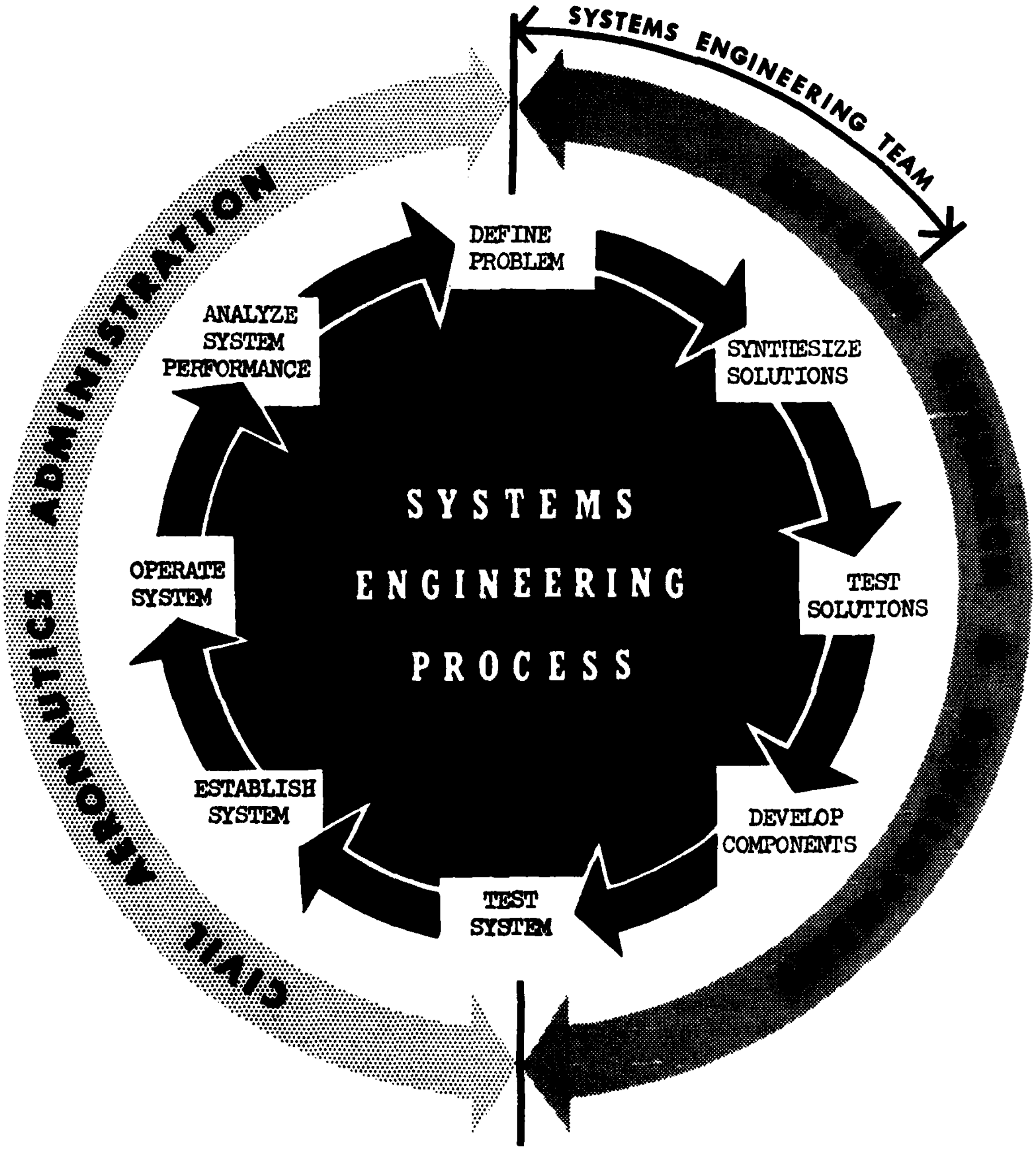
Enroute areas.—High-capacity fixed airways, such as the Washington-New York airways, flexible high-altitude airways, and arbitrary track-type enroute flight.

Cooperation with air defense.—Acceleration of current programs for investigating cooperation between air defense and air traffic control. Particular attention should be paid to the problems of exchange of position data and the setting up of nonconflicting climb and descent paths for interceptors.

Airports.—Development of location and design criteria for airport facilities that serve the air traffic control system.

We recommend that actual airport experimentation begin as soon as the joint system experimental facility is in being. This effort should concentrate on the following problems:

- High-speed turnoff strips, their radius of turn, and their impact on ground handling facilities.
- Running-start takeoff strips.
- Visual communication between controller and pilot, particularly for ground control, to alleviate the radio communication load.
- Separate short runways for use by low-performance aircraft when there is a mixture of low-performance and high-performance aircraft at the same airport. The distance which these runways should be separated from high-performance runways should be examined, as well as the distance that should exist between parallel runways serving aircraft of the same performance class.



MODERNIZATION of our national system of aviation facilities should follow the system engineering process. We need a single, high-level Government agency to be responsible for the entire process. In the interim, however, immediate steps are needed to set up a single agency to carry out the research and development part of this system engineering process. The Systems Engineering Team has begun the application of this process by partially carrying out the first two steps.

- Runway layout and its effect on airport capacity. This should include airport location and runway layout in multiple airport complexes.
- Helicopter pads, and helicopter traffic patterns.

In the overall system research process, operations research is concerned with finding ways to improve the system. System experimentation tries out these improvements, using new and improved equipment. Thus, the interim agency must have the authority to select, acquire, modify, and develop equipment. In addition, it must have the authority to select, acquire, modify, and develop the research tools needed to carry out the system research program.

X. CONCLUSIONS

A. The problem of meeting the aviation facilities requirements for all users of the domestic airspace on an equitable basis is inherently soluble, but not without a stepped-up, unified, intelligently directed effort based on sweeping organizational improvements.

B. The most immediate need is for centrally planned and directed emergency measures. These measures are needed to apply more effective procedures to the existing system, and make more efficient use of existing equipment and system elements. A considerable immediate improvement seems possible as a result of these efforts. But they are stopgap measures only.

C. The primary and underlying need is for a single, permanent organization that will anticipate and respond to future aviation facilities requirements on a national basis. This activity must have unusually broad technical scope, breadth of interest, and the facility to recognize and develop solutions for aviation's problems before they become acute.

XI. SUMMARY OF RECOMMENDATIONS

A. That the Civil Aeronautics Administration establish a full-time operations analysis group to insure that the maximum operational advantage will be obtained from the extensive procurement and expansion program now underway.

B. That the CAA institute a more comprehensive training program for air traffic controllers, using dynamic simulators.

C. That a Government mechanism be established as soon as possible for the purpose of continuously modernizing the Nation's aviation facilities.

D. That this modernization program be defined so as to include, not only equipment but also procedures, regulations, airports, and the role of humans in the system.

E. That an independent interim organization be established immediately to start this modernization, with clear-cut responsibility for developing and selecting improvements for use in the system.

F. That development and selection of improvements be based on factual data derived from operations research and system experimentation rather than be restricted to theoretical considerations alone.

APPENDIX A. SYSTEM ENGINEERING

I. INTRODUCTION

The Systems Engineering Team activity constitutes the initial phase of a system engineering process. Our recommended plan is in itself a plan to organize and continue this process to its completion, as adapted to the special problem of modernizing the national air traffic control and navigation system.

The system engineering process applies method to the entire series of events, starting with the enunciation of national aviation policy by the Government and culminating in a vast nationwide operation supporting civil and military operations in the United States.

Two important elements of this process are decision-making and development. Decisions are required, starting with a few broad policy decisions and spreading out to thousands of decisions on detailed operational procedures, equipment characteristics, and regulations. In the system engineering process, an arbitrary decision is not final until it has been analyzed and tested by whatever scientific methods of analysis can economically be brought to bear. These decisions are interrelated, and in the field of air traffic control this has caused a great amount of difficulty. By tradition, decisions have been classified as either "operational" or "technical," where in fact most decisions are neither—but both.

Another difficulty which has proved detrimental to progress is the general lack of means for analysis and testing of vital system decisions. This has worked two ways: to prevent decisions being made, and to perpetuate arbitrary, and often wrong ones.

Development, the other keystone of system engineering, involves the development of *all* elements of the system concerned. A system adequate in technical performance can fail unless well-developed procedures are utilized, or adequate regulations are provided.

Too often have development programs been wrongly restricted to only electronic equipment. The components of a system are *all* the elements which are required to interact to form a working system.

In the air traffic control system, the components include such diverse things as manpower skills, regulations, approach procedures, radar equipment, aircraft instrumentation, weather-gathering stations, and even penalties.

Air traffic control is special in several senses. One, it must support private aviation operations—therefore, the system must be responsive to the policies and requirements of private organizations and individuals insofar as the Government is able to do so within national policy and the national economy. The system at the same time supports military aviation as well, and therefore must be responsive to the policies for defense and military aviation requirements in peace and war.

Also, the system offers a supporting service to the public. In its expansion to meet a growing demand, the system cannot have a hiatus of reduced service during "remodeling." This applies a constraint to the improvements. They must be compatible with the current operations during a transition period required for reinstrumentation and training.

The system engineering process must, therefore, take full account of these special conditions, which place complex requirements and constraints on the system.

II. ELEMENTS OF THE SYSTEM ENGINEERING PROCESS

The specific elements of the system engineering process are:

a. Defining the problem.

b. Synthesis of postulated solutions.

c. Testing of solutions.

d. Developing the components.

e. Testing the system with the developed components.

f. Establishment of the system.

g. Operation of the system.

h. Analysis of the system performance.

Analysis of the system performance, definition of the problem, synthesis of solutions, and testing solutions are lumped into one activity which we call *systems research.*

Developing, testing, and producing the components or elements of the system are classified as *system development.*

III. METHODS

We recommend the following steps in consonance with the principles set forth above.

A. Systems Research

1. Operations research

a. *Analysis of the current system performance.*—Gathering data on critical segments of the operating system and analysis to determine specific nature of shortcomings "vis-a-vis" the current demands.

b. *Forecast of requirements.*—This is a continuing forecast of the requirements, and research to continually improve these techniques.

c. *Research in theory of air traffic control.*

d. *Research in procedures and human factors.*

e. *Analysis of policies of Government and aviation interests.*

2. Synthesis of postulated systems

This is the creative process of establishing tentative system concepts and configurations. This should be carried out by a team of operationally experienced scientific and engineering personnel, on a full-time basis. The product of this activity is a number of tentative solutions to the systems problems.

3. Analysis of solutions

a. *Gaming Techniques.*—"Monte Carlo" techniques are used to analyze the postulated systems. This results in a crude comparison of systems subjected to comparable demands. Because it idealizes many functions which may be critical, the system must be subjected to a more comprehensive analysis. This phase requires scientific personnel to program and operate the "games," and operationally experienced personnel to assist in establishing "rules of the game." The result of this analysis is to furnish a crude filter for systems and data for modifications to the initial schemes or creation of new ones.

b. *Theoretical analysis.*—This phase pertains to the analysis of elements which are amenable to classical mathematical analysis, such as closed-loop operation of dynamic elements, analysis of radar performance, navigation accuracies, etc. This requires essentially scientific personnel and will furnish additional data to the synthesis group.

c. *Real-time simulation.*—In this phase, experiments are performed with *real* equipment, if available, and human operators with simulated traffic. This requires scientific personnel to design and program simulator equipment, engineering personnel to develop and maintain the equipment, and a team of scientific and operationally experienced personnel to design and operate the experiments. The results of this phase are fed back to the synthesis group to add an additional note of realism for modifications of the original concepts, and to generate new concepts.

d. *Field experimentation.*—The final analysis for a new concept before development is conducted in the field. By this stage the concepts have been reduced in number, and this phase is undertaken to ensure that analysis is carried out on those elements of the problem not amenable to gaming, theoretical analysis, and real-time simulation. This phase is the most expensive, involving larger numbers of personnel, operation of aircraft, and real equipment and facilities. Again, the personnel is formed of scientific-operational teams to design the experiment, develop and maintain breadboard equipment, develop, operate, and maintain measurement and data analysis systems, and maintain and operate the system under experiment. The results of this phase again are fed back to modify the original concepts, and serve as the most realistic data on which to base new concepts.

4. Results of systems research

The results of a continuing systems research program are:

a. A continually improving *system* "state of of the art."

b. Functional requirements for the development of equipment and facilities.

c. Training requirements for operators.

d. Requirements for procedural developments.

e. Data on which to base improved regulations.

Some of the requirements can be decided upon as a matter of policy, some from theoretical analysis alone, and some must await data from actual experimentation. **We believe that it is necessary to establish a mechanism to carry out systems research, and use it as the principal technique to furnish data for the complex decisions necessary in setting forth the requirements listed above.**

B. System development

System development acts to convert component requirements into a steadily growing system to keep abreast of the demand.

System components are defined as those elements of equipment, facilities, human skills, procedures, and regulations which compose the system.

It is clear that, in the United States today, we know how to harness the industrial and institutional effort to develop systems of great magnitude and complexity. Techniques of system management, system engineering, have developed rapidly under the stimulus of a potential enemy threat to this country. System research is required **prior** to proceeding on system development to define the requirements, and to ensure that no major technical "breakthroughs" are required.

The principal ingredients of successful system development are adequate development funds, an effective organization capable of administering and supervising the program efficiently, and facilities for service testing the system developed, not only functionally but for reliability for all required environments, and suitability for particular local conditions.

C. Introduction of timely improvements into current operations

Although we believe that the system research and system development process will, by its nature and personnel composition, result in the necessary improvements, additional formal processes should be utilized to ensure swift improvements of the system.

a. Use of operational facilities in different geographical areas for conducting in-service testing in the process of system development.

b. Rotation of operational personnel into system research and system development, analytical, experimental, and test environments.

c. Periodic public demonstrations of the state of progress in system research and equipment development.

d. Furnishing data from studies and experiments to bodies for debate of regulatory recommendations.

e. Early reorientation of training programs for users and ground operational and maintenance personnel.

f. Educational and indoctrination programs for users on forthcoming changes to the system.

APPENDIX B. PRINCIPLES OF AIR TRAFFIC CONTROL

I. INTRODUCTION

We recommend the concepts outlined in this section, and the means proposed to meet them, as the starting point for system modernization. They are, in our considered opinion, a first approximation under the requirements we have outlined for an air traffic control system. We recommend that they be continually examined, and revised as necessary, in the application of the system engineering process to the modernization of the national system of aviation facilities.

II. TRAFFIC MANAGEMENT

A. Centralized vs. Decentralized Management of Airborne Traffic

Central management of traffic is used today chiefly in bad weather (roughly 12 percent of the time), and only by those pilots who ask to have their flights managed. Whenever a pilot applies for the service by filing an IFR (instrument flight rules) flight plan, he contracts with the system to fly a particular ground track and schedule, at a particular altitude, and with certain tolerances. The control agency, in return, undertakes to protect him from collision with any of its other clients. Pilots who are not clients of this agency are expected to remain safe and harmless by flying VFR (visual flight rules), on a see-and-be-seen basis.

For most of the flights and for most of the time, traffic management for collision avoidance is completely decentralized and is in the hands of the individual pilots. The two types of management often coexist in the same airspace. While some of the pilots are depending primarily on the ground-based central system to keep them safely separated, other pilots about them are depending solely on a common observance of the rules of see-and-be-seen flight.

What is the future of collision prevention by such decentralized methods? Can the vision of pilots be extended artificially so that safe VFR flights become practicable in all weather and at all speeds?

We believe firmly that see-and-be-seen flight is a good and safe thing for a slow aircraft—

- with a wide, unobstructed field of view from the cockpit.
- piloted by an alert man who has no other urgent duties but to look and steer.
- in clear weather.
- in airspace occupied only by a small population of similar aircraft.

Under these conditions, it becomes, in fact, a see-and-avoid flight.

By taking occasional detouring maneuvers the pilot can keep himself from harm almost no matter what his neighbors are doing or planning to do. No safety is gained, and freedom is lost, by subjecting him to a centralized management.

We have discussed the idea that, except in extremely dense situations, all flights might be handled safely on a decentralized see-and-avoid basis—if pilots could be given eyes to see, in any weather, all the traffic for miles around. In principle, the pilot's vision might be so extended artificially, either by airborne devices that individually search the surrounding airspace and display their findings, or by a system on the ground. Such a system would gather in position information on all the traffic and broadcast its picture of the air situation upward for pilots to receive and use. We know of no active and promising developments along either of these lines. Nevertheless, we recommend that the possibilities not be overlooked.

It is conceivable, though unlikely, as we see it, that such a system could be devised and put into effective use, at least by aircraft that now call for occasional IFR handling. It might even work well enough to eliminate the need for any centralized management of en route traffic. Centralized management might still be required for extremely dense traffic situations, where the flow pattern must first be put into order before it can be safely managed by a central agency or safely traversed by an individual pilot. In any case, centralized management is obviously required for the traffic in terminal areas. It is in the terminal areas that the valuable commodity of runway usage has to be parcelled out with little wastage. And these are the areas where significant conflicts of interest appear—conflicts that have to be resolved by arbitration, not by mutual agreement among the pilots.

We believe, therefore, that a ground-based system of traffic management, capable of managing the traffic in a large part of the total airspace, will continue to be a national requirement for many years.

During the period of our study there has been some public excitement over the possibility of airborne collision avoidance devices. These devices would avert collisions at the last instant by dictating, to at least one of the pilots involved, a violent avoiding maneuver. We share what seems to be the common view, that any such very-short-range "aircraft repeller" should be regarded as an adjunct to—not a substitute for—more deliberate methods for keeping aircraft safely apart.

B. Prearrangement vs. occasional intervention

If we have a ground-based centralized system of air traffic management, with some sort of model of the air situation available to the manager, there is still a basic choice to be made between the different methods of management.

The system might work as the en route system does today. It would deal primarily with the plans and intentions of pilots and manage traffic essentially by prearrangement. The manager would always have an understanding with each pilot as to where that pilot will be going for the next half hour or so. And, after reconciling the plans of all the pilots, the manager will be able to assure each pilot that he can safely go ahead as planned for the next half hour or so.

Alternatively, the manager might deal primarily with present positions and recent past positions of aircraft, letting each pilot do just as he pleases without ever any formal prearrangement. The manager would extrapolate the various courses, and intervene only when he saw in his model of the air situation that two aircraft were in imminent danger of collision.

This method is management by occasional intervention. The manager would be doing for each pilot just what the pilot would be doing for himself in see-and-avoid flight—letting the situation develop as it will and making an avoiding maneuver when needed to meet the occasional threat of collisions.

Management by occasional intervention has several attractive features. It relieves the pilot of the irksome limitation of having to make, and then faithfully fulfill, a contract as to his ground course, altitude, and schedule for many minutes ahead. The basic data for the ground element of the system is the position of the aircraft—now and in the recent past. Being facts, these position reports are more concrete and dependable than pilots' estimates of their future positions can possibly be. Further, these facts can presumably be more easily obtained by automatic means than can pilots' intentions. And short-term extrapolations can be made with confidence. The position of an aircraft a few seconds from now is almost completely determined by the laws of dynamics and is nearly independent of the pilot's actions and intentions.

One might imagine that without prearrangement, the traffic pattern would inevitably be completely chaotic, with hazardous incidents arising much more often than they need to. This fear is eased in part when we realize that a certain ordering of the flow happens automatically.

Every pilot would need to be constantly alert to receive and obey promptly an occasional vectoring order from the manager. A stream of "testing" communication between ground and air would be needed to make sure that the channel for such an emergency order is kept open. This might, however, be a small price to pay for the freedom of the pilot to do as he pleases almost all the time.

Finally, as evidence that flight without prearrangement is not an entirely fantastic notion, we observe that under VFR conditions a fair volume of traffic actually flows today with no central supervision. Each pilot makes the occasional intervention to his own flight that the immediate circumstances seem to call for.

Despite these considerations, we have not been able to persuade ourselves that management of en route traffic by occasional intervention can replace management by prearrangement. There are several reasons.

Centralization inescapably implies some sloppiness and some time lags. Pilots in VFR flight perceive the threats immediately and react to counter them, by trained habit, in fractions of a second. The manager, however, has to deal with a model that is at best always slightly out of date, or slightly in error—or both. It takes some time for him to judge the situation intellectually, not by habit, and then tell the pilot or pilots what he has decided.

Further, what many pilots can do in see-and-avoid flight to keep themselves safe, with each pilot acting for himself, is collectively too big a task for a single manager working with a model of the total situation. If we think of putting many managers at work with the model, we face the problem of dividing the labor among them. When the task consists of the immediate handling of a random succession of unpredicted crises, no clear solution for this problem comes into sight.

If we think of setting a machine to watch the model, detect incipient collisions, compute appropriate avoiding maneuvers, and issue appropriate instructions to the pilots, we come up against two difficulties. First, no such machine is in existence or apparently just around the corner. Basic techniques and equipment for doing various parts of the job seem to be available, but no elegantly simple and inexpensive device for the overall task is in prospect.

Second, and more fundamental, we think it would be essential for the machine to display its work to a human monitor for review, and approval or veto, before issuing an order to a pilot. No one, we believe, will trust an unmonitored machine to pick out all the incipient conflicts, analyze each one wisely, and call for action that will always dissipate the particular crises without making the general situation worse instead of better. No matter how agile the machine, all its operations will have to be open for inspection, review, judgment, and understanding approval or veto by human engineers.

Whenever the judgment leads to veto, there must be enough time left for man or machine to have another try at the problem. **The men, not the machine, have to set the pace of the centralized management operations.** We imagine that they can, with appropriate aid from machines, keep a fairly dense flow of enroute traffic moving safely by orderly prearrangement with a forecasting time of 30 minutes or so, and by substituting preplanned leisurely turns, climbs, and descents for last-second avoiding maneuvers executed on emergency orders. We imagine they cannot—no matter how much machine help they have—safely handle the same flow by occasional interventions to resolve randomly occurring situations that have almost become crises.

We believe that prearrangement of en route flights, in contrast to occasional intervention with flights otherwise unconstrained, will remain the basic method of collision prevention. We believe that occasional intervention is also an essential element of the management process for dense traffic in terminal areas. At the other extreme, for very sparse traffic, we also believe that human surveillance with occasional intervention—instead of prearrangement—is a useful technique.

A word about the equity of prearrangement seems necessary. The principle of first-come-first-served is basic in our thinking. But we find it desirable to examine, in particular cases, how it can be applied justly. Is an aircraft carrying 100 passengers ever to be given any sort of priority over an aircraft carrying only its own pilot? There are arguments for doing so, in equity—but the 100 persons might be on an outing while the single pilot might be carrying essential medical supplies to a stricken community.

As a practical matter, we must recognize that the vehicle, not the person, is the appropriate unit for application of the first-come-first-served principle. On the other hand, it is not clear that a vehicle desiring an exclusive license to a large segment of airspace for a long time should—simply because it is first to apply—be permitted to prevent the use of this same airspace for the prior passage of several other vehicles that are able to occupy it in close succession or along parallel tracks. From the viewpoint of justice, an aerial vehicle that is respectable under some circumstances may, under other circumstances, become a menace to navigation.

C. Mixing or segregation of airborne traffic

The Team starts with the premise that the airspace is public property and that all of it should be freely available at any time to anyone who wants to use it. We are immediately forced away from this position by the obvious realities, including the fact that there are many people who would like to use a single airspace at the same time. We come finally to the less broad but more practical principle that the airspace should be so managed as to yield the greatest benefit to the Nation.

This statement is still far too general to be of much practical use. But it does serve to justify such rules as one that all other traffic must stand aside for military traffic on genuinely hostile missions and a rule that none of the airspace is to be reserved indefinitely for the exclusive benefit of any specific interest. We make a little more progress toward definiteness by adopting—as a matter of convenience rather than of strictly logical equity—the rule that when two pilots have asked for the use of a particular part of the airspace, little weight is to be given, in deciding between them, to the nature of their errands or the number of passengers each one is carrying, while much weight is to be given to the time order in which they arrive and ask for entry. However, we cannot quite concede that only this order should be considered, for this would imply a right of the first arrival at the table to eat the whole roast while the later guests sit by and starve.

What actually happens, of course, is that detailed rules are adopted for the use of the airspace and it is then made available—usually on a first-come-first-served basis—to every vehicle whose pilot is able and willing to follow the rules. The rules have two general purposes: (1) to insure that airspace desired by many users is not wantonly wasted by any one user, and (2) to insure that no vehicle is unduly endangered by the presence of others. The rules must be reasonable, observable, and enforceable. And they should be adopted deliberately, after debate, not suddenly and arbitrarily. They may (in fact, they often do) apply nonuniformly over the airspace. In some cases they act to exclude certain vehicles from certain parts of the airspace, and thus to segregate aircraft. Visual and instrument flight rules, other civil air regulations, and the rules for entry into certain terminal areas, are examples of today.

It seems clear, from the opinions we have heard and the estimates we have made, that early in the next two decades additional rules will be needed for safe flight and efficient use of airspace. These rules will have the general effect of segregating different types of aircraft even more than they are segregated by regulation today. We believe that the rules will, at least for many years, allow any aircraft to proceed from almost any terminal area to almost any other terminal area, but we foresee that the rules will have the effect of excluding from large parts of the airspace those aircraft that are able only to fly. On the other hand, we foresee that the rules will also exclude from certain parts of the airspace those vehicles that need and can accept a high degree of centralized flight management but are dangerous neighbors for aircraft not under the same management.

We recommend, as part of a sustained modernization effort, a continued study to find out what regulations are desirable for safe and efficient use of the airspace. The study should result in the proposal of rules that are technically observable and technically enforceable. Reasonableness of the proposed rules should be determined after public debate.

It appears attractive to consider altitude as the prime basis for zoning enroute, because already without regulations there is a general association between high altitude and high speed. Also, the barometric altimeter is a navigational device almost universally employed.

The Team has examined the concept of zoning enough to feel reasonably confident that the geometrical problems could be worked out on a case-by-case basis, and that safety, efficient use of airspace, and essential justice could all profit very soon by some such segregation of the traffic.

D. Blocks

Within controlled airspace today, aircraft are separated from each other by the use of fixed, reserved airspace "blocks." In this method, the airspace is divided into blocks that are fixed and defined with respect to the ground. Each aircraft under management is licensed to occupy a particular block for the length of time the pilot proposes to occupy it. Collisions are avoided by taking care not to license two aircraft to be in the same block at the same time.

The blocks must clearly be much more numerous than the aircraft under management, so that it will almost always be possible to find for each aircraft a succession of adjoining, unreserved blocks reasonably consistent with the path and schedule that pilot wants to fly. The airspace being finite, the size of the blocks has to decrease when their number increases.

Small blocks, however, are inconvenient for all concerned. If they are long they must be narrow. And the pilot is then required to navigate precisely, to be sure of staying within his block. If they are broad to ease the pilot's navigation problem, they must then be short. The pilot and the manager of the system are then caught up together in a negotiation to schedule a succession of many short forward steps for the aircraft. With high-speed vehicles and a limited capacity for communication between ground and air, this can easily be an impossible task.

Aside from these considerations of convenience and feasibility, there is another consideration that sets a lower limit on the size of a block and also puts some limits on its shape or form. Each block must be at least large enough to contain a holding pattern for the aircraft in case it has to wait within the block until a next block along the desired flight path becomes vacant. Further, each block must be somehow defined, relative to the ground, so that the pilot of any aircraft assigned to hold within the block can determine that he is, in fact, not straying into another block.

In today's enroute airways system the blocks are conveniently 1,000 feet thick. This is because a pilot with a barometric altimeter can fairly dependably maintain a constant altitude within a hundred feet or so, and because an altitude separation of a few hundred feet is a safe total separation for two passing aircraft. The blocks are conventionally 10 miles wide, in part because this is the width needed for safe holding over a fix, and in part because a pilot navigating between VOR or LF/MF fixes can be expected to err laterally by a few miles on the average. Their length is, crudely speaking, the distance from one ground fix to the next, about 50 miles on the average. So the typical forward step for an aircraft enroute is a step of about 10 or 15 minutes of flying time. Their number appears to be approximately suitable for today's enroute traffic volume. Holding enroute, because no block ahead is vacant, is occasionally necessary, but not often. The sum total of the blocks—that is, the structure of the airways—comes close to filling completely the enroute airspace over the Northeast. West of the Mississippi and in the South it occupies less than half the airspace.

We believe that basically this same concept should be used well on into, and perhaps throughout, the next two decades. Accordingly, we should consider the following question: If the traffic increases by 200 percent, as is predicted, what must happen to the number, size, and shape of the blocks and what effect will those figures have on requirements for airborne navigational accuracy?

In answer to this question, it appears that more blocks will have to be defined. And there will be an increasing need for efficient use of whatever blocks have been defined at any one time.

For efficient use, the managing process—the forecasting of occupancy, the search for blocks not yet on reservation, and the negotiations with pilots—must move along much more rapidly than the traffic itself moves, so that no block is ever left vacant for long merely because the manager has not yet recognized that it is available for reservation. Also, a distribution of aircraft according to velocity would increase the efficiency. Mechanical aids for speeding up the managing process are now in development. We have no doubt that a sustained modernization effort could rather quickly realize significant improvements in this area.

APPENDIX C. SYSTEM DESIGN CONCEPTS

I. GENERAL

The national aviation facilities consist essentially of a traffic control function, a navigation structure, communications between air and ground operators of the system, and an airport structure. A tentative design for the system is set forth here, following the basic operational concepts outlined in section III.

II. TRAFFIC CONTROL

Traffic control is exercised to maintain a safe separation between aircraft on diverse operational missions, air transport, air defense, pleasure, etc., and to assist in expediting individual users in achieving their operation desires. The traffic control element of the system will operate all the time over a major portion of the airspace to cover the operations in controlled zones. It will operate in the see-and-be-seen zones under instrument flight conditions. At the present time there are approximately 30 air traffic control centers to manage the enroute traffic, and tower control centers at all the major airports and on many of the smaller ones scattered throughout the country. The system will grow, starting with the present number and distribution of control centers, and be modified to handle the traffic by possibly redistributing the functions between terminal and enroute centers, and going into more, or possibly less, centralization as information becomes available from further analyses and experimentation on efficiency and economy of prospective changes.

Where the system is in force it will reserve air or airport space for individual aircraft as they progress in their flight from ramp to ramp.

As a general rule, the limits of the space assigned at one time to an aircraft will be defined geographically and used only by one aircraft at a time. Further, this block of space will be large enough to permit a safe orbit in the event that the next block to which the aircraft would proceed is occupied. Exceptions to this will occur where densities are higher than that obtainable by a block structure large enough to hold in; for example, in the multi-airport terminal areas such as New York in 1975.

A block structure throughout the airspace is a fundamental feature of the traffic control portion of the system. The individual controller will have as data on which to base airspace reservation, flight plans, position reports, and information on the air situation by a ground surveillance system. A clearance can be issued to an individual aircraft to proceed from one block to another if it is known to be vacant. It is desirable to reserve additional airspace in sequence, but only within the limits of time that aircraft times of arrival can be predicted with sufficient accuracy to insure efficient use of the blocks of airspace.

In order to accomplish this reservation, the individual controller will have jurisdiction over a number of blocks of airspace, and information concerning the occupancy of these blocks, both actual and prospective, i. e., now and in the near future. He requires additionally rapid access to information on the occupancy of all adjacent blocks of space bordering the blocks under his control.

Exception to the unique occupancy of one block by a single aircraft will be made only occasionally in enroute areas where there are few aircraft compared to the number of blocks available for occupancy. However, as terminal areas are approached, the exceptions would need to be made more often, and in the terminal area close separations are the rule rather than the exception, particularly the multiple airport terminal. In order to permit passing, descent or ascent through an occupied altitude, or to fly into narrow access lanes to the final approach zone, or in the final approach zone itself, more precise information is required about the position of aircraft. A ground surveillance system will be used to determine aircraft position more accurately than is possible by knowledge of occupancy of a block of large longitudinal, lateral, and height dimensions. The more accurate information will be displayed to individual controllers for the space under their jurisdiction, correlated with the tabular data on the occupancy of the blocks of airspace under control.

Clearance can be issued then, based on a finer structure of position information. The clearance may involve utilizing a different navigation lane, to bypass or avoid other aircraft, or by close control if a complex path is required and is not definable in the aircraft. The extent of traffic control instruction during this phase is heavily dependent on the navigation capability of the individual aircraft.

In all cases, when clearing individual aircraft in a space smaller than that required to hold safely in, there must be a space beyond which is clearly reserved for this aircraft. There is a requirement, then, for position reporting (maximum of once per block traversed) and an independent ground surveillance system capable of differentiating aircraft in three dimensions well within the dimensions of the blocks of airspace. **We consider that surveillance should be exercised throughout the airspace to provide, in addition to better position information, the basis for guidance in the event of failure of airborne navigation equipment, and to prevent potential collisions generated by errors of controlled aircraft or by inadvertent violation of zone boundaries by uncontrolled aircraft.**

There is a requirement for concentrating and organizing traffic control information at individual control positions. At the present time, the human controller has little assistance in organizing the traffic control data at his disposal, and is often swamped by routine operations such as communications, making written records of his decisions, not to mention the lack of up-to-date precise air situation information. We have made preliminary analyses of the peak densities forecasted, and made tentative physical layouts of routes and navigation structures. This is discussed later in this section. **We have concluded that the human controller can retain his vital role of decision maker in the traffic control function, but that he must be assisted by a rather complete mechanization of data processing and display.** Even in the most complex operation that has been predicted (New York—1975) we believe that the space can be organized and the traffic control problem divided into reasonable parts, manifestly manageable by individual controllers. In order to accomplish this, several principles we believe must be adhered to—

a. The use of nonconflicting paths, wherever possible, to minimize the number of natural points of confliction.

b. Separation of paths in the multiple airport terminal area, for aircraft operating to and from different airports, so that the individual approach controller handles only those aircraft destined for LaGuardia for example, and is not concerned routinely with the inbound traffic to Idlewild.

c. Division of the jurisdiction along the flight paths in the terminal between controllers, so as to keep the number of aircraft under control at one time to a reasonable number.

The use of these principles, however, makes the requirements stringent for rapid intercontroller communication and transfer of jurisdiction, precise position data, definition of more precise navigation paths, and the use of computers, to assist in forming a suitable display of the air situation and to compute optimum delay paths to use the space efficiently.

Fortunately, there are many technical means available, or nearly so, to achieve rapid intercontroller communications and much higher precision navigation than is used at the present time. We believe the state of the art in data processing can, with a concentrated effort, result in meaningful and adequate displays and computer aids for the individual controllers.

In the Centers, where teams of controllers operate, each controller will be an independent cell, able to clear aircraft without delay along their desired flight paths, and able to hold safely, all aircraft under his jurisdiction. Each should have an information display tailored to the particular geometry of the aircraft traversing the space under his control. We believe that the universal, three-dimensional large area display is an illusory goal, not only difficult to achieve but not useful to individual controllers to pick out and interpret pertinent information on which to base traffic control decisions. **Decentralization of displays, then, is fundamental to the individual controller being able to be a part of the system of the future.** Again, we are fortunate in being able to find within the state of the art, the simpler displays which are required for decentralized control as outlined above.

III. NAVIGATION

The ability of aircraft to navigate for some distance within definable limits permits the traffic control system to utilize this to aid in organizing safe separation. Instead of having to separate aircraft unconstrained in proceeding to their destination save by their own desires, airspace can be divided in blocks. The traffic control problem then becomes a digital problem of allotting fixed space of air sequentially to aircraft. Otherwise, the problem of separation would have been a much more complex calculation. It would have involved considering the aircraft as velocity vectors, which could mutually interfere randomly in space, time, and amount.

Speeds of aircraft need not be a primary consideration in the allocation of airspace by individual controllers, except where two aircraft must come closer than the block dimensions. Aircraft can be segregated a priori by the system so that aircraft in one series of blocks will be going in the same direction and at about the same speed.

The ability to navigate reduces the rate of communication between the controller and the aircraft, particularly if a reliable surveillance system is used. A complex path can be agreed upon, the aircraft can negotiate this path, and the surveillance system can furnish the necessary position information to provide assurance to the controller that the path is adhered to within the prescribed limits.

The system must furnish, then, a navigation structure to provide paths for aircraft to fly anywhere in the airspace. The system should additionally furnish a reference of sufficient precision and reliability to permit navigation within limits narrow enough to accommodate the large numbers of aircraft in such a manner that lateral separation provided by the navigation is useful as a tool for safe separation.

Additionally, the navigation element of the system provides a system of reference which defines the block structure used for reservation of airspace. **The navigation element, then, has a triple role: a reference for pilots to find their way to their destination, a means of providing safe lateral separation by providing nonconflicting paths, and to form the grid structure to define the boundaries of blocks for airspace reservation.**

Vertical navigation is required for providing separate nonconflicting paths in the vertical dimension, and to define the vertical boundaries of the block structure. In level flight, altimetry will be utilized to provide this reference. For climb-and-descent operations near terminal areas and in the terminal areas, the third dimension can be defined where there is space by a slant navigation reference. Ideally, this reference should furnish path information on several different elevation angles.

The need has been cited for parallel paths between large nearby centers of population, flexible airways for high-altitude transcontinental operations, arbitrary tracks in sparsely traveled space, and precise three-dimensional paths for intercept and terminal operations. Limiting access to these various paths according to velocity and direction will serve to simplify the traffic control computation, and permit a higher utilization rate of the airspace.

The requirements for navigation are—

a. A navigation reference throughout airspace from the ground to the highest altitude.

b. Accuracy in the en route areas sufficient to permit lateral separations for the highest demands in particular geographical areas.

c. The airborne requirements to utilize this reference should be kept to a minimum of cost, weight, and complexity in both the equipment and the operation.

d. The equipment should utilize techniques that are inherently reliable, and which *fail safely*.

e. It should be a design goal to provide navigation reference throughout the system so that one simple receiver will serve for en route as well as terminal and surface navigation.

Although we believe the system should provide the basic navigation reference for using aircraft, those aircraft having self-contained equipment, or using other references for navigation, should not be excluded from the system, providing their equipment performance meets the minimum criteria designated for navigation accuracy.

IV. COMMUNICATIONS

The ability of any system to control remotely is based on the rapidity and reliability of communications between the control centers and the elements under control. Communication is required in the system—

a. Between operators and the control system prior to flight to negotiate flight plans.

b. From controllers to aircraft to issue clearance.

c. From aircraft to controllers to report position and to negotiate changes in flight plans.

d. Between controllers to permit coordination and transfer of jurisdiction.

e. Between the ground surveillance element of the system and the controllers to transmit air situation data.

f. Between weather-data-gathering sources and controllers to exchange information to synthesize a comprehensive picture of the air weather situation.

g. Between controllers and aircraft to furnish weather information correction of airborne navigation devices, and emergency assistance.

The block structure outlined above reduces the routine air-to-ground communication to a maximum (routinely) of one position report per block traversed. The closest spacing expected routinely is not less than 10 minutes, so that the position reporting need not be done at a higher rate normally. In the terminal areas, particularly multiple airport terminal areas, higher rates will be required—as high as one position report per minute. There will always be a requirement, however, for emergency communications with effectively immedate access between controller and pilot. The equipment in the aircraft should be kept to a minimum in cost, weight, and complexity of operation, both in the equipment and for the pilot. The equipment need not be the same for different classes of aircraft; for example, the controller should have access to ground equipment with which to communicate with military combat aircraft with complex communication equipment used normally for tactical control.

We believe that all ground-to-ground communication can be mechanized so as to prevent significant communication delays. Filing flight plans, intercontroller coordination, and transfer of jurisdiction, flow control information, weather data, information from the ground surveillance system to the controllers, should all be mechanized compatibly with the data processing regime used by individual controllers. Emergency communication should remain voice, in all aspects of the intercommunication of the system, to permit the flexibility necessary to handle the diverse message structures pertaining to emergencies which are not predictable by their very nature. Voice, we believe, can also serve the predicted small percentage of those operators who cannot, due to economic reasons, purchase more expensive mechanized communication airborne equipment. Consequently, it is an additional requirement to increase the efficiency with which voice communication is utilized.

V. AIRPORTS

Generally, the airports of this country are located and designed unilaterally by local organizations. As a consequence, they do not necessarily have a configuration which is integrated compatibly with the rest of the system. It is obligatory, however, in setting forth a system design to consider the airport both in location with respect to other airports, and as to the navigation structure on the airport itself.

Applying the principle of segregation by speed class, we believe that, wherever possible, separate runways should be provided for helicopters and STOL, low-landing-speed aircraft and high-landing-speed aircraft. On the runways per se the common path should be reduced to the minimum, by providing multiple runways, even for the same class of aircraft, high-speed turnoff, and other means that further analyses and experimentation should yield.

Airports in the terminal area should be separated as far as possible, and runways oriented in parallel. This will minimize the interaction between the approach and climbout paths necessarily in line with the runways for some distance and altitude. These approach and climb paths should be nonconflicting to eliminate the need for coordination of separation between aircraft of different airports. The approach and outbound patterns for runways and pads for different classes of aircraft should also be separated, first by altitude, and then laterally and longitudinally if the operation of the different classes involves common use of enroute altitudes.

Three-dimensional navigation paths should be provided for approach and outbound operation, using the same airborne equipment as for enroute surveillance system. Here is a clear-cut exception to the block reservation, where higher precision navigation is required, precise information is necessary, and a reservation of airspace is required beyond these paths. In the case of final approach, a dynamic holding must be provided. That is, a go-around pattern that does not conflict with other paths and merges back with the approach pattern in the most expeditious manner.

The navigation structure on the surface must include the landing and takeoff runs, high-speed turnoffs, and taxiways. These paths should be monitored as well with a ground surveillance system.

For communication between ground controller and aircraft, we believe that visual communications can be used extensively and thus release the use of radio communications for other purposes.

It is clear that the most difficult terminal problem to be faced is the terminal area where a large number of operations take place on several airports located in close proximity. The outstanding example of this situation is the New York complex. The system design for terminal areas was made with this kind of complex in mind. **The essential conclusion that was drawn concerning the control of traffic in multi-airport terminal areas is that the airspace exists and techniques are available to permit a solution of the traffic problems expected in the next two decades.** The principles we have outlined and set forth are first approximations of a solution which requires analysis, and particularly experimentation to determine their essential adequacy. We fully expect other techniques to be analyzed, and modification to these concepts to be made. For example, we have briefly considered other general schemes to manage traffic in the complex terminal areas.

a. Assignment of airspace and optimum paths by a single computer for multi-airport complexes.

b. The adaptation of long-distance, path-stretching computer systems, such as VOLSCAN and the AN/SPA–13 to multiple airport terminal areas.

After a brief analysis, it was not clear whether these techniques are, in fact, practical for the multiple airport area. However, we believe that their possibilities should continue to be explored, and that if warranted, experimentation be carried out on such techniques, and for that matter other techniques, which will be synthesized for further study and analysis.

The single airport terminal is patently amenable to solution by many techniques. The classic twin-stack, inner-feed system now being used in the New York area, the Volscan technique, the SPA–13 technique, all appear to be adaptable to feeding a single airport to capacity safely and efficiently. Therefore, we did not concern ourselves particularly with the solution to the single airport problem, but do believe that it should be the subject of analysis and experimentation as outlined in section IX.

Finally, from the numbers of aircraft predicted for the next two decades, additional runway capacity will be required. We believe that further analysis and experimentation will yield data on which to build higher capacity airport configurations, and data on which local organizations can logically locate new runways and airports to furnish the maximum overall increase in airport capacity.

APPENDIX D. TECHNIQUES

I. GENERAL

A considerable storehouse of techniques exists with potential application to air traffic handling. The pairing of techniques with functions, shown on the accompanying chart, represents a selection based on present knowledge and judgments. It will without a doubt undergo change as more experience is gained with the techniques.

Operational Concept	*Method of Implementation*	*Possible Techniques*
Marking of boundaries between controlled and uncontrolled airspace.	Altitude boundary marking	Pressure reference.
	Terminal approach funnel boundary marking.	Elevation angle reference or distance-altitude equivalent.
	Controlled airway "ribbon" boundary marking.	Sensitive altimeter, possible hyperbolic marking system for airway edges.
	Marking uncontrolled lanes into terminal airspace.	Visual means—lights, paint, etc.
Improved navigation	Extension of present system capabilities.	VORTAC improvements.
	Introduction of continuity, using self-contained navigation.	Intermittently corrected automatic dead reckoning, course computation, program computation.
	Further investigation of other alternatives.	Hyperbolic navigation (for special purposes), airborne radar.
Approach and landing	Flareout	Radio altimetry, radio beams.
	Approach	Radar in conjunction with airborne flight-path stability components.
Surveillance of traffic	Noncooperative surveillance	Sub-VHF radar.
	Cooperative surveillance	Automatic navigational position reporting via ATCSS.
		Triangulation at ground points based on difference of arrival times of a reporting signal.
Communications	Automatic communications	Selective calling, common system data link (air *traffic control signaling system*) may be time or frequency multiplex.
		Experimental reporting method to be used with ground triangulation surveillance network.
Traffic control	Automatic data handling	Programing for—automation of data reporting transmission, storage, and display.
	Monitoring by human controllers.	Improved displays of 3–D data.
Ground handling of aircraft	Ground guidance	Visual, magnetic, and electromagnetic techniques.
	Monitoring	Airport surface detection radar.

II. ZONE MARKING

Demarcation in altitude requires a common reference. Practical considerations make it difficult to use ordinary sensitive altimeters because of their considerable errors in the upper altitude regions, and the possibility of improper altimeter setting. Ground height-finding error as a calibration means also can involve gross error as a result of propagation considerations. Absolute radio altimetry is unsatifactory for these purposes except possibly over water. It appears that the use of a pressure reference accurately calibrated at the altitude boundary will be required above the boundary. This implies that aircraft above the boundary will be flying constant pressure rather than constant altitude.

Marking of controlled volumes below the altitude boundary may be done in a number of ways. Controlled approach funnels to terminal areas could be marked by radiating a signal (electromagnetic and/or optical) omni-directionally in azimuth, with identifiable characteristics above a boundary angle such as 2°. Alternatively, a family of hemispheres could be established with the aid of a suitable distance-measuring mechanism; used in conjunction with an altimeter, these could give the closest radius of approach for the altitude flown. The advantage of these types of marking would be to permit VFR aircraft to skirt controlled areas without having to do accurate visual navigation.

The marking of the limits of controlled airway lanes between discrete altitudes does not appear to be practicable by any simple means. It appears that uncontrolled aircraft will have to navigate sufficiently well to determine when they are in the general vicinity of these "ribbons," and avoid the reserved altitude ranges with reference to airborne sensitive altimeter information. There is a possibility that a wide baseline hyperbolic reference method could be developed to approximate the airway boundary lines.

Uncontrolled access lanes into terminal airspace for the benefit of VFR traffic could be marked by lights, paint, or other suitable visual means.

III. NAVIGATION TECHNIQUES

The various kinds of flight consistent with the system concepts—along airways, arbitrary flight paths, curved approach paths, and time navigation—can be accomplished by a variety of navigational techniques. It is desirable to extend the capabilities of the present VORTAC system as much as practicable to take full advantage of what exists. It is also desirable to introduce new navigational techniques on an evolutionary basis to satisfy properly the expected future navigational requirements.

A. VORTAC extension

The following extensions of the VORTAC technique merit consideration for further development.

a. Increased VOR antenna heights and improved antenna designs to give straighter, more accurate courses.

b. Experimental addition of a vernier, narrow-beam azimuth capability, compatible with present receiver operation.

c. Auxiliary audibly determinable azimuth indications.

d. Experimental application of a phase distance-measuring mode using the VOR station and the airborne VHF transmitter.

e. Experimental use of a two-station hyperbolic ground system in conjunction with essentially unmodified omni receiving equipment.

f. TACAN improvement studies to assess the possibilities of increased reliability, decreased cost, and simultaneous voice.

B. The provision of simultaneous accuracy and continuity

A basic weakness of the VORTAC type of concept is its lack of continuity—the need for switching stations enroute—the lack of coverage below a critical angle—the fact that all information in the system vanishes during loss of signal. At large distances from the ground facilities, accuracy also becomes a consideration; a small angular error can result in a relatively large position error. For these reasons, it is desirable that a navigational method be made available with both accuracy and continuity, and having the capability of meeting all the system operational requirements. Continuity considerations may be satisfied by an airborne position-keeping system such as automatic dead reckoning. Accuracy considerations may be satisfied by intermittent correction of the dead reckoning displacement and rate information.

The system requires more than a knowledge of position. It is necessary to have steering information to attain the desired terminal conditions of arrival. The fact that these may be attainable through ground vectoring does not necessarily rule out the desirability of providing this capability in many aircraft. Vectoring involves expense and a high communication rate. The alternative of airborne course and program computation can have advantages as regards cruise control, and may be required in any case for mission functions.

C. Self-contained navigation

In view of the foregoing, consideration should be given to—

a. Development of lightweight, low-cost automatic dead-reckoning apparatus, with associated computation of course and distance, and program computation.

b. Development of means for inserting corrected position and rate information into the dead-reckoning apparatus from a suitable fixing device in a different coordinate system.

c. Development of simple course and program computation apparatus suitable for general use to give distance and direction to destination, and steering information for arriving there with prescribed end conditions of altitude and track.

d. Development of simple, economical doppler velocity apparatus as an input for precision dead reckoning.

e. Experimental application of inertial navigation techniques of moderate cost and intermediate accuracy, with intermittent position correction from the ground. Application of flight path control techniques.

D. Hyperbolic navigation

A wide selection of hyperbolic navigation methods is also available, including Decca, Cytac, Radio Web (based on the difference between hyperbolas to give a nearly rectangular grid), and many others. These have the capability of providing accurate fixes, and can be effectively combined with dead reckoning for continuity. Hyperbolic systems have been under consideration domestically for special purposes such as helicopter navigation. They have been successfully used abroad, and appear to merit a place in future evaluations of comparative methods. It is not believed that any extensive additional development of hyperbolic systems of these types would be justified.

The introduction of the foregoing navigation techniques should not require that all aircraft carry any one form of navigation. Flexible airways and arbitrary point-to-point flight both can be approximated by dead reckoning with an ordinary hand computer, with occasional fix correction by any suitable means. Flight directly between VORTAC facilities approximately along the desired path is alternatively possible.

E. Air-to-air surveillance

An alternative method to those previously considered involves holding a station relative to another aircraft that is navigating to the same destination. All-weather, station-keeping means, both cooperative and noncooperative, appear practicable using radar or a variety of airborne position-keeping aids. Their use would permit dispatching of a large number of aircraft within a single block of airspace.

Also, it is probable that aircraft having apparatus such as AI radars will be able to use their air-to-air surveillance capability for emergency collision avoidance in proceeding through traffic to their targets. However, under ordinary conditions, their use would conflict with the traffic control concept of controlled traffic separation by prearrangement rather than laissez faire with last-minute avoidance.

IV. APPROACH AND LANDING

Full instrument landing at high traffic rates, as required by the general operational requirements of the Armed Forces, includes high-performance types. An essential part of any landing system for such aircraft is tight stability control over altitude and flight paths, with flareout programming appropriate to their aerodynamic requirements. A comprehensive flight control activity is needed for this. The ground reference may be supplied in a number of ways, such as radio altimetry, radio beams including localizers, radars both tracking and scanning, etc.

Developments in flareout altimetry and the use of tracking radars are currently well along toward completion. A service test program is needed to assess the possible extent and desirability of their general application.

Methods of potential future interest have been studied, including narrow fast-sweeping beams capable of providing simultaneously an angular reference received in the air and a surveillance indication on the ground.

Investigation of promising techniques for landing should be carried to the point where an enlightened choice can be made as to a preferred method for common system use.

The functions of approach to the landing path may be dealt with in a number of ways. Close control based on computed information from surveillance data is one possibility, currently available using military development-type equipment. Another possibility is the use of airborne navigation and programing to make good an assigned schedule. If the same computation takes place in the air as on the ground, no communication is necessary to state intent when the program is being properly followed. A third possibility is the present procedure used in the absence of radar—flight to fixed points, holding, and dispatching at discrete intervals.

V. SURVEILLANCE OF TRAFFIC

Air traffic control has the advantage that controlled aircraft may be counted on to cooperate, so that a cooperative reporting system is applicable. However, there are the possibilities of mistaken position, equipment failure, or the illegal entry by extraneous aircraft into controlled areas. In such cases, noncooperative surveillance is necessary. But not all aircraft can count on being seen by noncooperative means so that neither method alone is sufficient to assure safety from collision.

A high blip-scan-ratio radar net in the lower frequencies is desirable to give optimum noncooperative detectability through weather. In addition three-dimensional radars are needed to give noncooperative altitude information as a check on aircraft operating cooperatively, and to be able to observe when uncontrolled aircraft begin to wander into controlled airspace.

Cooperative systems of two types appear to merit investigation. In the first, airborne automatic navigation information is relayed via a data link. In the other, aircraft position is determined directly on the ground by measurement of the difference of arrival times at fixed receiving points, and computation by triangulation means at a central computer. In either case, reporting of barometric altitude appears likely to be the most accurate means for obtaining relative height, and will probably be needed.

VI. COMMUNICATIONS

Although military data-link coding and modulation types may eventually turn out to be usable for a common system signaling system, the automatic signaling technique for air traffic control should be chosen on its own merits. Various frequency division, time division, and slowed-down television methods have been proposed in connection with the RTCA SC-41 and SC-52 committee activities and thereafter. It is still necessary to arrive at a practicable, inexpensive fail-safe solution.

It is not intended that automatic communications should displace voice, but rather that they should relieve the congestion on voice channels, while at the same time providing more rapid communications for users of the automatic system.

VII. TRAFFIC CONTROL

In large measure the success of the traffic control system will depend on automatic data handling and *computation.* It appears that digital data-handling techniques are to be preferred for the storage and updating of flight plans, correlation of tracks, determination of schedules, and the like. For certain special purposes, analog computation has advantages—for instance, for tracking a small number of aircraft, or for extrapolating a flight program on the ground which is being calculated in the air by analog means.

The bulk of the traffic control problem lies in terminal areas. Here it is necessary that aircraft be handled on a dynamic basis where they are spaced too closely to be held in blocks. In multiple airport terminal areas, the sharing of airspace becomes a major problem, although some simplification is attainable by the reservation of approach paths to each airport. An extension of semiautomatic computation techniques is needed to cover multiple airports.

Since it is a principle of the system design that the human controller remain the basic decision-making element, and inasmuch as his displays are not adequate to do a satisfactory job in future traffic densities, improved displays of both situation and tabular data are needed. In particular, it is necessary to remove from his consideration aircraft separated in altitude from his area of interest, but which he now sees in two-dimensional display and must therefore allow for with unnecessary "rug weaving." What is needed is a better instrumentation as well as display—presenting selectively three-dimensional radar and reported position data, although not necessarily in three-dimensional presentations.

The programming of machine data operations for air traffic control will differ from those for air defense largely in that the former is concerned with a selection from a store of preplanned possibilities, whereas the latter must handle each aircraft as a special case. A different computer program, with slower followup rates, should be appropriate to ATC.

In some cases, special handling will be desirable, such as at the intersection of busy airways, or where aircraft approaching terminals must descend or climb into other blocks which may be occupied. The surveillance net will have the capability of keeping aircraft separated safely within a block during such procedures. Where traffic would be delayed by holding and could be expedited with special handling by human controllers, it is contemplated that special handling will take place.

VIII. GROUND HANDLING OF AIRCRAFT

The principle of minimizing the common path of aircraft for expediting traffic is as important on the ground as in the air, and in this case a concrete mixer is as important a traffic-handling tool as an electronic guidance system. Fast turnoff strips are necessary to remove traffic from runways before it has occupied them very long. The determination of optimum airport turnoff and taxi configurations is a problem to be dealt with by analysis, simulation, and experimentation.

Ground guidance in all weather is an, as yet, unsolved problem. ASDE is helpful as a surveillance aid, but is not suited to steering and speed control of a large number of taxiing aircraft. Visual signals are in general use, but are not satisfactory down to zero-zero conditions. Magnetic leader cable has been used successfully in some experiments, but requires special apparatus in the aircraft and special means for the transmission of speed control data.

An activity is needed to determine optimum airport configurations, and to investigate and develop suitable ground guidance techniques to permit rapid ground handling of aircraft in all weather.

APPENDIX E. INITIAL CONFIGURATION

I. GENERAL

A major recommendation of the Team pertains to the adaptation of existing technology to the modernization of the system of aviation facilities. The modernization effort should take a long-range view from the outset, so that the improvements which result will fit reasonably well into a consistent national pattern. We set forth in this section, then, initial configurations of the system, and significant segments of the system in consonance with the operational and system design concepts set forth in Sections III, IV, and V of this report.

We recommend that these initial configurations be utilized as the starting point in the modernization process. But, we also recommend that these configurations be subjected to further analysis and test, and corrected as their faults come to light.

II. THE TERMINAL AREA

A. Introduction

Ideally, an aircraft entering a terminal zone would fly a straight descending track to the airport of destination. Similarly, an aircraft leaving an airport would climb out and head directly for this distant destination.

Natural conflicts arise from potentially crossing tracks of aircraft—

- Arriving from different directions and merging into the final approach pattern.
- Arriving and departing.

Additionally, potential conflicts arise from—

- Aircraft arriving from various directions proceeding to different airports.
- Aircraft proceeding from different airports to destinations in various directions.

In the initial configuration, the principle of nonconflicting airspace is utilized to segregate—

- Traffic to and from different airports.
- Inbound and outbound traffic from the same airport.
- High performance, low performance, and helicopter aircraft.

B. Airport air traffic control

The airport will have both visual and electronic paths defined for guiding aircraft on the runway and taxiways to the ramps. Visual and electronic means will be utilized for control of crossing runways, takeoff, and taxi operations. A high definition radar will be utilized to monitor the surface traffic.

The surface situation will be displayed to a controller with a pictorial display, with identity available on the individual targets. Additionally, there will be an associated tabular display showing the clearance status of all aircraft under the ground controller's jurisdiction.

Essential equipment required:

a. Visual aids for guidance, approach, runway and taxiways.

b. Magnetic cable for runway and taxiways.

c. Display "billboards" at takeoff end of runway, crossings and taxiways to provide visual display of clearance to aircraft.

d. ASDE and PPI display, modified to provide alphanumeric data associated with targets.

e. Appropriate data processing equipment, as determined by experimentation.

f. Appropriate voice and ATCSS ground equipment.

C. Final Approach

The final approach configuration is essentially the same as in today's operation. The principal difference lies in the parallel and segregated final approach and outbound patterns.

A three-dimensional navigation path is defined by electronic means to furnish guidance to aircraft.

The final approach is monitored by a traffic controller using conventional GCA techniques. The controller will have access to automatic display of aircraft position and pertinent associated flight plan and clearance information, and will have provisions for automatic transfer of data and control responsibility.

In order to increase the efficiency of runway utilization, experimentation will be necessary on scheduling computers for use during final approach. This will aid the controller in providing safe, accurate spacing for aircraft of different speeds, in order to increase runway utilization.

Essential equipment required:

a. ILAS.

b. GCA with PPI display, modified to display appropriate scheduling, identification and clearance data.

c. Final approach scheduling computer, to be obtained by programming a general purpose digital computer.

D. Initial Approach

Several configurations are required to investigate single airport and multiple airport terminal operation. In all cases a zone will be defined at the beginning of the final approach to permit "path stretching" to reschedule aircraft whose times of arrival differ from that predicted, and holding in the event that runway stoppage occurs. Figure 1 shows a detail of such a path-stretching, or buffer, zone.

In the critical multi-airport case, such as New York, separation of traffic of different airports requires a careful layout of initial approach and outbound lanes connecting the enroute zone with the various airport zones. Figure 2 shows a plan view of an approach configuration with nonconflicting inbound and outbound paths. The lanes are 3 miles wide and 1,000 feet thick, achievable by present techniques of navigation.

These paths are defined by the navigation system (in azimuth) and a glide slope (in the verticle plane). The performance requirement for the equipment is estimated to be:

Navigation System

Azimuth	±0.3 mile.
Range	Area coverage, 40×40 miles.
Vertical coverage	1°–10°.

Glide Slope

Accuracy	±0.1°.
Range	15 miles.
Azimuth coverage	90°.
Vertical angle range	1.5°–5.0°.

In particular areas where there is space to expand the limits of the access lanes, path stretching can be accomplished in the lanes themselves. The glide slope would then be required to furnish vertical guidance for, perhaps, as high as 90° in azimuth. In the New York case, however, the equipment need only cover the width of the access lane.

Figure 3 shows separate "path-stretching" zones used for high- and low-landing-speed aircraft, each with several initial approach lanes, designed to be nonconflicting with other lanes to airports in the vicinity. It will be noted that each "path-stretching" zone feeds separate runways, one long and one short.

A plan view of the pattern showing the relationship between the "path-stretching" zones for both classes of aircraft is shown in figure 4.

In order to provide a high-accuracy definition of the access lanes, and to provide guidance for holding in the path-stretching zones, a hyperbolic system will be utilized to cover the terminal area. Such a hyperbolic pattern is depicted in figure 5.

In considering the capacity of such access lanes, it was assumed that—

Number of landings per hour	60.
Average length of access lane	12 miles.
Average approach speed	180 miles per hour.
Number of paths	4.

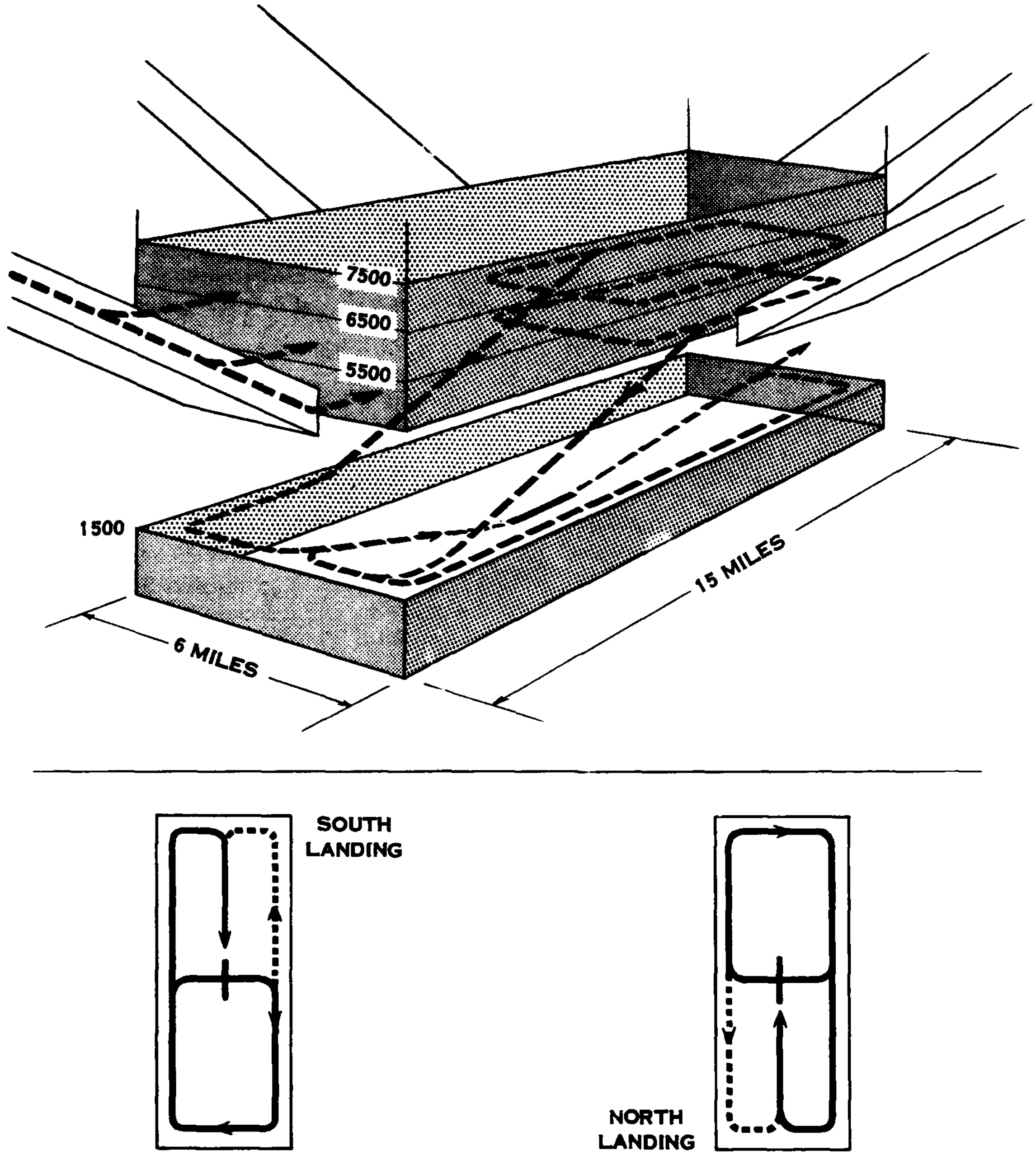


Figure 1.—*HIGH PERFORMANCE BUFFER ZONE.*

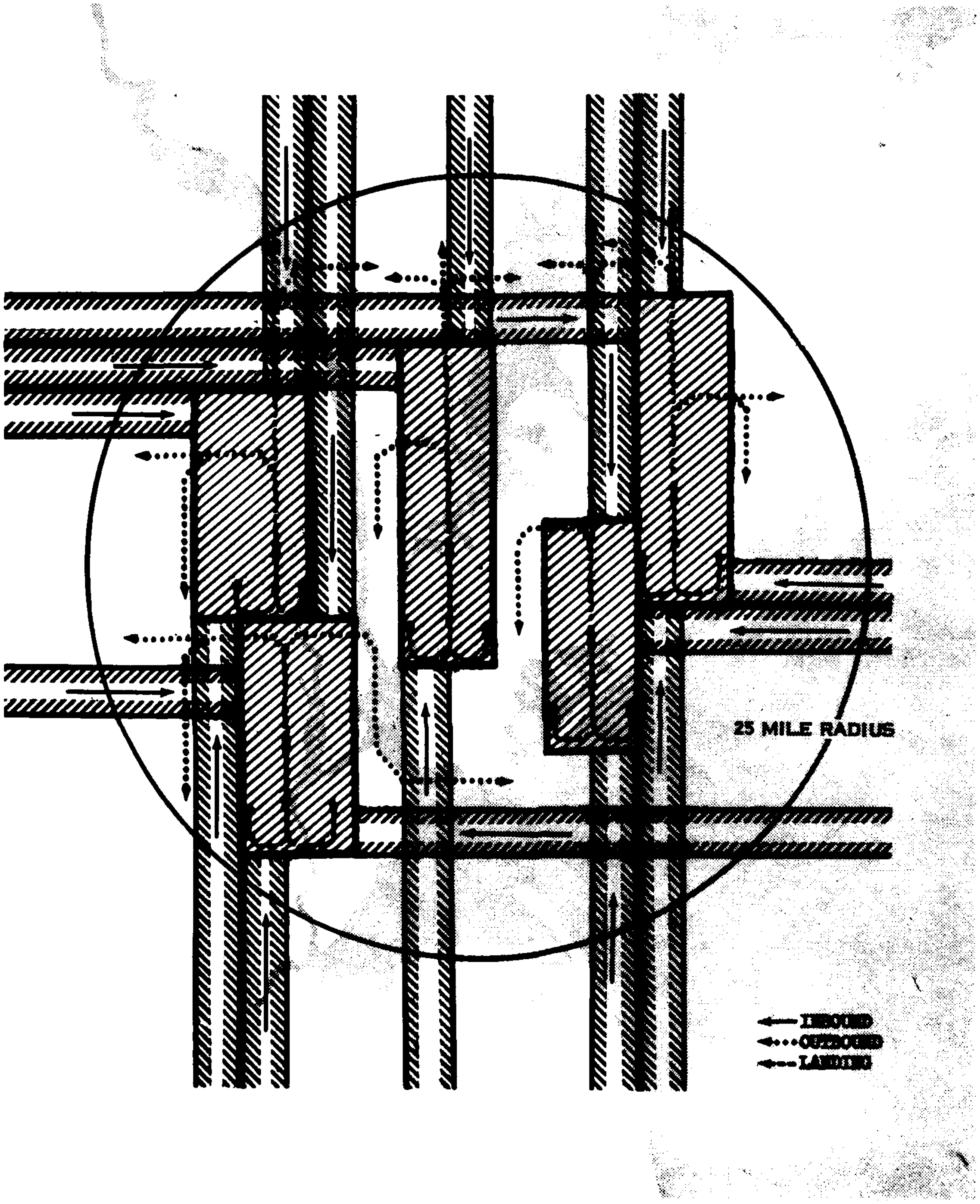


Figure 2.—*MULTIPLE TERMINAL AREA (NEW YORK).*

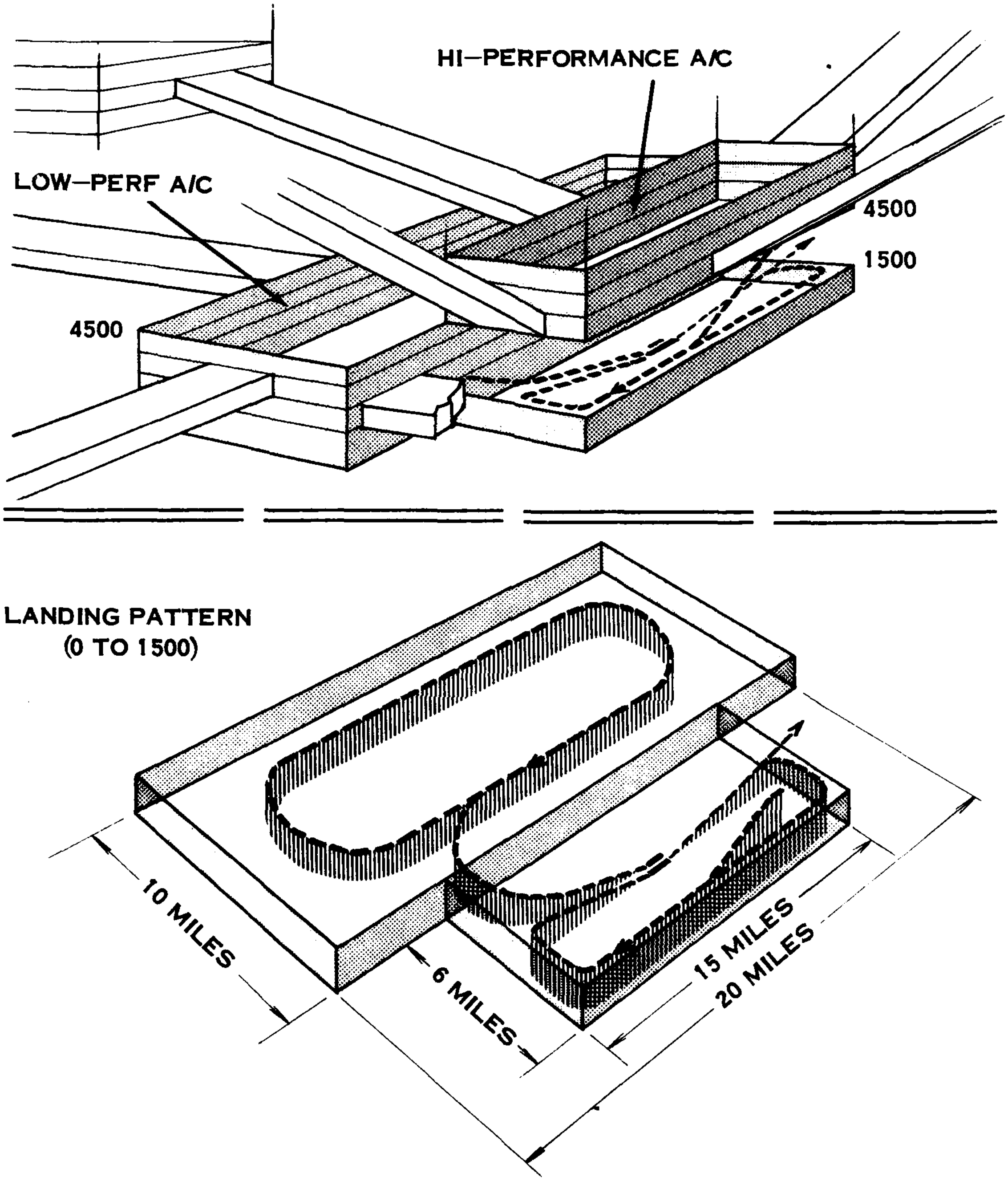

HI—PERFORMANCE A/C
LOW—PERF A/C
4500
4500
1500
LANDING PATTERN
(0 TO 1500)
10 MILES
6 MILES
15 MILES
20 MILES

Figure 3.

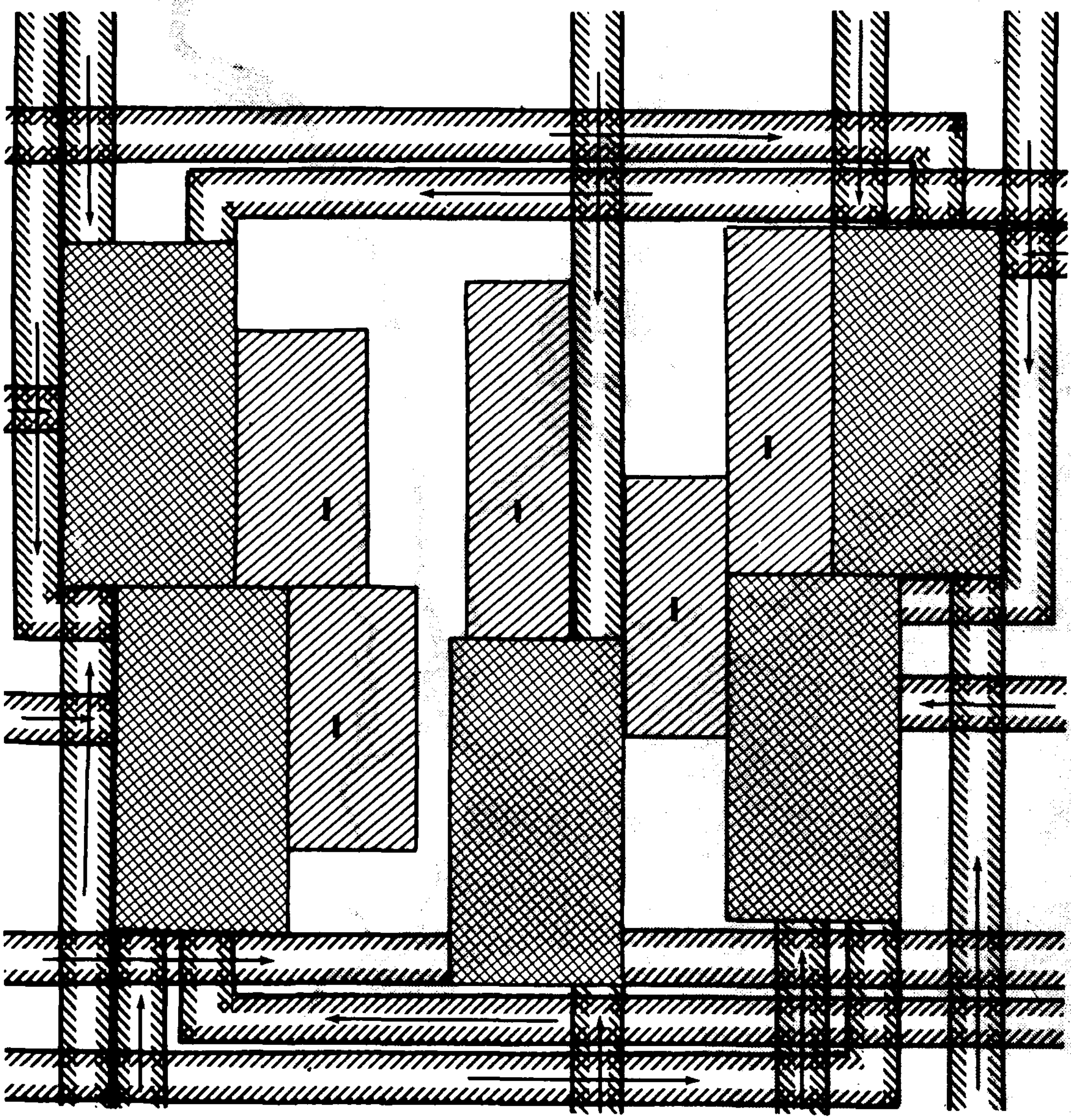


Figure 4.—*LOW-PERFORMANCE TERMINAL PATTERN.*

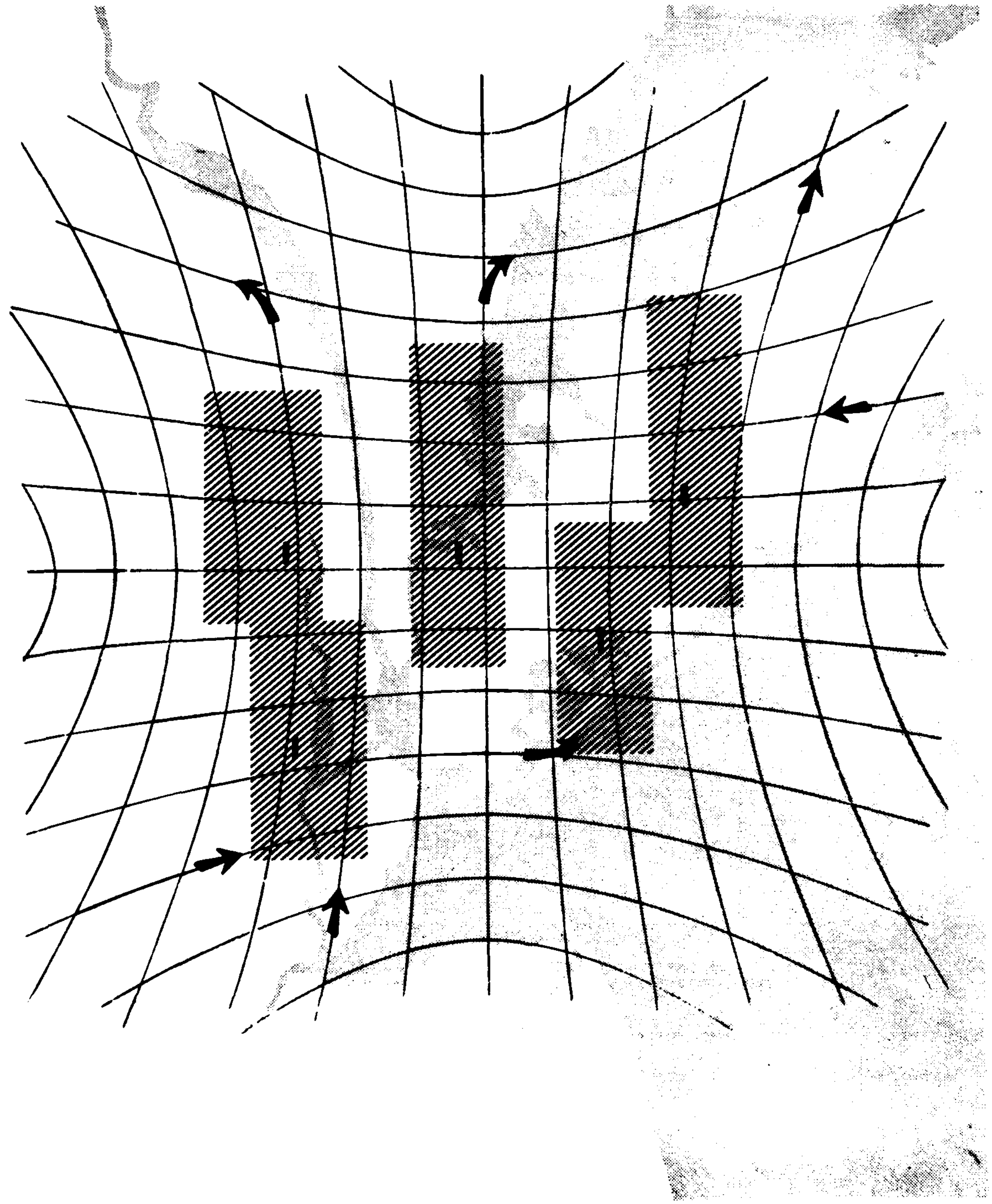


Figure 5.—*USE OF HYPERBOLIC REFERENCE IN MULTIPLE TERMINAL AREA.*

If each path is equally in demand, there will be an average of 15 operations per hour per path. This gives an average of one aircraft on each path at any instant. If minimum separation of 2 miles is used, the loading factor would be on the average 25 percent, giving a peaking factor capability of 400 percent, to allow for partially random input, the effect of varying approach speeds, and unequal short period demand for the different initial approach lanes.

Each initial approach path will be monitored by a traffic controller furnished with a display essentially the same as that furnished the final approach controller.

The equipment performance requirements of the surveillance equipment are estimated to be:

Range	25 miles, 100 percent blip-scan ratio.
Azimuth accuracy	0.3 mile at 25 miles.
Vertical accuracy	0.1°.
Azimuth coverage	360°.
Vertical coverage	1.0° to 10.0°.

If four paths are monitored, the surveillance equipment must cover each path in turn. The minimum data rate per target is considered to be approximately once every 3 seconds.

NOTE.—Experimentally, this technique can be investigated by use of several multi-purpose 3–D radars now in production.

The display to the controller should indicate the position and identity of aircraft under his control, and the optimum position relative to landing time. Figure 6 shows a representation of this kind of display.

While it is not critical that the optimum position with respect to landing time be maintained accurately, the system performance will be more efficient if it is approximated. This can be achieved by—

a. Controlling the time of changeover from high- to low-approach speeds.

b. Requests to increase or decrease speed by small increments.

Tabular information on flight plans and inter-controller transfer of control equipment will be associated with the display. An illustration of this is shown in figure 7.

Essential equipment required:

a. Ground-corrected, self-contained airborne navigation equipment.

b. Hyperbolic navigation system.

c. Vertical glide-slope equipment.

d. Multi-purpose 3–D radars and associated displays.

e. Automatic data processing and display equipment, such as SRS–1 or equivalent, modified to permit symbolic display and transfer of jurisdiction.

f. Voice and ATCSS radio communication, with directional antennas.

g. Scheduling computers for optimum position determination, to be obtained by programming general purpose digital computer.

E. Go-Around

There will be a conventional go-around pattern at each airport for helicopter, low-performance and high-performance runways, each nonconflicting, of minimum distance, returning to the final approach path-stretching zone as expeditiously as possible.

F. Climbout

On takeoff, after traversing a minimum distance consistent with the time required to stabilize climb speed, aircraft will turn on one of several outbound paths leading to the enroute zones. In the case of the multiple-airport terminal area, the outbound lane will connect with an intermediate altitude in a zone peripheral to the terminal zone proper, for further transition to cruise course and altitude. The same equipment is required for this phase as in initial approach.

The climb path will be defined in azimuth by the hyperbolic system, and glide slope in the vertical plane. The path-stretching zone containing those aircraft holding, on final, go-around, and initial climb is located directly over the airport, so that, in the event of wind change, the same navigation reference can be utilized.

G. Initial path-stretching zone

In the single airport terminal case, path stretching can be accomplished throughout the initial approach. Care need only be taken to prevent confliction between inbound and outbound aircraft in general, and when inbound paths merge toward the final approach zone.

In the multi-airport case, path stretching is not done in the access lanes, because of lack of space to do so. Consequently, space must be provided ahead of the access lanes to carry out some path stretching.

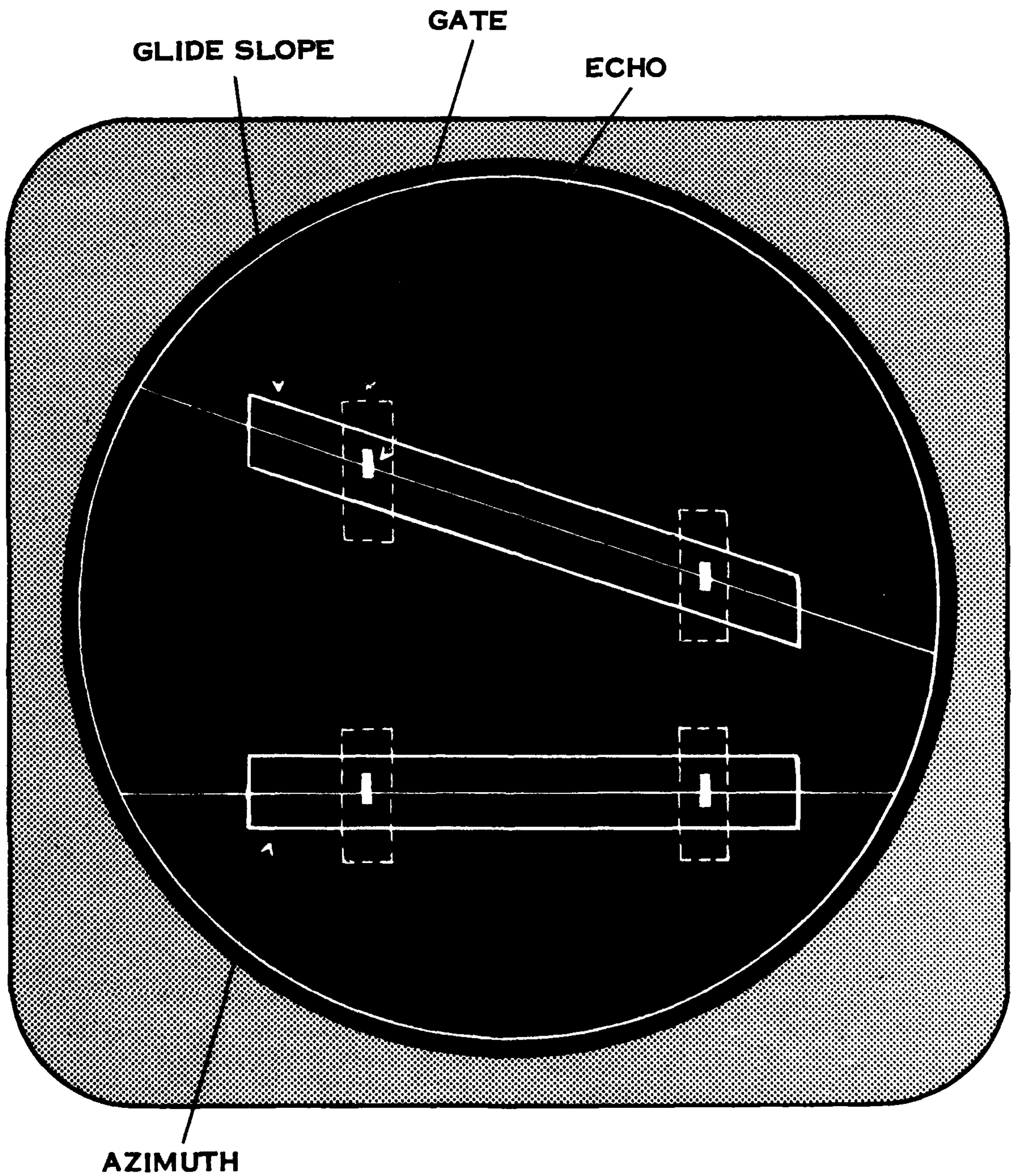


Figure 6.—*APPROACH DISPLAY.*

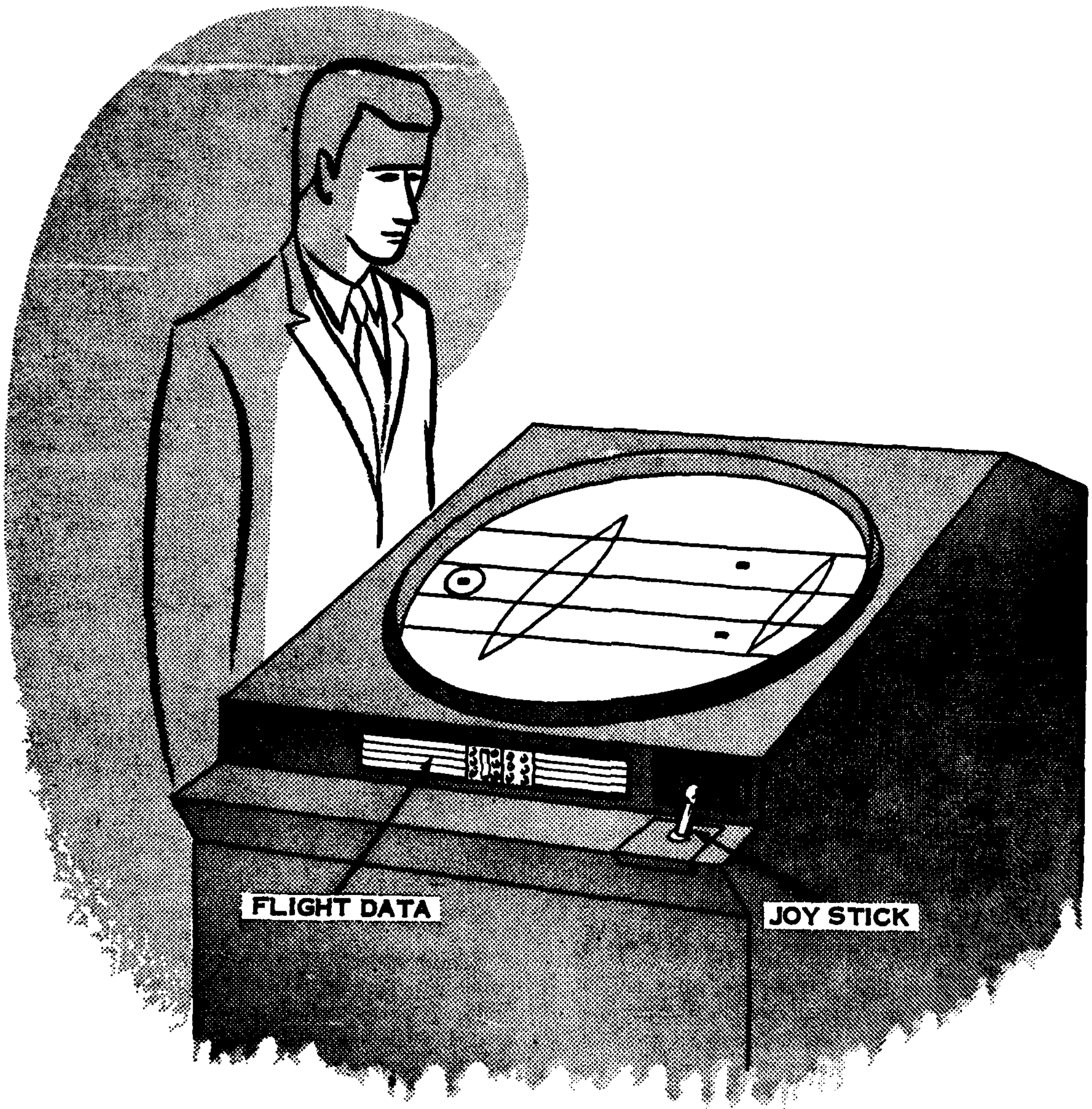


Figure 7.—*DATA PROCESSING.*

Displays A/C with ring for DR position and spot when tracked by radar.

Transfer of control done by displaying flashing ring to adjacent controller. When adjacent controller takes over he pushes button which removes ring from previous display to his display.

Controller can call up data by joystick.

In order to do this, an initial path-stretching zone will be defined which surrounds the terminal areas. Separation of aircraft bound for different airports is maintained in this zone to reduce the necessity for conflict prediction. One or more altitudes are used in each quadrant in the initial path-stretching zone for each individual airport. A scheduling computer, such as the AN/GSN–3, will be used to control the time of entry of each aircraft into the access lane for initial approach. Figure 8 shows the relationship of the initial path-stretching zone to the other elements in the terminal area.

If a pictorial display is provided in the aircraft, the traffic control instructions need not be as rapid as in the classical use of AN/GSN–3 techniques.

In examining the application of this technique to the New York area, it appeared feasible to establish three sets of access lanes to the final approach zones of the various airports: one for high rates of descent for aircraft cruising at high altitudes; one set for conventional rates of descent; and level approaches for low-performance and helicopter aircraft, all separated by altitude. Separate outbound paths would be established for helicopters and conventional aircraft.

Essential equipment required:

a. Ground-corrected, self-contained airborne navigation equipment.

b. Hyperbolic navigation system.

c. 3–D multi-purpose surveillance radar.

d. Scheduling computer—AN/GSN–3.

e. Display and data processing as for initial approach.

f. Radio and ATCSS communication.

H. Transition from cruise to approach altitude

Aircraft cleared to the transition zone will be "fanned out" for easy identification on radar displays, on preselected courses defined by a hyperbolic navigation reference, and cleared to descend to the intermediate altitude and enter the initial path-stretching zone at that altitude. Figure 9 depicts aircraft carrying out this transition on one airway.

In the case of a single airport terminal, a simpler version of this technique can be utilized, and aircraft could be cleared directly to approach control altitude and path-stretching zone.

Aircraft are cleared outbound on leaving the terminal area by this same technique. In areas of low density, classical departure techniques are applicable.

Essential equipment required:

a. Ground-corrected, self-contained airborne navigation equipment.

b. Hyperbolic navigation reference.

c. 3–D multi-purpose radar for surveillance of the transition zone.

d. Same display and data processing as for the initial approach.

I. Control operations

In our analysis of the control operations, with the configuration set forth above, it appears that there will be on the average about three aircraft per controller at any one time. The most demanding operation for air traffic controllers occurs during "close control" conditions. The twin-stack procedures used today involve 3 to 4 aircraft on the average, and can be handled adequately by the controllers. We believe that this postulated configuration is within the possibilities of traffic controllers. We also believe that, with mechanical data processing, meaningful displays, this figure can be increased. In that event, a lower total number of controllers can be utilized.

More important, however, is the conclusion that the human controller can remain the basic control element in the system, and apparently be able to manage much higher traffic densities safely, thus providing flexibility not foreseeable with automatic computation alone.

III. ENROUTE

A. General

A major objective for the management of the air traffic is to permit pilots to fly as nearly as practicable according to their operational desires. For short-distance enroute flying, between proximate centers of population, direct flight paths are desirable. Even if no airways were provided, aircraft would fly directly between, for example, San Francisco and Los Angeles, and between New York and Washington.

For transcontinental flight, the paths flown are variable to take advantage of pressure patterns and to avoid adverse weather conditions. These flights commonly occur above 18,000 feet, and in enroute areas are naturally separable by altitude.

Arbitrary direct flights to and from smaller population centers must also be accommodated. Such

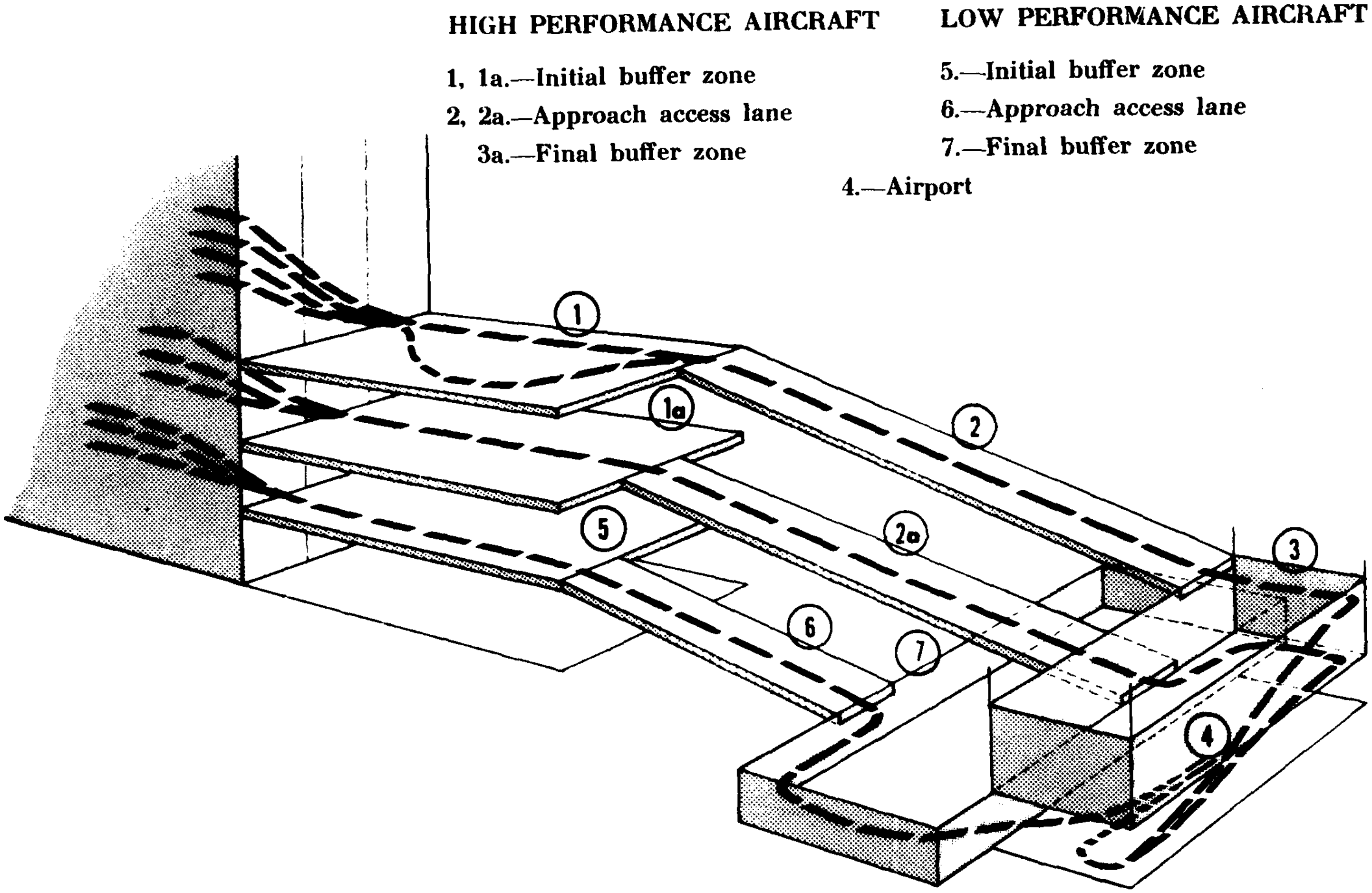


Figure 8.—*INITIAL PATH-STRETCHING ZONE.*

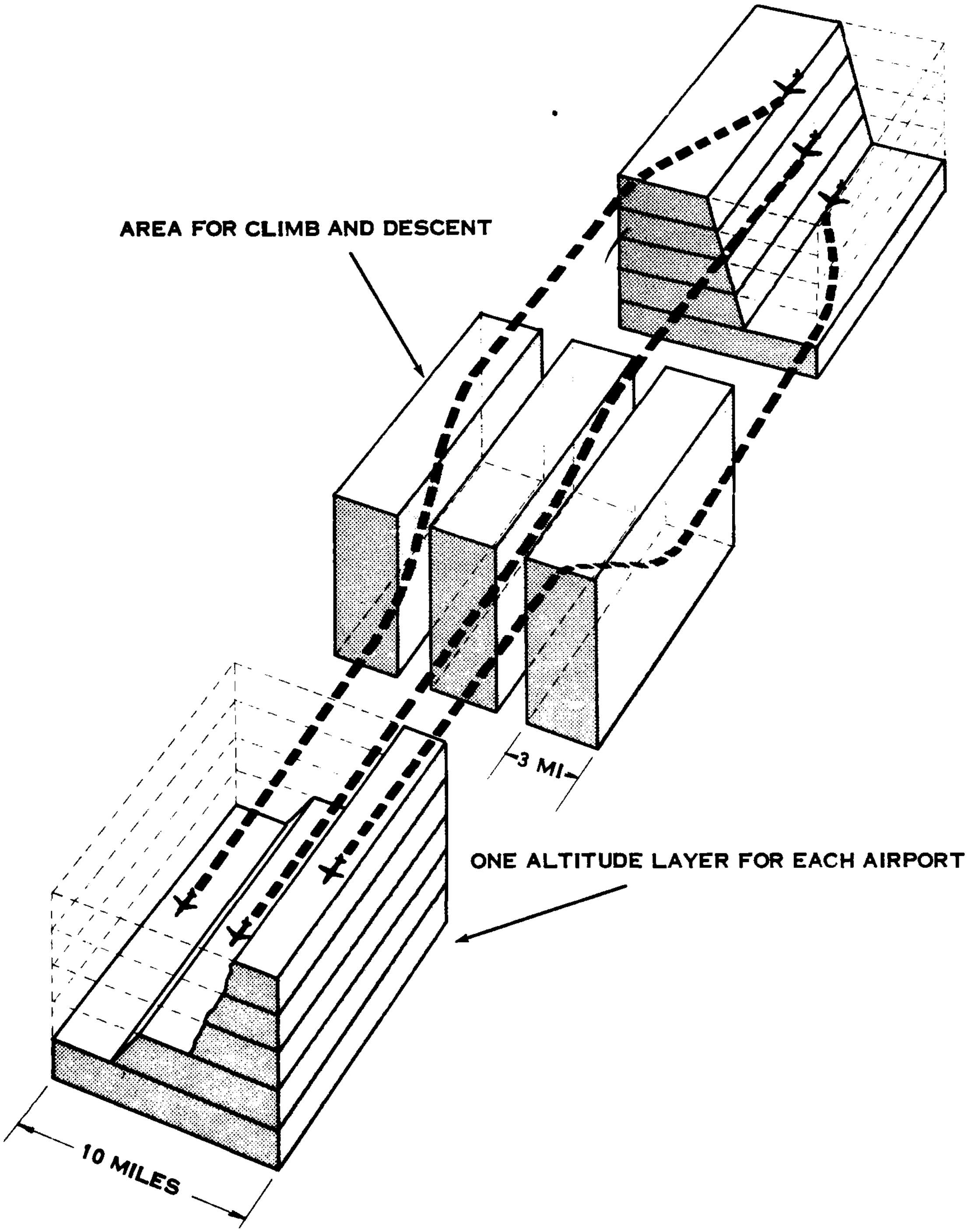


Figure 9.—*ALTITUDE TRANSITION.*

traffic is a modest percentage of the total, and tends to be distributed throughout the country.

Interceptor aircraft need to climb at a high rate of ascent directly from their airbase to a high altitude in the direction of impending attack. Other military aircraft flying at high altitude must increase their altitude as fuel is consumed to obtain maximum endurance.

Helicopters travel at low altitudes on short hauls, directly from point to point. Helicopters, however, because of their low speed and maneuverability can also be separated naturally from other aircraft by flying at lower altitudes and by more precise navigation.

Provisions must be made in the system for all of these kinds of enroute flying. Conflicts arise enroute from—

- Aircraft overtaking on the same course.
- Aircraft whose paths cross.
- Aircraft going in opposite directions on the same course.
- Aircraft whose descent or ascent paths cross.

The principal problem in enroute operations is establishing enough order in the basic path and intersection arrangement so that temporary congestion does not endanger safety, but stays within the manageable limits of the traffic control system.

If this is to be accomplished, several principles should be observed:

a. Minimize traffic control computation by using nonconflicting paths, whenever possible.

b. Separate aircraft by velocity.

c. In high-density operations, lay out paths with a fixed number of intersections, so that in the event of congestion the control stays within manageable limits of the system, and thus does not endanger safety.

B. High-density enroute operations

The paths will be organized in parallel airways, using enough altitudes to accommodate the traffic. A typical high-density enroute area amenable to this kind of path structure is the Washington-New York area. The expected nonstop traffic under the most favorable visibility conditions in this area in 1975 is predicted to be about 150 operations per hour.

Figure 10 shows the initial configuration for the traffic enroute between Washington and New York. There are 6 parallel airways, using 8 altitudes. If aircraft were dispatched at 20-minute intervals, and were segregated by direction of flight and airspeed, about 150 aircraft per hour can traverse this area. If average speeds were 300 miles per hour, there would be an average of approximately 1.5 aircraft on each lane at one time. Two blocks will be used in each lane to provide unique airspace in which each aircraft can hold in the event of stoppage. Two position reports will be required during the flight in the enroute area.

Surveillance equipment will be used to monitor the operation and to provide safe separation at closer spacing for flight-plan changes and for emergency action.

The airways are 10 miles wide, and defined either by a complex of VORTAC's or by a hyperbolic system. Figure 11 shows an airway structure obtainable by the addition of six VOR's.

Assuming that altitudes from 6,000 feet, and above, are used for the nonstop operation, low-altitude "Pogo" airways can be defined for Washington-Baltimore, Washington-Philadelphia, Philadelphia-Atlantic City, etc. Additionally, if warranted, one or more altitudes can be blocked for traffic crossing the New York-Washington airway system.

Several controllers will manage a number of segments of this airway system. Their displays will be mechanized, with provisions for correlation with radar surveillance data and for transfer of control to adjacent segments of the system. Figure 12 shows a possible basic control transfer portion of the display.

The display and correlation of three-dimensional position data requires analysis and experimentation to develop adequate techniques. Initially, position determination will depend on reporting of air-derived position information.

Flight-plan information will be transmitted from the terminal areas involved, both by voice and by teletype, where they will be procesed and displayed automatically.

Essential equipment required:

a. Ground-corrected, self-contained airborne navigation equipment.

b. Hyperbolic navigation reference.

c. Marker beacons.

d. Experimental three-dimensional radars.

e. Voice and experimental ATCSS communication equipment.

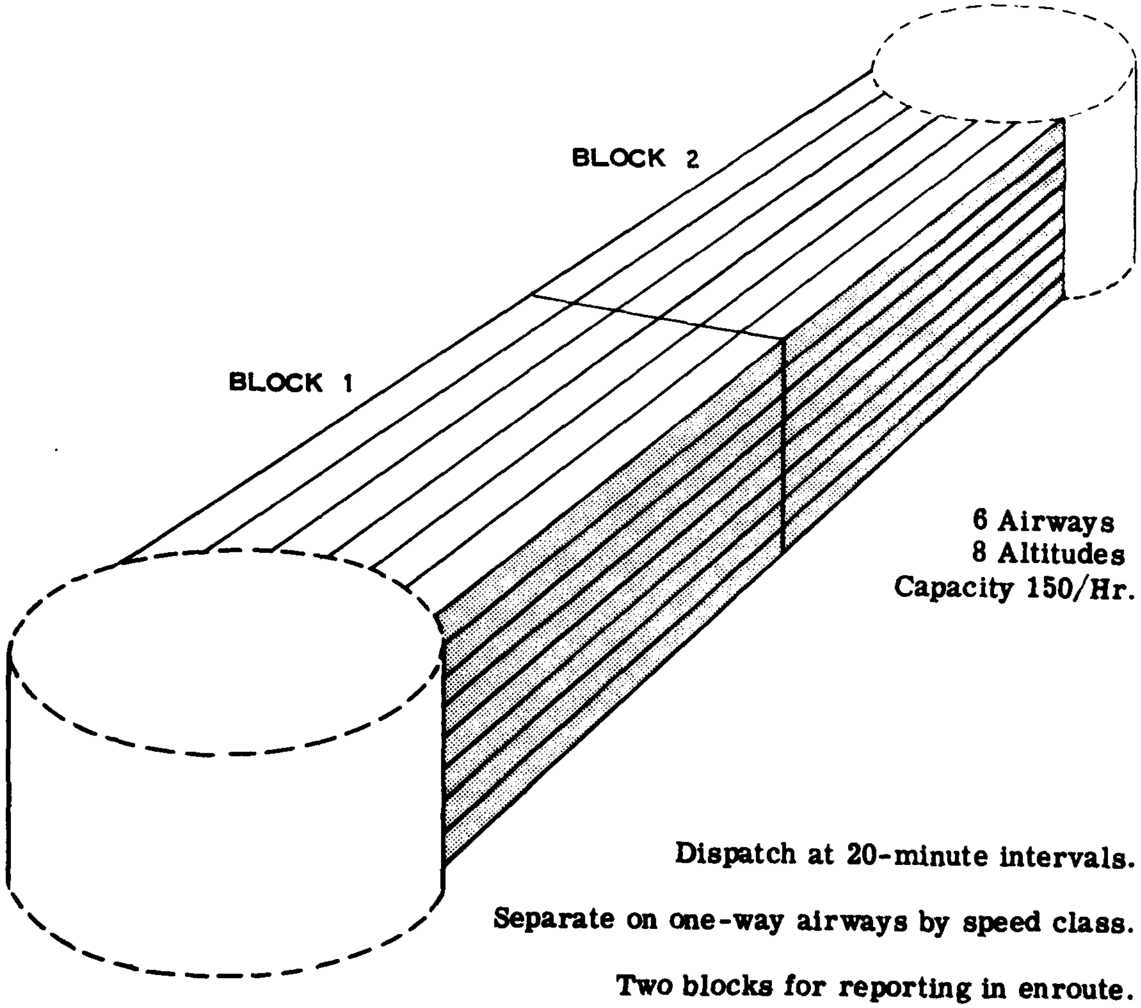


Figure 10.—*ENROUTE. Washington-New York high-density airways.*

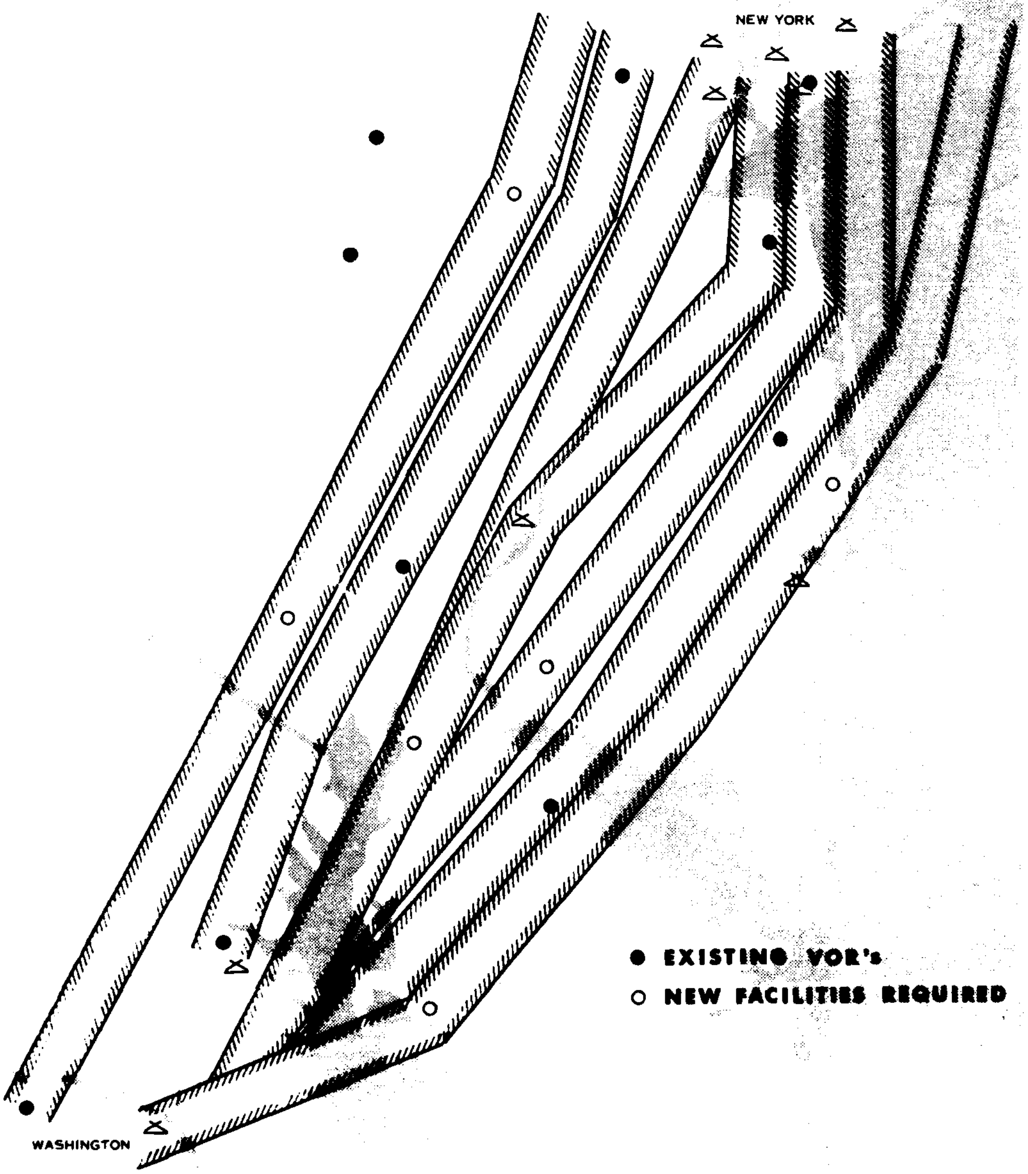


Figure 11.—*PARALLEL AIRWAYS.*

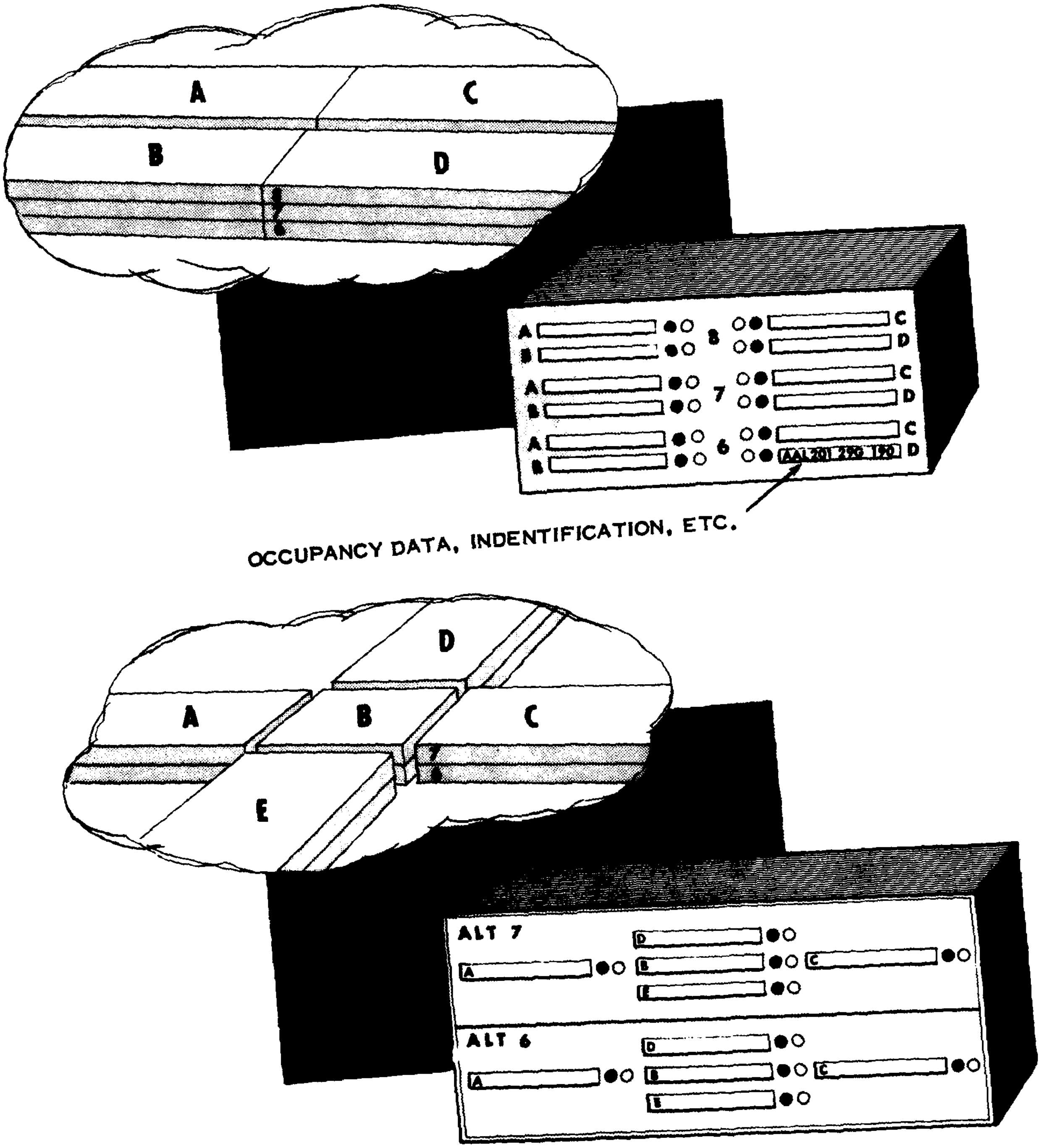


Figure 12.—*DATA TRANSFER.*

f. Data-processing equipment, to be provided by experimental digital equipment, and associated mechanisms, as determined by further analysis and experimentation.

C. Flexible airways

Where space permits, flexible airway structure can be established, movable within limits, so that favorable meteorological conditions can be taken advantage of, and adverse ones avoided. In a particular area and at particular densities of aircraft operation, the bending of airways without introduction of substantial additions in "fixes" or intersections leaves the air traffic control problem substantially unchanged. The exception is that an additional detailed agreement must be established between pilots and controllers on the exact pattern desired.

Figure 13 shows an airway structure in position, and also "bent" to bypass certain areas. It will be noted that the intersection is transposed, but does not add another intersection if the "normal" and bent airways are not used simultaneously at the same altitude. If they are, four intersections occur where one was before.

Transposition of fixes and airways can be mechanized by manual insertion of new parameters into the data-processing equipment, so that transposed distances and positions automatically are calculated for a particular "bent" configuration.

On the ground, there will be a pictorial display of the area, on which aircraft and airways will be displayed along with pertinent identification and clearance data.

For this kind of operation, computational capability will be necessary in the aircraft in order to form a basis for *defining* and *agreeing* on a particular transposition. This computation need not be furnished by particular equipment, as long as the function can be performed with the required accuracy. A fundamental technique which will be part of the initial configuration is an airborne pictorial display, on which can be laid out the transposition required. Using a hyperbolic navigation system as the basic grid reference, paths can be defined, and compulsory reporting points can be established by plotting on the hyperbolically distorted coordinates. Figure 14 illustrates such an arrangement. Surveillance radar, even without height finding, is more useful in this configuration, because of lower aircraft densities making the identification problem simpler.

Essential equipment required.

a. Ground-corrected, self-contained airborne navigation equipment.

b. Hyperbolic navigation system.

c. Marker beacons.

d. 2–D long-range radars.

e. Voice and experimental ATCSS communication equipment.

f. Pictorial display.

g. Mechanizing data processing for display, correlated with tabular information on clearance, etc., to be provided by SRS–1 equipment or equivalent, modified for symbolic information and data transfer.

h. Airborne pictorial display equipment.

D. Arbitrary track flying

Where the demand for airspace is light, arbitrary track flight can be accommodated without an inordinate amount of controller and computation effort. Again, the hyperbolic reference is used as a grid system, with blocks defined by the navigation reference structure.

Clearance is issued as a function of the block structure similar to that performed in the Atlantic sector of the New York center. Figure 15 shows the configuration for arbitrary flight air traffic control.

Essential equipment required:

Same as flexible airways, with exception of displays and data processing tailored to arbitrary block clearance.

E. Intercept operations

Figure 16 shows an arrangement of precise three dimensional paths to be used for outbound intercept operations, and which may also be useful for return to base operations. Multiple high-precision beams are formed by a navigation system, pointed in the most likely direction of attack. Wherever possible, and determinable specifically only with respect to the local airway structure, the precise paths should be arranged so as not to conflict with the airways. Where this is not possible, one or more altitudes should be reserved through which a precise attack beam may pass. If these altitudes are needed to handle routine traffic, then the intersection will be treated as a potential path-stretching zone, and

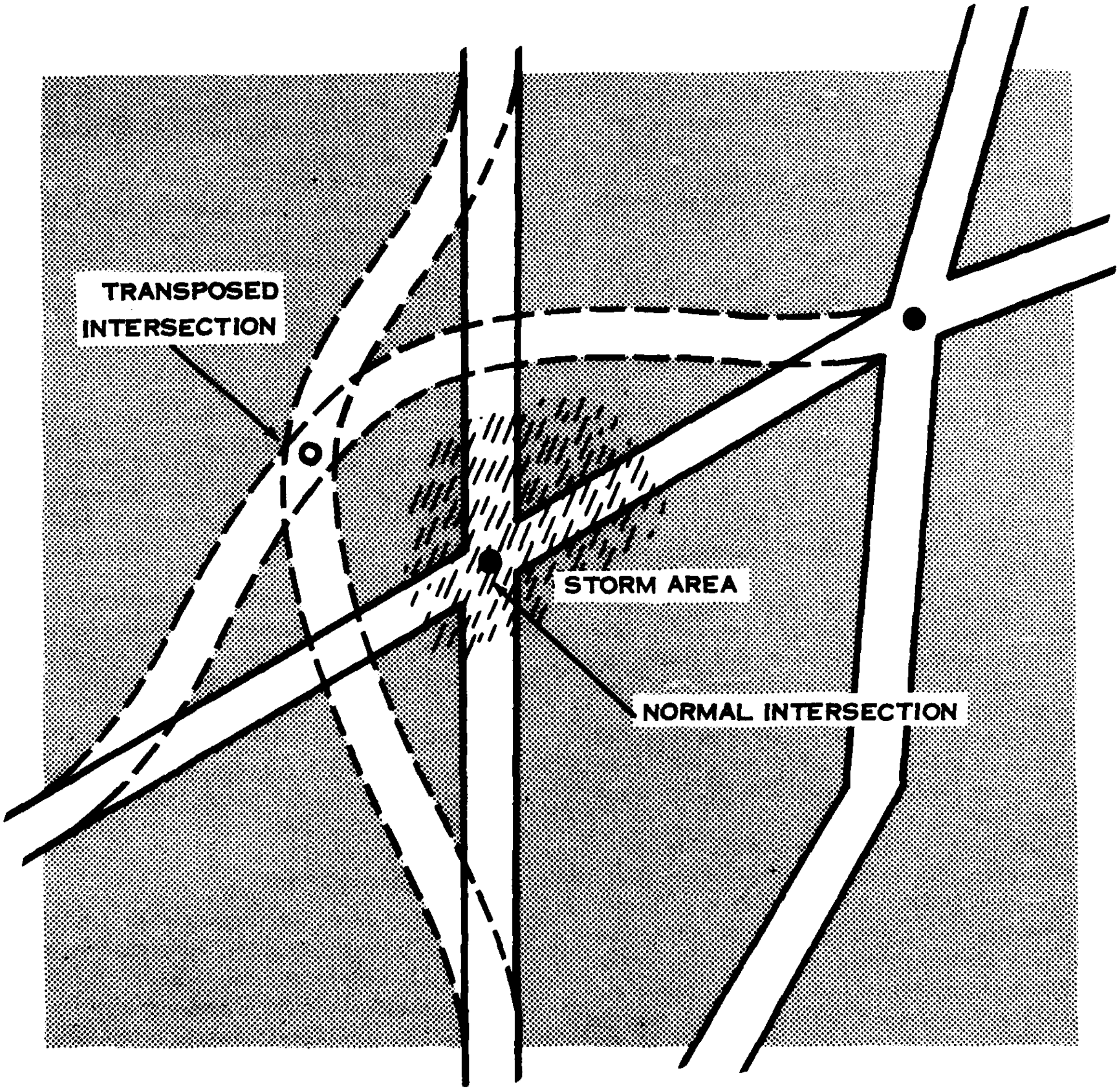


Figure 13.—*FLEXIBLE AIRWAYS.*

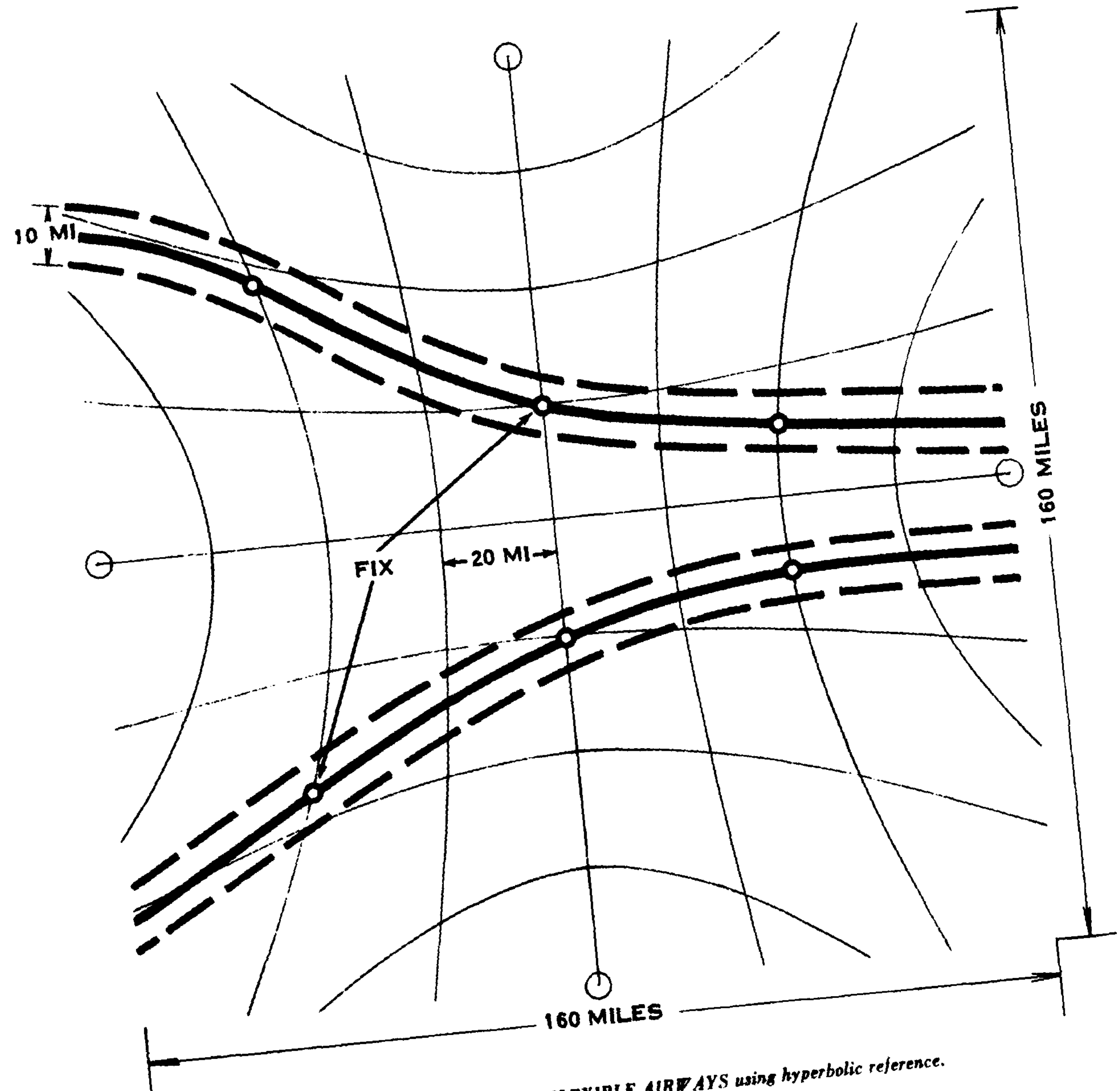


Figure 14.—*HIGH-ALTITUDE FLEXIBLE AIRWAYS using hyperbolic reference.*

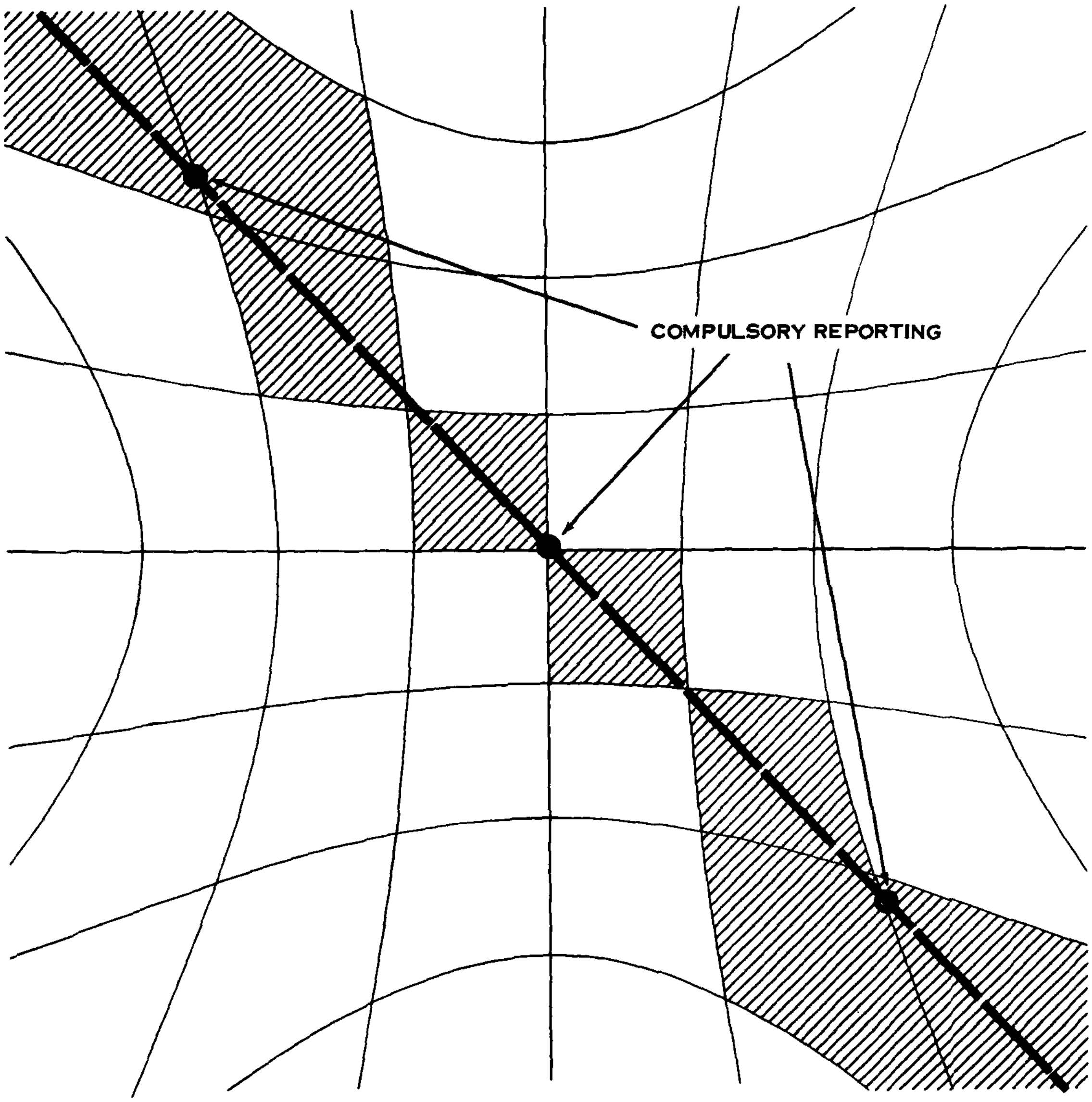


Figure 15.—*ARBITRARY AIR TRAFFIC CONTROL.*

routine traffic will be controlled through the intersection by radar separation.

Takeoff of an interceptor aircraft will be coordinated with the appropriate air traffic control center, *and acknowledged*, in order that appropriate vectoring procedures will go into force. It is expected that a clearance limit will be necessary at these points.

Essential equipment required:

a. Precise 3–D attack beams formed experimentally by parabolic localizer and glide slope, modified to obtain longer range.

b. Mechanized communication equipment between interceptor airborne and air traffic control centers.

F. Variable altitude flight

It is expected that, with the establishment of controlled separation above 18,000 feet, variable altitude flight can be accommodated by step-climb techniques now in force.

G. Airports

The typical high-density terminal will require separate runways for various classes of aircraft. Figure 17 shows the general relationship between flight patterns of three runways at the same airport. The initial configuration for a multi-purpose airport will have:

a. A helicopter pad.

b. A short runway for STOL and slow-landing aircraft.

c. A longer runway for conventional aircraft.

No initial geometric configuration is postulated here, because of the lack of analytical and experimental data on this subject. Before carrying out experimentation on airports, initial work will be done on analysis and simulation of various configurations.

The equipment believed to be required includes—

a. High-intensity approach and runway lights.

b. Runway marking.

c. Runway visual range equipment.

d. Runup and bypass pads at runway ends.

e. Standby power for facilities.

f. Bidirectional navigation facilities.

H. General

Apparatus for predicting future loads on various elements of the national aviation facilities, and to disseminate this information throughout the system will be provided in the initial configuration. The equipment will consist of a system of counters using estimated time of arrival data on aircraft, and displays to show predicted load against time. Figure 18 illustrates a form of display which can be produced simply. These displays can be made available, not only throughout the system but in connecting dispatch offices and airports operations office.

APPENDIX F. AIRPORTS

I. INTRODUCTION

Long-range planning for the Nation's aviation facilities requires thorough consideration of all elements—airways equipment, airports, procedures, manpower, regulations, and aircraft. We have found that airport capacity can be predicted with reasonable certainty, but there is a greater possibility of growth in capacity of the airspace. Further, many airports today are operating to capacity. Airports must be planned as an integral part of the aviation facilities to assure that adequate airport capacity is available as the remainder of the system capacity grows, and as air traffic grows.

We have considered those phases of airport planning that affect airport capacity—procedures, approaches, runways, taxiways, and navigational aids. We have also examined the information and assistance needed by airport planners to increase present airport capacity and construct new facilities. Thus, our report covers airport capacity, the need for and design of new operational facilities, and recommendations on the role of the Federal Government in airport development.

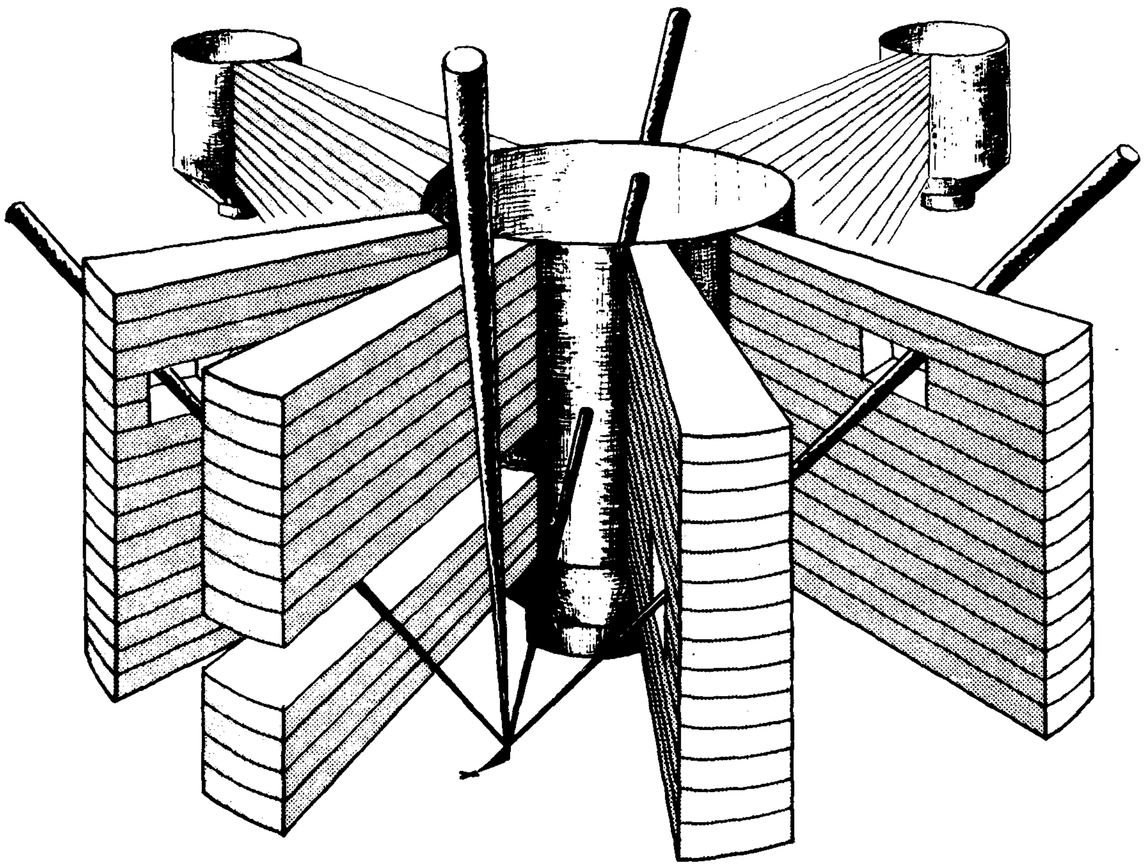


Figure 16.—*INTERCEPTION AND RETURN TO BASE.*

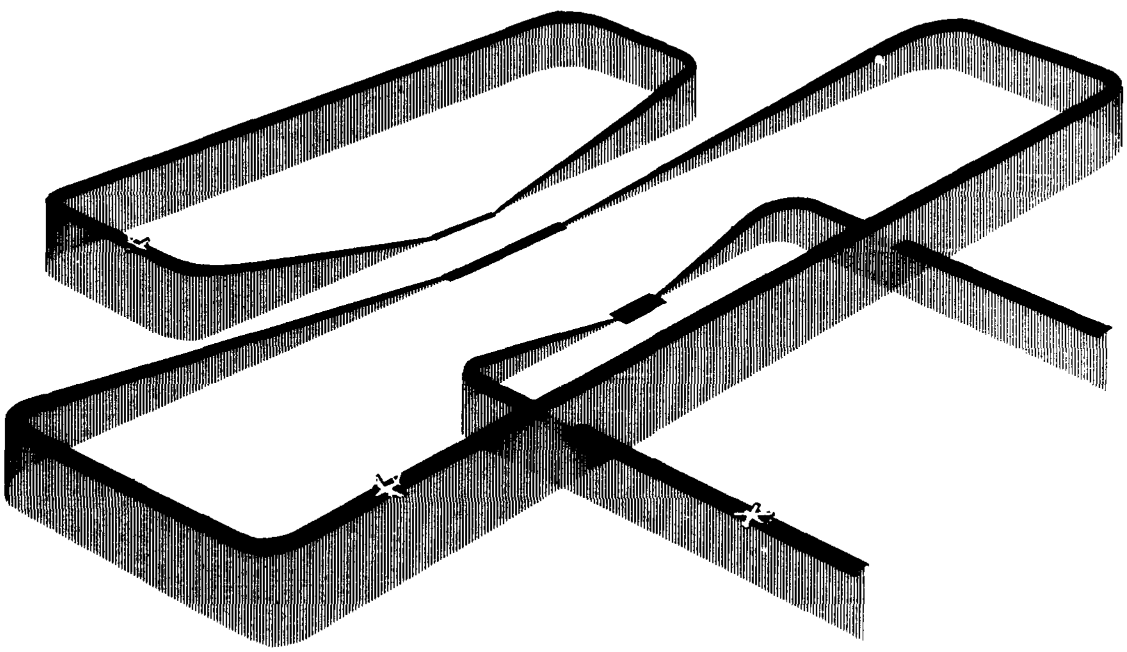


Figure 17.—*MULTI-PURPOSE AIRPORT PATTERN.*

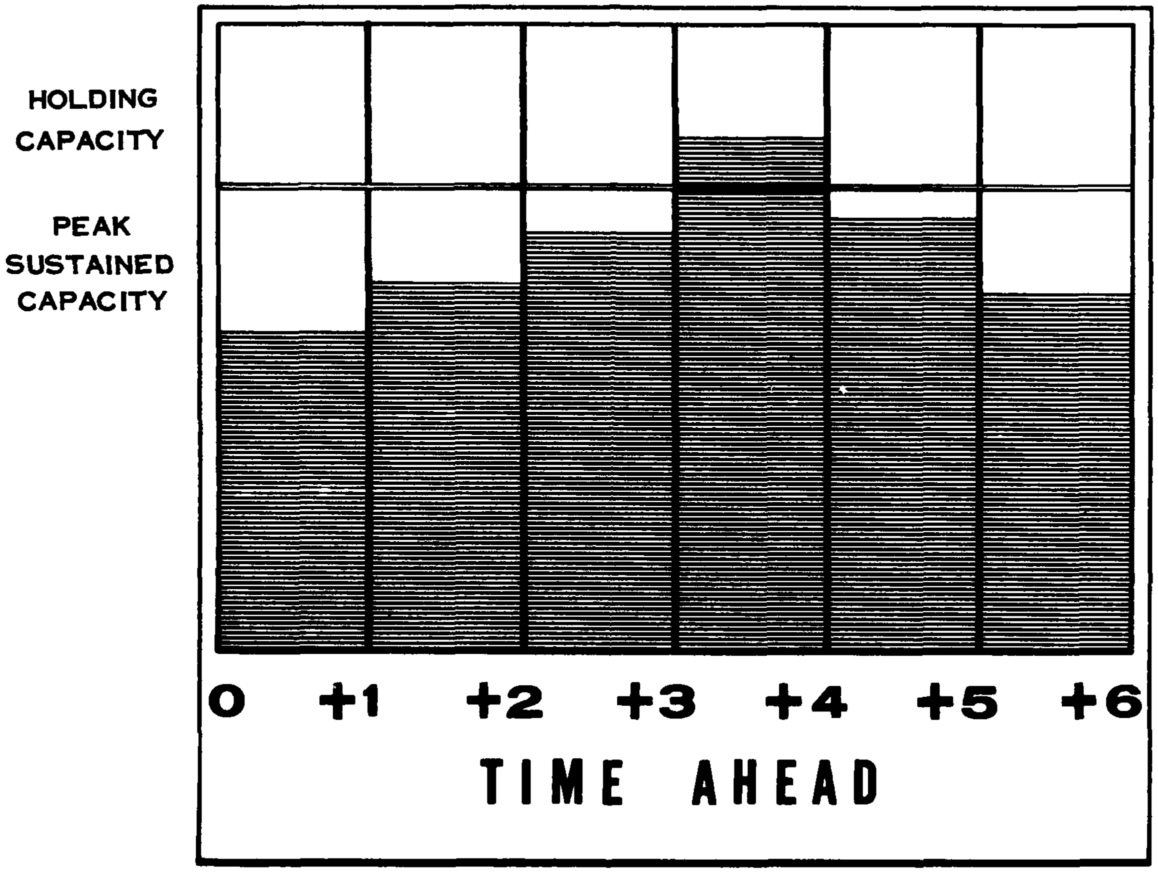


Figure 18.—*FLOW CONTROL DISPLAY.*

II. THE NEED

The air traffic control system controls an aircraft from the time it leaves the originating terminal gate on one airport until it ends its trip at another gate on another airport. To attain maximum capacity of this system, uniform facilities, procedures, and regulations should be applied throughout all phases of the system.

By 1975 we must provide aviation facilities to accommodate air traffic composed essentially of the following:

a. Air carrier traffic—increase to 150 percent of plane movements today.

b. Itinerant air traffic—increase to 400 percent of today's traffic.

c. Helicopter or STOL traffic—one-third the total 1975 air-carrier movements in large metropolitan areas as New York.

This projected increase in aircraft movements means that we must do all that is practical to increase the capacity of existing airports and then plan ahead to provide additional airports as they are needed in the large metropolitan areas.

III. AIRPORT CAPACITY

The outstanding growth forecast in itinerant air traffic indicates that its composition should be studied to determine the extent to which this traffic can be integrated with air carrier traffic and still keep airport facilities operating at maximum capacity. The forecast indicates that a large percentage (70 percent) of this traffic will be the type whose gross weight is 10,000 pounds or less. It is probable that the bulk of this type aircraft will have a low approach speed and short runway requirements compared to the transport types. Thus, where maximum airport capacity is required, it is desirable to provide separate landing and takeoff facilities for small aircraft. Preliminary criteria are included for such facilities.

IV. AIRPORT CAPACITY FOR TRANSPORT TYPE AIRCRAFT

The installations needed at airports to give acceptance rates are reasonably well known. Those in common use today are listed as follows:

a. Surveillance radar, such as ASR–3.

b. Instrument landing systems and precision approach radar.

c. High-intensity approach lights on all instrument approaches.

d. Runways of adequate length and width.

e. High-intensity edge runway lighting.

f. VHF and UHF communications.

g. Runway painting.

h. An adequate taxiway system properly marked and lighted.

Additional navigational facilities needed to increase airport capacity are—

a. ASDE radar.

b. Flush runway lighting.

c. Runway visual range measuring equipment for each approach.

d. High-speed turnoffs clearly marked for all-weather recognition.

e. Runup and bypass pads on taxiways leading to runway ends.

f. Bidirectional approach facilities.

g. Provision for standby power and components at all facilities.

Airports equipped with these modern facilities will have predictable runway capacities as shown in figure 19.

It should be realized that the achievement of these capacities is dependent on unrestricted use of the airspace for approach to the airport. Airports which are located such that they interfere with the traffic of one another cannot be expected to attain the capacity indicated. The determination of their capacity will require detailed local analysis.

Speed variation between aircraft on final approach has an effect on airport capacity. Therefore, we based the capacity forecast on a mixture of transport aircraft such as might occur in the future at a large commercial airport and with corresponding long runways:

30 percent large jet-type aircraft (DC–8, B–707).
30 percent large piston or turboprop aircraft (L1649A).
30 percent medium piston or turboprop aircraft (CV440).
10 percent slow aircraft (DC–3).

A more uniform composition of aircraft would tend to make the forecast capacities conservative. Assumptions made with regard to final approach conditions are discussed in greater detail later. The forecast of future IFR capacities is based on the use

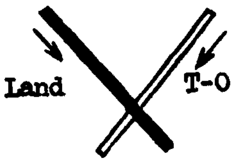
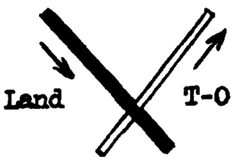
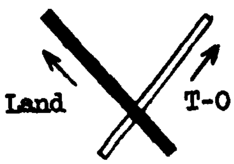
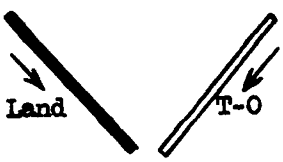
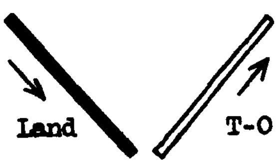
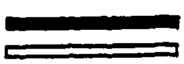
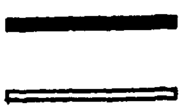
Runway Configuration	*Operational Description*	*Capacity in Movements per Hour*	*Qualifications*
	Alternate landings and take-offs.	50	
	Do.................	55	This combination usable only during light wind conditions.
	Do.................	60	Do.
	Do.................	85	Do.
	Do.................	65	Do.
	Do.................	100	Do.
	Do.................	75	This combination usable for parallel runways with minimum of 750 feet.
	Simultaneous landings on one runway and takeoffs on another.	100	This operation dependent on runway separation. Current opinion on separation required is 3,000 feet.

Figure 19.

of runways equipped with high-speed (60-knot) turnoffs.

If we are to achieve the capacities predicted in figure 19, it appears necessary to reduce separation on the glide slope to a minimum of 2 miles. In addition, a mild form of speed control appears necessary to assist in obtaining the optimum spacing along the approach path. It may also be possible in the future to shorten the distance from the outer marker to the runway, which will make possible a further increase in approach capacity.

The combination of these three factors has been analyzed in the CAA Technical Development Report No. 251 to indicate that, with these criteria, the acceptance rate per hour of a runway would be 50 aircraft. This capacity would apply to a mixture of 20 percent high-speed (L1659A) type aircraft, 33 percent medium speed (CV-240) type aircraft, and 43 percent (DC-3) type aircraft. Changes in this sample to get a higher percentage of the medium and fast aircraft whose approach speeds are similar will tend to increase the runway acceptance rate. This increase would bring it in line with the runway capacities predicted in figure 19.

Another item which may control, or at least seriously affect, runway capacity is turbulence along the approach path due to wingtip vortices. The data which are available indicate that the separation required between aircraft to avoid loss of control due to excessive turbulence is about 60 seconds in calm air. This value must be verified. It appears, however, that it is not a limiting factor, for the predicted runway capacities.

It should be borne in mind that the predicted capacities are meant to be working capacities and thus can, and possibly will, be exceeded for short periods such as 15 minutes. In planning airport facilities it may also be desirable to study traffic predictions over periods longer than a peak hour. If the peak at an airport is of short duration, such as an hour, it may be possible to avoid additional runway construction for some time by letting the peak-hour traffic be delayed into the adjacent hours. The effect on service at the airport and service to the community will have to be weighed in adopting this approach.

V. AIRPORT CAPACITY FOR SMALL ITINERANT AIRCRAFT

Aircraft of this type will generally weigh less than 10,000 pounds and have the following operational characteristics: landing and takeoff area—2,500 feet in length, approach speed not in excess of 80 miles per hour. Approach at this speed and letdown to a landing strip at the standard rate of 500 feet per minute results in a 14:1 approach angle as compared to larger aircraft where a 20:1 approach results. Other differences result from the slower approach speed. Straight-in approaches to a runway need not be as long, even under instrument conditions. And these aircraft can maneuver and divert from a much lower altitude than can the large transport aircraft. These basic differences should make it possible to achieve maximum safety along with maximum airport capacity if the airport traffic patterns and runways for both types of aircraft can be separated

Typical of small itinerant aircraft would be the Aero Commander, the Twin Bonanza, and the Piper Apache. In the air these aircraft can efficiently use smaller patterns, steeper descents, and then on the ground use shorter runways. Their ground facilities can be independent even though they are located on a transport airport. This will make the entire capacity of the longer runway available for transport-type aircraft, and at the same time will keep the light aircraft out of the areas of turbulence caused in the air by wingtip vortices and on the ground by jet blast. The added ground facilities will provide an appreciable overall increase in airport capacity.

The capacity of runways serving itinerant aircraft is difficult to predict, for there is a lack of recorded data available on current operations. It appears, however, that the hourly capacity of a single well-planned and controlled runway should be in the neighborhood of 75 to 100 movements.

To accommodate small itinerant aircraft at an airport used mainly by transport aircraft, it would be desirable to provide short runways, parallel to the main transport runways. It will be preferable to locate the short parallel runways so that they are almost a separate airport on the main airport, and thus provide a natural separation of ground traffic. On large airports already planned or in existence with parallel runways for transport-type aircraft, the addition of a third parallel short runway may complicate the ground handling and crossing problem to an extent that will make it undesirable to add small runways for itinerant aircraft. This subject must be studied locally to determine the best approach.

The layout of the parallel runway will require much study, particularly if it cannot be isolated from the main runways. In such case, there will be a problem in laying it across paved taxiways and runways due to the problem of matching existing pavement contours. Fortunately, the runway for the small aircraft would be light paving, and the aircraft can accommodate pavement variations to a greater degree than the heavy aircraft. Where runway layouts are such that aircraft must cross another parallel runway to reach a terminal area, it is desirable to use visual or electronic control aids to accommodate this crossing problem during high-capacity operation. Development is needed to provide for this crossing signal.

Many of the aircraft using the small runway are the type which can operate in IFR weather, possibly not to the low minimums of transport-type aircraft, but certainly they can operate in or above clouds and descend out of an overcast on instruments. Accordingly, an attempt should be made to establish separate approach procedures and separate instrumentation for the small runway handling itinerant aircraft. The slower approach speed and the steeper glide path provides to some extent a natural separation between the glide path to the transport-type runway and the itinerant runway. In fact, the difference in glide path is sufficient that at an altitude of 1,500 feet, the outer marker for the two runways would be 2 miles apart, even though the runways are only 750 feet apart on the ground. This spacing will help increase approach capacity, although staggered approaches between the two glide paths may be necessary.

VI. HELICOPTERS

Helicopters or STOL aircraft will generally be operating directly from one downtown facility to another downtown facility. However, a substantial number of helicopter and STOL movements will operate into airports in order to accommodate connecting traffic and for the delivery of fixed-wing passengers to and from local communities. Accordingly, the landing area for this operation and the air traffic patterns should be carefully considered.

Helicopter approach and departure paths into an airport should be completely isolated from fixed-wing approach and departure paths, so that the operation is almost completely independent from fixed-wing activity. There will be a requirement for the controller to provide coordination between the two aircraft types, but this should not be time consuming and should only be a monitoring operation. The landing area should also be independent of fixed-wing activity, so that the helicopter does not interfere with, or does not suffer interference from, fixed-wing aircraft. Once the helicopter has approached the landing area, it may be desirable to air-taxi under ground control, just as fixed-wing aircraft, to a loading position. However, it may be more convenient at some airports to isolate the loading and unloading of the helicopter to avoid mixing it with fixed-wing traffic.

If helicopters are handled as indicated above, their operation at an airport should not affect its capacity for handling fixed-wing aircraft. Thus the addition of the helicopter will again make for higher utilization of existing airport facilities.

VII. LOCAL OWNERSHIP BUT FEDERAL LEADERSHIP

Our national system of aviation facilities in large part is a federally owned and operated system. The major exception in the system is the airport. Almost without exception airports are owned and operated by local, municipal, State, or independent groups. This is a desirable situation in that it permits the local governmental bodies to control and develop their airport.

In addition to the local ownership of airports, there is one other factor which distinguishes them from other aviation facilities—this is the factor that airport financing, in general, is based on relatively long writeoff periods—20 to 30 years. To assure the financial stability of bond issues on such a long-term base, it is important that airport planning be based on sound, long-range forecasts.

These characteristics of our airport system and the need for additional airport capacity point up the need for vigorous Federal leadership in the advance planning and development of our Nation's airports. Federal leadership or assistance is needed in airport location, airport community problems resulting from aircraft growth and noise, airport experimentation and long-range air traffic forecasts.

VIII. SPACING BETWEEN AIRPORTS

The location of multiple airports in a metropolitan area will greatly influence their respective capacities.

In fact, if airports are located too close together they can hinder one another to the extent that two airports will have no more capacity during IFR weather than a single airport. Further, it is desirable to develop one airport site to its maximum potential before constructing another airport. The greater the number of airports, the more complicated is the approach system which must be utilized. The general operational criteria for airport location can be summarized as follows:

a. An airport should be developed to its maximum capacity with parallel runways before a second airport is constructed. The second airport, or any others needed, should be located on either side of the first airport with the instrument runways of both airports parallel.

b. The recommended spacing between airports is on the order of 16 miles, although this figure must be finally determined through operational experimentation. Existing airport complexes have lesser spacing between airports, and the air traffic control system must be developed to accommodate these existing complexes. However, where new planning is being undertaken, a separation such as 16 miles is desirable, with the understanding that each airport is to be developed on a multiple-runway basis.

c. Airports along the extended centerline of the instrument approach to another airport should be avoided, if possible. If built, they should be located about 40 miles away from the existing airport.

d. Airport location must be consistent with the overhead airways traffic pattern and avoid creating unnecessary airspace problems. Traffic flow to and from the airport should be considered and airports located to avoid unnecessary cross traffic through terminal areas.

The overall coordination of airport location is a function which only the Federal Government can perform. All military and civil airports must be considered, often involving more than one community and sometimes more than one State. Thus, to insure the efficient use of our existing airport system and plan intelligently for new airports, the Federal Government must provide for general supervision of airport planning and location.

The Federal Government is not providing this needed supervision today. As a result, new airports, both civil and military, are being planned and constructed without due regard to the proximity of other airports and the airways.

It is recommended that the Federal Government:

a. Develop a long-range plan, indicating in broad terms the growth needed for military and civil airports.

b. Develop a procedure requiring Federal approval of proposed locations of new military and civil airports to ascertain that their location is consistent with the long-range plan, and to determine that the required airspace is available to serve the long-range development of both the existing and the proposed airports.

As the concept of controlled airspace is expanded to include the larger transport airports, it will be necessary for the Federal Government to designate such airports as reserved for controlled operations. Prior to such designation, it will be necessary to consult with the local airport management and airspace users to assure that adequate alternative airport facilities are available.

IX. AIRCRAFT NOISE

A factor exerting tremendous influence on current airport design is the consideration of aircraft noise resulting from landing and takeoff operations as well as maintenance operations on the airport. This consideration becomes increasingly important as air traffic grows, as airports approach capacity operation, and as the new jet aircraft are introduced into operation.

To minimize the potential effect of this factor, the airport planner should—

a. Align runways consistent with operational considerations, such as air traffic control and wind requirements, to make maximum use of natural open areas, such as waterways and parks, for approach and departure paths.

b. Provide areas on the airport which, through location or construction of physical facilities, will keep ground runup noise level to a reasonable value.

The Federal Government should—

a. Encourage research to minimize the noise generated by both military and civil aircraft. Obviously, to avoid interference with the primary defense mission, the limitation on military aircraft may, from necessity, be less severe than that for civil aircraft. However, much pioneering work in this field can be accomplished and applied to military aircraft, and thus benefit the communities in those areas where military operations are conducted.

b. Consider the noise factor in adopting air traffic control procedures, in order to minimize noise to the communities, within the limits of providing safe, efficient air traffic control.

c. Provide the installations needed to support noise control procedures adopted as a result of item b. For instance, instrument runways should be completely equipped for bidirectional use, thereby practically eliminating the need for low-altitude circling during IFR conditions. For the very small percentage of approaches during IFR weather which cannot be accommodated on the main instrument runway when it is equipped for bidirectional use, procedures should be developed for straight-in letdown to cross runways.

The control of aircraft noise during landing and takeoff operations must be accomplished in the manner which will permit maximum development of our present airport system. To assume that the problem can be solved by moving airports out of developed areas is fallacious. Airports must be located to serve the traffic-generating areas, which means they must be relatively close to these areas. Further, large metropolitan areas have such a tremendous potential for air traffic development that existing airports, as well as new airports, will be needed to handle this capacity. The air traffic control system needed to feed airport complexes in large metropolitan areas will require that existing airports be expanded to their maximum, and that new airports be located far enough from existing airports to avoid conflict between approach and departure paths. The solution to the aircraft noise problem will lie in reducing the noise at the source—the aircraft engine.

X. GROWTH OF AIRCRAFT AND THE AIRPORT

Examination of aircraft growth and their demand on airport facilities over the past years indicates a continuous growth in all airport facilities—particularly runways. It appears that the new generation of jet aircraft now on order will raise runway length requirements to a new level, particularly where the aircraft are used for maximum trip lengths. Hopefully, this level will remain and become a plateau which is not exceeded by future aircraft. This factor is vital in assuring the availability of the Nation's airport system. Both the airport and the surrounding community must be assured of reasonable stability in planning to avoid inconveniencing the airport neighbors or spending exorbitant money to expand into built-up areas. The Federal Government can assist the industry in this regard by continuing research and development in aircraft components and devices which point toward reducing runway-length requirements, and in encouraging their application.

XI. EXPERIMENTATION NEEDED

Research and development are urgently needed on many basic airport design parameters. The effort required is of such magnitude that an establishment is needed which will have comprehensive staffing to provide analytical study, simulation, and flight tests for numerous items. This is part of the research and development effort for the entire national aviation facility program.

The urgent need for experimentation in airport design includes items such as the following:

a. What separation is required between parallel runways for various operating conditions, both VFR and IFR? What is the resultant increase in runway capacity which can be expected under various spacings between runways and during various weather conditions? This study should include determination of the optimum spacing and capacity ratings for a parallel runway layout, designed to serve transport-type aircraft on one runway and itinerant type aircraft on a short parallel runway.

The need for this experimentation is justified by the large expenditure for a parallel runway facility, particularly at an existing airport where demolition of existing facilities and the acquisition of new property may be required. To determine the economic feasibility for such a project a more accurate measure is needed of the net result in increased capacity for providing a parallel runway.

b. Determination, simulation, and flight tests should be extended to determine more accurately maximum runway capacity and the minimum spacing of aircraft on final approach to the runway. This should include time on the runway during landing in relation to various turnoff speeds, and time on the runway during takeoff. Aircraft size in relation to runway capacity should be studied. The study should include tests with various types of aircraft to determine the limiting effect of wingtip vortices on succeeding aircraft when traffic is in line as on the glide path.

It is vital that we determine ultimate runway capacity to more accurately plan for long-range development of adequate airport facilities on a schedule which will meet the projected increase in traffic. At least five years' headway must be provided in planning to construct a new airport and equip it for operation.

c. Standard signals should be developed to control an aircraft crossing a parallel runway installation. This must be handled today by voice radio which takes time from the controller. This time could be reduced by use of a standard visual signaling system.

d. Instrumentation for IFR approach and takeoff should be developed and standardized to accommodate the predicted small itinerant multiengine-type aircraft.

To accommodate the large increase for this type of aircraft, we need an inexpensive instrument approach facility. The small aircraft should not be required to carry extensive airborne equipment. The required accuracy rating of equipment should be examined in relation to approach speeds and probable minima at which this type aircraft will operate.

e. Experimentation should be conducted to determine the new procedures needed to feed, at capacity, a multiple airport complex with airports spaced as close as those in the New York area. Current procedures require a spacing of about 16 miles between parallel runways at adjacent airports to feed the airports at capacity. A system must be developed which will permit reduction of this spacing and still feed airports closer together at high capacity. This will enable full use of existing airports in metropolitan areas, and give planners the means of meeting the natural demand that airports be located adjacent to the population areas to be served.

f. Study and experimentation is needed to determine optimum runway configuration with regard to such physical aspects as high-speed turnoffs (their location, marking, configuration) and high-speed entrance taxiways for takeoff. The effect of these items on runway capacity should be determined.

g. Research and development in visual aids should be continued and extended to determine the aids necessary for properly marking large radius, high-speed turnoffs and for the standardization of visual aids to approach and landing, such as flush lighting within the runways. Research should include the development of hardware, such that these needed aids can be added to existing facilities, including flush lights in runways without undue expense or excessive shutdown time of a runway for construction purposes.

h. Existing airport design criteria should be reviewed and brought up to date in consideration of current operational techniques and aircraft developments. The examination and updating should include such items as construction clearance required in both approach and transition zones, clearance between runways and taxiways, runway and taxiway width requirements.

i. In the future, we can anticipate that the minima to which operations are conducted will be lowered until practically all-weather operation is achieved. Such operation may require the development of new means of taxi guidance on airports. Study and research indicated should be undertaken to accomplish this on a time schedule consistent with the probable lowering of aircraft operating minima.

XII. GOVERNMENT FORECAST DATA

To assist all phases of aviation in adequate development of the national system of aviation facilities, Government assistance is required to provide accurate forecast data which will serve all segments of industry, thereby assisting the coordination of systems planning.

The long-term financing of airport projects requires that this forecasting be accomplished on a long-term basis. Existing Government forecasting should be expanded and improved to become the basic source for planning information.

The forecast data should include the usual information, such as forecasts of passengers, passenger-miles, freight, mail. In addition, it should include numbers of aircraft broadly categorized as to type. It should indicate the changes in aircraft types which can be anticipated, and general guidance as to the years in which aircraft types will change. The forecast should also include, in broad terms, the characteristics of these future types of aircraft.

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