A Development Plan for an Improved Air Traffic Control System

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FOREWORD

The nation's airway system requires a strong, continuing, technical development program directed toward its day-to-day problems, necessary in-service improvements, and long-range requirements. Such a program must be designed to meet the special and individual requirements of air traffic control and navigation, and it must not be incidental to military tactical or civil product-development programs. The projects included must be carefully planned from a system concept to provide the necessary capacity and to meet the individual user's requirements.

In order to keep pace with the schedule outlined in the Federal Airway Plan, the research and development effort must increase at an accelerated rate. The plan outlined in this report is designed to provide the research, development, and evaluation steps necessary for the improved air traffic control system. As a companion to the Federal Airway Plan, it also provides a program for further development efforts beyond the five-year period for basic system improvements. Available operational requirements contained in the various reports of the Air Coordinating Committee, Radio Technical Commission for Aeronautics, and other organizations, and the results of work completed to date under programs of the Air Navigation Development Board, Civil Aeronautics Administration, and military, were used in developing this plan.

An improved air traffic control system based on the best known technical approach is described. Each element under the recommended program for accomplishment is divided into an in-service improvement section and a research and development section. In-service improvement items may require short periods of development and evaluation. The research and development sections include those longer range items on which initial development or major redevelopment for service application is required.

This program is directed toward the development of a semiautomatic air traffic control system. Increased use of radar data is recommended. Emphasis is placed on the automatic flow of data in the ground-control system. Computers for planning and problem-detection functions are included.

The need for an evolutionary approach to improvement in the air traffic control system is emphasized as a basic principle in this program. One of the primary purposes of the plan is to provide an orderly and thoughtful approach to budget requests to support in-service improvement and development projects during the next five years. Although it is believed that the plan is basically sound, it is anticipated that it will be revised in detail from time to time to keep it aligned with a changing situation. It will be revised, of course, as necessary to make it consistent with recommendations of Mr. Edward P. Curtis, Special Assistant to the President for Aviation Facilities Planning, as soon as they are forthcoming.

INTRODUCTION

History.

Since World War II, the field of air traffic control has not been lacking in proposals for improvements and new systems. Developments during and after the war have brought forth a large number of techniques and equipments; but, at the same time, they have presented new problems in obtaining agreement among the users on the best approach to improvements in the system. Many of the ideas advanced either failed to consider the total relationship of the system requirements or provided no ready means for an evolutionary approach in the improvement program. Although some of these ideas are promising, sufficient funds for their refinement and development into an integrated system have not been available. Thus, in the Federal Airway Plan, available equipments are being used to meet the immediate, urgent need for increased capacity and efficiency. In general, these improvements involve navigation aids for more extensive and more accurate track guidance and position reporting, widespread use of radar control, improved air traffic control displays, and expanded pilot-controller direct communications.

CAA Federal Airway Plan.

In the next five years, expansion of the air-navigation network will be based on two objectives: increased traffic capacity and extension of navigation coverage. Increased traffic capacity will be accomplished through installation of additional navigation aids which will permit revision of the Victor airway structure to make more efficient use of airspace and to provide inherent traffic separation insofar as possible. Extension of coverage will be effected by additional very-high-frequency omnirange (VOR) coverage on existing and planned airways down to 700 feet above the ground and in all airspace above 15,000 feet.

Top consideration will be given during the next five years to the expansion of radar control to extended terminal areas, to high-density routes, and to high-altitude area control. Longer range primary radar and secondary (beacon) radar will extend the advantages of radar-control methods beyond the present approach and departure areas; and it will expand the safe capacity of the air traffic control (ATC) system through better utilization of airspace, simplification of the control function, and extension of control of traffic to an area basis.

Airport surface-detection equipment (ASDE) radar will permit improved control of traffic on the surface of major airports under poor visibility conditions.

The Federal Airway Plan proposes to improve communications by means of additional peripheral facilities for direct controller-pilot communications. Improvements in point-to-point communications also are planned.

CAA plans to inaugurate manual control of all airspace above 29,000 feet in Fiscal Year 1957, and as experience is gained in handling traffic on an area basis, to lower the floor to accommodate a greater volume of high-speed, direct-route traffic.

Need for Additional Research and Development.

Although implementation of the Federal Airway Plan will do much to increase the capacity and efficiency of the ATC system, it will not correct certain basic deficiencies in the system. For example, one of the most difficult problems in the internal functioning of ATC facilities, particularly air route traffic control (ARTC) centers, involves the collection and processing of data for presentation on air-traffic displays for analysis by the controller. Controllers now are burdened with secondary duties such as relaying information, coordinating with other controllers, and manual posting of data, which seriously interfere with their primary function of analyzing traffic situations and making control decisions. As the controllers' areas of jurisdiction are decreased to smaller and smaller units to enable them to cope with rapidly growing traffic, the proportion of these secondary duties increases.

There are many shortcomings in the present methods of displaying traffic information to the controller, both where radar coverage is available and where it is not available. As a result, control cannot be accomplished as effectively as desired.

Rapid and positive identification of targets is one of the major problems in the effective use of radar. Improvements also are needed in the radar equipments to provide better coverage, to eliminate precipitation effects, to improve moving-target-indicator (MTI) performance, and to reduce radar interference. Such improvements will increase the reliability and usability of the radar. Because it is envisioned that extensive remoting of radar data will be necessary operationally, means of accomplishing this with necessary quality at minimum expense will be required.

In high-density traffic situations, the aircraft pilot and the controller are overloaded with communications required for position reporting and the necessity for continuous monitoring and screening of air traffic control transmissions. Ground/air data links should be investigated as a possible solution to this problem.

Improvements to the navigation system are needed to permit use of multiple parallel tracks for most effective use of the airspace by ATC. Although the five-year plan envisions positive control of all aircraft movements in certain designated airspace and provides for radar coverage of this airspace, improved techniques are needed to permit such control to be accomplished in the most effective manner. The limitations outlined can be solved only through an aggressive research and development program.

Research and Development Plans.

An essential part of the research and development plan is a well founded program which can be updated continually to take advantage of the latest thinking, experience, and scientific breakthroughs. Once this basic plan is available and the objectives are well defined, many laboratories devoted to such development work can participate and thus expedite the conclusion of the work. A well coordinated effort in the development phases obviously is essential.

The evaluation of the systems and equipments so developed will not be complete until they have been proved in a controlled test environment. It is in this manner that new ATC procedures and standards also are developed. This evaluation and procedural development requires a special type of environment such as is found in the Airways Operations Evaluation Center (AOEC); therefore, it will not be carried out easily or economically in more than one area.

Further, it seems logical that the control agency should conduct such evaluations because the same agency ultimately will have the responsibility for the system implementation, if it is found acceptable. Projects for in-service improvement do not involve basic system changes, but they are aimed primarily at improving the over-all performance and reliability of systems already implemented. The responsibility for the proper conduct of these programs traditionally has been an exclusive responsibility of the CAA. In many cases, however, the improvements required are suggested as the result of operational experience of users of aircraft, both military and civil.

CONCEPTS OF AN IMPROVED ATC SYSTEM

The principal concepts of an improved ATC system are:

1. All elements of the system must have characteristics which are compatible with ATC requirements.
2. The system shall be capable of providing positive control of all aircraft movements in all airspace. (This does not imply that all aircraft movements or all airspace will be controlled.)
3. Normally, navigation will be accomplished in the aircraft; however, under certain ATC situations, navigation will be ground-directed.
4. Normally, air traffic control will be provided by ground facilities.
5. Preplanning and advanced reservation of airspace will be used to the maximum extent possible to provide for aircraft movements on a first-come, first-served basis. Current position information will be used to revise airspace reservations.
6. When aircraft cannot be controlled efficiently on the basis of advance reservations of airspace, short-term control will be effected by use of current position data.
7. In low-density traffic areas, the system can use infrequent position data and relatively large separations between aircraft. In high-density traffic areas, the system will require a high rate of position data to permit relatively close spacing between aircraft.
8. The system shall be capable of regulating peak-load traffic to avoid exceeding system capacity. It also shall be capable of handling priority traffic.
9. Efficient control of high-density traffic and high-performance aircraft requires the progressive use of automatic equipments.
10. Rules and regulations applying to the use of airspace and operation of aircraft will require revisions from time to time to simplify the air traffic control program.

In considering an improved ATC system, every attempt has been made to be fair to all users of the airspace. An evolutionary progression to an improved system is described, although it should not in any way be construed to be an "ultimate" system. The system is believed to be as advanced in concept as is possible at this time; however, a continuing need for reappraisal of the program exists. It also should be borne in mind that this approach requires equipment development and operational evaluation which may show the need for changes prior to full-scale implementation.

To provide maximum performance, all elements of the ATC system must be designed to meet air traffic control requirements. The system should not be forced to make use of equipments primarily designed and operated for other purposes if by so doing the over-all design of the system becomes unduly complicated. Similarly, the system should not be forced to make mutual use of certain equipments if this would compromise the efficiency of the ATC system.

Today's ATC system does not control all airspace, nor does it control all aircraft movements within designated control areas. The difficulty in avoiding collisions by visual observation of other aircraft operating at high speeds indicates that positive control of all aircraft movements must be provided at higher altitudes and possibly in certain other airspace. Further, the capability of controlling all airspace to some degree is required in unusual situations such as national emergencies. From time to time, consideration has been given to system concepts which would provide for navigation by ground direction as a part of the ATC system. This report reaffirms the opposite view: that the air crew will do all of its own navigating on routes prescribed by the ATC system except where ground direction is necessary on a short-term basis to prevent traffic conflicts (either en route or in busy terminals) or to provide precise spacing and most expeditious movement of traffic in high-density areas.

In the future, automatic equipment will be required to inform the ATC system of aircraft position, altitude, and other data at the rates and degrees of accuracy necessary for proper functioning of the system. In addition, certain routine ATC messages (ground/air) may be handled automatically. Voice communications will be retained for nonroutine or emergency communications and for minimum-equipped aircraft.

Common System Aspects.

Many planners and designers in the past have attempted to create a common system through the design of common equipments. Progress toward development and implementation of this type of system invariably becomes stifled when it is discovered that the requirements of the different users are so divergent that no compromise acceptable to all is workable.

It is believed that a step forward toward the goal of an ATC system serving all users will have been taken when those who are concerned with its design and development recognize that:

1. The present ATC system is not based on totally common equipments, nor will any ATC system be so based in the foreseeable future.
2. Frequent changing of tactical requirements leads to frequent changes in military aircraft-equipment configurations, changes with which civil aircraft cannot be expected to cope.
3. A large percentage of aircraft, the missions of which are not widely divergent, can be similarly equipped.
4. There always will be certain military aircraft and probably certain civil aircraft which cannot be served by all equipments of the common system. The tactical requirements of some military aircraft may dictate equipment configurations which will not be feasible for common-system use. Low-cost, low-performance civil aircraft may be unable to use some common-system equipments because of weight, space, power, and economic considerations.

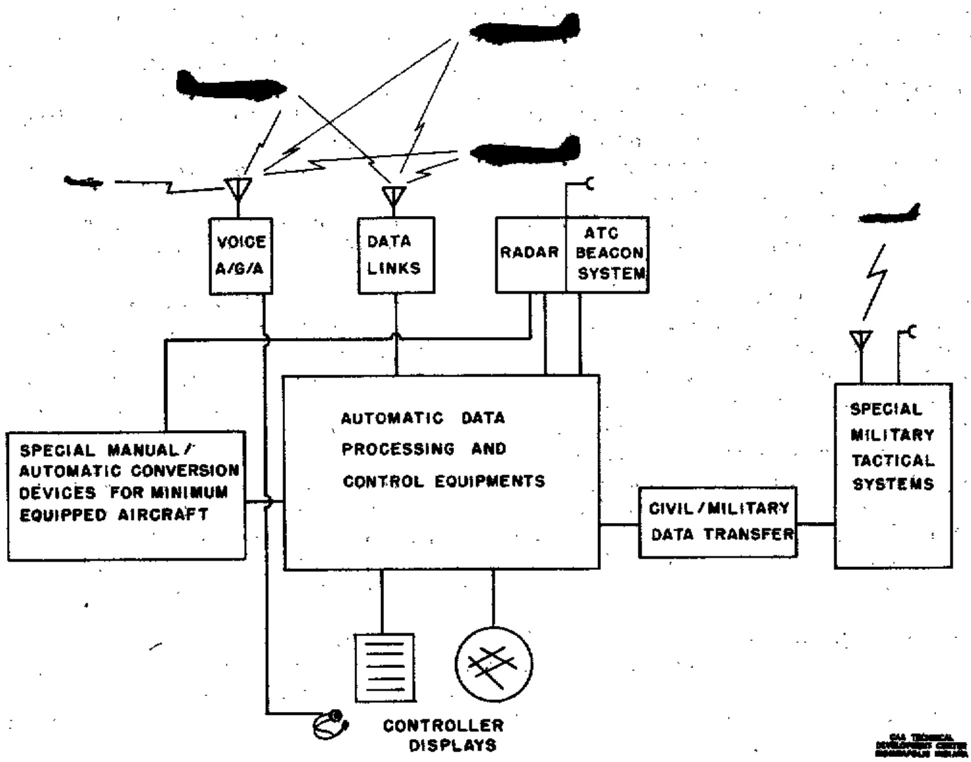

Fig. 1 Improved ATC System

Acceptance of these statements leads to a system configuration (Fig. 1) which includes:

1. Tactical elements designed for maximum effectiveness in meeting special military requirements peculiar to air warfare.
2. Elements peculiar to the internal functioning of the ATC facilities and designed to meet ATC requirements with maximum effectiveness. These include data-processing and -control systems within or between control facilities, radars, and so forth.
3. Elements which serve to interconnect military tactical systems and ATC facilities to permit the ATC system to accommodate tactical operations and to permit the tactical military system to obtain the desired information on friendly aircraft.
4. Elements which serve to interconnect automatically the ground environment with aircraft. These include air/ground/air (AGA) data links or an ATC beacon system.
5. Ground elements and procedures which accommodate, to the degree possible, minimum-equipped aircraft or aircraft experiencing airborne-equipment failures.

Development of the tactical elements in Item 1 can be carried out in complete security without compromising a common ATC system. Development and/or implementation of the elements in Items 2 and 5 should be carried out by the ATC agency. Development of the elements in Items 3 and 4 requires standardization and large-scale coordination, and this should receive immediate attention.

Evolution of an Improved System.

The philosophy has been expressed frequently that the present ATC system should be discarded in favor of a new and revolutionary system. The CAA, with statutory responsibility for the control of air traffic, cannot accept the premise that, overnight, a switch can be thrown which will change the present system to some new and relatively untried form. The present system, although deficient in many respects, is based on years of valuable experience which should not be discounted lightly. The advancements proposed herein, therefore, have been designed so that an improved ATC system will be produced by evolutionary growth. At the time these proposed equipments become available for implementation, there will be in existence a well established voice-communication system and an extensive network of primary radars. There also will be a complete navigation system for both high- and low-altitude flights. The existence of this environment will aid materially in the transition to the improved system even though some operators may be slow in implementing the airborne portions of the semiautomatic system.

In-service improvements to navigation aids, communications, radars, and so forth, can be accomplished without interruption to traffic-control service and with only minor interruptions to the facilities themselves. Installation of automatic equipments in the control facilities will be expensive and more difficult to accomplish because it must be done without interrupting service.

It is anticipated that the introduction of automation into the operating system will be accomplished in several stages. Some automation can be applied to the internal functioning of the control facilities without requiring equipment changes on the part of the users of the airspace. At some point, however, implementation of airborne equipments will be required in those aircraft desiring full and complete service. Because an implementation program of this type will cover a period of time, a step-by-step progression will be necessary.

It is visualized that the upper altitudes and/or certain high-density traffic routes will be the first areas to be placed in the semiautomatic environment. Initially, radar and radio-position reports may be inserted manually into the automatic system in place of direct inputs from the air/ground data link and/or beacon equipments. At some date, regulations requiring airborne equipments and automatic inputs from military tactical systems will be required on all flights operating above a certain level or on specific routes. Gradually the automatic environment will be expanded to additional airspace, and it will include penetration and climb routes through nonautomatic areas. It is not within the scope of this report to furnish at this time altitude layers and dates or a detailed description of transition routes. Advancements in equipments and operational experience will be required before such schedules can be provided. Special regulations governing use of airspace may be required to provide operating safety and minimum restrictions for both fully equipped and minimum-equipped aircraft.

How the System Works.

Air traffic control will be based on reservation of airspace in advance by preplanning of flight paths and airspace occupancy and by feedback of position data to verify predicted airspace occupancy and to report airspace vacancies. Feedback of position data from aircraft may be at relatively low rates when traffic density is relatively low, when all potential conflicts can be eliminated readily by preplanning, and/or when relatively large separations between aircraft can be used without sacrificing expeditious movement. Feedback of position data will be required at high rates when traffic densities are high, where much of the control must be accomplished on the basis of current airspace occupancy, and/or when small separations between aircraft are necessary to permit increased density of traffic movements.

It is visualized that in the improved ATC system, position data will be received in various ways, including voice reporting and telemetering of position data from aircraft to ground and by primary and secondary radar. Processing facilities on the ground would convert these data into a common, electrically coded form for the ground ATC equipments. Data from military tactical systems such as SAGE also would be fed into the ATC system, and a certain amount of data from the ATC system would be forwarded to these systems for identification of friendly aircraft or for other purposes as desired. It is anticipated that the required position data from many tactical aircraft may be inserted into the system in this manner when such aircraft are not equipped with compatible equipments for use in the common ATC system.

It is anticipated that initial control will be accomplished by comparison of proposed flight plans with other flight plans already operating and proposed to enter the system. Much of this control can be accomplished with automatic machinery by use of computers and adequate storage. Flow control also will be exercised at this stage to limit the number of flights to any particular airport, or through any other restrictive bottleneck in the system, to the maximum acceptance rate. To make this system effective, some degree of en route speed control may be required, plus a closer adherence to proposed departure times.

Where aircraft movements cannot be handled expeditiously and effectively by preplanning control or airspace reservations well in advance of the actual time used, separation will be provided on a short-term basis based on actual positions of the aircraft involved. When this type of control is required most of the time, as in high-density traffic areas where many changes of altitude or crossing-course problems are involved, a high rate of position information such as is available from radar systems will be required. Smaller separations can be used in these areas to increase the capacity of the system.

PROGRAM FOR ACCOMPLISHMENT

Projects of an in-service-improvement nature are those concerned with the improvement of facilities which already have been implemented on the Federal Airways or as part of the ATC system. The exact nature of the effort required may fall into any of several categories: (1) development of modifications to correct equipment deficiencies, (2) specific investigations and developments aimed at correcting specific local difficulties, and (3) modifications of equipments to expand service to meet new operational requirements.

Itemized herein are in-service-improvement projects now being conducted but not yet completed and those which should be initiated as soon as funds are available. Because of the nature of these projects, it is advisable to maintain and finance a continuing in-service-improvement project for each major facility already in service. The exact program items will not always be known until specific deficiencies arise or new operational requirements develop.

Under sections entitled "Research and Development," projects are listed for providing new equipments, new systems, and new procedures. In many cases these projects require original thinking and inventiveness. In some cases they require adaptation of techniques originally developed for other purposes. In some cases several approaches to a problem should be conducted simultaneously to reach the best solution at the earliest time.

Navigation System.

Within this category are included all developments and in-service improvements for ground and airborne navigation equipments. It is anticipated that navigation normally will be accomplished by the flight crew, with the exception of minor course adjustments provided by air traffic control to provide separation between aircraft. A basic radio navigation-aid system and airway structure will be provided by the Federal Government to serve the needs of interstate commerce. It is believed, however, that new and improved navigation equipments will be developed continually. Aircraft will be permitted to make use of any of these equipments desired, provided that the routes and tracks specified by air traffic control can be followed with the required accuracy. Techniques and equipments for navigation along slant airways and corridors for climb and descent will require development. Improved instrument approach and landing aids require development. Development effort must take into consideration special navigation requirements of new types of aircraft such as helicopters and vertical takeoff and landing (VTOL) aircraft.

In-Service Improvements, En Route and Terminal Navigation Aids.

1. VOR.

a. Vertically stacked VOR antenna. A vertically stacked antenna will permit siting flexibility of VOR stations by reducing the radiated energy directed toward the ground and toward nearby reflecting objects.

b. High-tower VOR installations. The high-tower VOR installation was designed as an additional means for reducing siting effects. It is not intended that high towers be standardized; however, the results of present experimental work may demonstrate that this technique is capable of solving certain particularly difficult siting problems.

In some cases it may be desirable to incorporate both Items a and b at the same site.

c. Multilobe VOR ground facility. A multilobe VOR system should have the inherent ability to reduce instrumentation error by the order of the number of lobes. Five are presently proposed. In addition, errors due to siting will be reduced, with the order of reduction depending upon the specific site. Techniques will be employed for positively eliminating the inherent ambiguity of a multilobe system.

d. Multilobe VOR receiver. Implementation of a multilobe VOR ground system will require development of a companion VOR receiver in order that full advantage can accrue to the user. The ground facility, however, will be designed to permit existing VOR receivers to continue to obtain single-lobe azimuth service.

e. Ground-speed meter. Accurate ground-speed information in the cockpit will make it possible for pilots to ascertain and to inform the control agency that they, in fact, are employing a track speed within the tolerances specified for the airways. Because it is proposed that all aircraft along an airway at the same altitude be in the same speed category, departure from the norm (due primarily to differences in aircraft loading and engine performance) in most cases should be correctible by moderate speed-control procedures. Ground-speed information, of course, will result in extremely accurate estimated time of arrival (ETA) prediction. In fact, the ground-speed device may be instrumented easily so that "minutes remaining to destination" (or ETA, if desired) can be displayed in the cockpit.

f. Slant-airway instrumentation. The purpose of this development is to provide, with simple instrumentation, a guidance system which will permit aircraft to follow accurate ascent and descent paths over specific horizontal tracks. The intent may be compared to that of the instrument landing system (ILS), but extending further beyond the terminal area and to considerably higher altitudes. Ultimately, complete tracks from the departure point to the destination may be defined. The ability of aircraft within the system to conform to tracks of this type will result in appreciable airspace savings. At the present time, large areas of airspace must be reserved for ascending and descending aircraft due to variations in the x, y, and z coordinates during these operations.

It is believed that the time-position accuracy of tracks defined in this manner need not be as good as present ILS-position accuracies but should be comparable to or better than the existing Rho/Theta system. In all probability, the first efforts will involve automatic coordination of altimeter and distance information with possible use of the glide-slope needle as the guidance instrument for ascent and descent.

2. VORTAC.

The Air Coordinating Committee (ACC) recently reached a unanimous decision on a program for implementation of the Federal Airways with an integrated system consisting of both VOR and Tactical Air Navigation (TACAN). This program is referred to as VORTAC. Under this plan, combined implementation of VOR in accordance with the Federal Airway Plan is recommended, as well as integration of the VOR network with TACAN facilities. The distance portion of TACAN will provide distance service to both civil and military aircraft, and it will supersede the present civil DME system.

In consonance with the program recommended by ACC, a vigorous TACAN implementation program will be initiated by the CAA. Parallel with the earliest possible implementation of currently available military TACAN equipments and to meet the requirement of distance service for air-carrier jet operations by July 1959, supporting programs should be conducted in order to provide TACAN-type ground facilities and airborne equipment specifically designed to meet civil requirements for later installation. Certain specific projects may be recommended at this time:

a. Establish TACAN siting criteria. Experience with the TACAN system has shown that careful attention must be paid to siting in order to insure optimum azimuth accuracy. A large percentage of planned facilities will be installed at VOR sites. Present configurations for accomplishing co-location may or may not be satisfactory at all sites. A criterion for evaluating suitability prior to installation of equipment should be developed. In cases where the presently proposed VORTAC antenna configuration is unsuitable, alternate configurations must be developed.

b. Install and evaluate a VORTAC facility.

c. Obtain a portable TACAN facility with adjustable tower for siting investigations.

d. Determine practicability of conversion of present DME ground facilities to provide TACAN distance service.

3. General.

a. Channel capacity of navigation system. The channel capacity of the VOR system presently is adequate; however, the number of proposed installations and the increased altitudes of flight soon may dictate additional channels. Fortunately, the number of channels can be increased by a factor of approximately two without compromising the existing systems or airborne equipments thereof. Techniques for accomplishing the channel expansion have been developed and demonstrated. The transition to the higher channel systems consists primarily of installation and implementation.

Present airborne equipments can continue to operate with their present channel capability, and they can be replaced upon obsolescence by equipments having the greater channel capacity. The best estimates available indicate a requirement of 130 channels by 1965. Fundamentally, the VOR channel capacity will be increased by reducing the present channel separation from 100 to 50 kilocycles (kc).

b. Airborne computers. Control of aircraft on an area basis can be simplified greatly by proper airborne instrumentation. The pictorial display is ideally suited for this purpose. A number of different types of displays have been developed and evaluated. Based on experience gained with these equipments and recognizing the requirements imposed by ATC, a unit embodying the best features of the early models should be developed following coordination with all potential users.

c. Altitude compensation for distance measurement. In connection with Item b, electrical and/or mechanical provisions for the conversion of slant to horizontal distance will be made. This is considered necessary in order to eliminate position errors inherent at high altitudes when operating near the ground station.

d. Altimeters. Present altimeters are not sufficiently accurate above approximately 29,000 feet to permit use of altitude separations of 1000 feet. In order to avoid a 2:1 loss in airspace utilization at the higher altitudes, it is essential that improved altimeters be developed.

In-Service Improvements, Approach and Landing Aids.

1. ILS directional glide slope. The glide-slope antenna array in current use depends on ground reflections for the formation of the desired field patterns necessary to form a straight-line glide slope. At sites where the terrain either rises or falls abruptly in the approach area, bends are produced which distort the glide-slope shape and seriously affect the pilot's ability to establish the correct rate of descent during his approach in instrument weather. Experiments on an antenna array which does not depend on ground reflections for the formation of the glide slope show encouraging results. This antenna should be developed for use at those sites where a conventional array cannot produce an acceptable path.

Research and Development, En Route and Terminal Navigation Aids.

1. Civil TACAN distance-only airborne equipment. The only airborne TACAN equipment currently in production is of military design and incorporates both azimuth and distance functions. Inasmuch as a large percentage of civil aircraft will be equipped with VOR and continued use of this equipment is intended, it will be necessary to develop an airborne unit meeting civil requirements to provide TACAN distance service only. This unit, in conjunction with the VOR, will provide full Rho/Theta service to these aircraft.

2. Civil TACAN azimuth-only airborne equipment. Inasmuch as the Federal Airways system is to be implemented with TACAN in addition to VOR, a civil version of TACAN azimuth-only airborne equipment should be developed. This development is intended to

provide a TACAN counterpart to the private-flier-type VOR receivers, and it will permit an evaluation of the suitability of TACAN azimuth to meet private-flier requirements.

3. Civil airborne TACAN equipment (distance and azimuth). Development of this unit will permit operational evaluation of the ability of the military TACAN system to meet the over-all Rho/Theta requirements of civil aviation.

4. Civil TACAN facility. Requirements for Federal Airways ground facilities vary in a number of significant features from military requirements. For this reason, it is advisable to develop a TACAN ground facility consistent with established Federal Airways requirements.

5. Helicopter navigation system. Operating characteristics of helicopters may dictate the need for a type of navigation system not now in use. The chief requirements are low-altitude coverage, accuracy, and ease of operation and interpretation. The first steps toward development of a suitable system will be a study of (a) helicopter requirements, (b) proposed systems, (c) applicability of existing systems, and (d) analysis of tests and studies performed thus far.

6. Improved basic navigation system. Navigation systems are expected to play a major role within the ATC system to provide guidance in flight and to assist in maintaining safe separation of aircraft. The utility of navigation systems to air traffic control is directly related to their accuracy and reliability. Present navigation aids are suitable for coarse-grain position information and can be used for fine-grain data within the accuracy limits of the equipment. In-service-improvement efforts have been listed for improving the accuracy and utility of present navigation aids. Research and development should be directed toward increasing the utility of navigation aids, both to the pilot and to the ATC system. As the state of the art advances and as requirements change due to the ever widening range of speed and altitude characteristics of aircraft, development of new navigation aids will become necessary.

Research and Development, Approach and Landing Aids.

1. Extension of ILS service. Airports equipped with ILS allow a straight-in ILS approach in one direction only. In instrument weather and when the wind is unfavorable for landing in this direction, the ILS is used for guidance to the vicinity of the airport. A circling maneuver then must be executed to align the aircraft to the active runway prior to landing. An ILS which could be used to serve more than one runway would be very desirable to fill this operational need.

2. Glide slope. The trend toward higher performance aircraft, especially jet-propelled aircraft, is associated with more demanding requirements of the glide slope. A glide-slope antenna system, submerged in the runway, would accomplish several desirable improvements. It would facilitate automatic approach to touchdown, and it would remove the undesirable obstruction created by the present antenna array.

3. Landing aids. Development and evaluation of aids to permit completely blind landings have been under way in the military services for some years. These equipments and techniques should be thoroughly investigated and adapted if possible to meet the requirements of civil aircraft.

Radar Systems.

The Federal Airway Plan provides for a network of traffic-control radars, both primary and secondary. These equipments will include airport surveillance (ASR) and precision approach radars (PAR), long-range surveillance for extended terminal area and en route coverage, and secondary radars for aircraft identity and long-range coverage. The plan also provides for remoting devices to permit collection of radar data from remote facilities. Aggressive in-service-improvement and research and development programs are required to adapt technological advancements to existing radar equipment and to study, evaluate, and develop new techniques required.

It is recognized that continuing research and development efforts are being made by the military to improve primary radar systems. The results of these efforts should be integrated into the civil system as rapidly as possible to obtain maximum performance and utility of radar as a traffic-control aid.

In-Service Improvements.

1. Circular polarization. Circular polarization is required to improve radar performance under adverse weather conditions. Kits have been developed for the ASR-3 and PAR-1 equipments, and basic development has progressed to the extent that kits for ASR-2,

AN/FPS-8, and PAR-2 equipments can be procured within a short time. Although evaluation of circular polarization is desirable, it should not delay the installation program because it is known that circular polarization is of benefit under precipitation conditions.

2. Radar-receiving systems. A study should be made of components and devices such as improved radio frequency (rf) amplifiers, detectors, duplexers, video-integration devices, and other equipments which will improve the over-all signal-to-noise ratio of the receiving systems and to improve system coverage. Such components or devices which can be adapted to ATC radars should be evaluated.

3. Elimination of radar interference. In some areas displays are degraded by interference between radars. Interference will become more severe as additional air traffic control and military radars are installed. Although efforts are being made to minimize future interference problems by proper frequency assignments, immediate action is needed to alleviate present interference. Improved rf filtering and rf selectivity components, interference-blanking devices, and other facilities should be developed and installed to minimize deterioration of displays.

4. ASR-2/beacon antenna. No satisfactory antenna combination of this type presently is available. An engineering study will be required prior to making a decision on any particular configuration, and perhaps several different models will be constructed and evaluated.

5. Improved altitude coverage for ASR. The present ASR antennas do not radiate sufficient energy to provide satisfactory surveillance of high-altitude aircraft. A study should be made to determine the feasibility of developing antennas to provide the desired coverage.

6. Radar beacon-siting criteria. Evaluation of and experience with the existing radar beacon system and with various associated antenna configurations have indicated that ground nulls and reflections from nearby obstacles and terrain can be a limiting factor in satisfactory and reliable performance of the radar beacon system. It is believed that there are a number of techniques which may be employed to reduce the seriousness of the two effects. Where a number of alternate sitings are possible for a specific facility, a careful propagation survey of the location involved should permit selection of the most favorable site. A study and investigation relative to the feasibility of employing a counterpoise with the beacon antenna should be conducted. The possibility of minimizing secondary reflections from surrounding objects through use of absorbent materials also should be studied.

7. MTI systems.

a. Improved MTI. A continuing effort to improve the over-all stability of surveillance radar MTI systems should be made. In addition, the possibility of modifications to existing equipment which will reduce blind-speed effect should be investigated. One such technique employs the principle of alternating the pulse period (effectively, the pulse rate) on a pulse-to-pulse basis between two discrete values selected for optimizing reduction of the blind-speed effect.

b. Simulated moving target. An equipment or device capable of producing a signal equivalent to that reflected from an aircraft would be of appreciable assistance in monitoring over-all MTI system performance and in indicating optimum adjustment. Such a moving-target generator would be installed some distance from the radar, preferably in an area of reasonably high, fixed ground clutter. The signal radiated from this device when primary radar energy is incident upon it should have a random phase variation in a manner similar to that of energy reflected from a moving object. There are a number of possible techniques which may be explored. Fundamentally, the requirements are low cost, low power consumption, and reasonable size.

8. Military radars for air traffic control. Careful study of existing and proposed military surveillance-radar installations must be continued from both engineering and operational points of view to determine their applicability to air traffic control.

9. Airport surface-detection equipment. Evaluation of an experimental ASDE has shown that the use of ASDE will aid materially in increasing airport capacity by providing controllers with a more complete picture of aircraft on the airport during all weather conditions. Evaluation of new and improved ASDE equipment is now under way and should be continued.

10. Radar remoting systems. It will be necessary to remote information from some radar sites to ATC facilities. To obtain the necessary service at minimum cost, different types of narrow- and wide-band remoting systems should be procured and evaluated from technical, operational, and economic standpoints.

Research and Development.

1. Radar beacon system. An ATC radar beacon system is needed to provide more reliable aircraft-position information, regardless of the weather conditions or the type or size of aircraft, to extend radar coverage effectively to higher altitudes and longer ranges and to facilitate identification of the aircraft. Subject to establishment of satisfactory equipment operational doctrines to alleviate system traffic-capacity problems, the following program items should be undertaken to increase the utility of the beacon system for air traffic control and to encourage procurement and installation of airborne equipments. Most of the program items are short-term items because much, if not all, of the basic development work has been completed.

a. Transponder altitude-coding provisions. Because transponder reply codes can be used to denote aircraft altitude and present ATC radars do not provide altitude information, an automatic altitude-coding switch for transponders should be developed and evaluated. The coding switch should control the transponder reply code in accordance with aircraft altitude in order to convey altitude information to the controllers. The use of codes to denote altitude is one method of obtaining filtered displays so that controllers can determine readily whether aircraft on collision courses are at the same altitude.

b. Multichannel and active readout decoders. Single-channel decoders now undergoing evaluation are useful in connection with the tracking of aircraft to which particular codes have been assigned and for obtaining filtered displays which display only those aircraft which are segregated on the basis of altitude, destination, control jurisdiction, or similar factors. If it is desired to identify a target having an unknown reply code, however, determination of the code is time-consuming and laborious. Multichannel and active readout decoders which have been developed should be evaluated to determine their utility for aircraft identification and for integration with data-processing, data-transfer, and computing systems to coordinate flight data and position information.

c. Integration of decoder-control unit with data-transfer equipment. In order to increase the utility of the data-transfer equipment by facilitating coordination of the flight data with the aircraft position on the radar indicator, such equipment should be modified to indicate the reply code assigned to the aircraft and to permit selection of various means of identifying the corresponding target indicator (double blip, bloomer blip, colored blip, and so forth).

d. Methods of using beacon system for automatic reporting purposes. The ATC radar beacon system can be used as a means of obtaining automatic position reports of equipped aircraft. By use of range and azimuth-gating provisions, indications of aircraft passing over any desired point can be obtained automatically. Equipment which is necessary to provide the indications should be obtained and installed for evaluation to determine the operational advantages of such a system.

e. Low-cost, lightweight beacon system. The operational advantages of any system involving airborne equipment depend to a great extent upon the percentage of aircraft which are suitably equipped. Characteristics of the ATC radar beacon system now under evaluation are such that immediate development of a low-cost, lightweight transponder is not anticipated. New components, circuits, and fabrication techniques may permit such a development; in that case, development and evaluation of a low-cost, lightweight transponder should proceed on a high-priority basis.

f. ATC radar beacon ground antennas. The results of evaluation of the Rho/Theta transponder system and the present ATC radar beacon system have shown that the ground antenna is the heart of the beacon system and that ground-antenna characteristics are of major importance. Resolution and system traffic capacity depend, to a great extent, upon the beamwidth and side-lobe levels, respectively. Coverage in the vertical plane depends upon the vertical pattern. Development and evaluation of antenna systems having improved vertical and horizontal radiation patterns should be pursued on a high-priority basis. Plans to evaluate the Cossor side-lobe suppression system should be continued.

g. New ATC radar beacon system. Although the use of the ATC radar beacon system now being evaluated is expected to facilitate control of air traffic, a beacon system designed specifically for ATC use should prove to be of greater benefit. Further study of ATC requirements should be conducted in order to determine the required performance characteristics and operational features. Particular attention should be paid to the choice of operating frequencies to obtain improved resolution, traffic capacity, and system coverage, and to assure the choice of interrogation modes and reply codes to obtain maximum utility in connection with semiautomatic traffic-control systems. The system design should be such as to minimize airborne performance requirements in order to permit the design and production of a lower cost, reduced size, and lighter weight airborne transponder.

Communications Systems.

Within this category are included: (1) the link from air to ground for passing position data, requests for changes in flight plan, and for other miscellaneous communications, and (2) the link from ground to air for forwarding control instructions and requests for information.

The additional communication workload required by increased radar implementation and high-altitude area control will demand immediate improvement in the AGA communication system. Such improvement is in the short-term category and must be pursued aggressively to permit full benefits of present implementation plans.

Development efforts are required to increase channel capacity, to increase utilization of channel time, and to expedite transmission of routine data. The introduction of automatic ground equipments will make the use of automatic air/ground data links more feasible.

In-Service Improvements.

Some of the more immediate investigations which can be made are:

1. Investigation of single sideband systems.
2. Use of tone or narrow-band digital modulation systems for more rapid transmission of routine data, and hence, for greater utilization of channel time.
3. Selective calling features.
4. Greater spectrum utilization by improvements in airborne-equipment capabilities.

Research and Development.

1. Telemetering system for automatic position-reporting (air/ground). The idealized ATC system visualizes airspace-occupancy information being received and processed automatically by the traffic-control agency. Although either ground-based radars or the radar beacon system could provide this information, it appears that the most desirable medium of the improved system might be via an air/ground telemetering system. Telemetered data can be coded easily to show identity, and it can contain altitude and other message-type information not easily obtained by radar systems. It is easier, therefore, to process this type of data.

Typical of the data which might be remoted desirably to the traffic-control-processing system are (a) identity, (b) position, (c) altitude, (d) heading, and (e) destination and/or special information regarding the flight or request for changes in flight-plan clearance.

Error-checking or feedback devices which will alarm if errors or unauthorized changes occur should be incorporated in the system.

The accuracy of the navigation system, the accuracy of the telemetering system, and the ATC separation standards required will determine those portions of the controlled airspace where automatic reporting will function as a primary device. There seems to be little doubt that it is more than adequate for furnishing data for coarse-grain control. In a more refined stage and with complete or nearly complete airborne implementation, the data-link system may be capable of furnishing sufficiently accurate data for fine-grain control. If not sufficiently accurate for high-density fine-grain control, it certainly would be of measurable assistance in furnishing identity and altitude, and it possibly could be used as a medium for airborne requests.

The study and development of this system definitely is in the long-range category. It is an extension of improved air/ground communications. Its study and development should parallel the study and development of ATC integration with the SAGE defense system. Recognizing that air traffic control can depend upon the cooperation of the users, much of the complexity of SAGE could be omitted. Even though SAGE or other methods of determining airspace occupancy may be used eventually, simultaneous pursuit of a telemetering development would make the eventual decision a wiser one. At a minimum, it would offer marked improvement to the present voice-communication system.

2. Integrated ATC signal system. The improved ATC system, in addition to obtaining and processing airspace-occupancy information automatically, also would furnish coarse-grain control instructions to the aircraft. Such instructions may be integrated with the automatic position-reporting system (air/ground) which furnishes position information, or it may be an independent system. This, of course, depends to a major extent upon the methods of obtaining airspace-occupancy data and upon the additional capacity of this medium. This system is perhaps the longest of the long-term communications objectives because it depends upon the others being accomplished and it envisions the use of automatic traffic-control-processing equipment.

A few of the salient features of the ATC signal system can be described at this time, although much study needs to be done to pinpoint the requirements of the system fully. It is visualized that control instructions will be in terms of route, altitude, and required ground speed or time over certain fixes. Depending upon the accuracy obtained, it is conceivable that this signal system could be integrated with the flight director associated with automatic approach devices and, at that time, it could include navigation information and flight direction. Development work on this system may alter the thinking considerably; as it is presently visualized, however, an independent approach computer and flight-director system eventually will be required for the fine-control and high-density areas.

Considerable work already has been done by the military in ground/air data-link systems. This should form a good basis for continued development of an ATC signal system. Although it depends to a measurable degree upon the air/ground link and upon the output of the data-processing system, study should begin as early as possible.

Automatic Data-Processing and -Control System.

The nationally accepted and endorsed Report on Air Traffic Control dated May 12, 1948, prepared by the Radio Technical Commission for Aeronautics (RTCA), contained this important conclusion: "The use of additional controllers will be of considerable benefit, but, as traffic increases, will reach a point of diminishing returns." The introduction of automation into the ATC system has been needed for several years from the standpoint of increased traffic-handling capacity. The development of a semiautomatic system now is economically justified. This trend is illustrated in Fig. 2. This curve shows that beyond a traffic load which requires an increasing expenditure rate-determining slope θ, automation is dictated by economic considerations.

As stated previously, many proposals for improvements and new systems of air traffic control have provided no ready means for an evolutionary approach. Systems have been described in detail, but the process and means of transition from the present system to the proposed system have not been well defined.

Before outlining a research and development program necessary to produce a semiautomatic system for collection, storage, processing, and display of flight data, a step-by-step process of evolution toward this system should be described. Although navigation aids, terminal aids, primary and secondary radar, and other facilities are important parts, the basic description will be slanted toward the operational aspects of the system.

It should be emphasized that the concepts described represent a research and development program intended to produce an experimental system which can be evaluated under simulated and live traffic conditions. Implementation of the system can take place at any stage of the evolution where it may be demonstrated that improvements will result.

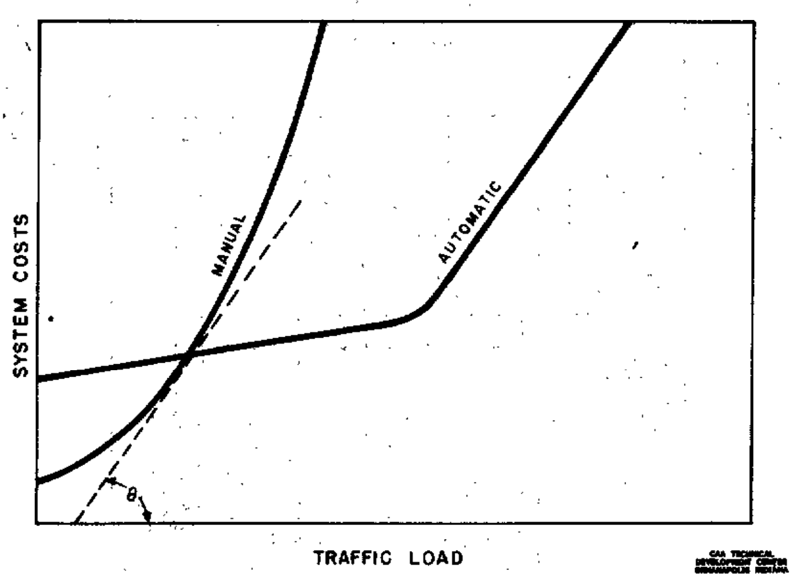

Fig. 2 Typical Cost Curves for Manual and Automatic Systems

The first barrier which exists against a semiautomatic system of air traffic control is the means by which flight data are fed into the system. As long as voice communications are used to file flight plans, and as long as pencil and paper are used to copy and produce a display of flight data, very little assistance can be provided by automatic equipment.

At the present time, numerous devices are being used to feed information directly into automatic data-handling systems. The various airline-reservations systems have a ticket agent set which is a device for pushbutton entry of data into a reservations computer. In at least one such system, provision is made for the sets to be located at long distances from the central computer, connected by a standard communications line through switching equipment. Adaptation of such a device for filing flight plans could help to remove the barrier.

The first step in the evolutionary research and development program for an automatic data-processing and -control system is aimed at reducing control personnel effort in collecting flight-plan data and in setting up the display. As will be shown later, research and development is required for improved controller displays. Use of standard flight-progress strips is indicated in the following section as an interim output for display purposes.

Phase I, Automatic Printing of Flight-Progress Strips and Automatic Center-to-Center Data Transfer.

1. System requirements.

a. Teletypewriter communications system for collection of flight plans and intercenter flight-data transfer.

b. Flight-plan input device for rapid and accurate composition, checking, and transmission of flight plans.

c. General purpose computer with multiple input and output capabilities for on-line operation. The computer will check the accuracy of flight-plan input, break up the flight plan into a series of fix-posting messages, compute first estimates, and send to appropriate printers. It also will send flight data to adjacent centers when flights are due to leave the area.

d. Automatic printers for producing flight-progress strips in conventional form.

2. Operation (see Fig. 3). In a control area, flight plans will be filed by pushbutton operation or by inserting perforated tape or a punched card into the input device at a local

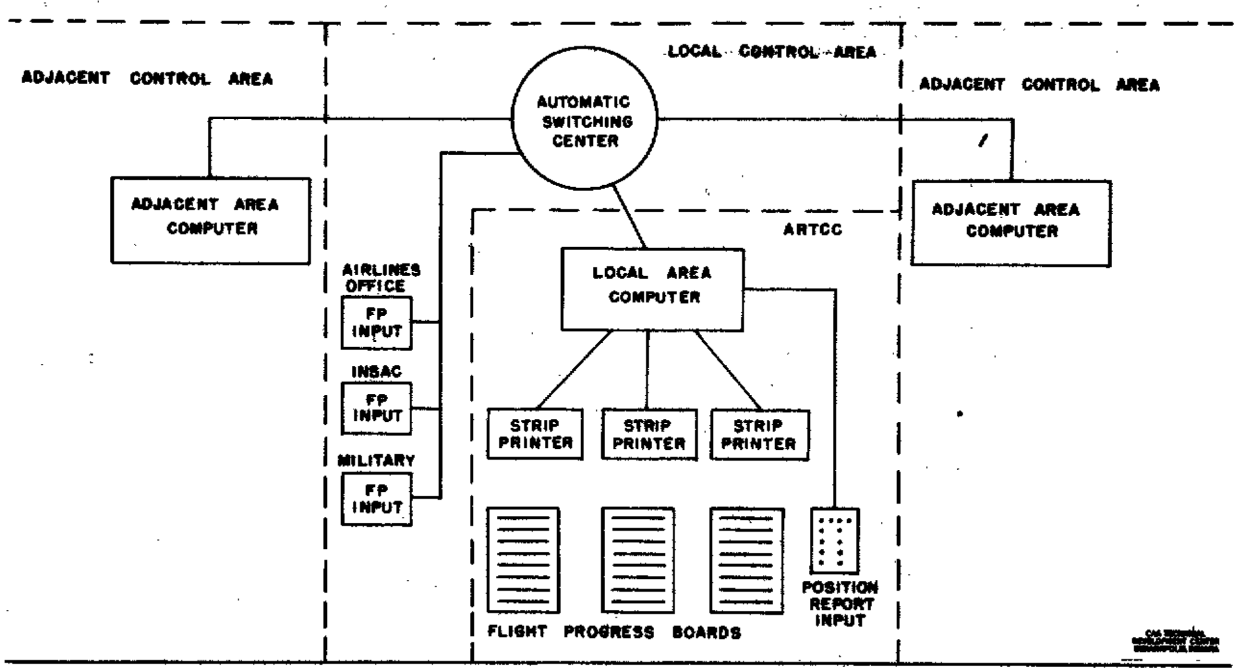

Fig. 3 Phase I, Automatic Printing of Flight-Progress Strips and Automatic Center-to-Center Data Transfer

airline office, INSAC, or military operations office. The message as it is composed will be displayed in front of the operator for visual verification that this is what he wants to send. A keyboard will be provided for setting up the original message or correcting the displayed information. The device also will check the information automatically for proper format. Then, by pressing a transmit button, the flight plan will be sent over the teletype circuit and checked during transmission by parity-checking or repeat-back techniques.

Passing through the automatic switching center, the flight plan is fed into the computer where it is broken up into fix-posting messages, ETA's are computed, and the messages are distributed to printers at each sector or group of sectors. The printed strips then are removed from the printer and inserted in strip holders by the assistant controller. The computer will retain current flight data in its magnetic-drum memory for all aircraft in the area.

From this point the operation of the ARTC Center would be the same as it is at present except for forwarding the flight data to the next center. When time for this operation arrived, a pushbutton device associated with the peripheral sector board would be operated by the controller to feed the latest ETA data for that aircraft into the computer. The computer then would send the proper flight data automatically to the adjacent computer which would go through the same process as for the original file action.

3. Advantages.

a. If provision can be made for encoding flight data properly and storing these flight data in an electronic memory, a major breakthrough will have been accomplished toward the ultimate semiautomatic system.

b. Under present procedures the primary duties of the assistant controller are preparation of flight strips and preliminary estimation of reporting times. By having these duties performed automatically, the majority of the assistant controller's time will be available for aiding the controller.

Under Phase I, control personnel effort is required to insert strips in holders; make revisions in time, altitude, speed, and route by pencil on the printed strip; and to pass such revisions along to other controllers. An automatic display directly connected to the computer, which would be capable of showing original postings and all revisions automatically, would greatly reduce controller effort of this type.

Phase II, Automatic Display and Automatic Revision of Tabular Data.

1. System requirements (in addition to requirements under Phase I). An electronic display device will be required, with provisions for displaying data now carried on flight-progress strips by means of a Charactron, Typotron, or similar tube, or by projection techniques. Provision also should be made for on-line operation with the computer and for allowing the controller to feed data into the computer.

2. Operation (see Fig. 4). The original file of flight plans and computation of first estimates will function as described under Phase I. Under Phase II the fix postings will appear automatically in front of the controller on the face of the display and normally will be sequenced automatically. When a position report is received by radio or interphone, the controller will correct the displayed information and cause the revised data to be sent to the computer. The computer will recalculate estimates over all subsequent fixes in the area and will transmit the revisions automatically to the proper controller's displays. The corrected information will cause flashing of a light or of the displayed information until acknowledged by the controller by a pushbutton.

At this stage intercontroller coordination regarding clear altitudes still could be done by interphone, but passing flight data within and between control facilities can be handled by the automatic equipment. In addition, it will be possible to introduce another concept, that of automatic conflict detection.

It is assumed that position information on each aircraft is being received by radio reporting, and therefore, is coarse grain in nature. The computer would be capable of comparing the current estimates for all flights in the area and determining whether separation standards are being maintained. The computer could serve as an aid to the controllers and provide a flashing light, flashing display, or different color display to indicate possible future conflicts.

3. Advantages.

a. Control personnel effort in setting up a display of control information will be greatly reduced.

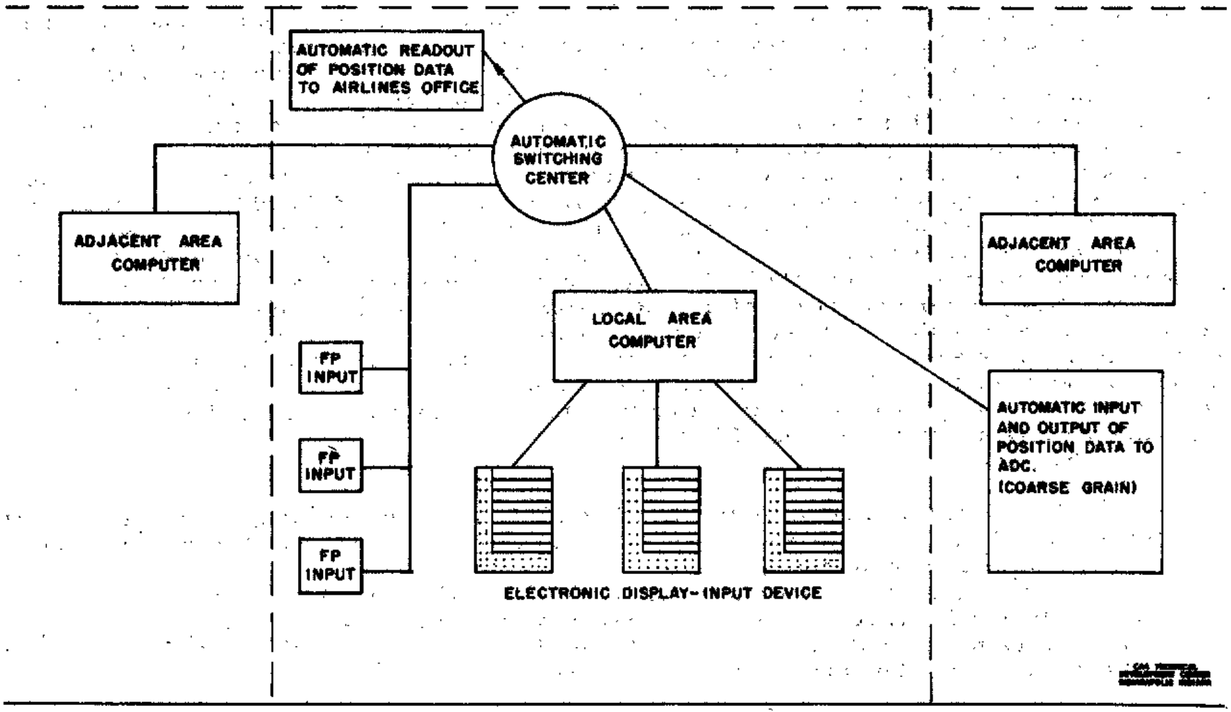

Fig. 4 Phase II, Automatic Display and Automatic Revision of Tabular Data

b. A large portion of control personnel communication time required in forwarding clearances and estimates to other ground agencies will be saved and can be applied to decision making.

c. Conflict prediction will serve as an aid to controller efforts in maintaining safe aircraft separation.

Thus far in the evolution of a semiautomatic system, most of the effort has been aimed toward improving the operation of control facilities. It is realized that a very important area for improvement is toward the reduction of pilot effort and attention to details of position reporting, altitude occupancy and vacancy, clearances, and other matters which make up a large volume of the pilot's communications workload. Although listed in the next phase, automatic equipment for position reporting such as data links logically could be added in Phase II. The data-link receiving equipment on the ground could be connected directly to the area computer which would keep the automatic displays posted with more accurate flight data. Controller effort required for feeding position reports into the system would be reduced further with respect to all aircraft so equipped.

The communications workload which the present traffic-control system imposes on the aircraft has made it difficult for airline offices to contact their flights and keep track of their progress. With position information stored in the computer concerning each flight in the area, either automatic or selective readout of these data to airline offices could overcome the difficulty.

By suitable data link with military data-handling systems, position information can be interchanged to keep the military system better informed on civil flights, and vice versa.

The third step in the evolutionary plan involves the application of fine-grain position information to the resolution of conflicts which cannot be eliminated readily by preplanning techniques. Radio reports from the pilot, advising that the aircraft is over a particular fix, are considered to be coarse-grain position information. Fine-grain information is the type produced by radar, air/ground data links, telemetering techniques, and similar facilities by which a high rate of accurate position information is obtained. Under Phase II, some fine-grain position information will be available from the radar system. The problems of identification, clutter, precipitation, and coverages will make complete radar control difficult. Phase III will describe the application of fine-grain data to air traffic control operations.

Phase III, Use of Fine-Grain Position Information.

1. System requirements (in addition to those mentioned under Phases I and II).

   a. Radar data link.
   b. Air/ground data link.
   c. Filtered pictorial-situation display.
   d. Fine-grain computing system.

2. Operation (see Fig. 5). Fine-grain position information in the form of x, y, and z coordinates or Rho/Theta and altitude data, together with aircraft identity, can be fed into the system in part or in entirety by radar, air/ground data links, or by special military tactical systems. This information will be received much more frequently than voice-radio position reports, and it will not require pilot effort because the information will be derived automatically.

The fine-grain position data can be used to keep the preplanning control data more accurate and can provide filtered information on aircraft position to a pictorial-situation display. This display will be capable of indicating the position and identity of all aircraft at selected altitudes. Its function will be that of a conflict-resolving tool. When conflicts are detected by the coarse-grain equipment, using any separation standard desired, the altitude involved in the conflict can be selected automatically, and all aircraft at the altitude involved can be shown on the display.

Instead of resolving conflicts by control techniques which will change materially the future flight path of the aircraft and produce repercussions down the line of flight, it will be possible in many instances to use fine-grain information to resolve the conflict without affecting preplanned separation. If a major change is necessary, however, the computer will determine which control action will provide the least conflict.

3. Advantages.

   a. Pilot-controller communications will be greatly reduced.
   b. Airspace utilization can be improved through more efficient use of fine-grain position data.

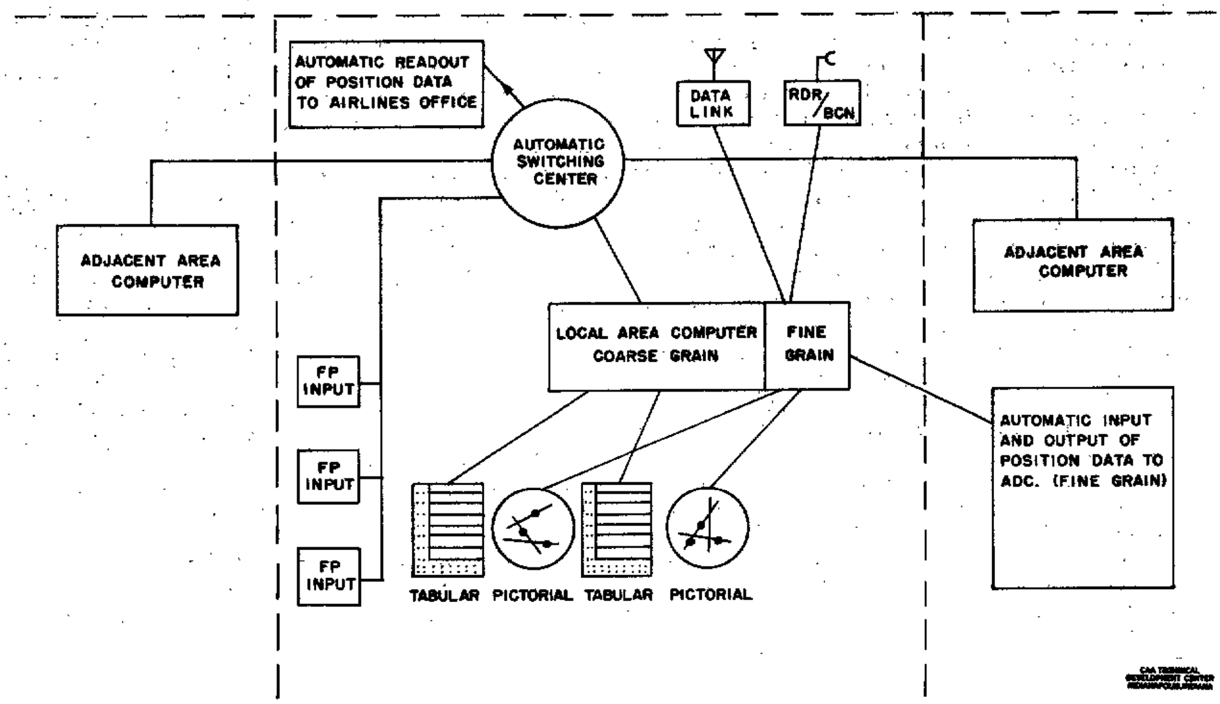

Fig. 5 Phase III, Use of Fine-Grain Position Information

Emphasis is required on this part of the program to provide guidance for procurement of an air-traffic coordinating equipment specified in the Federal Airway Plan. Installation of such computers, input devices, and teletypewriter circuits would serve as the most important first step toward the semiautomatic system.

Research and Development.

1. Flight-data computer and storage system. Under this project a general purpose computer will be procured for evaluation in simulated and live traffic environments. The problems of programming the computer to perform operations such as receiving flight plans, computing estimates, storing flight data, and composing and distributing flight data to displays will be worked out. Use of computers to perform flow-regulation functions also will be investigated. The amount of electronic storage necessary to handle all flights in a control area and requirements for center-to-center coordination will be determined.

2. Flight-data conversion equipment. This project will include development of a flight-plan input device as described under Phase I. Determination of suitable message format, means of inserting flight-plan data, and checking procedures both before and during transmission will be included in the development. The development of an input device also will be included by which the control personnel can feed position data directly into the computer to update it prior to center-to-center coordination.

3. Data-transfer equipment. Although this effort may be more rigidly classified as communications, for the sake of unity the development of a data-collecting and data-transfer system is considered here. This project will concern itself with a record communications system in which the flight-plan input devices mentioned in Item 2 may be connected to the central computer in the control area and in which one control-area computer may feed air-traffic data to another control-area computer. The problems of error checking, data transmission, traffic load, and speed of handling data will be considered.

To carry out Phase II of the evolutionary program, two items need to be considered. The first is an electronic or projection type of display with functions permitting controller input to the computer. This is described under "Display Systems." The second item refers directly to computer techniques and programming, and it is described here.

4. Automatic posting and automatic conflict-search techniques. The flight-data computer and storage systems described under Item 1 will have sufficient flexibility and storage capacity to store present and predicted aircraft-position data for all aircraft in the area. The computer capabilities will not be taxed severely to carry out functions under Phase I. Under this project the techniques of programming the computer to carry out a simultaneous operation of posting flight data, receiving position reports, and recalculating and posting new estimates will be worked out. In addition, the techniques for detecting conflicts and displaying conflict information on the automatic board will be determined.

Phase III in the evolution of a semiautomatic system will be concerned with the application of fine-grain position data. A pictorial display for presenting these data is a part of the development program in the section entitled "Display Systems." The role the data-processing system will play in handling this information is described.

5. Fine-grain data processing. Fine-grain position information will be fed into the system from radar data links, telemetering or air/ground data links, and military data-collection systems. Addition of such data into the systems concept necessitates additional computer functions to receive, store, process, and filter the information. The input and output requirements for handling such data and for providing the data in the form necessary to produce the pictorial display will be determined. Development of programming techniques involved in correlating and filtering fine-grain information to produce automatically or selectively the position of all aircraft at a particular altitude will be necessary.

6. Integration of military tactical data with the ATC system. Various military commands will be collecting large quantities of data on aircraft movement which will be in electrically coded form suitable for direct insertion into the ATC system. In addition, data stored in the electronic memory of an automatic ATC system could be made available to these commands by selective request or on an automatic basis. The research and development program for data-processing and data-transfer equipment should include efforts to make most efficient use of the capabilities of both systems.

Display Systems.

As long as a human controller is part of the traffic-control system, a key element will be the display. This is the medium through which the controller visualizes the traffic situation. Much of his capability of handling traffic safely and expeditiously in quantity depends on the adequacy of the display.

Improvements in displays fall into two categories. The first of these is of an interim nature involving improvements in radar-display techniques, improvements in flight-progress board displays, and similar effort. The second category involves more completely automatic displays.

In-Service Improvements.

Improved display, coordinating, and data-processing equipment for air traffic control. A continuing program is required to improve the radar pictorial and flight-data symbolic displays now in use or which will be introduced in the near future. Controller coordination and data-transfer devices are required for interim use prior to completion of the automatic data-processing and -control system. The changes required will be determined from field experience, from simulation tests, and from the program at AOEC.

Research and Development.

An automatic data-handling system is capable of presenting flight data to traffic controllers in any display form which might be desired. This display may be a printed flight-progress strip, tabular or symbolic display using electromechanical indicators, symbolic display on a tube such as the Charactron or Typotron, or pictorial display giving aircraft position with references to x, y, and z coordinates or Rho/Theta coordinates from data stored in the system. The choice of a suitable display will be determined by operational requirements, the amount of radar information available, complexity of the traffic pattern, amount of data-link information available, and similar requirements. Different types of displays may be required for different geographical locations.

Displays which can present flight data automatically and provide for revising the displayed information automatically will save time and effort of the controller and will release his time for decision-making functions.

The development of improved displays for air-traffic data should be accomplished under the following items:

1. Electronic display of symbolic data. The Charactron tube, Typotron tube, and other new tubes under development are means by which information similar to a printed page may be displayed electronically on the face of a tube. Various projection techniques or closed-circuit television also are capable of this form of display. Use of this type of display to present information similar to that now used on a flight-progress strip can be a logical step in the gradual evolution toward an automatic system.

As a further step in this evolution, if pictorial displays are used to present fine-grain position information, the controller still will need to make reference to the entire flight plan of an aircraft in making some control decisions. This type of symbolic display can serve to provide additional data which cannot be displayed on the pictorial presentation. In Phase II of the evolutionary program, application of this type of display is described. In addition to developing a means of data presentation to the controller, a means by which the controller may feed information into the computer is needed and will be considered as an integral part of the display.

2. Electromechanical displays. Experimental models of electromechanical displays already have been developed and are being evaluated in the form of limited-data-transfer equipment and Type C display boards. Such displays have an advantage over the electronic equipment listed under Item 1 in that they are less complex and they provide a nonvolatile type of information storage. The chief disadvantage lies in the fact that the physical size of the electromechanical indicators used precludes the display of large quantities of data in an area which can be scanned by one controller.

Electromechanical displays are ideally suited for rapid transfer of small quantities of control data from controller to controller to provide intercontroller coordination. Although such displays may find greatest application in terminal-area control, they also should be investigated to solve controller coordination problems in en route control areas.

3. Pictorial or panoramic displays. Bright-tube or projected displays, giving aircraft position by a pictorial or panoramic presentation, show great promise as a means of displaying fine-grain position data to traffic controllers. Information from radars, beacons, and automatic data-processing equipment can be combined to provide a panoramic picture of the traffic situation in a controller's area. In addition, data irrelevant to a particular problem may be filtered out if desired so that only aircraft involved in a specific conflict problem are displayed for control action. This would be particularly useful in a system where conflicts

were being determined automatically. Aircraft proceeding without conflict would require no attention on the part of the controller. In projected or storage-tube displays, color can be used to distinguish altitude, conflict, or other control information on controller displays. Further development of color equipment should be undertaken to meet traffic-control needs.

Operational Research.

A continuous program of operational research will be necessary to develop and evaluate the various concepts, procedures, and equipments of the improved ATC system, and to refine and adapt them to the changing requirements of the rapidly advancing aviation industry. In this type of research, simulation has proved to be a most useful tool. Analytical and graphical simulation is extremely effective in exploring new concepts and parameters. Static and dynamic simulation is well adapted to the development and evaluation of new types of equipments such as displays and new procedures.

Following simulation tests, and prior to system-wide implementation, there is a need for testing and evaluating new procedures and components in a live traffic environment under closely controlled conditions. The ACC, having recognized this need sometime ago, recommended the establishment of the Airways Operations Evaluation Center at the Technical Development Center of CAA at Indianapolis. This has been accomplished, and over the past several years, through the help of ANDB and the military, considerable implementation already has been accomplished to provide a complete radar and communications environment in a large portion of the Indianapolis ARTC Center area. The area includes a number of terminals and a complex airway structure. All types of flight operations are included, both military and civil. The AOEC test area includes the all-weather test activities of Wright Air Development Center, and a peripheral facility of the AOEC has been established near Patterson Field to expand civil/military developments under a TRACALS/AOEC agreement. Much of the CAA and joint CAA/military evaluation work described in this report is ideally suited for this already existing environment.

In-Service Improvements.

1. ATC simulator. The present 18-target optical-type dynamic simulator at Indianapolis is being expanded to 24 targets. This appears to be its ultimate capacity because of space limitations. It also is being modified to permit investigation of certain improved types of display systems.

2. AOEC. Continuous modification of equipment arrangements will be required in evaluation tests of new equipments and procedures. Adequate funds must be provided for these changes as required.

3. Area-control procedures. With early implementation of area control in the high-altitude airspace, emphasis on improved methods for display and control of this traffic is required.

4. Express-airway concepts. It is believed that one-way airways, speed segregation by altitude levels, and elimination of crossing traffic will provide increased capacity with reduced control problems in the airway system. Additional studies and evaluation of these express-airway techniques are required. Some modifications to Civil Air Regulations very likely will be required to make these procedures most effective.

Research and Development.

1. ATC simulator. Although 24 targets will be adequate for handling the problems of simple terminal areas, this number will not be sufficient to populate large en route areas or complex terminal areas at the traffic densities predicted for future operations. For this reason, it is desirable to increase the simulator capacity to at least 50 controllable aircraft targets. Use of electronic instead of optical means of target generation is desirable from the space standpoint as well as for increased realism in simulating the output of air/ground data links and the type of presentation obtained from primary and secondary radar equipment.

2. Procedural studies. Some of the more important phases of the simulation and AOEC programs include the following types of studies:

a. Investigation of the effects of new types of aircraft on the system.

b. Investigation of ways of displaying traffic data to controllers to obtain maximum efficiency.

c. Investigation of the parameters for radar beacons and/or data links as these affect separation standards and utility of the data for display to the controller.

d. Investigation of the human engineering aspects in the design of control equipments.
e. Investigation of modifications to rules and procedures to provide a more efficient and economical ATC system.

Auxiliary Functions.

1. Monitoring equipment. A continuing program for the improvement of monitoring equipment for Federal Airways facilities must be conducted. This is true particularly of navigation and landing facilities which are designed for unattended operation. The importance of accurate and reliable monitoring devices cannot be overemphasized.

2. Flight-inspection equipments. Continuing effort in the development and improvement of flight-inspection equipments also is essential. The requirements for a satisfactory airborne system for monitoring a specific type of ground facility are reliability, accuracy, ease of operation, and minimization of data reduction from recorded outputs.

3. Airborne radar. An extensive program of airborne-radar installation currently is being conducted by airlines in the United States. A certain number of installations are being made in business-type aircraft, and many military aircraft are so equipped. Although the primary purpose of the airline implementation of radar has been for thunderstorm detection and avoidance, the inherent nature of radar systems is such that flight experience may demonstrate that the utility of these devices extends well beyond this primary purpose. To the degree that airborne radar may be effective for navigation, terrain avoidance, and related purposes, it can become a valuable tool to the ATC system. It is essential that the ATC system be prepared to take advantage of any assistance which airborne radar may offer.

Initial steps in this effort should be directed toward familiarization with the types of airborne radar in use or on order and toward procurement of at least one model for CAA evaluation.

4. Airport design. Simulation studies have been directed toward increasing airport capacity through better utilization of runway and taxiway facilities. Additional work is required in this area. In addition to improving the capacity of single airports, the layout of multiple airports in congested terminal areas requires further study to obtain maximum traffic capacity. This will be increasingly important as the characteristics of aircraft become more widely divergent.

TIME AND COST SUMMARY

In the report prepared in the early part of 1948 by Special Committee 31 of RTCA, the research and development costs for an interim program were estimated at 5.7 million dollars and the target program at 69.7 million dollars. The recommended program level was 34.5 million over the first three-year period and 32.5 million for the second three years, with an average yearly level of approximately 11.2 million dollars. In reviewing the recommendations of the SC-31 document, it can be seen that most of the development work on the interim program has been completed and a start has been made on the target program. The level of fiscal support has been far below that recommended by RTCA, however, and some changes in the original program were required as a result of the study and development phases completed on certain items.

In compiling the estimates of time and cost required for the program, it was found that an improved longer range program with a reduction in time and money could be obtained if the research and development appropriations were removed from the one-year obligation requirement. It is difficult to prepare accurate estimates of some of the development phases required, especially those involving large contracts. As a result, because the funds allotted to many of the projects are based on estimates of requirements which may vary after the project is under way, effective and efficient use of the funds is not obtained always. As indicated previously, a certain level of in-service-improvement projects will be required because of problems encountered during the use of the various facilities and changes in service requirements. Because the funds allotted for this purpose during the past five years have been much less than the requirements, however, an increase over the normal recommended fiscal level will be required for several years in order to reduce the backlog of improvements necessary. The attached estimates outline the recommended fiscal program for in-service improvement and research and development projects.

FISCAL ESTIMATE FOR IN-SERVICE-IMPROVEMENT PROJECTS

Item	Year 1	2	3	4	5
Navigation Systems	$1,040,000	$ 900,000	$ 900,000	$ 700,000	$ 700,000
Primary and Secondary Radar	1,375,000	1,000,000	1,000,000	700,000	700,000
Improved ATC Equipment and Procedures	2,010,000	1,500,000	1,500,000	1,000,000	1,000,000
Airborne Radar and Miscellaneous Items	85,000	100,000	100,000	100,000	100,000
Totals	$4,510,000	$ 3,500,000	$3,500,000	$2,500,000	$2,500,000

FISCAL ESTIMATE FOR RESEARCH AND DEVELOPMENT PROGRAM

Navigation Systems	$ 300,000	$ 700,000	$ 200,000	$ 300,000	$ 600,000
Primary and Secondary Radar	500,000	2,000,000	1,000,000	1,000,000	1,000,000
Communications	1,000,000	2,000,000	1,000,000	1,000,000	1,000,000
Automatic Processing and Control System	2,100,000	3,800,000	3,150,000	2,150,000	2,150,000
Data Display	500,000	2,000,000	1,000,000	1,000,000	1,000,000
Operational Research	1,500,000	500,000	500,000	500,000	500,000
Totals	$5,900,000	$11,000,000	$6,850,000	$5,950,000	$6,250,000