used for information input and output in such a fashion that the controllers were more fully able to spend their time analyzing the data. The literature dealing with this installation and other associated plans for an automatic posting system is very interesting;[1] unfortunately the equipment was not reliable and it was taken out of service just before the war. No further attempts at obtaining satisfactory operation have been or seem likely to be made.

As a concluding remark to this discussion of the control procedures and methods, it should be noted that present arrangements permit human failure or errors on the ground to occur without the pilot's knowledge. Similarly, because the controllers possess no direct evidence that their instructions are being followed, a pilot's error may be unknown on the ground for a considerable length of time. Neither the pilots nor the controllers, then, have a method by which one can check the proper functioning of the other.

B. Future Needs

1. Commercial Airlines

At the present time commercial airlines carry some 15,000,000 passengers each year, this figure representing 50% of the total first-class passenger travel in the United States.[2] A further increase in this percentage seems quite likely in as

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1. Reference 20.

2. Reference 21.

much as both the fares and safety records of the airlines are fast approaching and in some cases have already passed the corresponding figures for first-class rail and ship transportation. The experience of the past two years has clearly indicated the potentialities of low-fare "air coach" service,[1] while the field of air freight transportation, relatively undeveloped before the war except for a limited amount of air mail service, now seems capable of a considerable growth.

Despite this rather optimistic picture of possible expansion, the progress of commercial aviation is presently being retarded by the lack of dependable and reliable service. It is obvious that air travel will not reach its true proportions as a means of transportation until people are reasonably certain that they can arrive and depart on schedule. Similar remarks apply to freight and cargo movements where the advantages of the high speeds of aircraft are quickly nullified by cancellations and delays encountered in poor weather.

Although complete figures on delays and cancellations in all types of weather are not available, it is interesting to note the figures for a representative airline operating in and out of New York City.[2] During the relatively fair-weather month of June 1947, 89% of the arriving aircraft of this airline were late, and 46% of all arriving aircraft were over one hour late.

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1. Reference 22.

2. Reference 26, Page 107.

Of the departing aircraft 41% were late, with 16% being delayed over an hour.

The air traffic control problem has economic implications. Despite rather lucrative airmail contracts, scheduled airlines with but several exceptions are operating at a definite financial loss.[1] The total loss was estimated at $22,000,000 net during 1947. Typical figures resulting from a study of active and potential revenue losses by airlines during 1946 showed the following items:

a)	Cancellations due to weather	$ 6,200,000
b)	Low load factor resulting from unreliability	$12,200,000
c)	Congestion at 13 stations at which studies were made	$21,100,000
		$39,500,000[2]

The losses to private operations, military operations, and non-scheduled services, as well as losses at airports at which studies were not made, are not included in these totals. The inclusion of these other items would further highlight the necessity for improvements.

The basic need, in light of the above considerations, is for a comprehensive system of air traffic control capable of implementing and handling all-weather flying without delays. To quote from one study made of this subject:

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1. Reference 24, Page 41.

2. Reference 25, Page 5.

> This country has an estimated six billion dollars invested in civil airports which are closed approximately 15 per cent of the time due to weather. All-weather flying would be equivalent to increasing our airport values by $900,000,000 even before an additional acre of land is condemned or a yard of concrete is laid.[1]

2. Military Considerations

The need for an improved and expanded system of air traffic control does not result solely from the problems of civil or commercial aviation, for considerations of national defense and security require that any new system of control be one which is integrated with respect to military as well as civil and commercial requirements. This was clearly expressed in a report of the Research and Development Board of the United States Government:

> Despite some diversity in requirements for tactical and civil operations, the studies made indicate that the national interests of security and economy would be served best by a navigation system providing the greatest common utility for military and civil aircraft....In order to achieve a system that could provide in time of emergency a single integrated facility for the purpose of national defense, it is essential that the common requirements be kept always in the forefront of development planning....The need for a unified civil and military policy is clearly indicated.[2]

In the event of a national emergency the United States will become an active air-supply area, and both civil and military aircraft will be used to transport large quantities of men and

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1. Reference 25, Page 6.

2. Reference 23, Page 12.

equipment. The success of the Berlin Airlift and associated operations[1] emphasized the practicality and advantages of large-scale air supply operations, and in future supply operations the amounts of traffic can be expected to increase to values almost beyond imagination. It is essential, therefore, that the traffic control system be geared to handle this activity and that all classes of pilots be familiar with this system.

These reasons alone suffice to explain the need for an integrated system; yet in the event of a future war there is every indication that the United States might also become an active air-combat area. In this event it would be important to be able to quickly clear civil aircraft out of a combat region and to be able to direct fighter planes into the region and direct their actions. It is even more important to provide the means for carrying out a mission according to plan, with the assurance that the aircraft can return to their bases and land regardless of the visibility or weather conditions.

3. Future Aircraft

In making plans for any future air traffic control system, an important consideration must be of the future aircraft -- their size, number and speed.

At the present time there are about 100,000 private aircraft and 7000 commercial aircraft (about 1000 scheduled, 6000 non-scheduled) in operation.[2] These aircraft range from

1. Reference 27.

2. Reference 28.

an extreme of a one-passenger capacity with a cruising speed around 100 mph to larger commercial aircraft with capacities close to 100 and speeds between 250 and 335 mph. The smaller aircraft with non-pressurized cabins are limited to altitudes below 8000 feet, while with cabin pressurization it is possible for commercial aircraft to cruise as high as 20,000 to 30,000 feet. These aircraft are all powered with propellers and conventional piston-type engines.

Present developments and future plans point to turbined-powered jet-propelled aircraft. Although jet aircraft are already in extensive use by the military and complete conversion to a jet-powered Air Force seems imminent, there has as yet been relatively little development along commercial lines. The principal work has been done by British and Canadian engineers, and each country has already flown models which may be in active passenger operation in a few years.[1] Considerable speculation has been done concerning future commercial jet aircraft,[2] and this, coupled with what is already known about the operating principles of jet aircraft,[3] points to the following facts:

a) The aircraft will fly at between 20,000 and 50,000 feet.

b) Speeds will range between 300 and 600 mph.

c) High fuel consumption requires maximum flying time at high altitudes, thus ruling out extensive delays and the use of holding patterns at low altitudes.

1. Reference 29.

2. Reference 30.

3. Reference 31.

d) If the necessary traffic control can be provided, the aircraft will be economically practical and can be used for flights of upwards of 300 miles.

The present traffic control system was not designed to handle high-altitude high-speed aircraft. This system, and principally its navigational equipment, was best-suited to the years from 1936 to 1940 -- the era of the DC-3's, a non-pressurized aircraft with an airspeed of 170 mph. At airspeeds of 600 mph the present check-points or fixes are but a few minutes apart, and the en-route control system necessarily breaks down. Even greater problems exist during approach and landing. Fortunately the military services presently restrict their jet operations as much as possible to fair-weather conditions. Such restrictions could not be tolerated with commercial jet aircraft which could easily fly above the en-route weather; their operations should not be limited by weather or visibility conditions at airports.

It is extremely difficult to estimate the number of jets which might be used in future commercial operations. To a certain extent this will depend upon the economic range of these aircraft and also upon the sizes and capacities. This latter factor would seem to depend upon public acceptance of multi-deck, multi-passenger aircraft.

Helicopters have also received widespread publicity. These aircraft have not as yet achieved the rather extravagant claims made for them, although new designs and new propulsive

units may change this situation.[1] Basically it appears that the chief limitations are upon speed (about 100 mph), capacity, and payload. If these limitations are overcome, the use of these aircraft in short-range flights may be quite extensive. Their control and separation with regard to conventional aircraft may offer serious problems.

The future operation of private aircraft is also a problem which must be solved. Although present-day operation is generally restricted to fair-weather conditions and flights are kept off the airways, the relatively large numbers of such aircraft have created and will create congestion problems. A further complication to their effective control is the general lack of navigational or communication equipment in such aircraft.

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1. Reference 34, page 16.

CHAPTER IV

Future System Components

The inadequacy of the present system of air traffic control both for current and expected needs is quite evident. New techniques, concepts, and equipment must necessarily form the basis for an integrated all-weather system of the future. This chapter discusses several of the so-called "building blocks" upon which the conception, planning, and implementation of a future system may depend.

A. Radar Aids

Radar, RAdio Detection and Ranging, reached a high stage of development during the last war. The underlying principle is the reflection of electromagnetic energy from obstructing surfaces in the path of high-frequency radiation. By directing short pulses of energy in a particular direction, the presence of an obstruction or target(aircraft, ship, mountain, etc.) may be discovered by the "echo". Accurate measurement of the interval between transmission of the pulse and the reception of the echo provides a direct indication of the distance of the target; the orientation of the directional transmitting antenna indicates the azimuth of the target.

1. Surveillance Radar

If the directional antenna of a radar set(ground-based or airborne) is allowed to rotate continuously, the echoes may be appropriately displayed on a high-persistence cathode ray tube to give a plan position indication (ppi) or map-like view

of the surrounding ground and air-space. This general application is known as primary or surveillance radar. The ability of such radars to "see" in the dark or during inclement weather conditions has opened new possibilities for air traffic control, although for reasons not generally realized the full potentialities are not immediately attainable. These reasons are briefly described below.

In addition to a basic limitation to "line of sight" distances, all aircraft appear as similar spots or pips on the radar ppi oscilloscope, and identification or accurate measurement of the position of aircraft is difficult. This was clearly pointed out by the experiences of the Berlin Airlift.[1] The scope presentation, unfortunately, is not of the actual horizontal separation between the aircraft and radar, but is the slant-height distance. (The difference is negligibly small at long distances, but not at shorter ones.) Surveillance radars in general are not capable of actual height measurement. An additional difficulty results from the fact that reflections and echoes are received from the ground. Such echoes, or "ground clutter" as they are called, tend to mask other information presented on the scope. Objects such as buildings, trees, or mountains appear as echoes and may be indistinguishable from moving aircraft.

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1. Reference 37.

Ground clutter on radar scopes has been reduced considerably by the use of the moving target indicator (MTI)[1] by which stationary objects are eliminated through a comparison of phase relations between succeeding echo pulses and a reference signal generated in the radar receiver. Another recent development is that of video mapping.[2] With this technique, ground reference data (airways, danger areas, etc.) and the radar-echo data can be presented simultaneously on a ppi scope. These two methods, MTI and video-mapping, were employed with the radar sets used for traffic control purposes during the Berlin Airlift. Representative scope pictures are shown in Figures 3 and 4.

Surveillance radars can be airborne as well as ground-based. In this case the ppi presentation is of the ground below, and as such can be used for navigational purposes although not with high accuracies. Airborne radar can be used to give an indication of other aircraft, and in this way it may possibly serve to a limited extent as an aid to traffic control in maintaining safe separation. In general, however, airborne radar is too heavy, too expensive, and requires too much attention to be seriously considered as a widespread non-military aid. As an alternative, ground ppi scopes pictures could be televised to the aircraft along with superimposed navigational pictures and traffic control instructions.[3]

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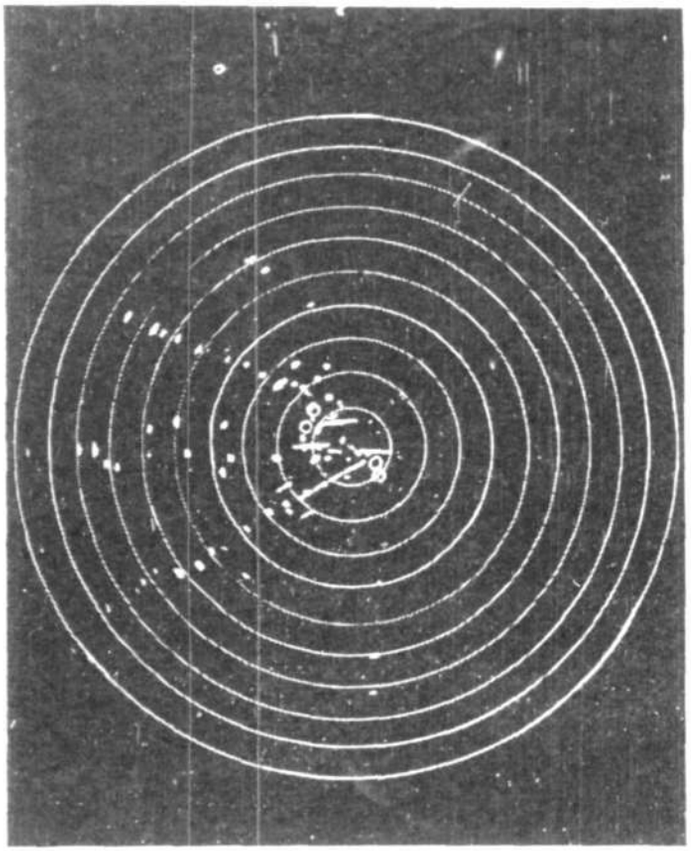
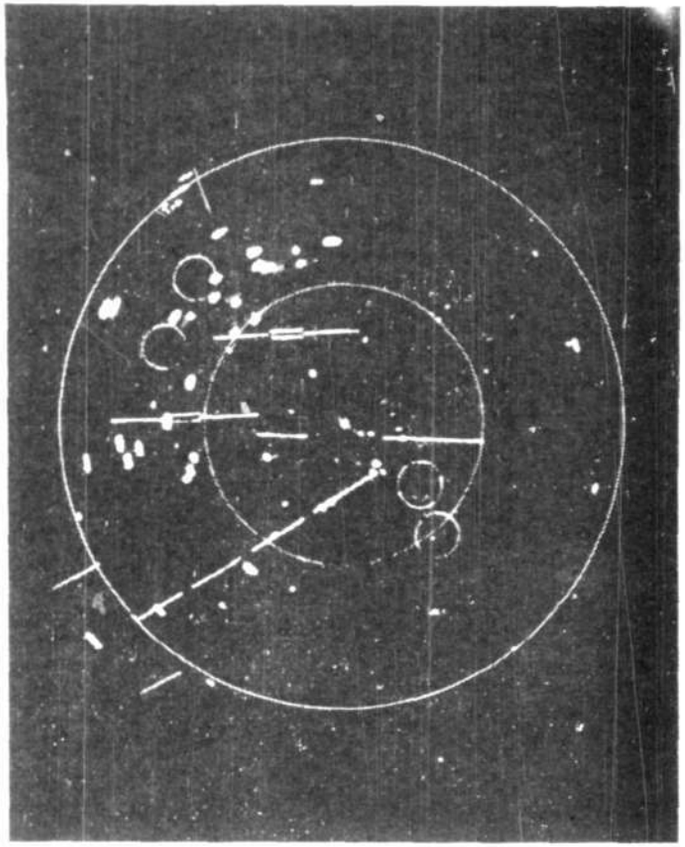
1. Reference 35.
2. Reference 37.
3. Reference 38.





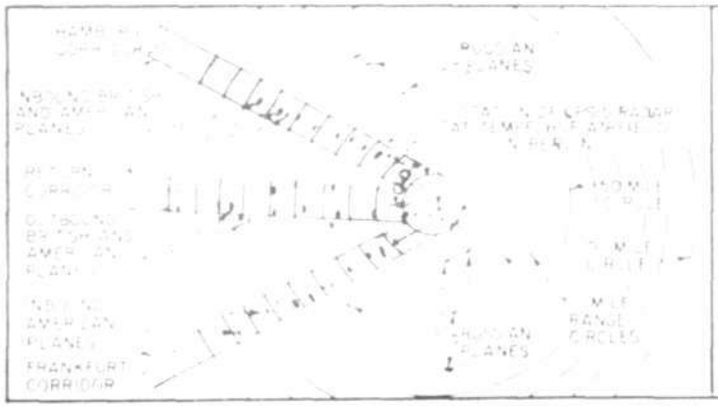


FIG. 3 Pattern seen on 100-mile screen of CPS-5 search radar on typical maximum-effort day near close of airlift operations. Diagram below identifies target pips and range circles

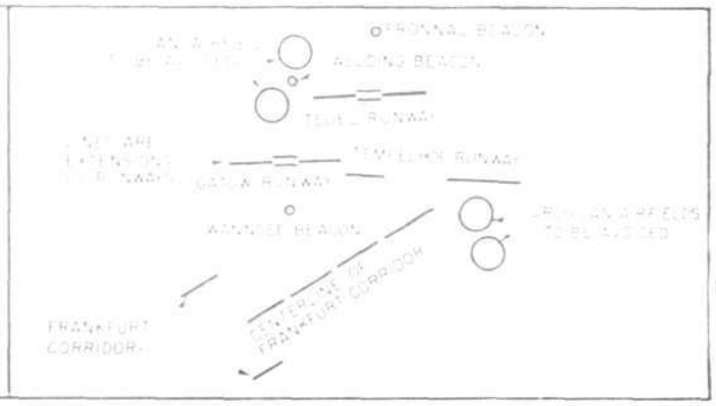


FIG. 4 Enlargement of pattern of Fig. 3 taken at approximately same time and obtained by switching scope to 20-mile range. Diagram identifies superimposed video mapping

from
Reference 37, P.81

2. Ground Controlled Approach (GCA)

Rather than being rotated, highly-directional precision radars may be kept stationary for observation of a particular volume of space or may be directed at a specific moving target for purposes of tracking.

The Ground Controlled Approach (GCA) is a combination radio-radar system using a surveillance and a stationary precision radar to guide aircraft in an approach to a runway during adverse weather. Whereas the Instrument Landing System employs special receivers and aircraft instruments to indicate to a pilot his deviations from an approach path fixed in space by radio beams, the GCA monitors the aircraft progress by ground radar, while controllers inform the pilot via ordinary radio-telephone channels of deviations from an imaginary approach path.

The search or surveillance radar of GCA "picks up" the aircraft about 30 miles away. On the basis of positive identification of the presentation on the radar scope, aircraft are directed by radio commands to a point about 10 miles distant where they enter the beam of the precision approach radar. The proper approach path is projected or traced on the range-azimuth and range-elevation scopes of the precision radar. Observations of the deviations of the aircraft from this path enable the ground controllers to advise the pilot of the proper flight procedures. Control may be continued down to about 50 feet above

the ground where radar reflections and inaccuracies set in, although generally speaking, the equipment is not used below ceilings of 200 feet. Further developments of microwave systems may, however, provide the ultimate answer to complete instrument landings.[1] Landing intervals of three minutes with GCA appear to be the lowest practical even under best conditions at the present time.[2]

3. Secondary Radar and Distance Measuring Equipment

The difficulties which would be encountered in the use of radar for air traffic control applications have been listed by one author as:

A. Technical problems:

1. Discerning moving targets in the presence of fixed targets
2. Discerning aircraft in presence of storm clouds
3. Discerning small aircraft at long ranges

B. Operational limitations:

1. Communication with aircraft
2. Determination of altitude
3. Determination of identity
4. Efficient use of radar data [3]

Certain of the difficulties listed under A may be lessened by improved electronic design and a better choice of operating frequencies; large-scale improvements in all of the above items are possible with the use of secondary radar.

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1. Reference 40.
2. Reference 37.
3. Reference 41.

Secondary radar, as opposed to the conventional or primary radar which utilizes the initial pulse transmission to produce an echo from an aircraft, uses the initial transmission only as a means of "triggering" a return pulse from a transmitter in the aircraft. The name interrogator is generally used in referring to the equipment transmitting the initial pulse; transponder is used to refer to the equipment providing the return pulse.

The advantages and variations of the interrogator-transponder arrangement are numerous. The return pulses from the transponders are more powerful and sharper than regular radar echoes. These replies can also be made at a different frequency and can be sorted out from the ground clutter or regular echoes. A change in the frequency or other characteristics of the reply pulses can be used as a means of identification.[1] In a more general sense the characteristics of the interrogation and transponder pulses may be used as the basis of a communication system. As an example, the transponder might be constructed so that the reply pulse would be altitude-coded; that is, the transponder would be connected to the altimeter in the aircraft in such a manner that the pulse coding of the reply would indicate the altitude of the aircraft. Transponders can also be constructed so as to reply only to specified types of interrogation pulses, and can be used to transmit short coded messages in return.

Since the delay time in the transponder is known, an interrogator-transponder functions as a means of distance

1. Reference 42.

measurement in addition to being capable of the communication functions mentioned above. The idea is conveniently adaptable to navigational purposes since airborne interrogators can be used to "trigger" one or more ground transponder beacons, measuring the distances to each.

The use of airborne interrogators to measure the distance to selected beacons or ground stations is presently being developed as Distance Measuring Equipment (DME). Designs differ, but in general this equipment measures the distance to a selected ground station and presents the result as meter reading. Due to frequent interrogations, DME essentially presents a continuous measurement of the distance. Present accuracies are of the order of $\pm \frac{1}{4}$ of a mile,[1] although figures of $\pm$ 250 feet do not seem unlikely in the future.[2]

8. Omniranges

Various systems of navigation may be compounded through the measurement of distances or differences in distances to two or more ground stations.[3] These systems, although capable of high accuracy, suffer somewhat in comparison to R-θ navigation in which an aircraft's position is fixed by a measurement of the azimuth and distance with respect to a single ground station. Difficulties in finding proper ground sites and in using the data

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1. Reference 43.
2. Reference 44.
3. References 45, 46.

from a hyperbolic system for display purposes or for automatic equipment (see page 57) seem to be the principal reasons for the decided preference towards the use of R-θ facilities in the United States.

In the previous section the use of DME for obtaining a near-continuous measurement of distance was described. DME, then, is capable of supplying the R for an R-θ system; to complete the picture a means of measuring θ with respect to the ground station is required.

Several methods for obtaining measurements of azimuth with respect to a ground station have been developed,[1] the most promising of these appears to be the Omnirange (VOR). Basically, two signals are transmitted into space such that the phase angle between them varies as a function of the azimuth. By the use of a suitable radio receiver and indicating mechanism, the azimuth can be continuously displayed on a meter in the aircraft. As opposed to the four-course range which permitted the indication of only four distinct courses, the omnirange supplies an infinite number of radial courses within the 360° arc about the ground station.

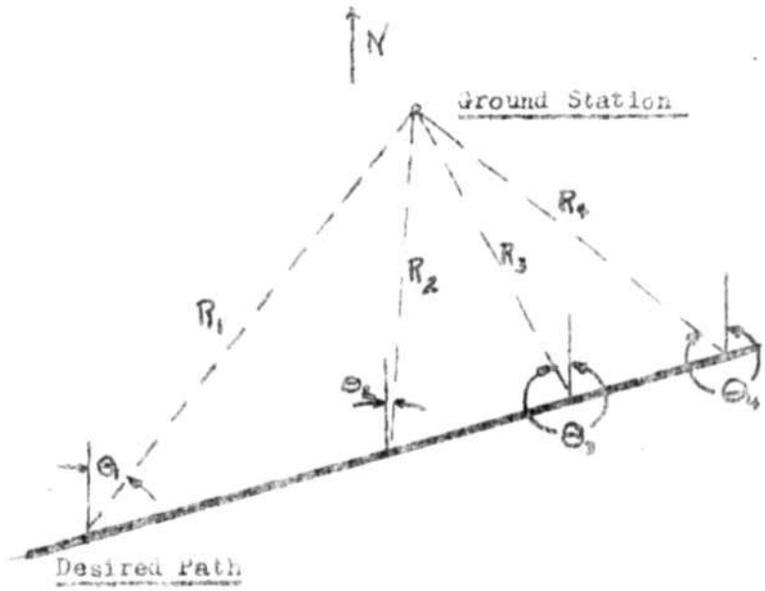
As with DME equipment, the omnirange is limited to line-of-sight distances because of the high frequencies used. Several models of the equipment have been constructed and tested.[2]

1. References 47, 48.
2. References 49, 50.

These tests have indicated that at favorable angles of elevation the inaccuracy is less than $\pm 2^{\circ}$, while at unfavorable elevations the inaccuracy is at least $\pm 3^{\circ}$ during 94% of the time.[1] With the use of improved electronic techniques, accuracies of $\pm .1^{\circ}$ do not seem out of the question.[2]

C. Course Line (Off-Set Course) Computers

By flying so that the reading on the DMN meter remains constant, an aircraft will follow a circular orbit path about the ground station; straight radial courses can be flown if the omniranges reading is kept constant. Other straight paths not passing over the ground station are expressable by a continuous relation between R and θ. This is shown pictorially below:



1. Reference 50, page 10.

2. Reference 51.

Actually it would be possible to calculate beforehand the R's and θ's at a suitable number of points along the path; the path would then be flown by checking the corresponding readings of the DME and omnirange indicators and making the appropriate corrections in the heading of the aircraft. A more convenient method of executing the flight would be to have an equipment which could be preset to the desired course, and which would then combine the DME (R) and omnirange (θ) measurements so as to provide the appropriate left-right flight indication. Equipments which accomplish this have been designed and built; they are known as course-line or off-set course computers.[1]

Calculations of the R's θ's, and deviations from the desired path are performed in these computers by electrical analog techniques. A study has been made of the errors arising within the instrument,[2] and actual flight tests have been made.[3] Unfortunately these tests were made with relatively inaccurate DME and omnirange equipment and the results (an average deviation of 3/4 mile from the path) do not indicate the accuracies that may be obtainable in the future.

D. Automatic Control of Aircraft

The control of a large aircraft, commercial or military, presents a difficult problem even to a veteran pilot. The magnitude and complexity of the control problem can be expected to

1. References 52, 53.
2. Reference 54.
3. Reference 55.

grow with the increases in size and speed of aircraft; the desire for future all-weather operation will undoubtedly require improved techniques and methods of control. The exacting requirements of accuracy, reliability, and safety seem to point to the automatic rather than the manual control of these future flights. Automatic aids for the piloting of aircraft are not new and have been used in maintaining steady and level flight in commercial[1] as well as military operations.[2] Such devices are known as auto-pilots.

Control of aircraft, whether by manual or automatic means, is accomplished by the deflection of control surfaces (elevators, rudder, ailerons) and by changes in the factors affecting engine thrust and speed (throttle setting, engine mixture, etc.). In manual control the pilot observes the deviation of the aircraft from a desired position or altitude and then makes the necessary changes in the control settings. The pilot acts as a link in a feedback loop and corrects the error of the aircraft with regard to a desired reference -- the ground, horizon, or cockpit instruments. In a similar manner an automatic control device (servomechanism) can sense the error with regard to a desired reference and transform the low-power error signals to levels which can operate the control surfaces.

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1. Reference 56.
2. Reference 57.

It is the type of reference used which determines the flexibility of the automatic controls and paths which can be flown. In conventional autopilots the error signals are obtained from gyroscopes and such an autopilot provides level, straight flight. By introducing additional electrical reference signals the aircraft can be made to climb, dive, or execute coordinated turns. Automatic control on a beam-type navigational system is possible, and equipment has been built to enable an aircraft to follow a leg of a radio range, or to follow the path of an ILS beam.[1] It is possible to use a combination of such methods, and also to store desired instructions (movements of control surfaces, power settings, etc.) in the aircraft, these instructions to be put into effect at a prescribed time, after a certain altitude has been reached, or a specified distance has been flown. An example of such possibilities in automatic control was provided in 1946 when a trans-atlantic flight was made completely under the guidance of airborne equipment.[2] The take-off, en-route flight, and landing were all directed by the automatic equipment; the monitoring crew took over only after touchdown when they applied the brakes and taxied off the runway.

Several other methods of automatically flying a predetermined path might also be mentioned. A straight-line path between two points can be flown by utilization of a course-line

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1. Reference 58.

2. Reference 59, pages 88-92.

computer and R-θ navigational facilities. In the more general case, provision can be made for the following of an arbitrary path whose coordinates are available in the aircraft. The desired coordinates (supplied automatically from the ground or presented on a map drawn by manual means in the aircraft) are compared with the position of the aircraft as derived from airborne navigational equipment to give the input signals to the automatic flight control equipment. Such track-following schemes would use the more conventional autopilots for level flight, and vertical path control equipment for changes in altitude. Work on these proposals is presently under way; the results already obtained give favorable promise for the future.[1]

To this point we have considered only path control, that is, control in the three space coordinates. Efficient air traffic control may require careful supervision of the progress along a path. Not only will an aircraft be required to follow the given path, but it must be at a certain point at a certain time, regardless of the wind conditions. To each coordinate of the space path, then, a time is assigned, and an additional control unit -- a progress guidance or speed control -- can be used for automatic following of the schedule.

Some experimental work has been completed on automatically maintaining a time schedule along a straight path,[2] the results indicating that a track schedule can be met to within

1. Reference 60.
2. Reference 61.

one minute with present DME and omnirange facilities. More strenuous tests of such equipment under varying wind conditions, varying paths, and with more accurate navigational aids will be necessary before full evaluation of progress control can be made.

The systems discussed in the preceding paragraphs exist chiefly on paper, or are in the initial stages of development and experimental usage. Many mechanical and electrical problems exist in the realization and choice of any of the systems. Their realization would seem to depend on either a ground or airborne computer (see next section) to select proper and reasonable flight paths.

The value and reliability of automatic control must be fully demonstrated before it will be accepted by both pilots[1] and passengers. Further, the economic considerations and arguments of airline operators must be satisfied; otherwise such objections are likely to impede the full use of automatic equipment.

E. Computers

Any air traffic control system of the future which is to be capable of handling large numbers of high-speed aircraft will undoubtedly be either partially or completely automatized.

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1. In fuller explanation of this point, the following quote is taken from page 258 of reference 58. "This (pilot reaction) is hardly surprising. Of the two automatic pilots which have had the widest use in the past years, one existed for ten years with no provisions for making a coordinated turn without superhuman skill, and the other had 22 knobs and controls for the pilot to juggle."

This automatization and the replacement of human controllers or operators, except in emergency situations, should be possible in the light of present developments in the field of computing instruments and machinery. Two generic distinctions can be made in these developments: analog machines and digital machines, each with specific properties and operating characteristics.[1] Broadly speaking, both types are capable of automatically following sets of instructions or programs which have been prepared for them.

Analog machines are generally limited to following a fixed sequence of instructions or operations, and as such they are usually restricted to strictly mathematical applications. An example of their use has been mentioned in connection with the course-line computer. Another application might be that of the generation of the coordinates of curved paths in space.[2]

Digital computers are usually of a much more versatile nature. This is possible because in addition to the purely arithmetic functions (addition, subtraction, division, etc.), certain digital computing machines are provided with erasable memories (storage) and have the ability to change from one sequence of operations to other possible sequences. Provided with the necessary instructions, proper sources of information, and flexible external equipment such a machine is capable

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1. Reference 62.
2. Reference 63.

of acting as the central coordinating element in an air traffic control system.[1] These control capabilities, coupled with the high speeds and mathematical abilities of digital computers, should make them valuable in many phases of air traffic control. The computation of flight paths and schedules, the checking of position reports, the sorting and distribution of flight information, etc., are all possible applications. A study is being made of their application to the present system of air traffic control.[2]

In particular it might be mentioned that the path and progress control for automatic flight will necessitate the use of either airborne or ground computers. Theoretically, at least, path and progress control are realizable in either of two ways, or a combination thereof. If the desired path and progress schedules are available in the aircraft, the (error) input to the automatic flight equipment can be obtained by an airborne computer (analog or digital) from a comparison of the schedules and the actual position of the aircraft as determined by its navigational equipment. Alternately the position of the aircraft can be derived from ground measurements or can be communicated to the ground from the aircraft. The information would then be compared in a computer with the proper schedules, the (error) input to the automatic flight equipment being transmitted to

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1. Reference 64.

2. Reference 65.

the aircraft from the ground. In either case it would appear that a digital computer on the ground would be needed to calculate the various flight paths.

CHAPTER V

Planning for the Future

Present developments in techniques and equipment have brought the realization of a new and improved system of air traffic control within the realm of possibility. The actual formation of a future system, however, must be based upon careful planning and consideration of the desired characteristics or principles of system operation. This chapter discusses the nature of the planning for the future, dealing first with the system considerations among which proper choice and coordination must be made and then with the progress of the actual planning and implementation of a future system.

A. System Considerations

Space does not permit either a detailed or complete examination of all the various factors or considerations which are inherent in the planning for air traffic control of the future; the following sections merely intend to indicate the general nature of some of the problems involved. It should be noted that all of these considerations should be carefully analyzed with regard to the requirements of an integrated system capable of dealing with civil, commercial, and military aircraft.

1. Fixed vs. Variable Paths

Flight paths in space may essentially be fixed or variable in nature. An example of fixed paths is the present system of airways with its single lane of traffic separated into altitude layers.

This idea of fixed paths can be extended to multi-lane airways, not necessary composed of straight-line segments but adjusted so as to best accomodate the desired routes and approaches to airports. A good deal of detailed planning would be required for the initial selection of the layout of the routes, but once this selection has been made the major control effort would be to keep the aircraft upon these paths and to keep them properly separated. Two general concepts which arise in connection with fixed paths are fixed-block and moving-block systems[1]. A fixed-block system is one in which the airspace along the path is broken up into definite fixed blocks and the control system is such that only one aircraft is permitted to occupy a block at a time. A moving-block system is one in which the blocks are volumes of airspace about each aircraft, these blocks moving along with the aircraft. In this case it is the duty of the control system to prevent the overlapping of any two blocks. Extensive studies have been made of the capacity and implementation of each of these systems.[2]

A fixed-path system might be modified so as to have several alternative routes, these routes being chosen with regard to wind, weather, or traffic density conditions. As the extreme case the paths might be continuously variable rather than fixed. In such a situation a route would be chosen with regard to existing conditions of wind and traffic densities, and special equipment, most probably

1. References 66, 67, 68.

2. References 69, 70, 71, 72.

a digital computer, would be needed to further select a flight path with due regard to safe separation and aircraft capabilities. Essentially the variable path is chosen to fit the aircraft and the traffic, rather than fitting the aircraft to the path as would be the case with a fixed-path system. A variable-path system would afford large traffic capacities, and might be used as a link between fixed airways and the airports.

Between the two extremes of completely fixed and completely variable paths there exist other possibilities. For example, an aircraft might be restricted to the volume between two concentric cylinders which are contracting about their center-line above an airport. If only one aircraft is assigned to the volume, any path which the aircraft flies within it will be free from collision.[1] More sophisticated versions and modifications of this scheme have been suggested and investigated.[2]

2. Variation of Control

Granted that some system of control is necessary, the question arises as to whether the same system of control and the same procedures should be used under all traffic densities. If, for example, a system is formulated which will handle high densities of aircraft but which requires rather complicated flight paths and lengthy approach procedures, should this system be modified when traffic density is low and the complicated paths and lengthy approach procedures become unnecessary? If the system is to be modified, to what

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1. Reference 73.

2. Reference 74.

extent and under what conditions shall this be done? Similarly, should the same system of traffic control be made applicable to all flights or should special and separate procedures be established for different gradations of visibility and weather conditions?

3. Scheduling

The efficient and expeditious movement of aircraft would seem to depend to some degree upon the proper scheduling of traffic. With a system of complete advance scheduling one might be able to land aircraft at a rate close to the theoretical maximum landing rate of the system. If careful scheduling is not done and relatively random arrivals are permitted, studies[1] have shown that to handle a traffic capacity of say W, the maximum theoretical landing rate of the system must be cW, where c is a constant greater than unity and which is dependent upon the average delay which each aircraft must undergo before landing. A careful system of scheduling, in theory at least, should permit every aircraft to takeoff, proceed to its destination, and land without delay; yet it appears that the unpredictability of wind and weather conditions may make this impossible and careful scheduling may therefore be of small value. Between careful scheduling on one hand and complete randomness (as experienced with military traffic) on the other, there appears to be the possibility of a control over the average number of aircraft arriving at an airport during a certain period. Such a flow control offers a compromise which should be applicable and useful in dealing with commercial aircraft.

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1. References 75, 76, 77.

4. Authority

Another consideration is that of the degree by which the flight control and traffic control of aircraft will be exercised by the pilots or ground controllers. This will depend to a large extent upon the accuracies in positions and schedules which will be required by the system and upon the nature of the system itself. In a variable-path system, aircraft would probably have to be subservient to the control of a ground computer, and high positional accuracies would require the automatic control of the aircraft. Fixed-block systems can be created such that the pilot can assume some degree of traffic control by automatically determining if an adjacent block is unoccupied and hence safe to enter.[1] In low traffic-density conditions in poor weather airborne radar would not only act as an anti-collision device but could be used by the pilot as a means of traffic control; under moderate or high-density conditions, however, the coordinated supervision from the ground would be necessary. Even in the case of complete control from the ground, with or without automatic flight, the question of safety probably requires that certain information regarding the traffic situation be available to the pilot for monitoring and for emergency situations.

5. Economic Considerations

At the forefront of all the planning must be a consideration of economic factors. In planning an increase in landing rates, the cost of expanding airports and increasing the number of runways must be balanced against the alternative cost of the traffic control

1. Reference 66.

methods and equipment which would be otherwise required to improve landing conditions. In general the size, weight, personnel requirements, and cost of airborne equipment will probably not permit a uniform installation of traffic control aids in all types of aircraft, particularly civil and commercial. The size, weight, personnel requirements, and costs also dictate that airborne installations and equipment be kept to a minimum. The factor of safety either requires extremely reliable and hence expensive airborne installations, or dual installations in the aircraft as a provision against equipment failure. The expense of both airborne and ground equipment requires that the system be one which can be introduced in stages or by the process of slow evolution so that present equipment need not be scrapped immediately, nor would a large quantity of new equipment suddenly be required. The system should also attempt to arrive at a compromise in its control of aircraft such that non-economic aircraft operation (for example, jet aircraft at low altitudes) is not required; that is, the operational needs of the individual types of aircraft should be satisfied as much as possible.

B. Steps Toward A Future System

A number of organizations, both governmental and private, have been active in the planning for air traffic control since 1946. Of particular prominence among the non-governmental organizations has been the Air Transport Association of America (ATA), an association formed by scheduled air carriers with the objectives of developing operational requirements for air navigation and traffic control.

The ATA has an Operation Committee composed of representatives from various member airlines and an Air Navigation and Traffic Control Group composed of technical experts employed by the Association. This latter group published a rather comprehensive report in February, 1947, entitled: "Recommendations For Safe Control of Expanding Air Traffic".[1]

This ATA report was concerned chiefly with the requirements for the control of commercial aircraft. In this respect a number of general operational considerations were mentioned. The major emphasis was placed upon a multi-lane system for en-route flight. Flow control, fixed-blocks, and holdings patterns were envisaged for operation in an approach zone. The report considered the use of surveillance radar and gave careful attention to the problems of approach and landing with special consideration of the difficulties encountered in metropolitan areas where congestion arises due to small separations between airports.

The concept of an all-weather integrated system of traffic control was clearly expounded in a report on "Navigation and National Security"[2] prepared by a sub-committee of the Research and Development Board (RDB) of the United States Government. This report, issued in March of 1948 as a result of careful study of the problems of navigation for civil, military, and commercial aircraft, outlined the requirements for a truly common system. Among the requirements listed were those specifying that the system:

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1. Reference 78.
2. Reference 23.

1. Permit the effective use of all navigable air space.
2. Provide service for all types of aircraft. (Aircraft with limited equipment shall employ such elements of the system as they require without restricting maximum use of the system by more fully equipped aircraft.)
3. Function effectively regardless of weather or visibility conditions.
4. Have a traffic capacity equal to maximum Visual Flight Rules (VFR).
5. Place on ground controller responsibility for designation of flight path for traffic control purposes.
6. Place the primary weight, volume, and physical complexity of equipment upon ground components. The required aircraft components shall result in the minimum detriment to aircraft performance.
7. Provide a maximum of automatic control.
8. Be capable of furnishing reduced or alternate service to aircraft with partially inoperative equipment.
9. Provide immediate and positive indication of malfunctioning of the system.
10. Furnish facilities for high-speed aircraft, which impose severe weight, space, and power restrictions.[1]

The report also recommended that a committee with civilian membership be formed to:

> have special cognizance over the common air navigation system project....It should determine planning policies from the standpoint of national security and public welfare (and) determine balance of emphasis on various phases of the program.....[2]

Although the ATA and RDB reports were of great importance -- the former specifying the particular needs of commercial aircraft, the latter in expressing the need for an all-weather integrated system -- probably the most basic piece of literature concerned with planning a future air traffic control system is the SC-31 Report[3]

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1. Reference 23, pp. 35-37.
2. Reference 23, p. XV.
3. Reference 25.

of the Radio Technical Commission for Aeronautics (RTCA). The RTCA is a non-governmental group whose members are drawn from the Army, Navy, Air Force, Federal Communications Commission, CAA, commercial airlines, airline pilots, private pilots, and radio manufacturers and which undertakes to handle problems of a common interest.

This report, issued in May of 1948, had its origins in 1947 when the Air Coordinating Committee, composed of high officials from the CAA, CAB, and Department of Defense, suggested that the overall problem of air traffic control be studied by the Radio Technical Commission for Aeronautics. The RTCA undertook the study of the problem and appointed Special Committee 31. This committee began its deliberation in July, 1947, and issued the final report on May 12, 1948. Within two months after the issuance of the report, the recommendations therein were adopted by the Air Coordinating Committee, the Congressional Aviation Policy Board, the Research and Development Board, and the President's Finletter Committee on National Air Policy.

Among the basic principles suggested in the SC-31 Report were that:

1. The system must be capable of being set up on a single site and provide navigation and traffic control out to a line-of-sight distance.
2. The system must provide identification of all airplanes.
3. The system must drive information to be used in traffic control from the ground equipment and information to be used in the airplane from the airborne equipment.
4. The system must operate on the closed-circuit principle.
5. All elements of the system must be interlocked (i.e., provision for protection of wrong action) so as to preclude the possibility of human error.

6. A flow control system is required to sequence planes in crowded areas and complicated traffic patterns.

7. The system cannot be built by the addition of all desired techniques but must be designed with the minimum numberof equipments necessary and with an eye toward an orderly evolution and integration.[1]

The SC-31 Report included some general specifications for equipment which would be needed in a future system of control. It recognized that a period of 15 years would be needed for the development and installation of the system and for the training of operators and pilots. For this reason it was suggested that an Interim or Transition System be put into operation as soon as possible with equipments and techniques presently or soon to be available. During this Transition System the planning and development of an Ultimate or Common System would be carried out.

The responsibility for further planning for future air traffic control is now vested in Air Navigation Development Board (ANDB). This group was formed in November of 1948 for the specific purpose of consolidating the planning for a Transition System to be in effect until 1960 and an Ultimate or Common System to be operative after that date. The ANDB works in close relation with the Secretaries of Defence and Commerce, implementation of its plans being carried out by the Civil Aeronautics Administration.

The ANDB is presently planning new equipment to be used in the Transition and Common Systems. Chief among these is the Airport Time Utilization Equipment (ATUE),[2] which will serve as a

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1. Reference 25, Page 7.

2. Reference 81.

means of obtaining flow control. In preparation for the Common System the ARDB has made contracts with private industry and with educational institutions to study various phases of future air traffic control. Of major importance should be the study of the characteristics of future aircraft presently under way at the Cornell Aeronautical Laboratory.[1]

Progress towards the realization of the Transition Program is well underway,[2] with the developmental work expected to be completed by 1952. The CAA has signed contracts totalling several millions of dollars for equipment to be used in the Transition Program. Included are contracts for DME, omnirange, surveillance radar, course-line computers, GCA, and ILS. Although both approach and precision radars have been used for several years at New York,(LaGuardia Airport), Chicago, and Washington, these are wartime surplus equipment and are relatively obsolete by present standards. (The GCA facilities at New York, Washington, and Chicago are presently used for the monitoring of ILS approaches; although the CAA will permit the use of GCA alone for approaches only United Airlines have as yet been authorized for such service.) Improved radar equipment was recently installed at Los Angeles and is to be followed in the near future by commissionings at New York (La Guardia and Idlewild), Chicago, Cleveland, Washington, Atlanta, and Boston. In preparation for these installations new traffic control manuals

1. Reference 28.
2. Reference 79.

utilizing radar procedures have been issued by the CAA.[1]

Because the characteristics of the future air traffic control have only been generally specified by the ATA, NDB, and SC-31 Reports, there still remains much work to be done in planning for the future. Industrial concerns have been quite active along these lines, among them the General Railway Signal Company,[2] Radio Corporation of America (RCA),[3] General Electric Company,[4] Hazeltine Electronics Corporation,[5] Hughes Aircraft Company,[6] Panoramic Radio Corporation,[7] Teleregister Corporation,[8] Federal Tele-Communications Laboratory,[9] and Sperry Gyroscope.[10] Generally speaking, the proposals of these concerns do not meet the full requirements of a future system, but rather are proposals for the use of electronic equipments of the companies concerned; nevertheless, these proposals contain many ideas which should be subjected to further study.

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1. Reference 81.
2. References 66, 67.
3. Reference 38.
4. Reference 82.
5. Reference 83.
6. Reference 73.
7. Reference 84.
8. Reference 85.
9. Reference 47.
10. Reference 48.

As was mentioned on page 75, the ANDB is taking advantage of the resources and facilities of industrial organizations and educational institutions. The exploitation of the resources must be continued in the future on an ever-expanding scale. Air traffic control is a problem of a vital and urgent nature; no avenue of approach can be left unexplored in the development of a system capable of satisfying the present and future needs.

Signed David R. Israel
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Approved J. W. Forrester

DRI:lfu

BIBLIOGRAPHY

1. ANC Procedures for The Control of Air Traffic; U. S. Government Printing Office, Washington, D.C.: 1950.

2. Air Traffic Control; by Glen A. Gilbert, Ziff-Davis Publishing Company, Chicago and New York: 1945.

3. History of Radio Aids to Aircraft; by Salvador Castro, Electrical Engineering Seminar, Mass. Inst. of Tech., 1945.

4. The History of Aircraft Instruments; by R. S. Edwards, Electrical Engineering Seminar, Mass. Inst. of Tech., 1941.

5. History of Radio Aids to Avigation and Blind Landing; by Robert C. Habich, Electrical Engineering Seminar, Mass. Inst. of Tech., 1942.

6. Air Route and Airport Traffic Control Study Guides; Civil Aero. Ad., Washington D. C.: 1948, 1949.

7. Monthly Summary of Air Traffic Control Operations; Internal Memorandum of Civil Aero. Ad., Washington, D.C.: November, 1949.

8. Digest of Airways Operations Service, Vol. I-History; Civil Aero. Ad., Washington D.C.: 1948.

9. Digest of Civil Air Regulations for Pilots; Bulletin No. 22, Civil Aero. Ad., Washington,D.C.: 1943.

10. Airways Operations Training Series; Bulletins #1-8; Civil Aero. Ad., Washington, D.C.: 1948.

11. Resume of U. D. Planning in Air Navigation, Traffic Control, Communication; Radio Technical Commission for Aeronautics, Washington, D.C.: Paper 85-48/DO-19, 1948.

12. Federal Airways Manual of Operations; Civil Aero. Ad., Washington, D.C.

13. Basic Instrument Flight; Civil Aero. Ad., Washington, D.C.

14. Airport Approach Control; General Railway Signal Co., Rochester, N. Y.: Pam. 604, 1947.

15. Airport Planning: Airline-Travel Distances; Washington, D.C.: 1948.

16. Airport Planning: Peak Air Carrier Movements at Airport; Civil Aero. Ad., Washington, D.C.: 1949.

17. Human Factors in Air Transport Design; by Rose A. McFarland, McGraw-Hill Book Company, Inc., New York and London: 1946.

18. Study of Air Traffic Control: Reports #1-6; Washington, D.C.: 1943-1945.

19. Teleregister Automatic Aids for ATC; Teleregister Laboratories, New York, N. Y.: 1947.

20. Traffic Control Without Pilot Effort; Teleregister Corp., New York, N.Y.: 1947.

21. "Air Transport Facts and Figures"; Aviation Week, Vol. 50, No. 12, P. 35, March 21, 1949.

22. Editorial; Aviation Week, Vol. 50, No. 26, P. 54, July 4, 1949.

23. Navigation and National Security; Prepared by Ad Hoc Committee on Navigation, The National Military Establishment, Research and Development Board, Washington, D.C.: 1948.

24. "U. S. Domestic Airline Revenues and Expenses"; American Aviation, Vol. 13, No. 23, P. 41; May 1, 1950.

25. Air Traffic Control, Paper 27-48/DO-12; Prepared by Special Committee 31, Radio Technical Commission of Aeronautics, Washington, D.C.

26. Survival in the Air Age; A report by the President's Air Policy Commission, U. S. Government Printing Office, Washington, D.C.: 1948.

27. "Berlin Airlift"; by Charles J. V. Murphy, Fortune, Vol. XXXVIII, No. 5: November 1948.

28. Air Traffic Control Implications of Aircraft Evolution; Cornell Aero. Lab. Inc., Buffalo, New York, Report No-JA-654-J-1, 1949.

29. "British Jet Transports"; by Albert Douglas, Harper's Magazine, Vol. 200 No. 1198: March 1950.

30. "Economic Factors in Civil Aviation", by P. J. Masefield, Journal of Royal Aero. Soc., Vol. 52, No. 454, P. 575: October 1948.

31. Traffic Control Requirements for Jet Transport Aircraft; by W. T. Dickinson, Talk presented at SAE National Aeronautics Meeting, Los Angeles, California: October 1947.

32. "Jet Propulsion and Its Application To High Speed Aircraft"; by D. J. Keirn and D. R. Shoults, Journal of the Aeronautical Sciences, Vol. 13, No. 8, P. 411: August 1946.

33. "Some Factors Affecting Large Transport Aircraft with Turboprop Engines"; by A. C. Russel, Journal of The Aeronautical Sciences, Vol. 17, No. 2, P. 67; February 1950.

34. Aviation Week; Vol. 51, No. 23, R 16; December 5, 1949.

35. Radar Aids to Navigation; by J. S. Hall et al. Mass. Inst. of Tech. Radiation Laboratory Series, McGraw-Hill Book Company, Inc., Vol. 5, 1947.

36. Radar Beacons; by A. Roberts et al, Mass. Inst. of Tech. Radiation Laboratory Series, McGraw-Hill Book Company, Inc., Vol. 3, 1947.

37. "What We Learned from the Berlin Airlift"; by H. A. Chaffee and R. B. Corby, Electronics, Vol. 22, No. 9, August 1949.

38. "Teleran Air Navigation and Traffic Control by Means of Television and Radar"; by D. H. Ewing and H. W. K. Smith, Proceedings of NationalElectronic Conference, Vol. 2, October 1946.

39. "Ground Controlled Approach"; by C. W. Watson, Electronics, Vol. 18, No. 11, pp. 112-115, Nov. 1945.

40. "The Application of Microwaves to Instrument Landing of Aircraft"; by Joseph Layman, Aero. Engineering Review, Vol. 6, No. 4, P. 26, April 1947.

41. "Surveillance Radar Deficiencies and How They Can Be Overcome"; by J. Wesley Lees, Proceedings of the IRE, Vol. 36, No. 8, P. 1015, August 1948.

42. Distance Measuring Equipment; Civil Aero. Ad., Washington, D.C.; 1949.

43. "Some Operation Aspects of D.M.E. in the Transitional Air Navigation System"; by J. W. Lees, Inst. of Aero. Sciences (Preprint #233), 1949.

44. "A Discussion Concerning The Operational and Technical Criterion of the Air Traffic Control and Guidance Problem"; Talk given by George Litchford before Committee on Navigation of Research and Development Board on May 13, 1949.

45. Radio Aids to Air Navigation; by S. J. Fricker, Electrical Engineering Seminar, Mass. Inst. of Tech., 1950.

46. The History of The Development of Radio Navigation Systems; by H. E. Harris, Electrical Engineering Seminar, Mass. Inst. of Tech., 1947.

47. "Aerial Navigation and Traffic Control with Navaglobe, Navar, Naraglide, and Navascreen"; by H. Busignies, P. H. Adams, and Robert I. Colin, Electrical Communication, Vol. 23, No. 2, P. 113, June 1946.

48. Interim Report on the Further Development of a System for Airport Traffic Guidance and Control; Sperry Gyroscope Company, Great, New York.

49. "Electronics For Omni-Range Navigation"; by H. B. Yarbrough, Aero. Digest, Vol. 57, No. 11, May 1949.

50. "The Operation of VHF Omni-Range in the Transition System"; by F. L. Moseley, Inst. of Aero. Sciences (Preprint #240).

51. "A Precision Omni-Directional Radio Range For the Terminal Area"; by Joseph Lyman and J. Litchford, Institute of the Aeronautical Sciences (Preprint #246), 1949.

52. "The Course-Line Computer for Radio Navigation of Aircraft"; by F. J. Gross, Proceedings of IRE, Vol. 37, No. 7, P. 830, July 1949.

53. "Development of a Course Line Computer for the Air Navigation System"; by C. S. Watts, Sr. and F. J. Gross, Inst. of Aero. Sciences, (Preprint #232), 1949.

54. Errors of Position As Obtained From the Off-Set Course Computer; by J. S. Morrel, Bendix Radio, 1947.

55. Initial Flight Tests and Theory of an Experimental Parallel Course Computer; by F. J. Gross and H. A. Kay, Civil Aero. Ad., Washington, D.C., TD Report No. 83, September 1948.

56. History of the Development of Automatic Control of Airplane Flight; by Delvin T. Kendall, Jr., Electrical Engineering Seminar, Mass. Inst. of Tech., 1945.

57. The Use of Automatic Flight Control For Aircraft To Increase Bombing Accuracy; by Thomas F. Oliver, Electrical Engineering Seminar, Mass. Inst. of Tech., 1947.

58. Automatic Radio Flight Control; by Francis L. Moseley and Chester B. Watts, Proceedings of National Electronics Conference, Vol. II, October 1946.

59. "Automatic Control For Pilotless Ocean Flight"; Electronics, Vol. 20, No. 12, PP. 88-92, December 1947.

60. "The Sperry Zero Reader": by S. Kellog and C. F. Fragola, Institute of The Aeronautical Sciences, (Preprint #178), 1949.

61. Flight Tests of Off-Schedule Distance Computer; by F. J. Gross and H. Kay, Civil Aero. Ad., Washington, D.C., Technical Development Report #93, May 1949.

62. Calculating Instruments and Machines; by Douglas R. Hartree, University of Illinois Press, Urbana, Illinois: 1949.

63. A Preliminary Survey of Computer Applications to Air Traffic Control; Cornell Aeronautical Laboratory, Report UA-519-P-2, 1947.

64. "Digital Computers In Control Systems"; A talk delivered by C. Robert Wieser at meeting of American Institute of Electrical Engineers (AIEE), Providence, R.I., April 1950.

65. The Application of a High-Speed Digital Computer To the Present-Day Air Traffic Control System; by David H. Israel, Thesis Proposal, Mass. Inst. of Tech., February 28, 1950.

66. Navigational Functions of Air Traffic Control; General Railway Signal Co., Rochester, N. Y., Pamphlet 659, 1948.

67. Evolution of the Integrated System of Air Traffic Control; General Railway Signal Co., Rochester, N. Y. , Pamphlet 652, 1948.

68. The Application of Existing Techniques To the Development of An Improved System of Air Traffic Control; by W. D. White, Airborne Instruments Laboratory, Mineola, New York, Report #524-1, 1947.

69. The Application of a Moving Block System to RCA Telerun; by W. W. Felton, Franklin Institute, Report #354, 1947.

70. Interlock Features of a Moving Block System For Selective Assignment and Control of Air Traffic; by W. W. Felton and R. S. Brubmeyer, Franklin Institute, 1948.

71. Investigation of Capacity of Moving Block Traffic Control System; BY A. B. Faunce, J. N. Marshall, R. W. K. Smith, Radio Corporation of America, 1947.

72. An Evaluation of the Traffic Capacity of a Fixed-Block Traffic Control System in the Approach Zone; by W. R. Rambo and R. C. Wheeler, Jr., Airborne Instruments Laboratory, Mineola, N. Y., Report #514J, 1947.

73. A System for Air Traffic Control In the Terminal Area; Hughes Aircraft Company, Culver City, California, 1947.

74. Lantrac-Landing Traffic Control; Gilfillan Bros., Inc., Los Angeles, California.

75. "Operational Research Into Air Traffic Control"; by J. E. Ball, Journal of the Royal Aeronautical Society, Vol. 53, No. 466, P. 965, October 1949.

76. "Delays in Landing of Air Traffic"; by E. G. Bowen and T. Pearcy, Journal of Royal Aero. Society, Vol. 52, No. 456, P. 799, December 1948.

77. "Delays in Flow of Air Traffic"; by E. G. Bowen and T. Pearcy, Journal of Royal Aero. Society, Vol. 52, No. 448, P. 251, April 1948.

78. Recommendations For Safe Control of Expanding Air Traffic; Air Transport Association of America Air Navigation Traffic Control Group, Washington, D.C.: 1947.

79. "New CAA Actions Speed RTCA Transition Program"; by William D. Perrault, American Aviation, Vol. 13, No. 21, April 1, 1950.

80. Operating Procedures For ControlTower Surveillance Radar and Ground Controlled Approach; Civil Aeronautics Administration, Washington, D.C.

81. A Preliminary Analysis of Technical Problems Involved in the Development of Airport Time Utilization Equipment, ATDB Technical Memorandum #1; by L. R. Phelpott, 1949.

82. Fundamental Principles and Operating Characteristics of the TRICCH System of Air Navigation and Traffic Control; General Electric Company, Syracuse, New York: 1947.

83. Hazeltine Lanunar Air Navigation and Anti-Collision System(LANAC); BY C. Hirsch, Hazeltine Electronics Corp., Great Neck, N.Y., Report No. 2005 W-R, 1946.

84. Proposal for Aircraft Short Distance Navigation and Traffic Control System; Panoramic Radio Corp., New York City, N.Y., Technical Bulletin 171, 1947.

85. Teleregister Automatic Aids For Air Traffic Control; Teleregister Corp., New York City, N. Y.: 1947.