PB-151579 PRICE $0.75

Simulation Tests of a Tactical Airway System

By

Clair M Anderson

and

Tirey K Vickers

Navigational Aids Evaluation Division

TECHNICAL DEVELOPMENT REPORT NO. 279

FEDERAL AVIATION AGENCY
TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

1551

January 1959

FEDERAL AVIATION AGENCY
Elwood R. Quesada, Administrator
D. M Stuart, Director, Technical Development Center

TABLE OF CONTENTS

SIMULATION TESTS OF A TACTICAL AIRWAY SYSTEM*

SUMMARY

This report describes the testing of a number of route configurations and air traffic control procedures developed for an experimental tactical airway system which is to be established by the Department of the Army in the vicinity of Fort Huachuca, Ariz The tests were conducted on the dynamic air traffic control simulator at the FAA Technical Development Center at Indianapolis By-products of this program included the development of new procedures and displays for the control of high-density airway traffic These developments are expected to have future application in the common military/civil air navigation and traffic control system

INTRODUCTION

Early in 1954, the Department of the Army requested Air Navigation Development Board (ANDB) assistance in analyzing the special problems of tactical airlift operations and in developing basic traffic control procedures for such missions This project, which was concerned only with a single link in a supply chain, was assigned to the Technical Development Center (TDC). It was completed through the use of the dynamic air traffic control simulator, and a final report was issued within six weeks of the original project request [1,2]

As a subsequent step in developing all-weather field support procedures, it was decided to establish an experimental tactical airway in the vicinity of the Army Electronic Proving Grounds at Fort Huachuca, Ariz This airway was to provide a supply chain connecting one Army area, one Corps area, and three Divisional areas, arranged as shown in Fig 1 The Army placed a contract with Melpar, Inc , to provide engineering services and procure the navigation and traffic control equipment necessary for the establishment of the airway Another contract was placed with the Armour Research Foundation to cover the measurement and evaluation of the performance of the system in actual flight tests The ANDB was requested to provide assistance in the development and preliminary testing of traffic control procedures for the new airway This task was assigned to TDC under the terms of ANDB Project 6 7, Simulation.

OPERATIONAL REQUIREMENTS

Due to the highly specialized nature of tactical support operations, air traffic control (ATC) procedures developed for such systems must be tailored around a unique combination of operational requirements Some of these requirements are discussed in the following paragraphs

Aircraft Characteristics

Because of the necessity for flying in and out of small or improvised airports, aircraft presently planned for tactical support operations will be helicopters or small airplanes with low landing speeds Such aircraft will have a small turning radius and will not require a

---

*Reprinted for general distribution from a limited distribution report dated October 1955

[1] Richard E Baker, Arthur L Grant, and Tirey K Vickers, "Development of a Dynamic Air Traffic Control Simulator," Technical Development Report No. 191, October 1953

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

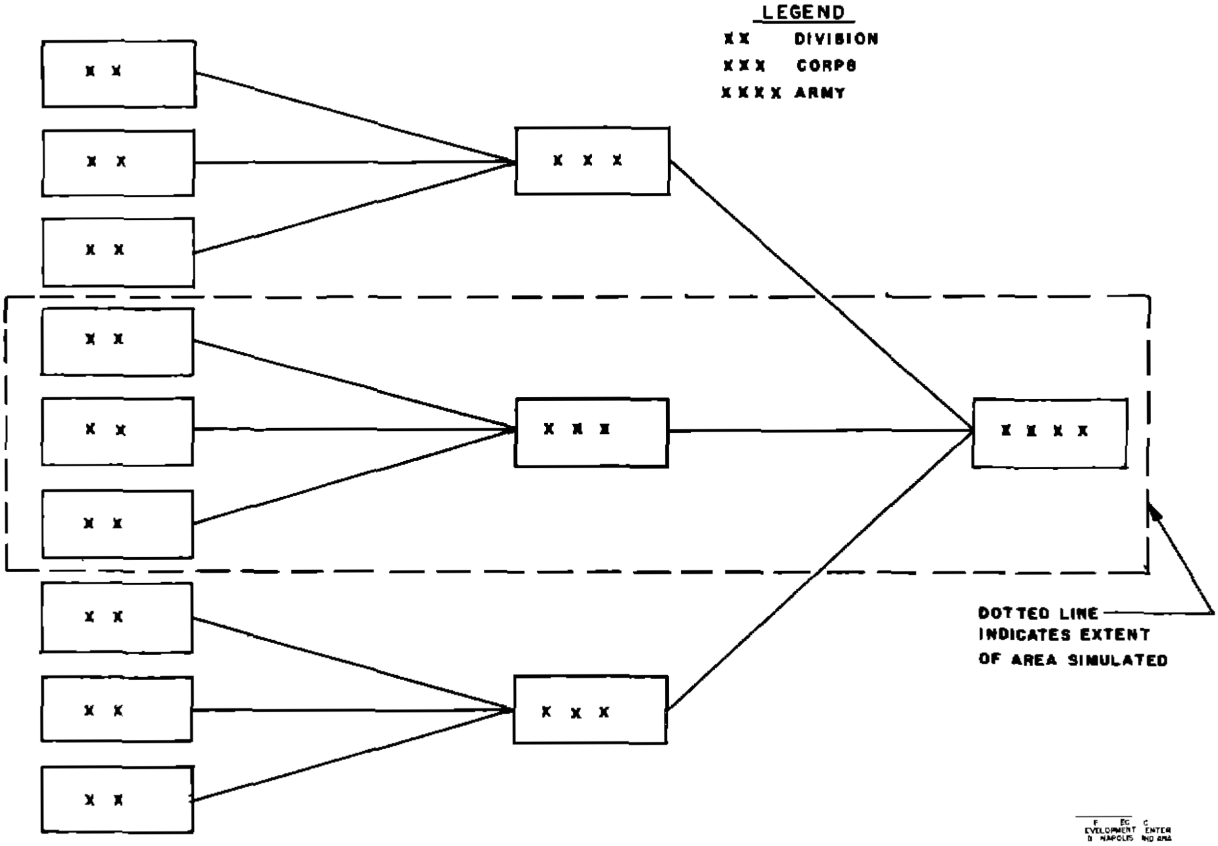


Fig 1 Military Supply Chain

long straight-in final approach These characteristics will tend to simplify flight patterns and reduce the amount of maneuvering area required around terminal airports

To date, little instrument flying experience has been obtained with helicopters because of the lack of suitable specialized instrumentation However, improved helicopter flight instruments are being developed. For the purposes of this simulation study, it was assumed that helicopter instrument flight was a practical reality It also was assumed that helicopters would be able to execute instrument approaches in a cross-wind direction, turning into the wind only for touchdown

The aircraft characteristics used in the simulation tests are shown in Table I

TABLE I

AIRCRAFT CHARACTERISTICS

Aircraft Type	Cruise Speed (mph)	Climb Speed (mph)	Approach Speed (mph)	Rate of Climb or Descent (fpm)	Turning Rate (deg./sec)
Fixed-Wing	120	100	100	500	3
Rotary-Wing	80	60	80	500	3

Altitude Limitations

Existing policy agreements restrict the use of Army tactical support aircraft to the lowest altitude levels available This provides greater protection from enemy detection and also leaves the rest of the airspace available for the other military services However, it places a limitation on the use of altitude separation and virtually precludes the use of vertical stacking procedures for holding aircraft in flight This requires the strict regimentation of flight operations, with traffic flow carefully metered to avoid exceeding the capacity of any traffic lane, and with route operations preplanned to make the most efficient use of the available airspace

Separation Standards

It is expected that aircraft separation standards utilized in tactical support operations will be lower than those presently in civil use It is probable that such standards will be reduced on a calculated-risk basis consistent with the urgency of the mission.

During the simulation tests, altitude separation minimums varied from the 1,000-foot standard specified by Melpar, Inc , for use with the Melpar system to the 500-foot minimum accepted by Army representatives for the other systems tested [3] In the absence of any specific directive, radar separation was fixed at 2 miles for successive fixed-wing aircraft on final approach, and 1 mile between all other aircraft under terminal radar control Time separation minimums, for use without radar, were fixed at 4 minutes, as directed by Melpar for their system, and 3 minutes for the other systems tested

Communications

A high-density tactical airlift is an important target for enemy attention Therefore, it is essential that the traffic control system be able to function with a minimum amount of radio communication to avoid enemy detection, interception, or jamming This factor is especially important at the Division fields, which would be closest to enemy territory It is probable that many pretakeoff clearances would be forwarded to the pilots via ground messenger and many takeoff and landing clearances would be issued by light gun to minimize the use of radio at such fields It also may be desirable to use directional antennas for ground transmitters to avoid furnishing intelligence to the enemy

Navigation Aids

Because of logistical limitations and the fluid characteristic of military operations, navigation aids for tactical airway systems normally will include only portable types of ground facilities which can be set up and moved quickly The number of aids will be limited to the minimum necessary to handle the traffic load Navigation aids near the battle zone may have to use directional antennas to avoid enemy detection and possible destruction by homing missiles.

During the simulation tests, it was not possible to evaluate the relative effectiveness of various types of navigation facilities such as low-frequency (LF) homing facilities versus very-high-frequency (VHF) omniranges, and so forth. All tests were based on the assumption that a satisfactory navigation system existed, capable of providing course guidance along designated routes and also capable of indicating when the aircraft was over designated intermediate check points

Terrain

The geographic area of the proposed experimental airway generally is mountainous. Although airport elevations are around 3,000 to 4,000 feet, surrounding terrain extends as high as 9,400 feet. This factor complicates terminal traffic control procedures by necessitating the use of long climb and descent paths. Route flexibility is restricted further by the presence of the Mexican border on the south and a large bombing range in the northwest portion of the area Because of the mountainous terrain, it is desirable to route the airways through valleys wherever possible, to take advantage of lower route altitudes. All airways are restricted to a width of 5 miles Eight airway configurations were tested. These are shown in Figs 2 to 9, inclusive.

---

[3] Discussion and Proposed Procedures for ATCAN Phase 1-A, Contract No DA-36-039-SC-67467, Melpar, Inc., 3000 Arlington Blvd , Falls Church, Va.

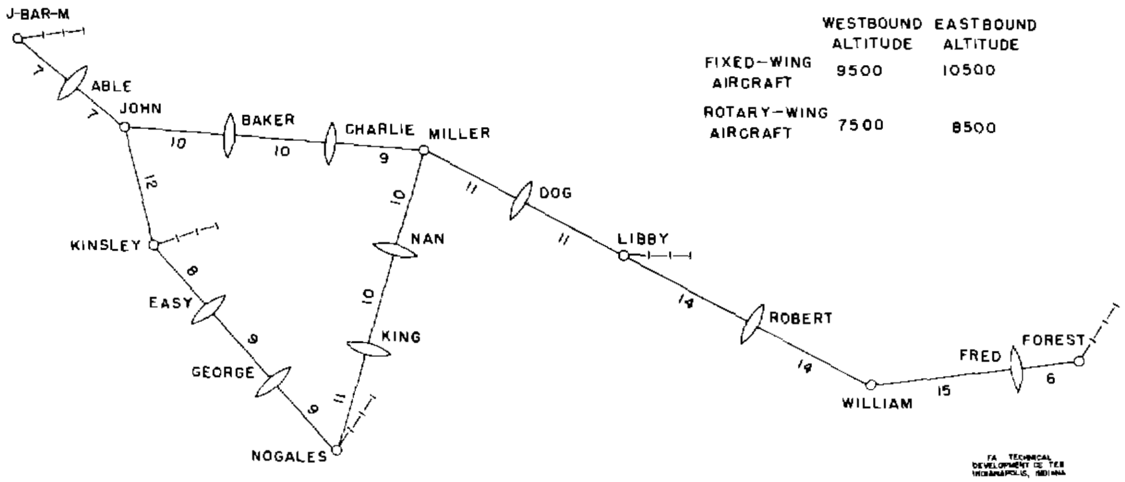


Fig. 2 Original Melpar System

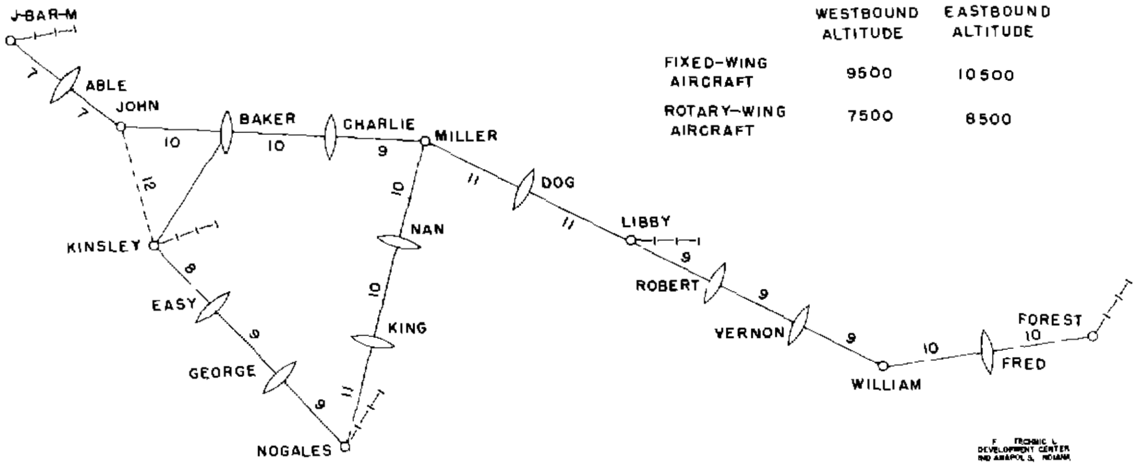


Fig. 3 Revised Melpar System

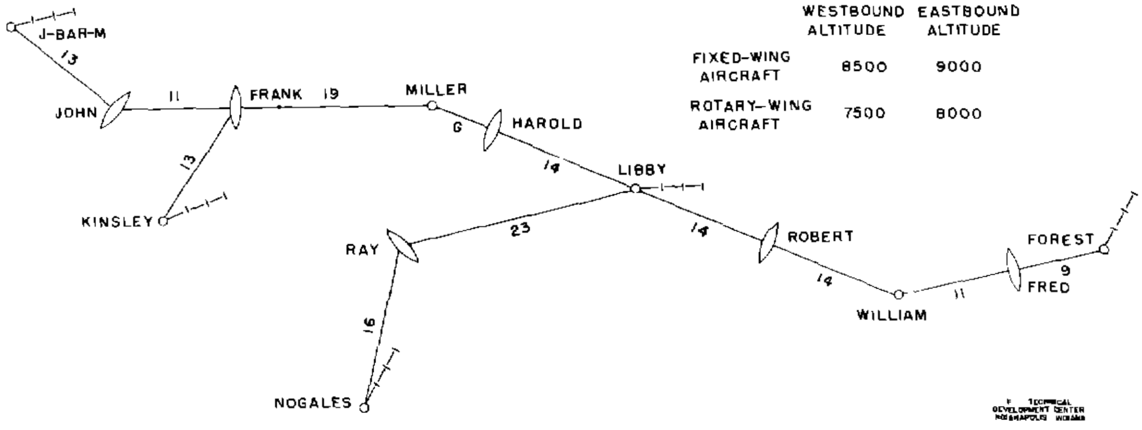


Fig. 4 Original TDC Single-Lane System

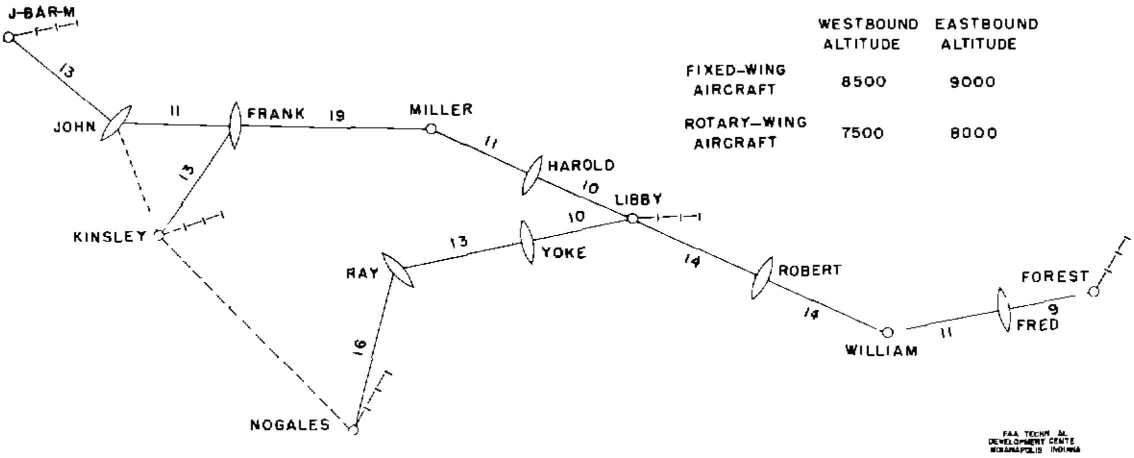


Fig. 5 Revised TDC Single-Lane System

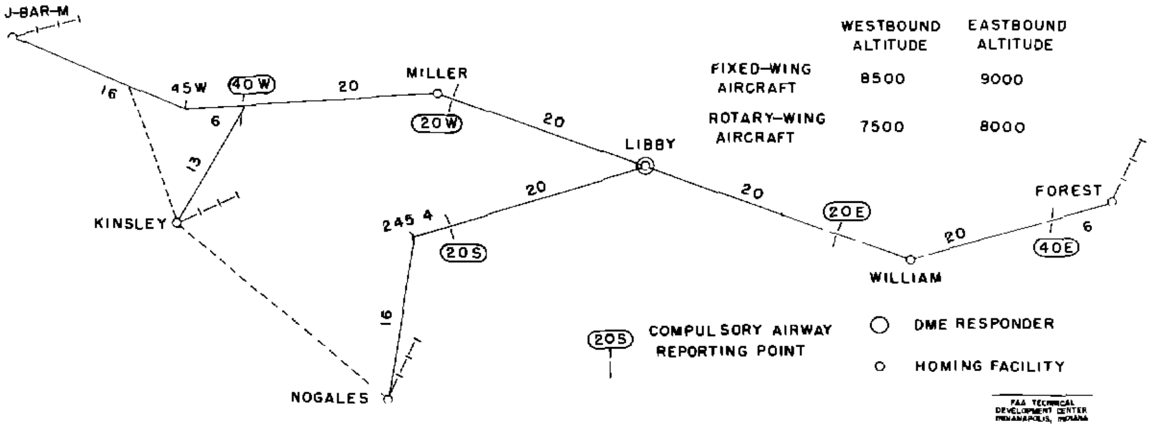


Fig. 6 TDC DME Single-Lane System

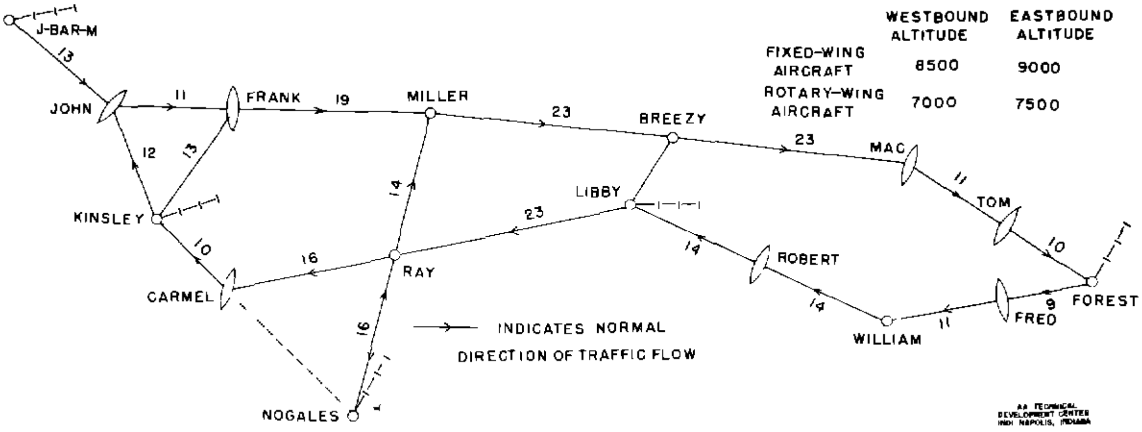


Fig. 7 Original TDC Freeway System

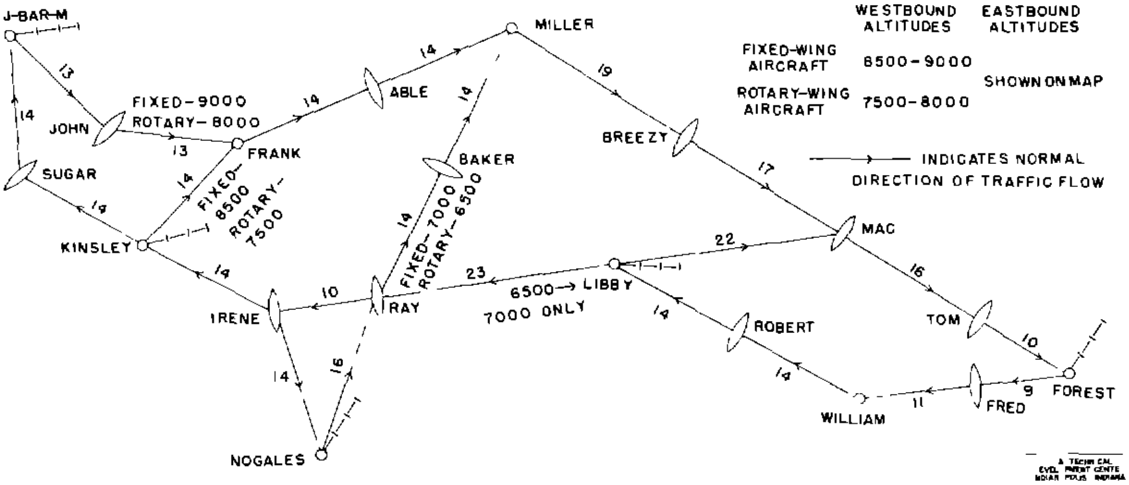


Fig. 8 Revised TDC Freeway System

AIRWAY TRAFFIC FLOW CHARACTERISTICS

General

In field support operations, the function of a tactical airlift is similar to a moving bucket conveyor system, its aircraft may be thought of as a series of containers which pick up material at one location, carry it to another location, and return for another load as soon as possible. For maximum output, the system should permit continuous traffic flow in both directions simultaneously.

Fixed-Block Systems.

For any fixed-block control system (such as the Melpar system), in which only one aircraft is allowed to occupy a given block of airspace, the capacity of any traffic lane is governed by the amount of flying time required to negotiate the longest block in the system.

Since it is necessary that a preceding aircraft report leaving the block before a succeeding aircraft can be permitted to enter it, the separation between successive aircraft must be increased further to allow time for necessary communications. This principle is illustrated in Fig. 10. The capacity of a fixed-block system can be expressed by

$$C = \frac{60}{F + L} \tag{1}$$

where

C = lane capacity in aircraft per hour

F = flying time of longest block, in minutes

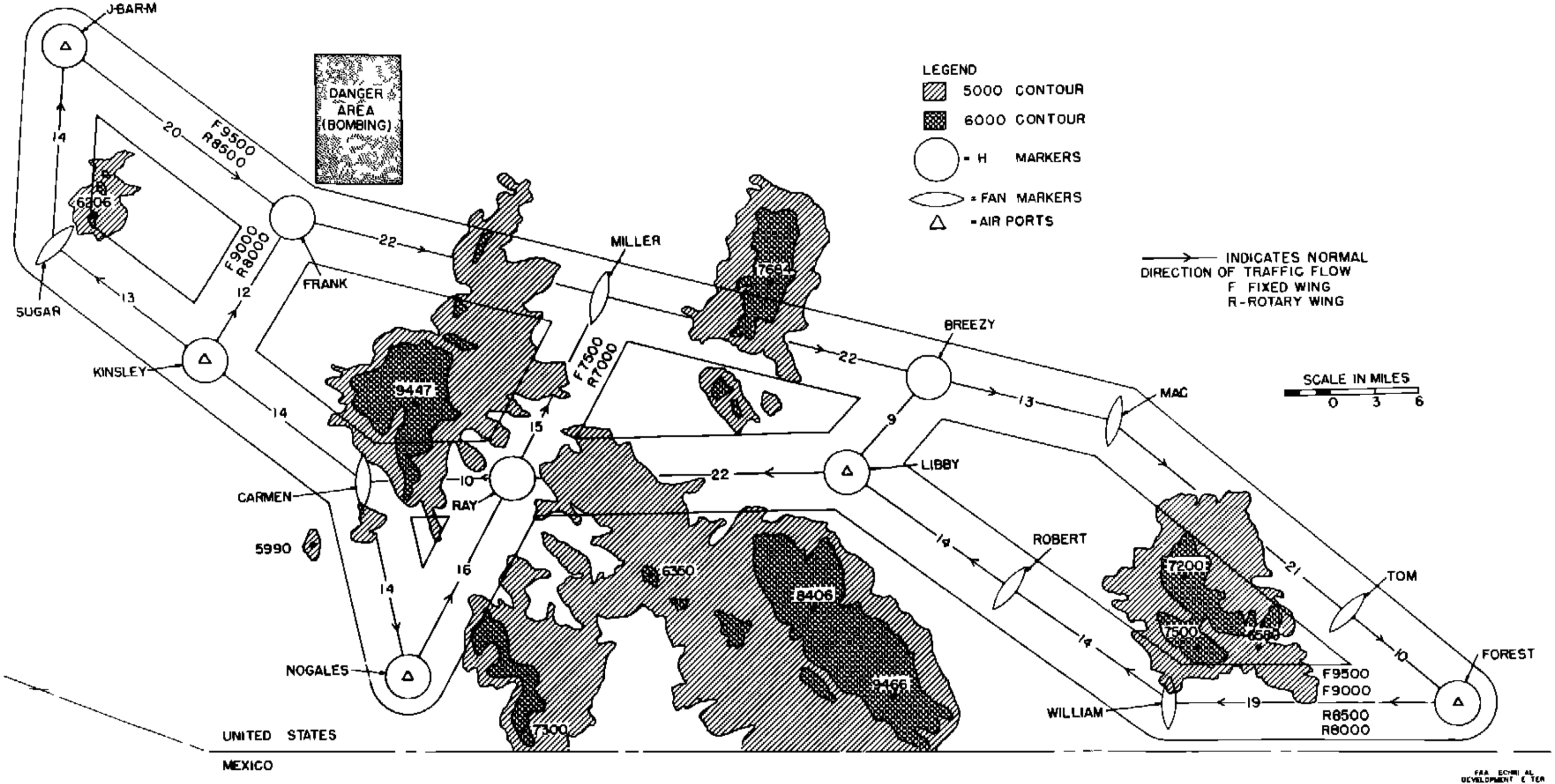
L = communications lag in minutes.

The quantity F equals $\frac{60D}{S}$

where

D = distance in miles and

S = average ground speed (mph).



FAA TECHNICAL DEVELOPMENT CENTER
INDIANAPOLIS, INDIANA

Fig. 9 Army Freeway System with Associated Terrain

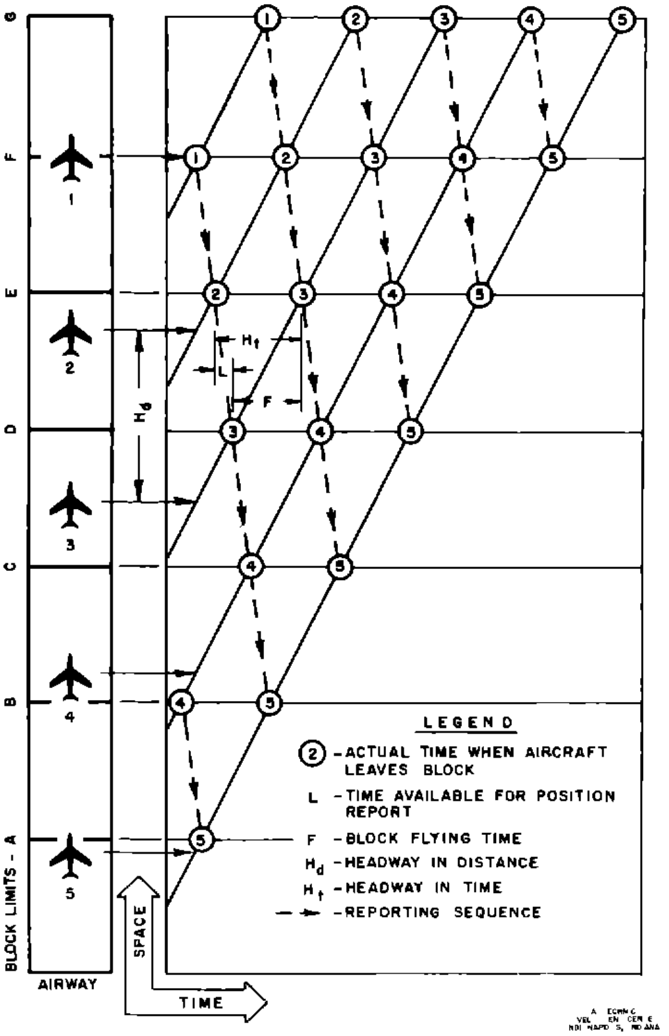


Fig. 10 Space-Time Curve Showing Optimum Spacing of Aircraft in Fixed-Block System

The system capacity of a fixed-block system is sensitive to changes in wind which affect the average ground speed Figure 11 shows the effect of a long block in the operation of the original Melpar system. Aircraft were started through the system at an initial separation of about 8 minutes, which usually was sufficient to allow preceding aircraft to vacate each block in turn before the next aircraft reached the block limit When the first aircraft reached the long block, the additional flying time required to get through this block precipitated a chain reaction of aircraft holding, which ultimately increased the spacing interval between all aircraft in the traffic lane

Moving-Block System.

In a moving-block system based on the use of time separation, the maximum capacity of a traffic lane can be expressed by

$$C = \frac{60}{H} \qquad (2)$$

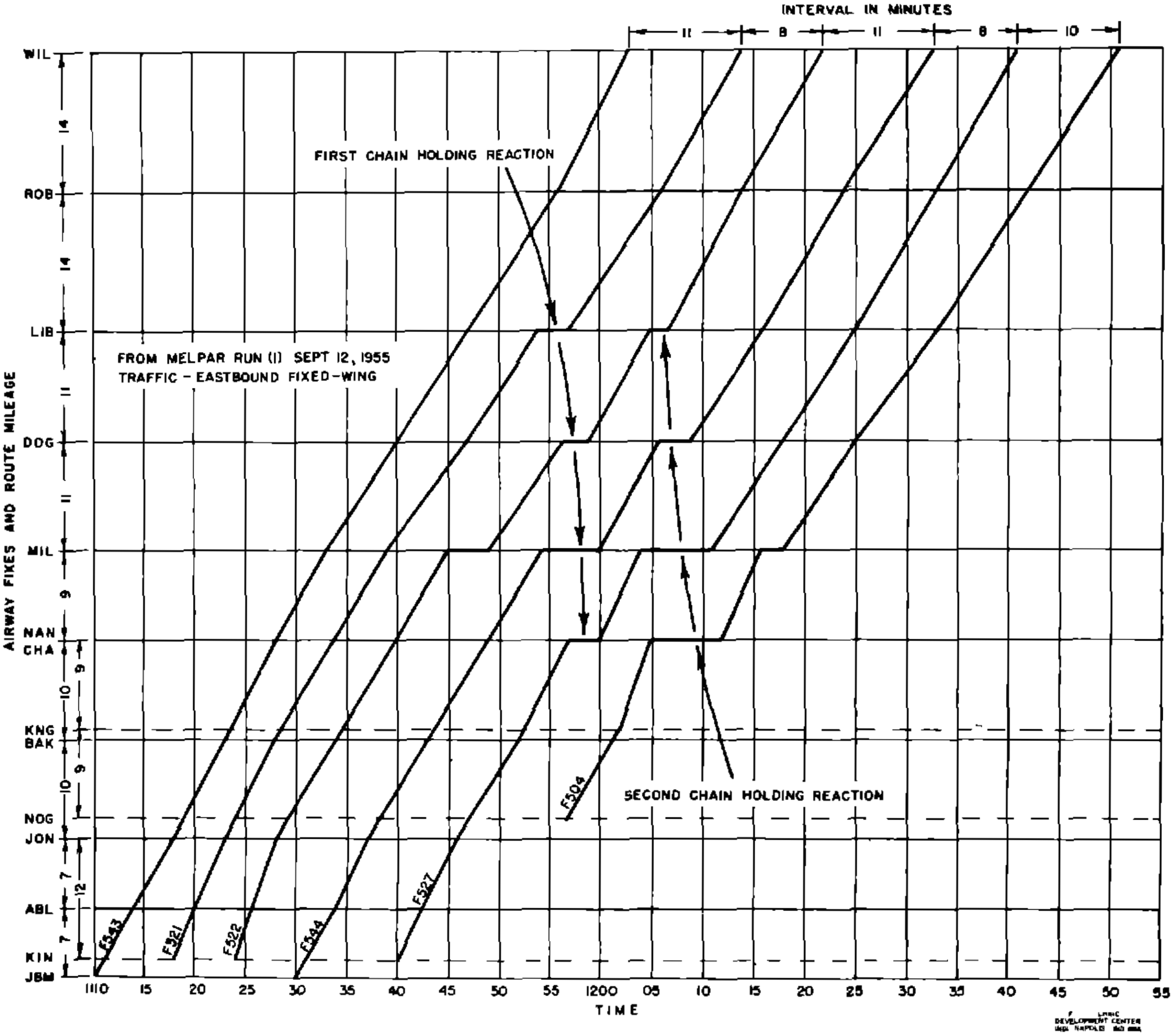


Fig. 11 Space-Time Curve Showing Effect of Long Block on Fixed-Block System Operations

where

C = lane capacity in aircraft per hour

H = average headway or separation between successive aircraft in minutes.

Capacity can be increased by reducing the headway to some acceptable minimum. Because of variations in flight times between fixes, the actual separation between certain successive aircraft in the system always will be less than the average (desired) headway. Such variations can be minimized by reducing the accumulative errors in the navigation system. Methods include the careful calibration of airspeed indicators, the thorough training of pilots, the installation of an adequate number of radio navigation facilities, and the use of simple control procedures which can minimize or compensate for accumulated errors.

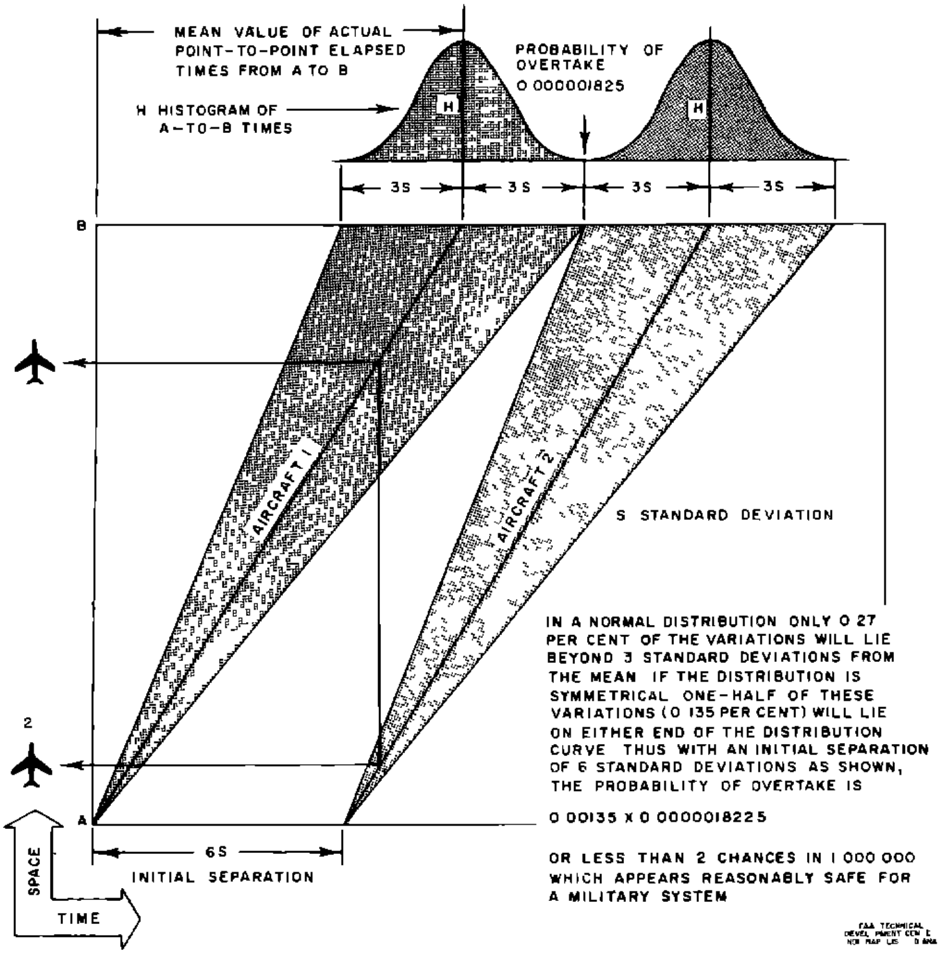


Fig. 12 Space-Time Curve Illustrating Possible Statistical Approach to Determination of Longitudinal Separation Standards

In calculating the minimum safe time separation which can be used in an actual airlift operation, the results of the simulation runs cannot be applied directly, since there is no means of knowing in advance what the correlation will be between the navigation errors accumulated in the simulation runs and the errors which will occur in actual flight operations

In determining the proper headway which should be used in the actual system, it is recommended that point-to-point flight times over various segments of the system be analyzed statistically to determine the distribution and the standard deviation If the histogram of this distribution follows a unimodal (one-humped) symmetrical curve, it is likely that less than 2 per cent of the variations will be more than three standard deviations from the mean Thus, as shown in Fig. 12, a standard headway of at least six times the standard deviation would appear reasonably safe

To keep errors from accumulating in an unsafe direction, a series of flight maneuvers has been developed for adjusting aircraft spacings en route. These maneuvers, which are shown in Fig. 13, functioned very effectively during the simulation program and are recommended for use in actual flight operations

In moving-block traffic control systems based on distance separation derived from a ranging system such as distance measuring equipment (DME) or TACAN, the maximum capacity of a traffic lane can be expressed by

$$C = \frac{S}{H} \qquad (3)$$

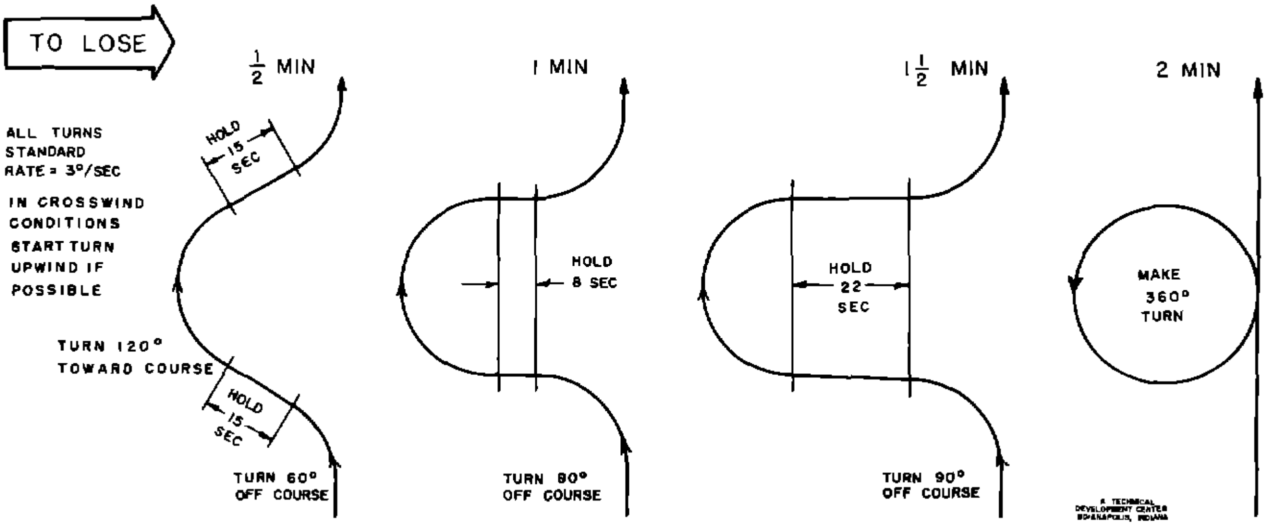


Fig. 13 En Route Maneuvers for Aircraft Spacing Adjustments

where

C = capacity of traffic lane in aircraft per hour

S = average ground speed of aircraft in mph

H = headway or separation between aircraft in miles.

It will be noted that the capacity of this type of control system also is sensitive to wind changes which affect ground speed However, the fact that the spacing reference in this system can be available whenever desired, instead of at certain arbitrary points along the airway, permits precise spacing adjustments During initial simulation tests of this system, extremely good results were obtained using a 10-mile headway with compulsory reporting points spaced every 20 miles Safety was based on the fact that a succeeding aircraft properly spaced behind a preceding aircraft at one check point would have to maintain an average ground speed 50 per cent greater than the preceding aircraft in order to overtake the preceding aircraft by the time it reached the next compulsory reporting point.

Fix Spacing Versus Communications.

Theoretically, navigation errors can be reduced, with a subsequent increase in traffic-lane capacity, if the spacing between airway fixes is reduced. However, there is a practical limit to this procedure--a limit which is imposed by the rapid buildup of the communication load as the number of compulsory reporting points is increased. Figure 14 shows the results of a study which illustrates this principle Based on the premise that aircraft headway can be reduced progressively as fix spacings are reduced, it is seen that the consequent increase in the traffic capacity of a single lane is accompanied by an exponential increase in the number of aircraft position reports required to operate the traffic lane at the increased capacity. This indicates that, from the standpoint of communications alone, it is more efficient to operate several traffic lanes with reduced capacity, rather than a single lane at high capacity, as listed in Table II. Simulation tests showed that the additional headway provided in traffic lanes operated at lower capacity also represented increased safety and a much more relaxed control operation

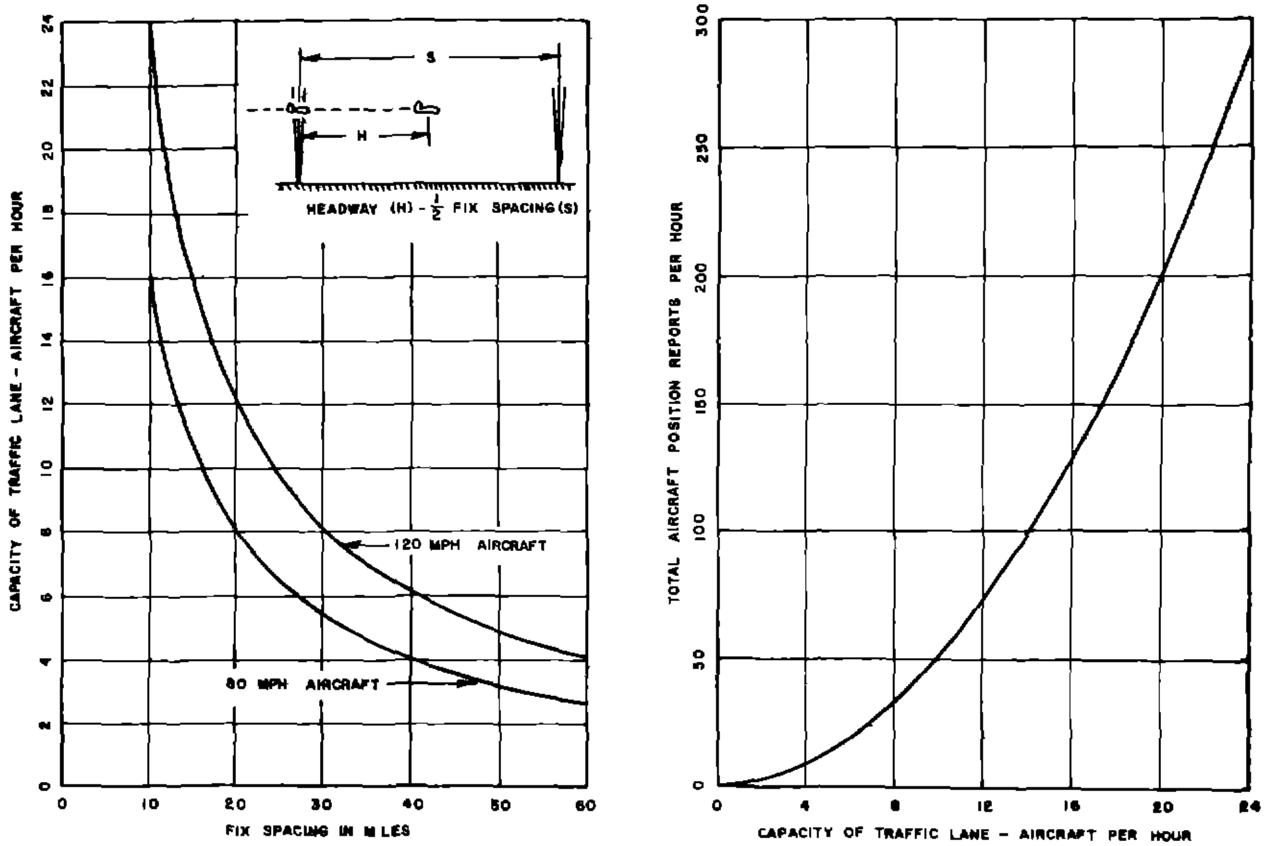


Fig. 14 Hypothetical Study Showing Relationship Between Fix Spacing, Lane Capacity, and Communications Load

TABLE II

NUMBER OF TRAFFIC LANES VERSUS COMMUNICATIONS REQUIREMENTS

Number of Traffic Lanes	Hourly Capacity of Each Lane	Fix Spacing, Miles	Aircraft Headway, Minutes	Number of Position Reports Per Hour, by Each Aircraft	Total Number of Position Reports Per Hour
1	24	10	2.5	12	288
2	12	20	5	6	144
3	8	30	7.5	4	96
4	6	40	10	3	72

Desired capacity - 24 aircraft per hour - 120 mph

TRAFFIC CONTROL FUNCTIONS

Lane Assignment.

All airway systems were based on the use of independent traffic lanes for each direction of flight and for each speed class of aircraft Thus, each system contained at least four independent traffic lanes. Wherever possible, rotary-wing aircraft were assigned lower cruising levels than fixed-wing aircraft and westbound aircraft were assigned lower levels than eastbound aircraft

Control Jurisdiction.

In all systems tested, "airway control" acquired and released all aircraft at cruising altitude and was responsible for maintaining proper aircraft separation between acquisition and release. Airway clearance responsibilities included the prior scheduling or metering of departures to avoid exceeding the capacity of any traffic lane and to integrate traffic flow on merging routes

Functionally, "terminal control" was responsible for

1. Releasing departures in accordance with airway control restrictions.
2. Maintaining separation between each departure and all other traffic from the airport to the release point.
3. Providing proper airway separation between successive departures in each traffic lane before release to airways control.
4 Providing separation between each arrival and all other traffic from the airway release point to the airport.

Metering.

Metering, as used in airlift operations, is a way of organizing and limiting the flow of traffic to avoid exceeding the capacity of any airway traffic lane.

In all systems it was assumed that, unless otherwise advised, Forest Tower could clear continuous streams of aircraft on the westbound airway traffic lanes without prior airway coordination. Here the metering function was performed by the Forest Tower through the provision of proper separation between successive aircraft in each traffic lane. Because westbound traffic routes diverged west of Libby, usually no further metering was required for westbound traffic.

In all single-lane systems, eastbound traffic from the Divisional airports was metered by airway control to insure that the combined output from the three airports did not exceed the capacity of any traffic lane. This metering was accomplished by a scheduling process and the assignment of departure times.

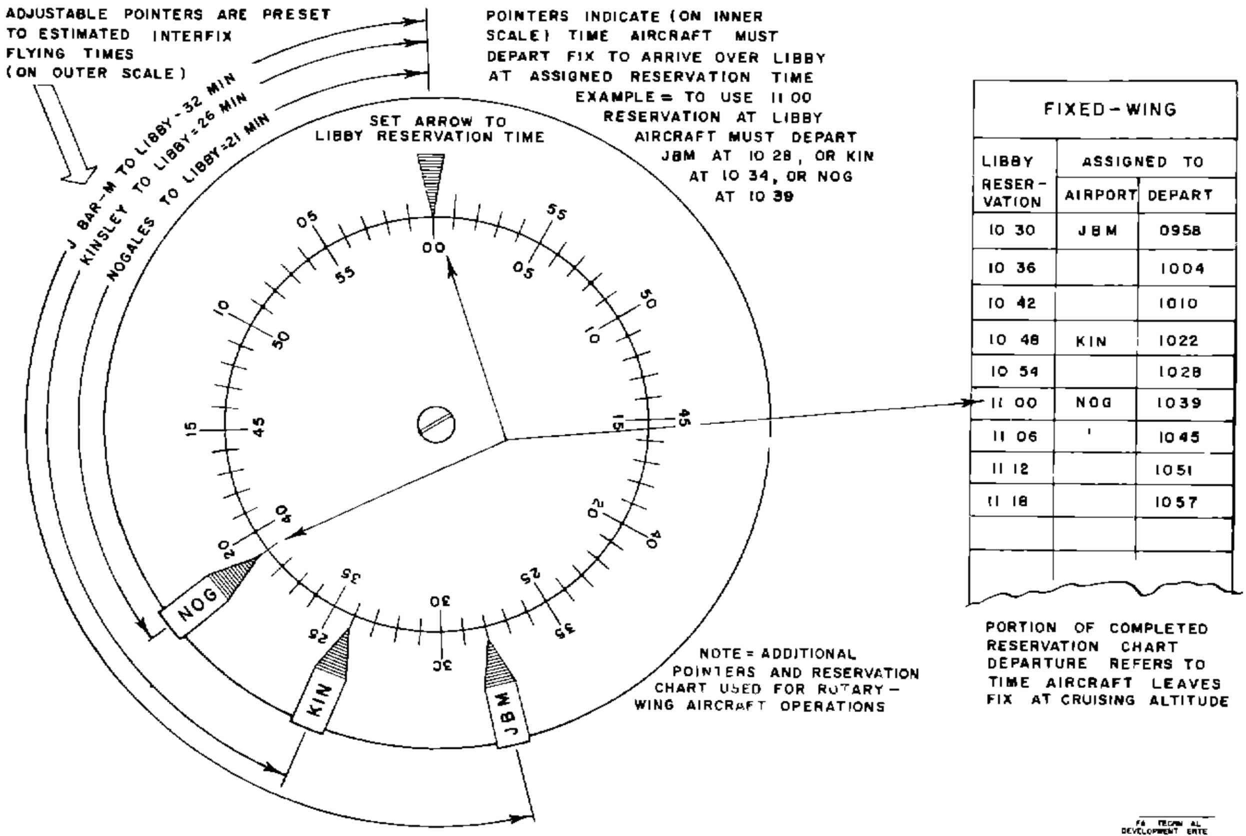
In the freeway systems which provided two independent eastbound traffic lanes from each Divisional airport, metering of the eastbound traffic flow was handled by the Divisional towers in the same manner as that performed by Forest Tower for westbound traffic.

Integration

Integration refers to the proper merging or coordination of streams of aircraft from different points of origin into a common traffic lane. In all systems tested, this function was performed by airways control. The procedure for integrating departures from Libby was similar in all systems. If eastbound traffic lanes already were operating at top capacity, it was necessary to hold an eastbound Libby departure on the ground or under radar control in the immediate vicinity of the airport to await a Libby arrival from the west. When the arrival left the airway traffic lane to begin approach, the departure was ready to take its place in the traffic stream. Here radar was extremely useful in slipping the departure into the recently vacated slot, with proper separation from other aircraft. In many cases, the preceding aircraft in the same traffic lane was changed temporarily to Libby approach control frequency for radar identification As soon as the departure was properly spaced behind this aircraft, both aircraft were changed back to the appropriate airway control frequency.

In the fixed-block systems and the freeway systems, westbound Libby departures were integrated in the same manner In cases where there were no westbound aircraft from Forest scheduled to land at Libby for a considerable period, it sometimes was necessary for airways control to request Forest Tower to leave a gap at the appropriate altitude in the steady stream of Forest departures to accommodate the westbound departures from Libby.

In the TDC single-lane systems where the westbound traffic streams diverged at Libby, a departure from Libby to either J-Bar-M or Kinsley usually had only to wait until a westbound flight from Forest to Nogales passed over the station. This left a vacancy in the



FIXED-WING		
LIBBY RESER-VATION	ASSIGNED TO	
	AIRPORT	DEPART
10 30	JBM	0958
10 36		1004
10 42		1010
10 48	KIN	1022
10 54		1028
11 00	NOG	1039
11 06	'	1045
11 12		1051
11 18		1057

PORTION OF COMPLETED RESERVATION CHART DEPARTURE REFERS TO TIME AIRCRAFT LEAVES FIX AT CRUISING ALTITUDE

FA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS, INDIANA

Fig. 15 Use of Computer for Integrating Traffic Flow in Single-Lane Systems

traffic stream northwest of Libby which was immediately filled by the Libby departure. The same procedure could be used for departures from Libby to Nogales Whenever a flight from Forest to J-Bar-M or Kinsley passed over Libby, this left a vacancy in the traffic stream west of Libby which could be filled by the Libby departure. Usually, however, it was not necessary to wait for this event to occur since the altitude levels of 6,500 and 7,000 feet, seldom used by over-flights, were almost always available for departure to Nogales

In all single-lane systems, the integration of eastbound traffic from the Divisional airports was performed through the use of a reservation system. In effect, this system set up a series of time reservations for aircraft in each traffic lane over the last junction point in the eastbound system (Libby or Miller). Thus, the reservation system performed the metering function for the eastbound traffic simultaneously

The reservation chart included a scheduling feature in which the estimated flying time from each airport to the last junction point was subtracted in turn from each reservation time to determine the time at which an aircraft should leave either airport in order to arrive over the last junction point at the reserved time. This system functioned very well as a rough spacing means to secure maximum utilization from the airway without overloading it, to reduce controller workload, and to enable aircraft to conserve fuel by taking necessary delays on the ground rather than in the air. To provide additional flexibility, the simple computer shown in Fig. 15 was developed. With this computer, the spacing interval at Libby could be changed as desired, and the estimated flying times from each airport to Libby could be adjusted to compensate for changing wind conditions.

Additional operational smoothness was obtained by handling reservations on a block basis instead of an individual basis Because successive aircraft from the same airport all were subject to the same wind conditions, relatively little variation accrued in their flying times from the airport to the airway junction point. Thus, a variation in the wind, which might have had some effect on their elapsed time from the airport to the junction point, had very little effect on the spacing between successive aircraft on the same route. For this reason, it became desirable to make the advance reservations in blocks, based on the traffic demand from each airport, dispatching perhaps four aircraft from one field followed by three from another, and so forth. Although this procedure probably increased ground delays somewhat, it worked very smoothly from the traffic control standpoint, since it minimized spacing variations between most of the aircraft, leaving only an occasional problem in adjusting the spacing of the first aircraft in the group from one airport, behind the last aircraft in a group from another airport, at the junctions in the route system

TESTS AND RESULTS

More than a week of simulation operations was devoted to preliminary tests before any measurement runs were made. The initial tests were of an exploratory nature to try out new control and communications procedures, traffic patterns, displays, and simulation techniques.

The final airway tests were made under programmed variable wind conditions with a 4-hour traffic sample having a demand rate of 48 operations per hour. Terminal tests were made with and without radar for all Divisional airports using an 80-minute traffic sample with a demand rate of 48 operations per hour. In connection with the freeway system, the Forest Airport traffic patterns were tested with radar using a 60-minute sample having a demand rate of 120 operations per hour. Each traffic sample included equal numbers of fixed- and rotary-wing aircraft. Results of the tests are detailed in the following sections, and are summarized in Table III

Airway Tests.

Melpar System. This system, shown in Fig. 2, originally was set up by Melpar engineers as a fixed-block system, requiring individual point-to-point clearances for every aircraft in the system Due to the extremely heavy control and communications workload that would be entailed with this clearance procedure, the system was modified by Melpar engineers. The modified control procedures still were based on the fixed-block principle, in this case, aircraft were permitted to be cleared initially to destination. However, the procedures also incorporated a scheduling arrangement. Each pilot was given a detailed schedule to make good over each check point. Separate procedures were specified for use at each check point

TABLE III - COMPARISON OF AIRWAY SYSTEMS

SYSTEM	NUMBER NAVAIDS			ROUTE MILEAGE FROM FOREST TO			TRAFFIC LANES			CONTROL BASIS	ESTIMATED MAXIMUM CAPACITY IN AIRCRAFT PER HOUR *				
	HOMER	FAN	DME	JBM	KIN	NOG	W	E	TOTAL		FIXED WING	W ROTARY WING	E FIXED WING	E ROTARY WING	TOTAL
ORIGINAL MELPAR	8	10	0	114	112	102	2	2	4	F	6	4	6	4	20
REVISED MELPAR	8	11	0	114	103	102	2	2	4	F	8.5	6	8.5	6	29
										M	10	10	9.5	9.5	39
REVISED TDC SINGLE-LANE	7	10	0	114	103	88	2	2	4	M	10	10	9.5	9.5	39
TDC DME	7	0	1	112	103	88	2	2	4	M	10	10	10	10	40
ARMY FREEWAY	8	7	0	123W 109E	95W 101E	95W 98E	4	6	10	M	15	15	22.5	22.5	75

W - WESTBOUND
E - EASTBOUND
F FIXED BLOCK
M - MOVING BLOCK

* BASED ON RESULTS ATTAINED IN SIMULATION PROGRAM

if the aircraft was on time, if it was less than 2 minutes early, if it was more than 2 minutes early, if it was less than 2 minutes late, or if it was more than 2 minutes late In addition, the fixed-block operation rule of only one aircraft per block was modified to permit two helicopters to fly in the same block provided they were more than 4 minutes apart.

The main advantage of the fixed-block system--its simple go/no-go control procedures--was completely nullified by these complicated additions. After a few runs, it was determined that the scheduling arrangement added nothing to safety or to system capacity. Instead, it greatly increased pilot and controller workload and actually reduced the capacity of the system when wind conditions changed so that all aircraft were running ahead of schedule. In the latter case, pilots following the original schedule would have to lose time, thus reducing the capacity of the traffic lane. Repeated modifications to the schedule to compensate for holding in flight, or for changed wind conditions, made the original schedule useless for control purposes. Operations were improved and greatly simplified when the scheduling concept was abandoned and the system was operated strictly as a fixed-block system

In the original Melpar system arrangement, block lengths varied from 6 to 11 miles, except for the blocks from Libby to Robert to William to Fred, which were 14, 14, and 15 miles in length, respectively. Tests showed that these long blocks reduced the capacity of the system just as though all fixes were spaced at the maximum length. This principle, described previously in this report, is shown in Fig. 11. Maximum output from any fixed-wing traffic lane in this layout was about six aircraft per hour due to the flying time required to negotiate the long blocks in the system The chain reactions set off by holding in flight also tended to lower system capacity because an aircraft established in a holding pattern seldom was in a position to proceed on course immediately when the block ahead was cleared by the preceding aircraft. These small delays accumulated in an alarming fashion. At times, 7 or 8 aircraft would be holding simultaneously at different points in the traffic lane.

Revised Melpar System. The Melpar system capacity was increased to about 8.5 fixed-wing aircraft per hour per lane when the facility arrangement was revised as shown in Fig. 3 This revision reduced the maximum system block length to about 11 miles Using direct air-ground communications, it was found that the maximum operating efficiency of the fixed-block system was attained when aircraft were scheduled initially to enter the system at an interval of (F + 1) minute where F is the estimated flying time for the longest block in the system, and the additional minute is provided to enable each pilot to report leaving a block before the following aircraft reaches the block boundary.

Under these conditions, the fixed-block system worked very smoothly with a minimum amount of control intervention. However, any reduction of the initial spacing interval below this point simply precipitated chain holding reactions which increased controller workload and lowered system capacity.

Later, the revised Melpar system was tested using moving-block, instead of fixed-block, procedures. Six-minute initial separation was used between successive aircraft in each traffic lane. The almost uniform spacing of fixes along the route simplified estimating procedures Tests indicated that the system could handle very close to the theoretical maximum of ten fixed-wing or ten rotary-wing aircraft per traffic lane This represented an appreciable increase in helicopter traffic flow over the 6-per-hour rate previously attained using fixed-block procedures.

TDC Single-Lane System. This system, which is shown in Fig. 4, was based on a previously designed configuration of navigation facilities closely resembling the original Melpar system. Without changing any facilities, two routes were changed with the idea of keeping all routes as short and independent of each other as possible.

The new route from Libby to Nogales was about 12 miles shorter than that used in the Melpar systems and also provided a route altitude 1,000 feet lower than that previously available The route from Libby to Kinsley was shortened about 10 miles by adopting the routing used in the revised Melpar system.

Tests indicated that the fix at Harold was too close to Miller to be of any value in the control of traffic, and also that the integration of eastbound merging traffic at Libby could be improved if an intermediate check point were installed on the long Ray-to-Libby route segment

Revised TDC Single-Lane System This system, which is shown in Fig 5, incorporated the improvements which the previous tests showed to be necessary. This system first was tested using 8 minutes' headway between fixed-wing aircraft and 10 minutes' headway between rotary-wing aircraft. Because of this relatively large amount of spacing, only four airway position reports usually were required from each aircraft, no control action was taken unless the actual separation became less than 6 minutes. The communications and control workload remained quite low in these tests.

Later, this system was tested using 5 minutes' headway between fixed-wing and 7 minutes' headway between rotary-wing aircraft. Control action was mandatory whenever the separation between fixed-wing aircraft became less than 4 minutes or the separation between rotary-wing aircraft became less than 5 minutes It was found that the higher system capacity and the smaller aircraft separation required an appreciably higher degree of controller skill than when the 8- or 10-minute separation was used The 5-minute average departure and arrival intervals at terminal airports also would require strict pilot discipline in the regimentation of speeds and rates of climb or descent, particularly under conditions where radar surveillance was not available. Under conditions of low average separation, the resolution error of the clocks assumed importance, since slightly unsynchronized clocks or misreading of the clocks sometimes caused the controller to take action that later was found to have been unnecessary. Using the block-reservation procedure described previously, tests were made assuming that conditions existed which required the maintenance of radio silence in the vicinity of the Divisional airports In these tests, fixed-wing aircraft were scheduled with 8 minutes' headway, rotary-wing aircraft, 10 minutes' headway. Prior to takeoff from either of the Divisional airports, each pilot was given a time to leave the airport radio fix at cruising altitude, no position reports were issued until the aircraft was over Harold or Yoke, 10 miles from Libby Occasionally, aircraft showed up at these fixes with separations as low as 1 minute, indicating that it would be desirable to increase the initial headway somewhat to allow for these variations.

TDC DME System. Although not considered seriously for Army use at this time, a system was tested in which a single DME ground transponder replaced all fan markers in the TDC single-lane system. These tests were made because of their value in determining the air-derived distance information in handling high-density airway traffic operations. Because all main routes extended essentially in a radial direction from Libby, it was assumed that the DME interrogator was located on the Libby airport.

This system, which is shown in Fig 6, was tested using a minimum spacing of 10 miles between aircraft with compulsory reporting points at 20-mile increments from the DME station. A control procedure known as chain control was used in these tests, based on the air-to-air relay of position reports to following aircraft. After the initial separation was provided by traffic control, each pilot was told to maintain the appropriate separation behind a specific aircraft, the pilot of the preceding aircraft was told to relay all position reports to the designated following aircraft. On receipt of such a report, the pilot of the following aircraft checked his own DME reading and adjusted his spacing as necessary. Airways control in this case monitored the air-to-air position reports to keep track of the various aircraft in the system.

Tests indicated that the chain-control procedure was quite practical for such operations and that the use of distance information by the pilots produced precise and con-consistent separation intervals.

TDC Freeway System. By rearrangement of approximately the same number of radio facilities as were used in the Melpar system, a dual airway system was established which doubled the number of traffic lanes and provided one-way airway operation over most of the system. This system, known as the TDC freeway system, is shown in Fig 7.

Revised TDC Freeway System. To secure additional traffic capacity, the freeway system was revised by moving the eastbound airway northward, as shown in Fig. 8. This enabled the use of a lower altitude for eastbound traffic from Nogales to Forest Two altitudes, one for fixed-wing and one for rotary-wing aircraft, were available for eastbound traffic from each Divisional airport back to Forest This eliminated the integration problem completely, except for occasional departures from Libby However, the increased number of available traffic lanes simplified this problem in most cases

The provision of independent routes from each Division back to Forest simplified control operations, as each Divisional airport normally could dispatch steady streams of aircraft without prior coordination with airways control

Army Freeway System Although the revised freeway system operated satisfactorily, the additional mileage necessary to route the eastbound airway around the high terrain was considered objectionable. It was found that by raising all cruising altitudes of the original TDC freeway system 500 feet, it would be possible to use the shorter routes of the original system and still provide each Divisional airport with two independent eastbound traffic lanes back to Forest. The improved airport routings developed with the revised freeway system then were incorporated with the original TDC freeway routings to produce a layout known as the Army freeway system, shown in Fig. 9

Using a rather conservative headway of 8 minutes in each traffic lane, this system could accommodate a maximum capacity of 75 aircraft (30 westbound and 45 eastbound) per hour. If the demand rate were low, the additional capacity furnished by this system could be utilized instead to provide additional separation between successive aircraft, thus producing a very safe and relaxed control operation.

Terminal Tests.

Traffic Patterns.

The most important consideration in the safe and efficient control of terminal traffic was the establishment of independent tracks for fixed-wing and rotary-wing arrivals and departures. It was necessary that each track be as simple as possible, with adequate length for altitude change, free of intersections or points of confliction with any other traffic lane.

High terrain and prohibited areas sometimes prevented the establishment of ideal arrangements by cramping the maneuvering area into a relatively small sector of the azimuth circle around the airport. These factors, plus the relatively large differences between cruising altitudes and airport elevations, made the establishment of suitable independent approach and departure tracks as difficult in this system as probably would be encountered in any operating theater. More cramped arrangements generally produced higher restrictions and higher controller workloads, with less margin for error by either controllers or pilots.

Operation of the freeway system without radar, as shown in Figs. 16E, 18E, 19E, 20E, and 21E, is not recommended at any airport if arrivals are using more than two route altitudes

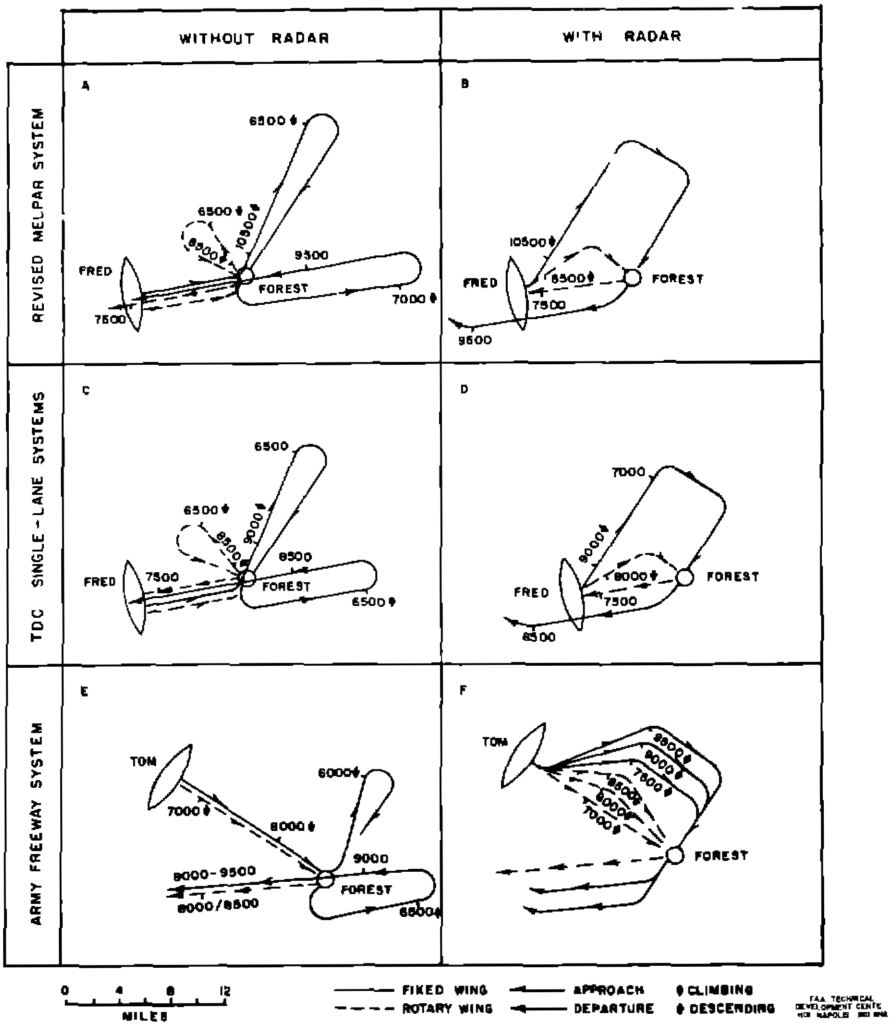


Fig. 16 Traffic Patterns - Forest Airport - Elevation 4,000 Feet

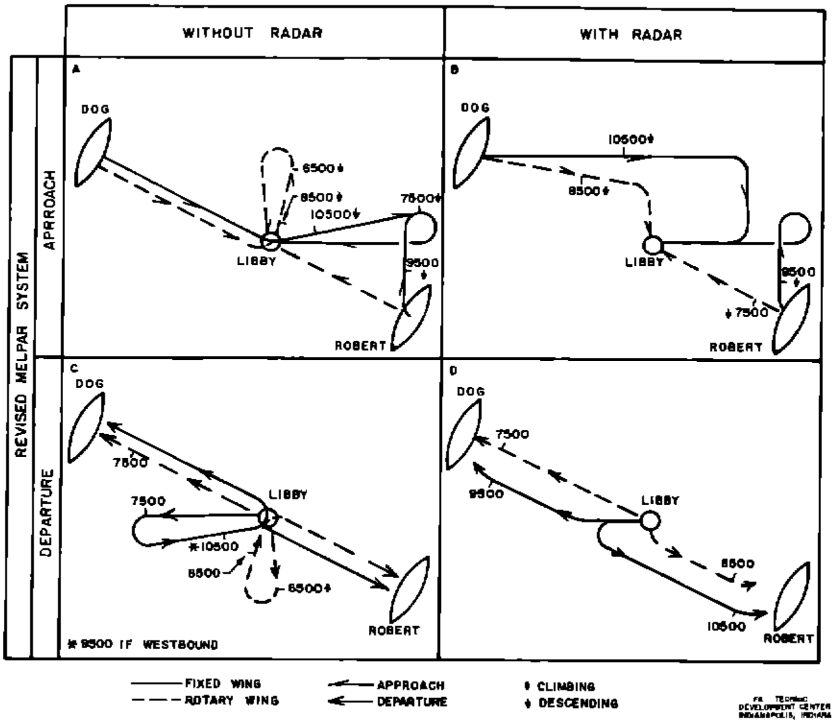


Fig 17 Traffic Patterns - Libby Airport - Elevation 4,665 Feet

inbound. Without radar it would be extremely difficult to integrate two or more streams of fixed-wing or rotary-wing aircraft into the same final approach course.

Forest Airport.

Traffic patterns are shown in Fig. 16. No tests were conducted at this airport without radar. However, based on results of other airport tests with similar patterns, this system still would be workable without radar, provided that the traffic demand did not exceed 24 approaches or 24 arrivals per hour, equally divided between fixed-wing and rotary-wing aircraft.

Patterns for the single-lane systems, shown in Figs. 16B and 16D, functioned very well with radar. Patterns for the freeway system, shown in Fig. 16F, also worked very well with radar. When tested with a demand rate of the maximum capacity of the ten traffic lanes at 5 -minute headway (120 operations per hour), it was necessary to have at least three radar controllers to handle the workload; one for fixed-wing arrivals, one for rotary-wing arrivals, and one for all departures, with a separate voice channel for each. Before operations ever reached that level, it would be desirable to establish an additional landing field for all helicopters at some point 1 or 2 miles northwest of the present airport.

Libby Airport.

The traffic patterns shown in Figs. 17 and 18 functioned satisfactorily under relatively light traffic loads, however, because of the airway configuration and the surrounding terrain, there is relatively little margin for error in the departure procedures It is anticipated that, without radar, flight operations would have to be severely restricted to preclude traffic conflictions due to aircraft converging on the airport from more than one fixed-wing arrival lane and more than one rotary-wing arrival lane simultaneously. Therefore, the use of radar is strongly recommended for all flight operations at this airport.

J-Bar-M Airport.

All traffic patterns shown in Fig. 19 functioned very well in simulation tests up to 48 operations per hour

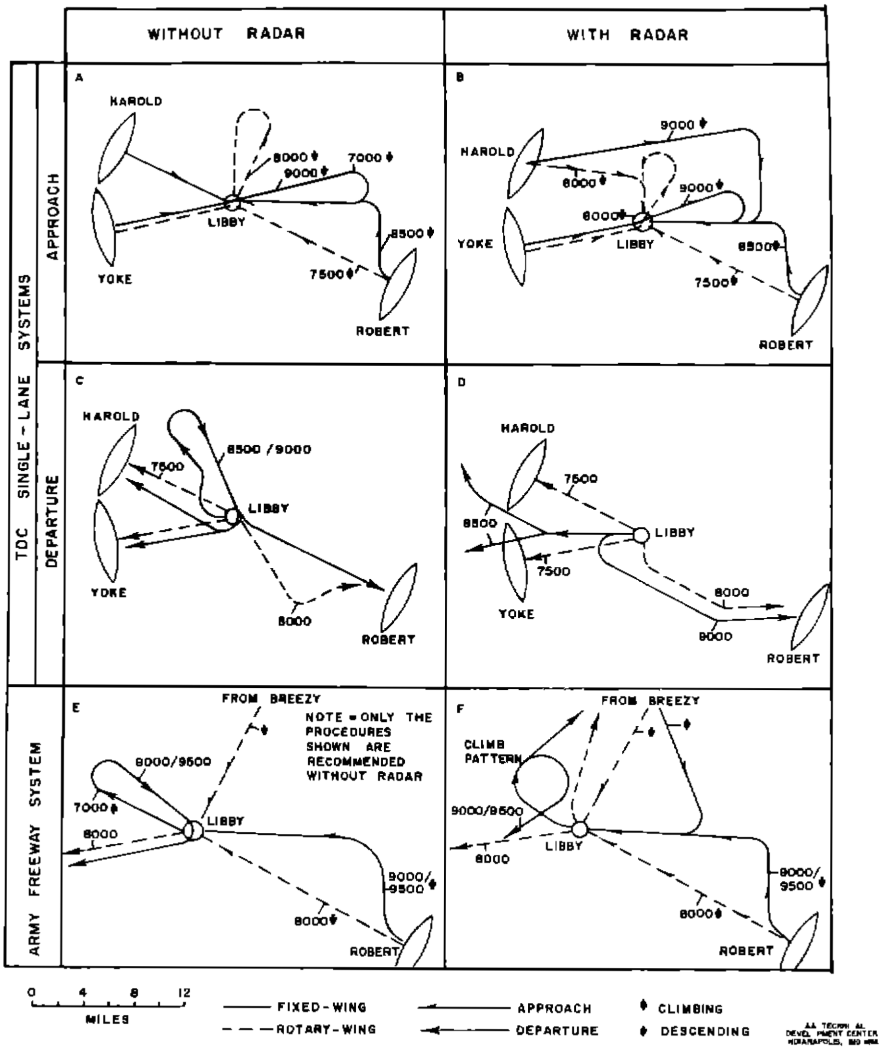


Fig. 18 Traffic Patterns - Libby Airport - Elevation 4,665 Feet

Kinsley Airport.

Traffic patterns for all systems, as shown in Fig 20, functioned very well in simulation tests up to 48 operations per hour.

Nogales Airport.

Because of the severe restrictions imposed by the Mexican border on the south and the high terrain north, northeast, and east of the airport, the traffic patterns for this airport were the least satisfactory of those tested. These patterns, shown in Fig. 21, were developed after it was determined that high terrain on the final approach course would not allow straight-in approaches for fixed-wing aircraft. As a result, procedures for such approaches incorporated a straight-in descent from the north-northwest, down to visual contact, with a circling approach to get lined up with the runway. This appeared to be the best alternative to a scheduling procedure which would require that departures and arrivals be handled at different times on a nonsimultaneous basis Such a procedure would reduce the airport traffic capacity to a very low value.

Airway Traffic Control Displays.

The inherently large amount of bookkeeping required for each aircraft, as well as the high degree of skill required to visualize aircraft positions, made the standard ATC flight

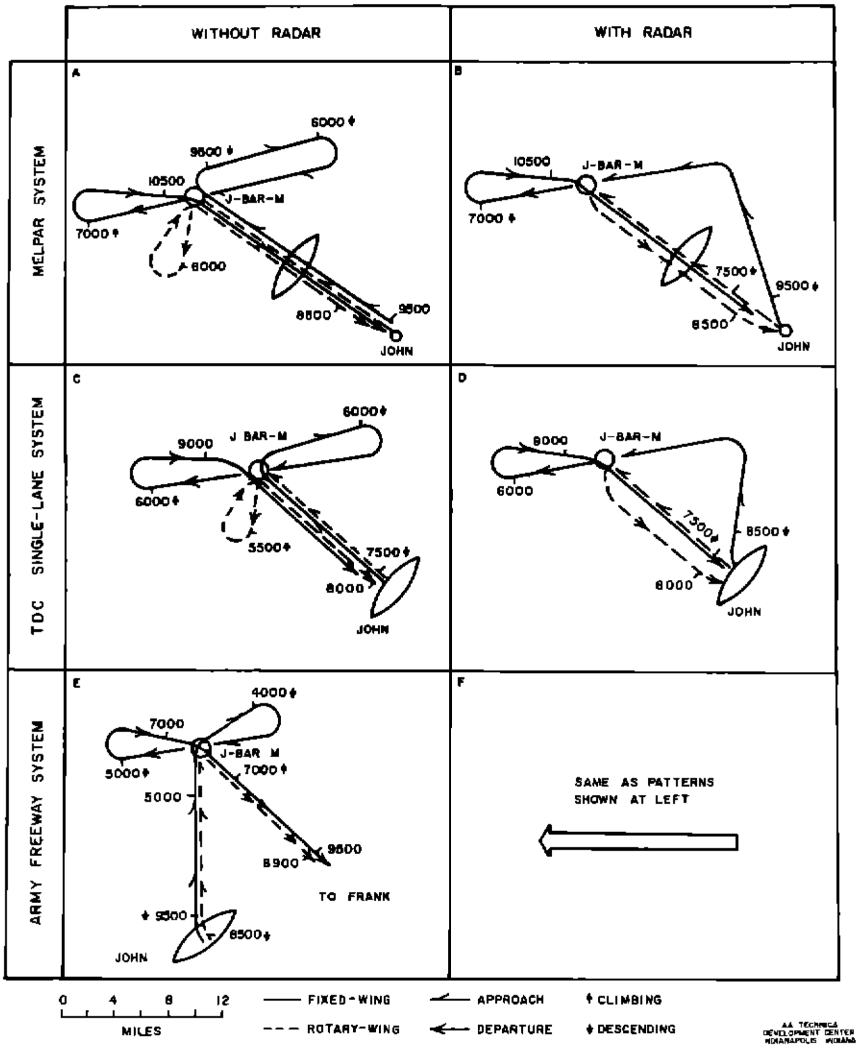
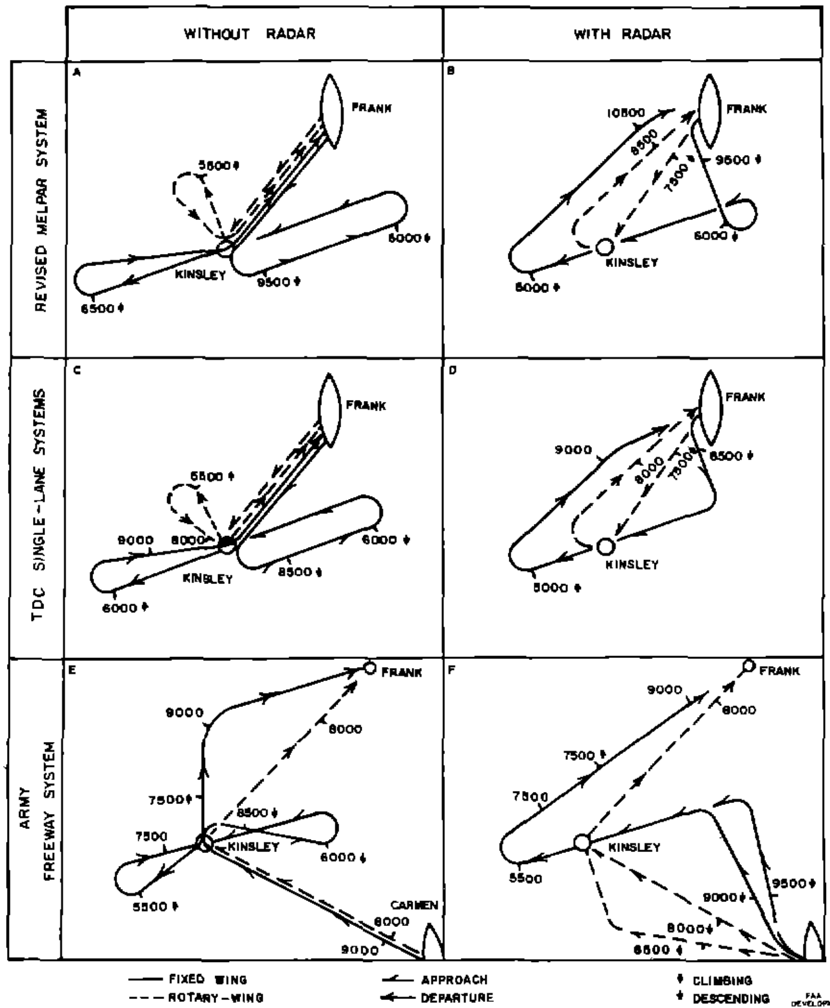


Fig 19 Traffic Patterns - J-Bar-M Airport - Elevation 2,860 Feet

progress board unsuitable for use in tactical airlift operations The extremely high traffic densities encountered in the early simulation tests also made the recently developed "shrimp boat" panoramic presentation inadequate due to the very congested and disorderly appearance of the board under such traffic conditions

The requirement was for an orderly method of displaying traffic data in a manner which would be simple to scan, interpret, and maintain, a display which could not be overloaded in any type of traffic condition These requirements were simplified somewhat by the fact that the air routes were relatively simple in configuration, that one-way traffic lanes could be used, and that aircraft could be segregated by speed class in each traffic lane Under these conditions, the main traffic problems were the prevention of overtaking in the same traffic lane, and the proper separation of converging traffic at airway intersections These system characteristics led to the development of a control display which was stratified by altitude levels to provide easy scanning of the relative positions of aircraft in each traffic level. To save display space in this multiple display, the airway configuration was changed from a pictorial to a schematic diagram. Horizontal tracks were used to indicate the various airways, as shown in Fig 22A. Aircraft positions were shown by the use of special "shrimp boat" target markers which were moved along the tracks.



FAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

Fig. 20 Traffic Patterns - Kinsley Airport - Elevation 3,000 Feet

The longitudinal dimensions of the schematic display were determined by making each route segment long enough to accommodate enough shrimp boat target markers for the largest number of aircraft which would ever be cleared into that particular segment of the traffic lane simultaneously. This consideration, which prevented overloading, also kept the display close to true scale longitudinally. The schematic concept sacrificed true lateral scale for the more valuable dimension of altitude.

The schematic control board was inclined 30° from the vertical so that target markers could be held in place by gravity. It was later recommended that this angle be increased to 35°. The sloping arrangement was well adapted for military use since airway traffic control operations would be conducted from motor vans where space limitations would preclude the use of a large horizontal display

As a further refinement of the schematic display, the modular control board was developed, as shown in Fig 22B This board was designed for fast modification to accommodate changes of airway route structure in a fluid military situation The base of this display was a piece of perforated hardboard, with 1/2-inch spacing between perforations

The horizontal tracks were made in various lengths, with a 6-inch spacing between the countersunk attachment holes Flathead machine screws were used for attaching the track segments to the perforated board Labels were made of masking tape and striping made of colored cellophane tape for fast, easy modification of the display It was interesting to note

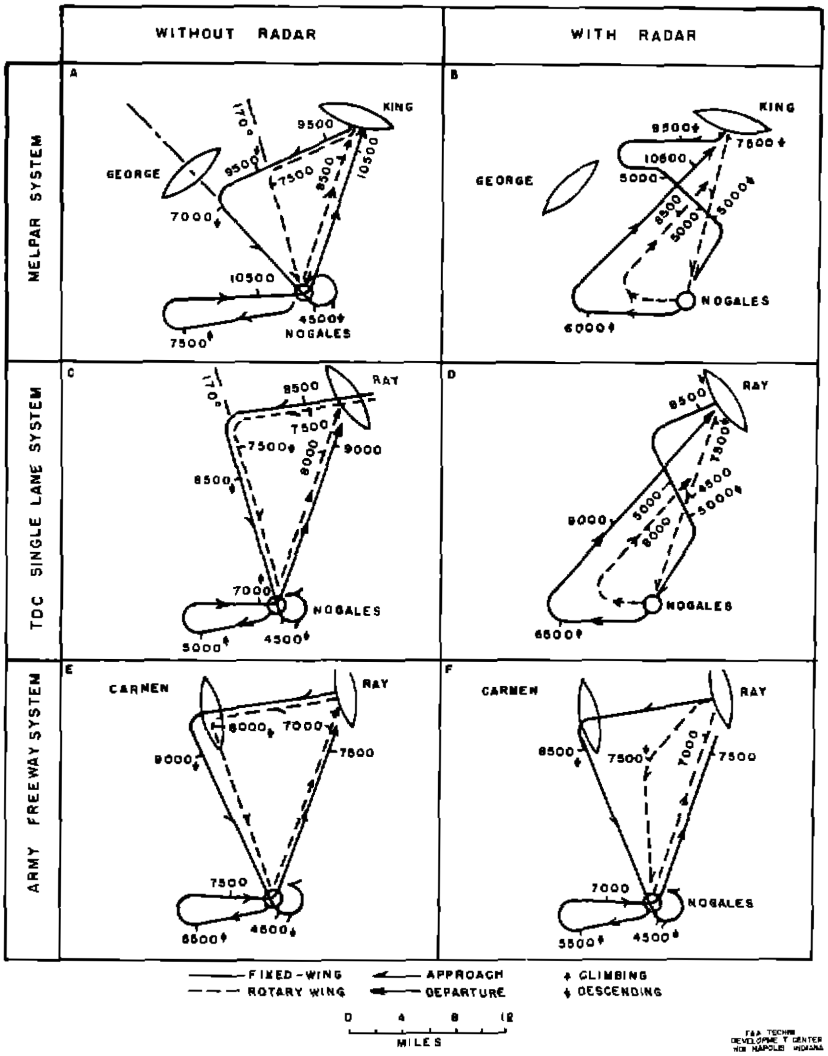
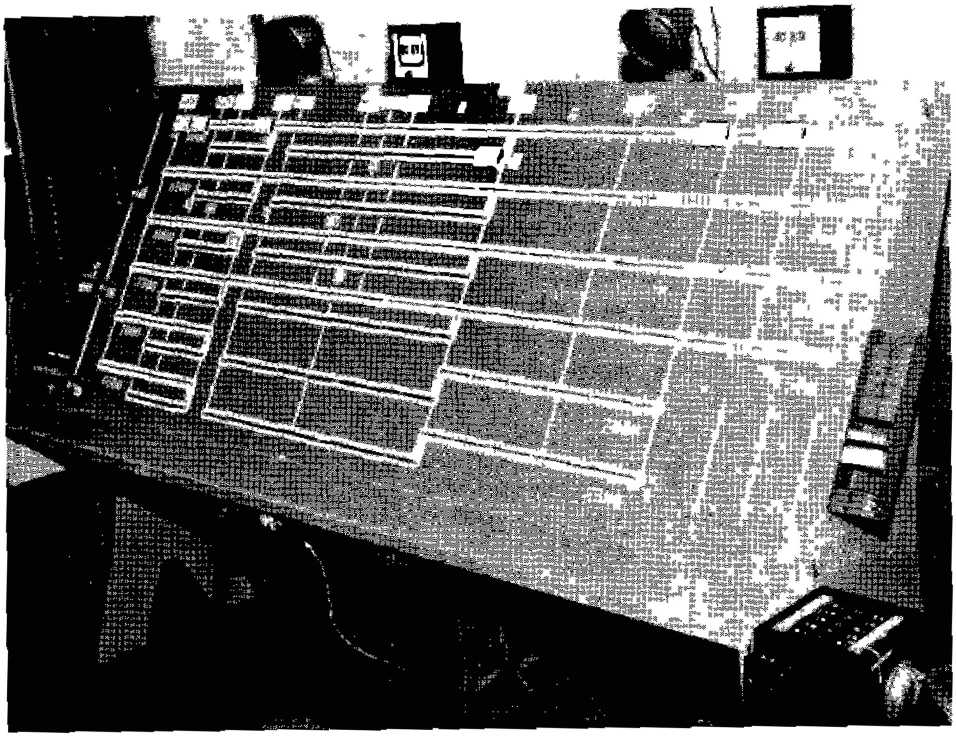


Fig. 21 Traffic Patterns - Nogales Airport - Elevation 3,938 Feet

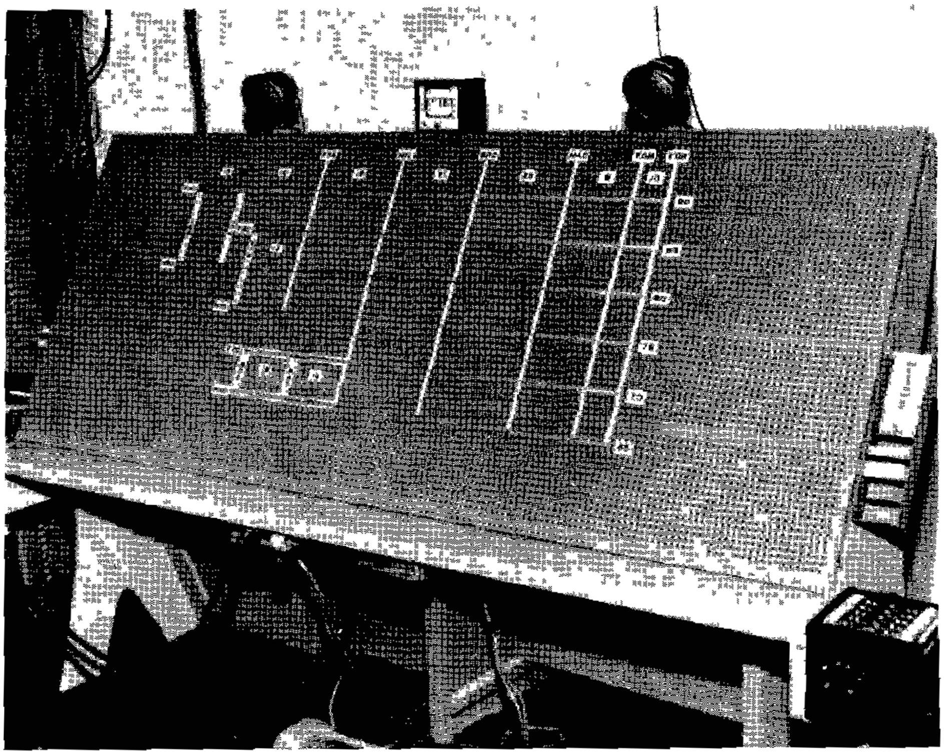
that the schematic concept led in one instance to a basic simplification of the route structure. While determining the best way of displaying the TDC freeway system schematically, it suddenly was discovered how to modify the airway configuration itself to secure a more simple routing which also increased the traffic capacity of the system.

Operation of the schematic display proved to be simple and satisfactory Target data were posted as shown in Fig 23. Boards could be operated by either one or two controllers, or the workload could be subdivided by altitude sectoring, with different altitudes controlled from different boards. Coordination between controllers was reduced to a bare minimum.

It is believed that the schematic display can be applied to the common system for handling high-density airway control operations on specially designated express airways It is true that this display works best on regimented speed-controlled routes that are relatively uncomplicated by intersections. However, the results of this simulation program indicated that prerequisites to high airspace utilization on any route will be the use of controlled speeds and specially designated limited-access traffic lanes for express operations.



A Original "Printed-Circuit" Display TDC Single-Lane System



TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA

B Modular Display for TDC Freeway System

Fig. 22 Schematic Control Boards

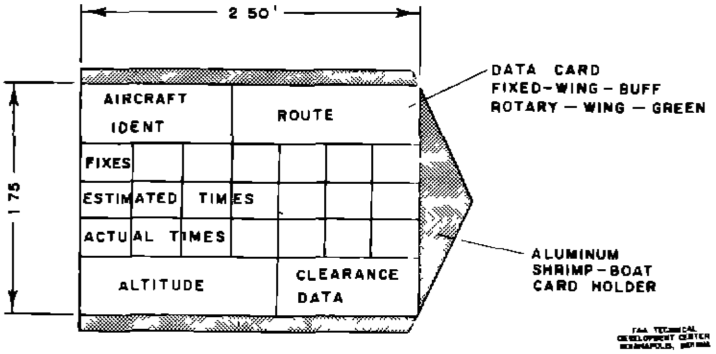


Fig 23 Details of Target Marker for Schematic Display

Use of Radar.

Airway Control

Complete airway radar coverage often has been advanced as the solution to airway traffic congestion. However, this simulation project provided an opportunity to observe airway traffic loadings much higher than ever encountered in previous tests The constant merging and separation of targets at the various altitude levels produced a very confusing plan position indicator (PPI) display It was found that the volume of traffic already had passed the point where primary radar, with manual target tracking, would even be usable, much less advantageous, for airway traffic control

Some improvement was encountered when radar beacons were simulated on all aircraft and a separate beacon code was assigned to aircraft at each altitude level. Then the controller could switch from code to code and inspect the traffic situation in each traffic lane separately. This procedure was of some value in monitoring aircraft separation at junction points where streams of aircraft from different airports merged into a common lane.

Tests indicated that, for the control of large masses of traffic with common origins, destinations, and speeds, it was desirable to abandon the idea of continuous individual attention for each aircraft in the system and to adopt the concept of blanket procedures for larger blocks of aircraft Through the use of independent, limited-access express routes and a regimented traffic flow, large volumes of airway traffic could be handled safely without radar.

Terminal Control

To reduce the amount of skill, workload, and fatigue entailed in handling terminal control operations, independent traffic lanes were established at each airport to handle fixed- and rotary-wing approaches and departures. Thus, each airport had at least four independent lanes to handle these operations.

At the Divisional airports, the use of these independent approach and departure routes furnished (at the rates of flow simulated in these tests) a system which functioned almost as well without radar as it did when radar was used. The fact that traffic flow was carefully metered in each airway traffic lane did much to keep terminal approach operations orderly even when radar was not used, since this degree of traffic regimentation suppressed any tendency for arrivals to enter the terminal area in bunches While the use of radar was not considered necessary for operations at Divisional fields, a comparison of the radar and nonradar tests showed that radar furnished these advantages

1. By permitting direct, instead of teardrop, approaches, the use of radar saved about 5 minutes of flying time for each fixed-wing instrument approach at J-Bar-M and Kinsley airports.
2. To protect against the possibility of a collision resulting from a missed approach, departures were restricted when arrivals were on final approach. Without radar, takeoffs were stopped when an arrival reported inbound on the final approach course With radar, takeoffs could be permitted safely up to the time the arrival was 2 miles from the end of the runway. In this case, the use of radar reduced departure delays, permitted more accurate scheduling of departures, and thus improved the utilization of the eastbound airway traffic lanes.

Because the traffic demand at Forest (Army) normally was higher than at any other airport in the system, it was desirable that radar be used at that point for all traffic operations.

Although the traffic load at Libby (Corps) was not expected to be very high, the nature of the airway configuration made the use of radar extremely desirable, particularly for the integration of departures in the appropriate traffic lanes during conditions when the airway was being used at high utilization rates.

CONCLUSIONS

1. The original Melpar system, operated on a fixed-block basis, is simple and safe. However, it has a very low capacity, which can be improved somewhat by revising the configuration of navigation facilities, as shown in Fig. 4 of this report.

2 The use of detailed pilot schedules, as specified in the Melpar manual, "Discussion and Proposed Procedures," page 11 (revised), is incompatible with fixed-block control procedures and detrimental to the operation of the system The provision for unacknowledged position reports, as specified on page 12 (revised) of this manual, is impractical due to the possibility of nonreceipt of the position report, an occurrence which quickly precipitates a chain-holding reaction and halts the flow of traffic in the system

3 Assuming that the navigation system permits the attainment of a fair degree of precision in point-to-point navigation, the capacity of the revised Melpar system can be increased further through the use of moving-block, instead of fixed-block, procedures. The disadvantage of this change is that, with the increased capacity, there would be less than one fix per aircraft in each traffic lane. This would entail a decrease in safety under the rare event that traffic had to be brought to a complete halt and all aircraft had to hold in flight. However, because of the nature of military operations, it would appear that this factor could be accepted as a calculated risk of the moving-block system. On the other hand, any fixed-block system is inherently vulnerable to failure of communications or ground navigation aids. Assuming that all fixes are equally spaced, the loss of one intermediate fix will double the maximum block flying time and reduce the capacity of the airway by 50 per cent as long as strict block rules remain in force. It does not appear reasonable for a military system to adopt a method of traffic control which depends on the perfect operation of every component.

4. If it is decided to utilize moving-block, instead of fixed-block, control procedures, the airway layout of the revised TDC single-lane system appears preferable to the revised Melpar system due to the consequent saving in route mileage, the provision of a lower minimum altitude between Libby and Nogales, and a reduction in airway traffic congestion between Libby and Miller.

5. If all single-lane systems have too low a capacity for the intended purpose, it will be preferable to go into a dual-airway layout rather than to decrease aircraft separations with present navigation facilities. If the additional capacity is necessary, the Army freeway system offers a dual-lane configuration which could be established with the same number of navigation aids used in the revised Melpar system

6. Tests indicated that the entire airway system can be controlled from a single agency in the vicinity of Corps In case this airway control agency became inoperative, its function could be taken over from any other location which had

a Complete information on the current traffic situation

b. Adequate means for communicating with the aircraft and ground agencies concerned Because of radio-coverage limitations, normally it would be desirable for this agency to be located near the center of the system rather than at one end of the airway.