EVALUATION BY SIMULATION TECHNIQUES OF PROPOSED TRAFFIC-CONTROL PROCEDURES FOR THE NORFOLK TERMINAL AREA

by

C M. Anderson

F S. McKnight

T. K Vickers

and

M H Yost

Navigation Aids Evaluation Division

Technical Development Report No 185

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT AND

EVALUATION CENTER

INDIANAPOLIS, INDIANA

January 1955

U S DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary

CIVIL AERONAUTICS ADMINISTRATION
F B Lee, Administrator
D M Stuart, Director, Technical Development and Evaluation Center

TABLE OF CONTENTS

EVALUATION BY SIMULATION TECHNIQUES
OF PROPOSED TRAFFIC-CONTROL PROCEDURES
FOR THE NORFOLK TERMINAL AREA*

SUMMARY

This report describes a study to determine methods of expediting air traffic to and from the five major airports in the Norfolk, Virginia, terminal area This study was made with the aid of simulation techniques developed jointly by the Franklin Institute Laboratories for Research and Development and the Technical Development and Evaluation Center of the Civil Aeronautics Administration

Comparative tests were made of five different layouts of radio navigational facilities These configurations included the present arrangement of navigation aids as well as one system based on the use of very-high-frequency omniranges Results indicated that the use of surveillance radar by Norfolk approach control would expedite the movement of instrument-flight-rule (IFR) traffic Further gains in operating efficiency and safety could be made by changing the navigational aids to provide separate routes for inbound and outbound traffic

The simulation tests were also useful in the development of detailed traffic procedures and in the development of arrangements of control-room equipment for handling the operation Recommendations on these subjects are included in this report

INTRODUCTION

The Present Problem

Control of IFR traffic in the Norfolk, Virginia, terminal area presents an extremely complex problem due to the proximity of airports, the many different types of aircraft, and the arrangement of navigational aids and of instrument runways The situation is further complicated by a lack of outer clearance limits for departing aircraft and by limited radio navigational equipment in many of the aircraft which operate in the area

Five major airports are located within a radius of 17 miles of the city of Norfolk These include Langley Air Force Base, Norfolk Navy East Field (since changed to Chambers Field), Oceana Naval Auxiliary Air Station, Norfolk Municipal Airport, and Newport News Municipal Airport (Patrick Henry Airport)

Air Force aircraft including training craft, transport types, and jet aircraft operate at Langley Air Force Base At Norfolk Naval Air Station, aircraft include all types from training planes through high-speed fighter craft to heavy transport and seaplane types Navy aircraft including trainer, transport, and jet aircraft will shortly be operating at Oceana Naval Auxiliary Air Station, and this field will serve primarily as a jet-aircraft base Scheduled air-carrier and civil operations are conducted at Norfolk Municipal and Patrick Henry Airports

Most of the present navigational aids in the area were installed to serve as instrument-letdown aids to the individual airports Since the resulting configuration does not provide adequate means of separating inbound and outbound traffic routes, the traffic flow under IFR conditions becomes extremely congested

The arrangement of instrument-approach paths is illustrated in Fig 1 It will be noted that the present range approach path at Patrick Henry Airport conflicts with the ground-control-approach (GCA) path at Langley Installation of an instrument landing system (ILS) at Patrick Henry to permit approaches from the southwest would eliminate this point of confliction and would reduce delay by permitting independent traffic operations at the two fields

When the Patrick Henry ILS is installed, all instrument-approach paths will be essentially parallel in a northeast direction, with the exception of the final-approach path to Norfolk Naval Air Station A railroad yard to the southwest and the water area to the northeast will probably preclude expansion of this airport to permit instrument approaches to the northeast Therefore it is probable that instrument approaches to Navy East Field will continue to be made to the east

Control of the IFR traffic in the Norfolk area is shared by several agencies The terminal area is included within the Washington Air Route Traffic Control (ARTC) area The CAA control tower at Norfolk Municipal Airport provides approach-control service for the area

---

*Manuscript submitted for publication October 1952

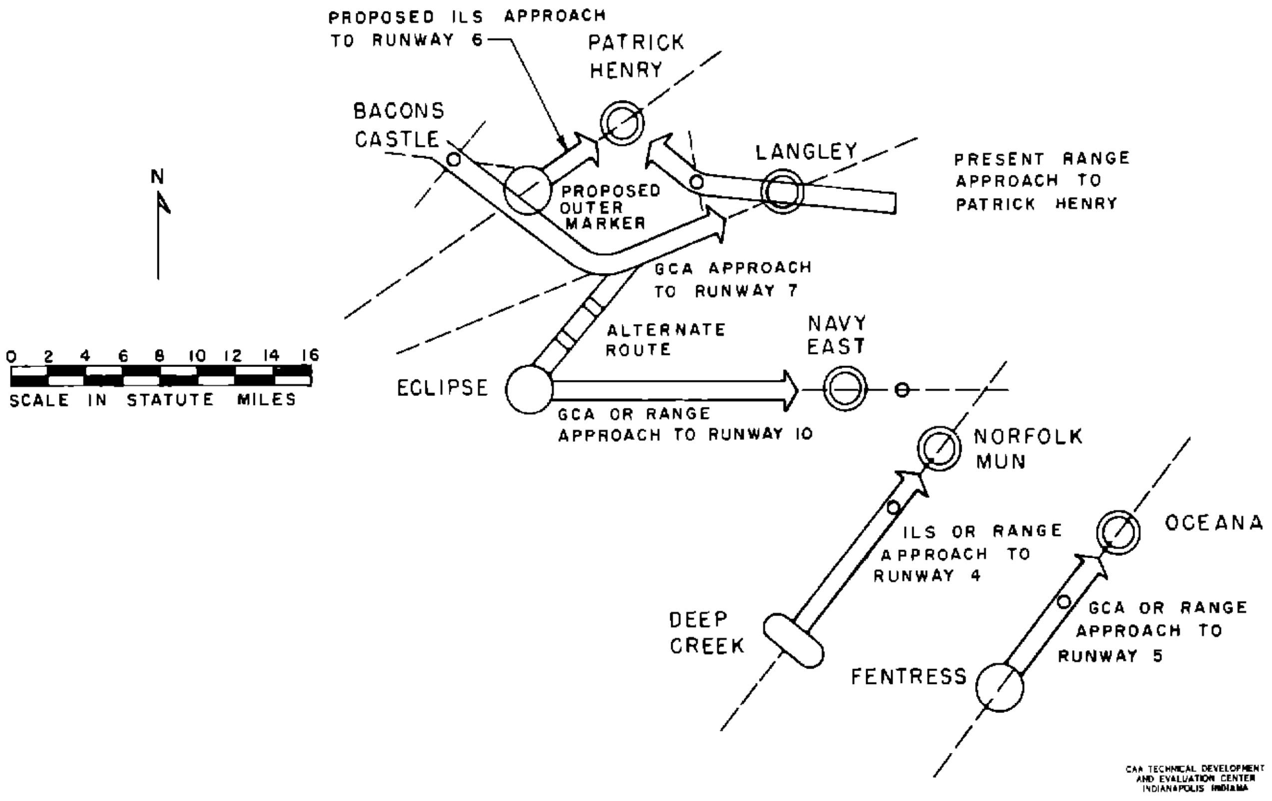


Fig 1 Configuration of Instrument-Approach Paths in Norfolk Terminal Area

Control of inbound traffic is released from Washington ARTC Center to Norfolk approach control when the aircraft enter the terminal area Flights en route to Langley, Navy Chambers, or Oceana Airport are then released to the appropriate GCA unit when the aircraft reach the approach fix for the airport concerned

Control of departing flights similarly involves several air-traffic-control agencies and frequently results in long delays due to the time required for co-ordination between agencies Control towers at the respective fields request clearances from Norfolk approach control (Norfolk Municipal Airport control tower), which in turn must obtain clearance from Washington ARTC Center prior to departure of the aircraft The Washington ARTC Center is in the difficult position of accurately estimating the time a departing flight will enter the en route airway system some distance away from the point of departure and trying to find an open altitude on heavily congested routes As a result, long d parture delays are quite common

Another factor contributing greatly to traffic delays in the Norfolk area is the operation of aircraft with limited radio equipment Frequently single-pilot, single-engine, military aircraft enter the area equipped only with a low-frequency radio receiver for navigation and four-channel VHF for communications Because of the lack of low-frequency navigational aids on certain routes, notably Amber Airway 9 (since redesignated Blue Airway 23), such aircraft may enter the terminal area at random points and off course, with consequent hazard to other aircraft Lost aircraft incidents occur frequently under these conditions, with a consequent tie-up of other traffic in the area Aircraft with limited radio navigational equipment may use as much as 30 minutes to complete an instrument approach

As a result of all these factors, IFR traffic at best flows very slowly in the Norfolk area Because of the inherent difficulties of the system, flow-control procedures are necessary to limit the number of aircraft entering the area under IFR conditions The acceptance rate is limited to three aircraft per airport per hour when ceilings are below 800 feet The flow rate is increased to five aircraft per airport per hour when the ceilings are between 800 and 1000 feet In actual practice, even these low rates are seldom realized because there may not always be a full quota of aircraft destined for Patrick Henry or Norfolk Municipal Airports at any specific hourly period

Objectives of Program

In order to improve the air-traffic-control capacity for the Norfolk area, the Office of Federal Airways requested the Technical Development and Evaluation Center to study the Norfolk problem by use of the ATC simulator To obtain needed background, TDEC air-traffic-control specialists visited the Norfolk-area installations and the Washington ARTC Center prior to starting simulation tests

Specifically, the Norfolk simulation tests were directed towards the development of a traffic-control system having the following characteristics

1 The system should permit a high rate of traffic flow in and out of the five major airports

2 The system should permit adequate letdown and climbout procedures for jet aircraft using Langley Air Force Base and Oceana Naval Auxiliary Air Station

3 Because of budget and frequency-allocation problems, the system should require a minimum number of additional low-frequency radio facilities

4 The system should be so arranged that it requires a minimum amount of co-ordination between control positions and between control agencies

5 The system should provide definite sector jurisdiction in order to permit satisfactory division of the workload under heavy traffic conditions Under light traffic conditions, the system should be capable of operation with a fewer number of operating positions

6 The system should be designed for use with radar-vectoring techniques It should also be capable of functioning efficiently during periods when the radar is inoperative

7 Detailed operating procedures such as data posting and transfer, radio communications, and clearance procedures should be as simple as possible The flight-data system should be adaptable to the use of proposed automatic data-transfer equipment

EVALUATION METHODS

The Dynamic Air-Traffic-Control Simulator

Since some readers of this report may not be familiar with the dynamic air-traffic-control simulator at the Technical Development and Evaluation Center in Indianapolis, a brief description of this equipment follows Basically, the equipment provides means of simulating actual flights of aircraft through an area while control instructions are issued to "simulated" pilots by regular air traffic controllers Various air-traffic-control procedures and techniques can be tried and compared In addition, various arrangements of navigational aids can be tried and compared in order to determine which system provides the most efficient traffic flow

The results of the simulation tests depend, to a large degree, upon the accuracy of the equipment, the ability of the operators to follow instructions, and the degree of simulation of important characteristics of a system Since the present dynamic simulator is not complete in all of these necessary characteristics, the results of any simulation tests can be stated only in terms of relative evaluation between systems and not in absolute values However, a large part of the evaluation results can sometimes be obtained from observations made during the tests

The ATC simulator equipment includes a large screen upon which a map of an area is projected Controllable spots of light are also projected on this screen to indicate the position of aircraft in the system These spotlight projectors are controlled from pilot consoles, as shown in Fig 2

Each pilot can control the speed and the heading of one spot of light over the screen to correspond to the movement of an aircraft through the terminal area Standard-rate turns are made when the direction of target travel is changed The pilots also have simulated altimeters, and the spots of light descend and climb at normal rates for the type of aircraft being simulated The entire screen is televised and, through suitable electronic techniques, is presented to ATC controllers as a surveillance-radar display at the control positions, as shown in Fig 3 A number of interphone channels connect the pilots with the control positions to simulate normal radio channels An ARTC Center position is set up to simulate the co-ordination required between air-route control and terminal-area control If desired, the radar display can be turned off and control continued without it

In practice an area is first studied, and a map of the desired navigational system is photographed and prepared as a lantern slide This slide is projected on the screen to form the navigational layout for the problem A standardized problem is set up with each aircraft target entering the area on a definite schedule and route Actual arrival and departure times recorded during the simulation test are then compared to mathematically derived ideal times in order to determine aircraft delays These delay figures form a basis for comparing one system against another Similarly, the time spent in air/ground communications is measured so that one system can be compared with another to determine the relative efficiency of each one

Simulated Operating Procedures

In running the Norfolk simulation tests with radar procedures, five control positions were used These were

1 Terminal-area arrival control
2 North-sector radar control
3 South-sector radar control
4 Terminal-area departure control
5 Departure radar control

The terminal-area arrival controller worked at a standard ARTC flight-progress board on which were displayed flight data for the inbound traffic All aircraft entered the terminal

Fig 2 Typical Pilot Console and Spot Projector With Operator at Controls

Fig 3 Dynamic-Simulator Control Desk With Simulated Radar Displays of Traffic Situation (For Norfolk evaluation tests the central portion of the desk between the radar scopes was replaced by a standard 5-board ARTC sector-control desk Each of the three radar controllers was provided with a small flight-progress board)

area with standard nonradar separation, and these standards were maintained as long as the remained under terminal control The terminal-area arrival controller established communications contact with the arriving aircraft, issued clearance to the proper holding fix, and transferred control to the radar controllers at the designated transfer points

The radar arrival controllers established communications and radar contact with aircraft at the transfer points As soon as an aircraft was clear of the traffic lanes under terminal control, the flight-progress strip was transferred from the terminal-control position to the appropriate radar position Using standard radar separation, the radar controller directed aircraft along the most expeditious route to the approach fix and turned them into the final-approach path in the proper sequence Theoretically, as soon as the aircraft was in position to start a GCA or an ILS approach, control was transferred to the appropriate GCA unit or airport-traffic-control tower In performing these operations, the north-sector radar position handled all traffic en route to Patrick Henry, Langley, and Navy East airfields The south-sector radar position handled all traffic en route to Norfolk Municipal and Oceana Airports

The terminal-area departure controller worked at a standard ARTC flight-progress board on which were displayed flight data for the outbound traffic When departure clearance was requested (theoretically by one of the control towers) the terminal-area departure controller, using the rules which are described in the next section, issued initial clearance to the terminal-area outer clearance limit and prepared an abbreviated flight-progress strip for the departure radar controller This strip contained the following data

1 Aircraft identification
2 Departure airport (one-letter abbreviation)
3 Outer clearance limit (one-letter abbreviation)
4 Assigned altitude at outer clearance limit (in hundreds of feet)

This strip was carried in a sawed-off strip holder 2 1/4 inches in length When a special flight-progress board at the departure radar position was used, three rows of these strips could be posted in the space normally required for one row of standard flight-progress strips

The departure-radar controller established communications and radar contact with the departing aircraft and, using standard radar separation between aircraft, vectored the aircraft along the most expeditious paths to the proper departure routes As soon as an aircraft was established on course at the assigned altitude with nonradar separation from all other aircraft in the area, control was transferred back to the terminal-area departure controller, who had (theoretically) contacted Washington ARTC and had secured the necessary air-route clearance for delivery to the pilot

Shuttle flights between different airports in the terminal area were handled by the departure-radar controller, who furnished radar navigational guidance to the aircraft until it had reached the appropriate arrival path and was in the radar sector of the destination airport Control was then transferred directly to the radar-arrival controller, who fitted the aircraft into the proper landing sequence During light traffic conditions, control positions could be combined so that one man would handle as many as three positions

General Rules and Restrictions

It should be noted that the arrival tests took into account only the internal restrictions of the terminal area itself For example, the tests previously described were based on the hypothesis that the Washington Center could feed inbound aircraft into the Norfolk terminal area at a rate not less than 31 per hour

Departure tests took external restrictions into account by use of an arbitrary rule which permitted each available altitude at an outer clearance limit to be utilized only once in any 15-minute period The purpose of this rule was to allow time for co-ordination with Washington ARTC and for the holding of aircraft at the terminal-area outer clearance limits, if necessary, until Washington ARTC could accept this traffic into their area

In the simulation tests, co-ordination between control positions was reduced by reserving certain outer-fix altitudes for arrivals and other altitudes for departures Table I lists the altitudes which were normally available for departing aircraft at the terminal-area outer clearance limits Since the present svstem has no terminal-area outer clearance fixes, they are not listed in this table

In order to avoid placing too many departing aircraft under the jurisdiction of the radar controller at any one time, the following take-off restrictions were used

1 The interval between successive departures from any one airport was at least two minutes This enabled the departure controller to obtain positive radar identification of a departing aircraft before the next aircraft was off the ground

2 In applying the preceding rule, Navy East and Norfolk Municipal Airports were considered as a single airport This rule was necessary because of their proximity and because of the converging paths of departing aircraft when the instrument runways at these two airports were used for take-off operations

These two take-off restrictions reduced the number of departing aircraft under simultaneous radar control in the critical area northeast of Norfolk Municipal Airport They also assisted the departure-radar controller in the maintenance of positive identification of targets The rules did not unduly delay departing traffic at any time

Construction of the Traffic Sample for Simulation Tests

Actual flight-progress strips from a recent IFR day were obtained from the CAA control tower at Norfolk Municipal Airport These strips furnished a typical sequence of the following combinations of data

Aircraft Identification
Type
Departure Airport
Route
Destination Airport
Altitude (jet aircraft only)

Since these strips represented actual traffic during IFR weather conditions, the flow rate in operations per hour was necessarily very small In order to accelerate this flow to a rate

TABLE I

ALTITUDES RESERVED FOR DEPARTING AIRCRAFT IN SYSTEMS TESTED

Outer Clearance Limit	Altitudes Available for Departures System			
	Savedge (hundreds of feet MSL)	Yorktown (hundreds of feet MSL)	Combination (hundreds of feet MSL)	Berlin VOR (hundreds of feet MSL)
Charles City	25 45 65 85	All, provided Yorktown was crossed at 25, 45, 65, or 85	25 45 65 85	
Ruthville				25 45 65 85
Chincoteague	25 35 45	25 35 45	25 35 45	25 35 45
Corapeake	*	*	*	
Lake Drummond				*
Gwynn	All	All	All	
Sharps				All
Aydlette	All	All	All	All

*Required prior co-ordination with terminal-area arrival control

---

more suitable for test purposes, much shorter intervals between successive operations had to be used This was accomplished by adopting a set of random intervals from one of the traffic samples previously furnished by Franklin Institute

Use of the Franklin Institute random intervals provided the time at which each inbound aircraft was due to cross the outer circumference of the terminal area By means of a speed program, these "rim times" were projected ahead in order to determine the theoretical arrival time of each aircraft at the appropriate approach fix Four arbitrary classes of aircraft were used with speed programming as shown in Table II.

Delay Measurements

The basic problem data furnished the theoretical time that each inbound aircraft should be over the approach fix at final-approach altitude, if no other traffic were involved Through the use of an Esterline-Angus recorder, pilots recorded the actual arrival time of each aircraft over the appropriate approach fix By comparison of the theoretical arrival time with the actual arrival time, it was possible to determine the absolute delay to each inbound aircraft

For departures, the random intervals developed by the Franklin Institute comprised a list of proposed take-off times which enabled the departure delay to be determined for each aircraft

Communications Measurements

For inbound traffic, voice communications included pilot reports and all approach-control instructions necessary to bring each aircraft to a point where final approach could be taken over by a GCA controller or by a pilot using ILS facilities No weather reports were issued

TABLE II

CLASSIFICATION OF AIRCRAFT FOR SIMULATION

Aircraft Type	Cruising Speed (mph)	Intermediate Speed* (mph)	Approach Speed** (mph)
Slow	180	150	120
Medium	240	190	140
Fast	290	220	150
Jet	420	300	160

* In zone extending from ten miles to five miles from the approach fix
**In zone extending from five miles from the approach fix to touchdown

Exception Jet aircraft continued at cruising speed until reaching the approach fix at 20,000 feet, then conducted a letdown at the intermediate speed, and finally slowed to the approach speed for the last five miles of approach

---

For outbound traffic, communications included the en route clearance to the outer terminal fix and all necessary radar-vectoring instructions and altitude-vacating reports

The number of separate communications contacts on each channel was recorded through the use of electric counting devices The total live time of each channel was recorded by means of electric clocks

Types of Tests Conducted

Because of a shortage of simulator consoles, it was not possible to conduct simultaneous tests using all inbound and all outbound aircraft in the traffic samples Therefore, comparative tests of the different systems were made in the following manner

1 Arriving Aircraft Only In these tests, it was assumed that specific airspace areas were blocked for the exclusive use of departures This phase of the evaluation provided a means for studying the problem of co-ordination between the terminal-area controller and the radar arrival controllers During this phase, the average demand rate was approximately 31 arrivals per hour for the area

2 Departing Aircraft Only In these tests, it was assumed that specific airspace areas were blocked for the exclusive use of arrivals This phase of the evaluation provided means for studying the data-posting and clearance procedures for outbound traffic During this phase, the average demand rate was approximately 27 departures per hour

3 Combined Arrivals and Departures This phase used demand rates of 50 per cent of those used in the first two phases of the study Such demand rates were obtained by omitting every other aircraft in the previous arrival and departure samples This phase provided an opportunity to study the complete co-ordination problem between all arrival and departure control positions

4 North-Sector Arrivals Only This phase used an increased flow rate which was obtained by changing the destination airports of the original sample so that all aircraft landed at Patrick Henry, Langley, or Navy East fields This sample furnished an average demand rate of 31 arrivals per hour for these three airports Several potential bottlenecks which were not apparent in the previous tests were discovered in the systems

After many practice runs had been made to work out the many details of each system tested, the measurement tests were run Each of the comparative measurements listed in this report is the result of one run of the sample and of the system tested These runs were made under as nearly standard conditions as possible During these runs, motion pictures of the simulator flight tracks were made in order to give some idea of the resulting flow patterns and of the airspace required for the operation of the various systems Many of these tracks were plotted and are shown in Figs 8, 9, 13, 14, 15, 19, and 20 It is pointed out that the actual

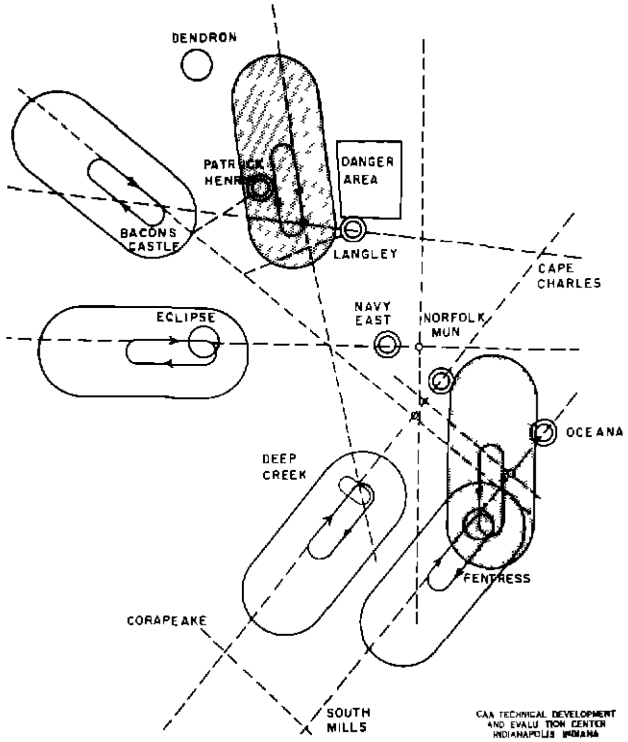


Fig 4 Holding Patterns of Present System (Shading Indicates High-Altitude Jet Patterns)

numbers used in the results are not absolute but are only relative in nature because of limitations in the simulation techniques used

SYSTEMS TEST AND RESULTS

Present System

A Navigational Aids

In order to establish a basis of comparison for evaluating possible improvements in the Norfolk traffic-control system, the present system of navigation facilities was tested first without radar, then with radar, procedures The layout of radio facilities and the holding patterns used with this system are shown in Fig 4

B Arrival-Control Procedures

Figure 5 shows the arrival routes used without radar In running the no-radar tests of this system, standard approach-control procedures with standard nonradar separation were used The terminal-area arrival controller maintained control of inbound aircraft until they reached the vicinity of the appropriate holding stack, at which time control was transferred to either (1) the north-sector approach controller for traffic inbound to Patrick Henry, Langley, or Navy East Fields, or (2) the south-sector approach controller for traffic inbound to Norfolk Municipal or Oceana Airports

Figure 6 illustrates the arrival routes used with radar A comparison with Fig 5 shows that the main differences are in the vicinity of Bacons Castle Aircraft inbound to Langley from the north were vectored away from the north course of Langley and brought to a lower altitude on a radar course to Bacons Castle, from which point they were fed into the final-approach course Congestion at the Langley Range Station was reduced by using plan-position-indicator (PPI) approaches from the southwest for aircraft en route to Patrick Henry Field

Current jet approach procedures were used at Langley Field with jets crossing the Langley range at 20,000 feet, proceeding two minutes north, descending on a heading of 330°, then making a left 180° turn to cross the Dendron marker at 1500 feet inbound to the GCA final-approach course

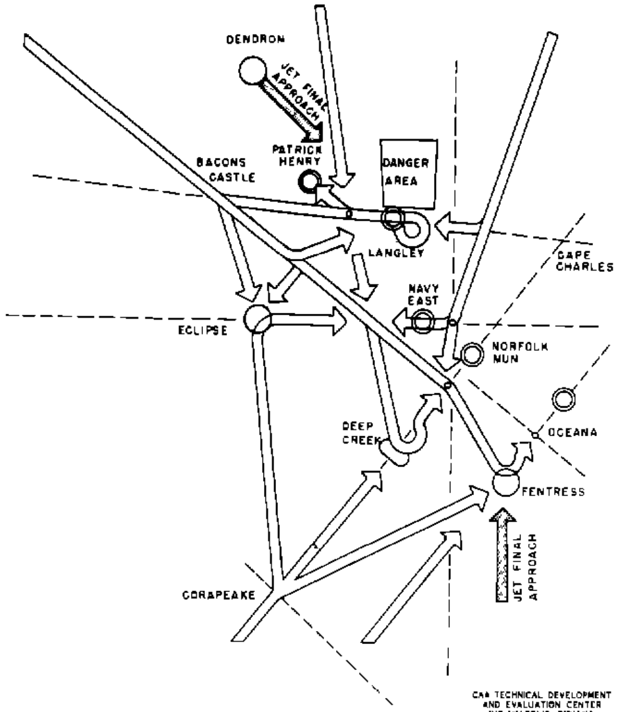


Fig 5 Arrival Routes, Present System Without Radar

Since no official jet letdown procedure for Oceana had been received, the following procedure was used Jet aircraft crossed Fentress outbound at 20,000 feet, started descent on a south heading, made a 180° right turn, and continued descent to cross Fentress inbound on final approach

Aircraft arriving from the north on Amber Airway 9 (from Chincoteague) were required to enter the area at 5500 feet or above to allow use of the lower altitudes for departing aircraft Aircraft arriving from the north on Blue Airway 56 (on the north course of Langley range) were required to enter the area at odd-plus-500-foot levels such as 3500, 5500, 7500, in order to permit departures to proceed via Red Airway 19 to Sharps Intersection at even-plus-500-foot altitude levels such as 2500, 4500, 6500

C Departure-Control Procedures

Departure routes are shown in Fig 7 Comparison with Figs 5 or 6 will indicate the main disadvantage of the present system, that is, departure routes conflict with arrival routes at many points

D Results

Delay and communications times are shown graphically in Fig 28 Recorded simulator flight paths are shown in Figs 8 and 9 Systems characteristics are listed in Table III

E Observations

1 The present system had the highest delays of any system tested The use of radar reduced delays somewhat by providing shorter flight paths and by eliminating the very inefficient Langley-range approach to Patrick Henry Field This time-consuming approach had restricted movement of traffic at both Patrick Henry and Langley airfields

2 The aircraft holding at Bacons Castle while awaiting approach to Langley or to Patrick Henry Fields restricted the flow of traffic on Green Airway 6 from Richmond to Navy East, Norfolk Municipal, and Oceana Airports Aircraft en route to the latter fields were required to stay at high altitudes in order to fly over this holding stack This condition resulted in additional delays due to the excessive descent time required

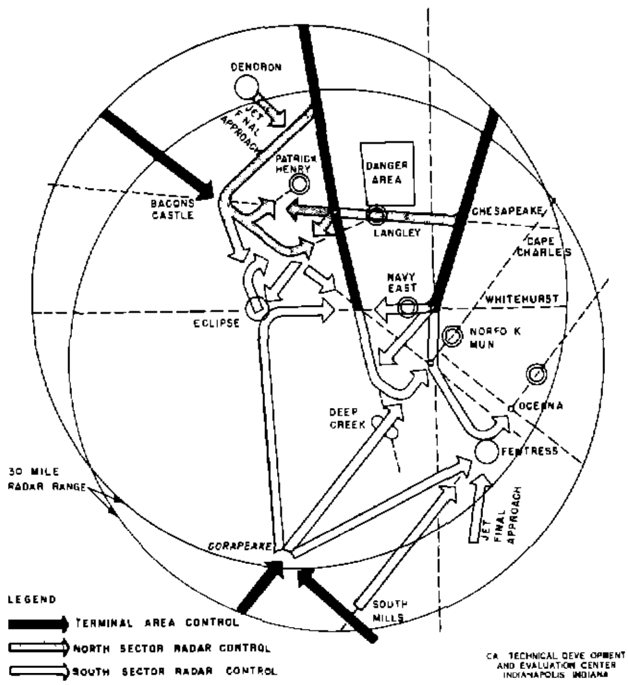


Fig 6 Present System With Radar Showing Main Arrival Routes, Desired Radar Coverage, and Division of Control

3 The confliction of arriving, holding, and departing traffic in the vicinity of Bacons Castle and Langley range produced a very confusing traffic situation and required a large amount of co-ordination between all control positions As a result communications were excessive, and the system had the highest workload of any system tested with radar

4 Lack of right-side separation on Amber Airway 9 between Norfolk and Chincoteague increased the workload of handling traffic on that route

The Savedge System

A Navigational Aids

In order to eliminate some of the bottlenecks which were found in tests of the present system, a new arrangement of navigational facilities was devised for simulation tests Known as the Savedge System this arrangement, which is shown in Fig 10, included the following changes

1 A low-frequency range was established near Savedge, Virginia This facility was designed to eliminate the confliction between traffic in the vicinity of Langley range and Bacons Castle by providing new inbound routes separated from the departure routes Blue Airway 56 was moved from the north course of Langley range and extended directly from the Tappahannock range to the Savedge range Green Airway 6 was moved to follow the northwest and southeast courses of the Savedge range This new range facility provided a "feeding-trough" for all five major airports in the terminal area

The southeast course of the Savedge range was aligned far enough southwest to permit traffic in the feeding trough to by-pass the holding patterns at Eclipse, Deep Creek, and Fentress By using nonstandard holding patterns at Eclipse and Deep Creek, ample clearance was provided

2 A homing facility was installed four miles southwest of Patrick Henry Airport, to serve as an outer locator for automatic-direction-finder (ADF) or ILS approaches to Runway 6

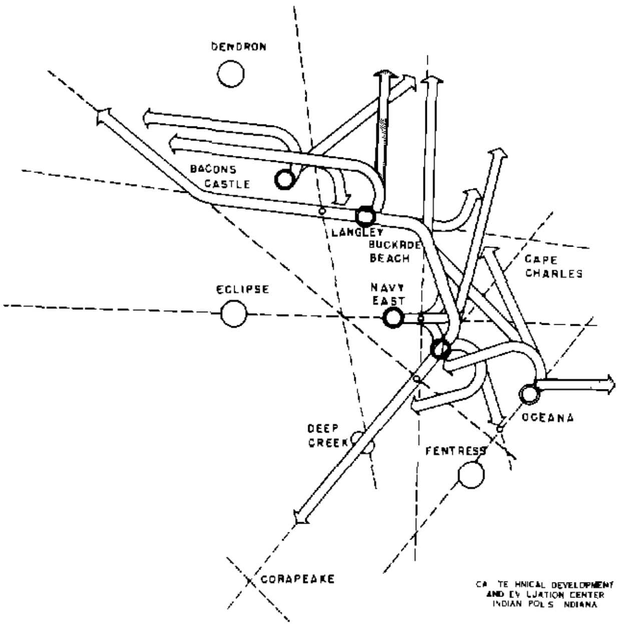


Fig 7 Present System, Departure Routes (Shaded Arrows Indicate Jet Climb-Out Paths)

3 Fan markers were established at Charles City and Gwynn to define these intersections better for use as terminal-area outer clearance limits by the terminal-area departure controller

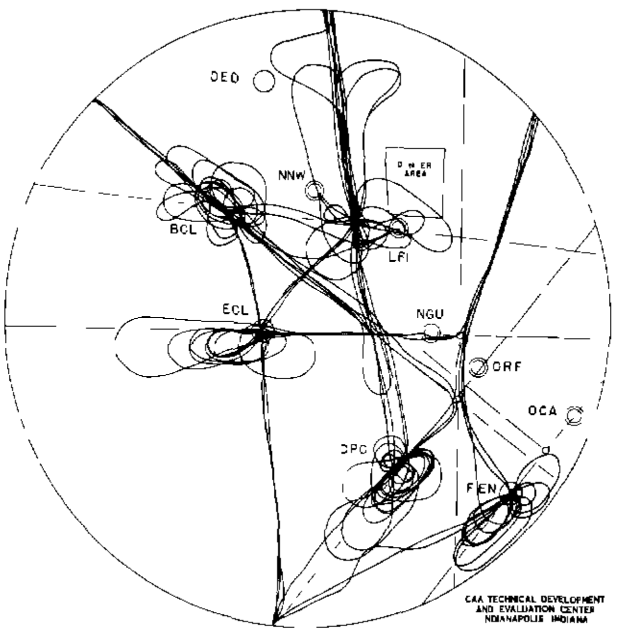


Fig 8 Recorded Simulator Flight Paths, Present Facilities Without Radar, Arrivals Only

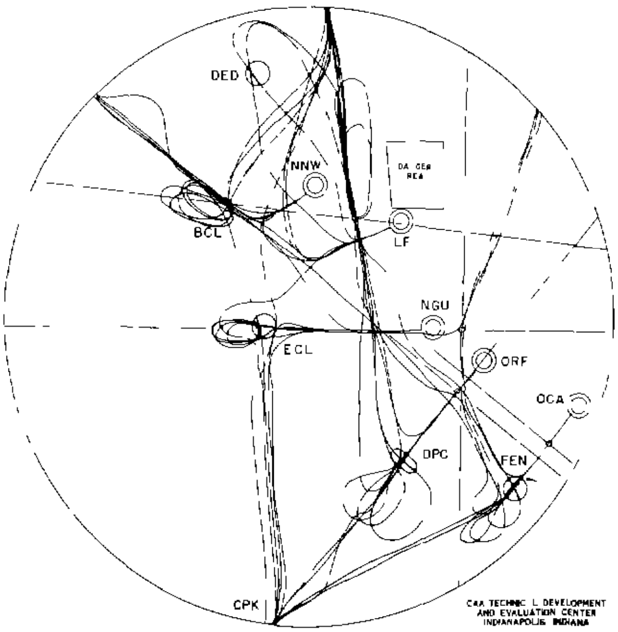


Fig 9 Recorded Simulator Flight Paths, Present Facilities With Radar, Arrivals Only

4 The south course of the Chincoteague range was realigned to the southwest directly toward the Navy Chambers range to provide a positive navigation course for aircraft with limited radio equipment This change also permitted right-side separation to be used for traffic on this airway

5 The southeast course of the Oceana range was moved clockwise and was directed toward the Aydlette fan marker, and the northwest course was moved to the reciprocal heading This provided two new routes for departing traffic

6 A homing facility was established at the Corapeake intersection, to provide a more positive navigational aid for traffic approaching the Norfolk area from the southwest and a terminal-area outer clearance fix for traffic departing in that direction

B Arrival-Control Procedures

Arrival routes are shown in Fig 11 Arrivals from Tappahannock were required to cross the Charles City intersection at odd-plus-500-foot altitude levels such as 3500, 5500, 7500 in order to permit departures to cross this fix at the even-plus-500-foot levels This change eliminated the need for co-ordination between the terminal-area arrival controller and the terminal-area departure controller for this intersection

Along the feeding trough from Savedge to Corapeake, all altitude levels were available for arriving aircraft

Arrivals from Chincoteague on Amber Airway 9 were usually restricted to 5500 feet and above until reaching the Navy East range, in order to permit use of the lower levels for departures

The Bacons Castle holding pattern was discontinued in order to eliminate confliction between holding aircraft and departing aircraft in the vicinity of Langley range and Bacons Castle The Eclipse pattern served as the feeding stack for all three airports in the north radar sector

Jet-approach procedures were unchanged from those previously described for the present system

C Departure-Control Procedures

Departure routes are shown in Fig 12 The terminal outer-clearance fixes at Charles City, Gwynn, Chincoteague, Aydlette, and Corapeake were used for initial departure clearance

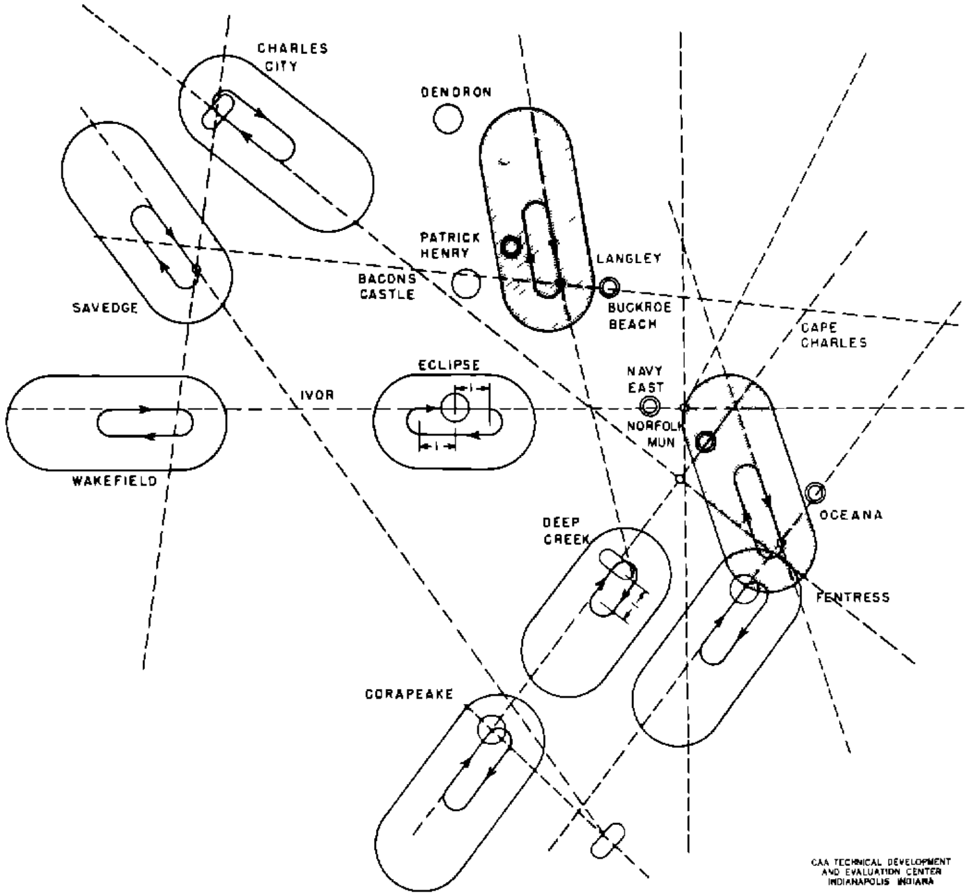


Fig 10 Holding Patterns of Savedge System (Shading Indicates High-Altitude Jet Patterns)

limits, to start aircraft on their flight without prior clearance from the Washington ARTC Center

Departures en route to Charles City crossed Langley range and Bacons Castle at or above 2500 feet, to allow the use of the 1500-foot level for landings and take-offs at Langley and Patrick Henry Airports

D Results

Delays and communications times are shown graphically in Fig 28, and system characteristics are listed in Table III Recorded simulator flight paths for arrivals are shown in Figs 13 and 14, whereas recorded departure paths are shown in Fig 15

E Observations

The general elimination of points of confliction between arrival, holding, and departure routes reduced delays and communications times Controller workload was reduced and safety was increased by the provision of a simplified traffic flow and of clean-cut jurisdiction between the various control positions

Inasmuch as nearly all radar arrival and departure routes closely coincided with established radio-range or ADF courses, the system continued to function very well in tests made without the use of radar The use of terminal-area outer-clearance limits produced a very efficient method of handling departures

The use of a single stack at Eclipse for aircraft destined for Patrick Henry, Langley, and Navy East fields functioned very well in light to moderate traffic As traffic increased to

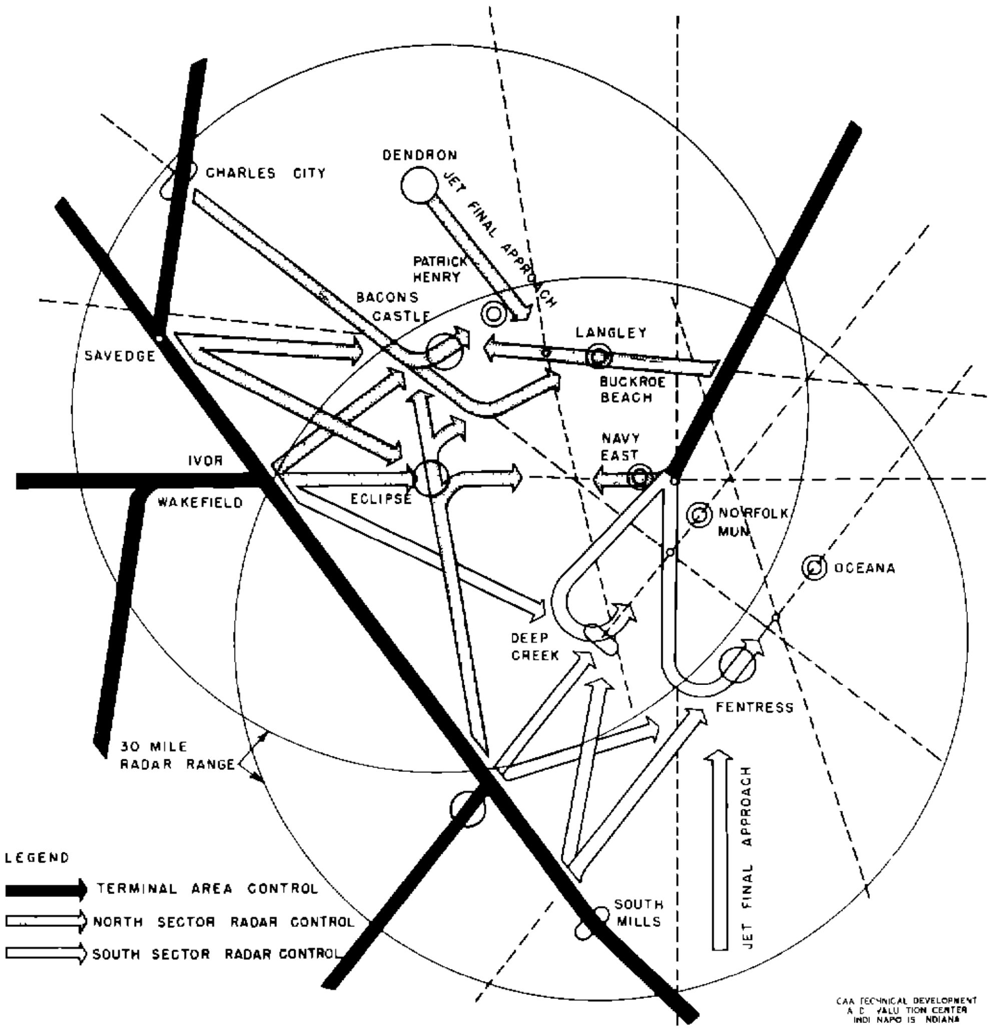


Fig 11 Savedge System Showing Main Arrival Routes, Desired Radar Coverage, and Division of Control

a high demand rate, the entry altitudes of aircraft cleared to this fix became quite high and excessive delays were created

Because the feeding trough had to be located far enough west of the airport area to by-pass the holding patterns, route mileages in this system were longer for aircraft arriving from Richmond and Tappahannock

The north and south courses of the Savedge range provided, for over flights, a by-pass airway from Tappahannock, Virginia, to Kelford, North Carolina It is believed that this by-pass would prove beneficial in relieving the congestion on Amber Airway 7 near Richmond, Virginia

The Yorktown System

A Navigational Aids

The Savedge System had functioned very well in its primary purpose of separating arrival and departure routes, but it required one new low-frequency range Inasmuch as it is the policy to avoid the installation of any new low-frequency range stations, if possible, the

TABLE III

SUMMARY OF SYSTEM CHARACTERISTICS

System	Co-ordination Workload With Radar	Adaptability for Nonradar Operations		Probable Radar Coverage With ASR-2 Equipment	Changes and Additions Required in Air Navigation Facilities
		Arrivals	Departures		
Present	High	Poor	Poor	Good	No changes
Savedge	Moderate	Fair	Good	Good	1 l-f range, 2 H-markers, 2 fan markers Realign southwest course of Chincoteague range, realign southeast and northwest courses of Oceana range
Yorktown	High	Poor	Good	Good	3 H-markers, 2 fan markers, realign south-west course of Chincoteague range, realign southeast and northwest courses of Oceana range, realign southeast course of Richmond range
Combination	Moderate	Good	Good	Good	Same as Savedge plus 1 additional fan marker, discontinue the Dendron H-marker, realign southeast course of Richmond range
Berlin	Low	Excellent	Good	Good	Discontinue 1-f ranges, 3 omniranges in area, 1 omnirange near Richmond, Va Relocate the Deep Creek fan marker, 1 H-marker

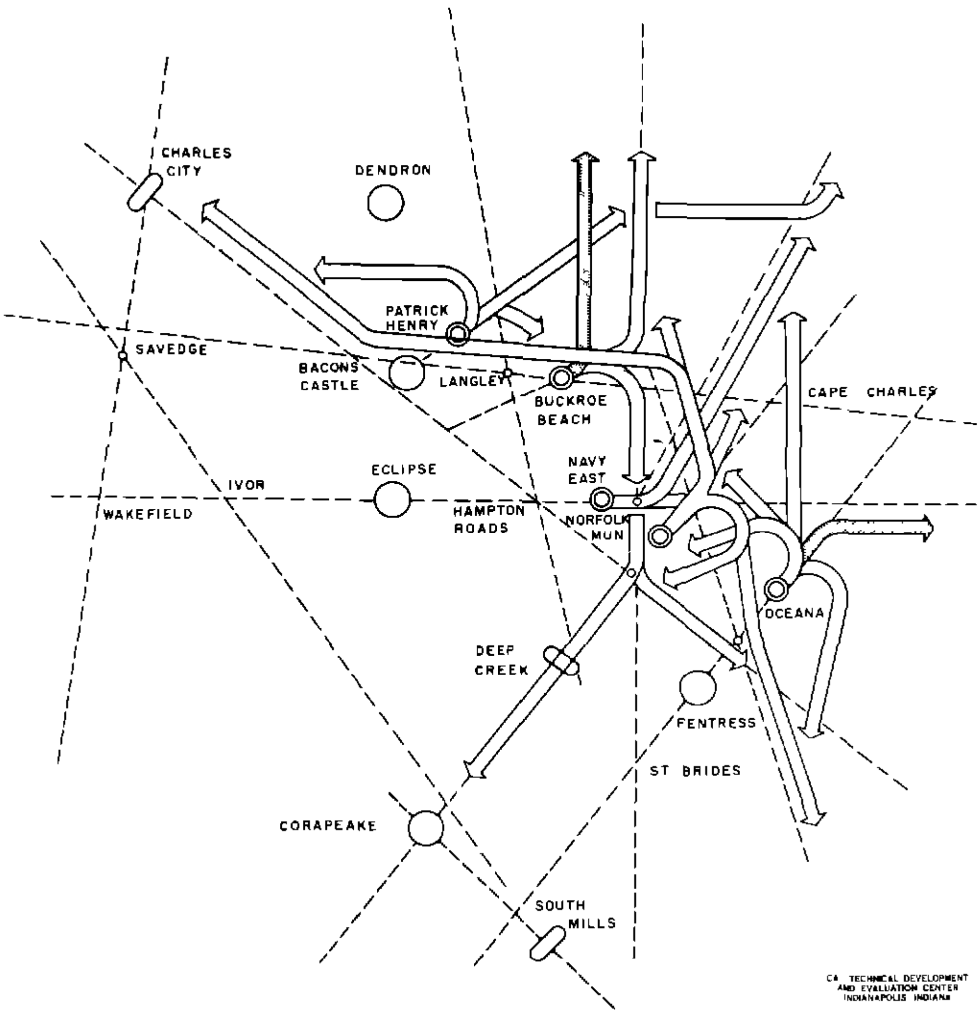


Fig 12 Savedge System, Departure Routes (Shaded Arrows Indicate Jet Climb-Out Paths)

possibility of providing the separate arrival and departure routes without the use of any new range facilities was investigated

It was decided to keep the arrival routes basically the same as in the present system but to provide a new route for departures This was accomplished by realigning the southeast course of the Richmond range counterclockwise to intersect the north course of the Navy East range at a point just north of the Plumtree danger area The realigned course crossed the north course of the Langley range in the vicinity of Yorktown, Virginia This system is illustrated in Fig 16

Because of the advantages indicated previously, the Oceana-Chincoteague range courses were realigned as shown in the Savedge System The Gwynn fan marker, as well as the Corapeake and Patrick Henry homing facilities, was retained and was used for the same purpose as in the Savedge System The Charles City fan marker was moved slightly to coincide with the realigned east course of the Richmond range

Since the north course of Langley range station was again used as an arrival route and since the new westbound departure route crossed it at Yorktown, the use of the present let-down area for Langley jet approaches was no longer practical To provide a straight-in jet

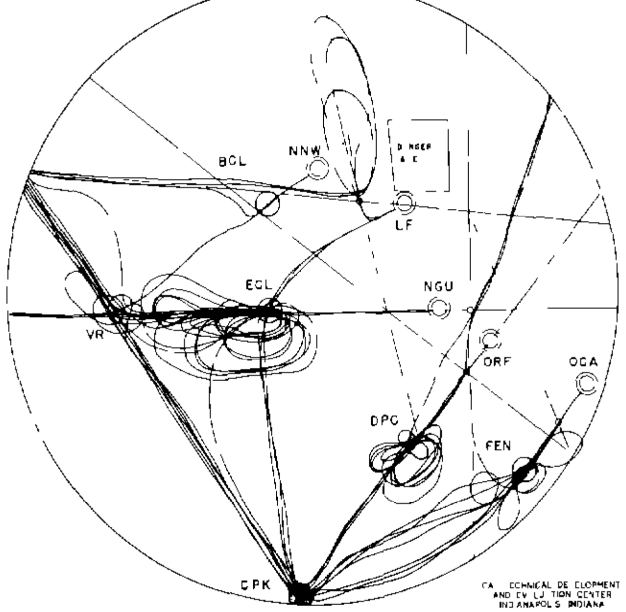


Fig 13 Recorded Simulator Flight Paths, Savedge System Without Radar, Arrivals Only

approach to Langley Field, the Dendron marker was removed and was relocated near Franklin, Virginia

B Arrival-Control Procedures

Arrival routes, radar coverage, and jurisdiction of control for the Yorktown System are shown in Fig 17

Arrivals from Richmond proceeded along the present Green Airway It was assumed that the northwest course of the Norfolk radio range would provide adequate coverage for this operation

Arrivals on Blue Airway 56 from Tappahannock were required to cross Yorktown at odd-plus-500-foot levels in order to provide separation from departures at this point Arrivals en route to Langley or Patrick Henry Airports were usually guided by radar on a direct course from Yorktown to Bacons Castle

Arrivals on Amber Airway 9 from Chincoteague were restricted to 5500 feet and above until reaching the Navy East range, in order to provide a clear channel for departures

Arrivals from the south or southwest proceeded via the Corapeake marker, which was installed primarily to aid this operation

Since the new north departure route took outbound traffic well clear of Bacons Castle, this intersection was again used for holding aircraft destined for Patrick Henry and Langley Airports, and because there was no longer a feeding trough to the west, standard two-minute holding patterns were used again at Eclipse and Deep Creek

Jet aircraft en route to Langley crossed Eclipse at 20,000 feet, began descent, and proceeded to the Franklin marker A procedure turn was made south of Franklin Such aircraft crossed Eclipse at 3500 feet on approach to Runway 7 at Langley Airport This procedure allowed the 2500-foot level to be used for a simultaneous approach to Navy East Field

In order to provide more room for the jet descent into Oceana, the jet approach path was started from the Oceana range instead of from the Fentress marker Descent was made on a south heading, with a 180° right turn to cross Fentress inbound on final approach

C Departure-Control Procedures

Departure routes are shown in Fig 18 Departures en route to Richmond proceeded via the north course of Navy East range or of Oceana range to the Mobjack Bay intersection, thence west on the east course of Richmond These aircraft were restricted to the even-plus-500-foot levels until three minutes past Yorktown West of this point, all altitudes were utilized

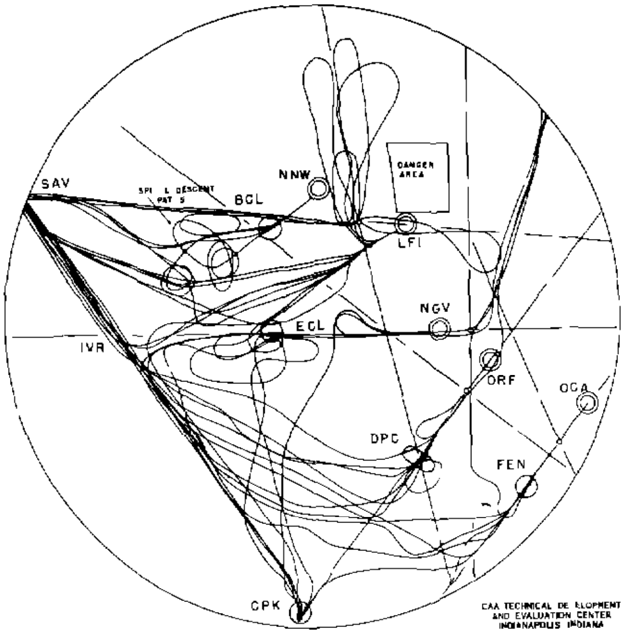


Fig 14 Recorded Simulator Flight Paths, Savedge System With Radar, Arrivals Only

Southbound departures were routed via the south course of the Oceana range to the Aydlette fan marker When traffic permitted, such aircraft could proceed directly out the southwest course of the Norfolk range over Corapeake

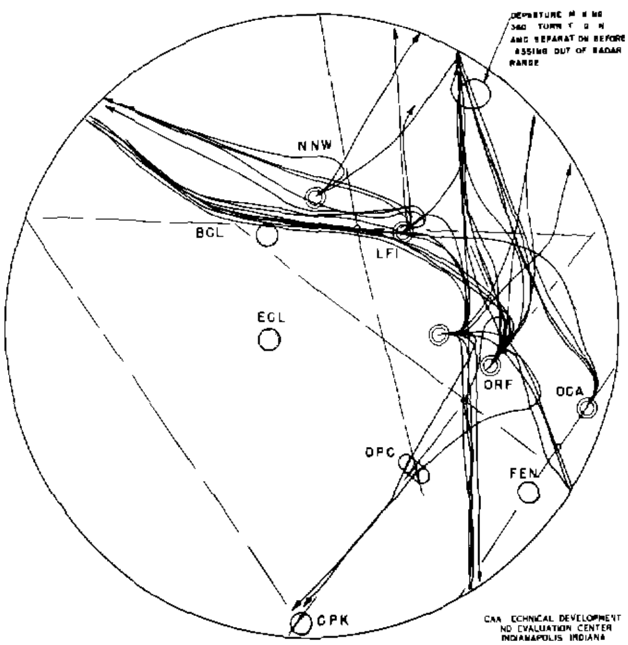


Fig 15 Recorded Simulator Flight Paths, Savedge System, Departures Only

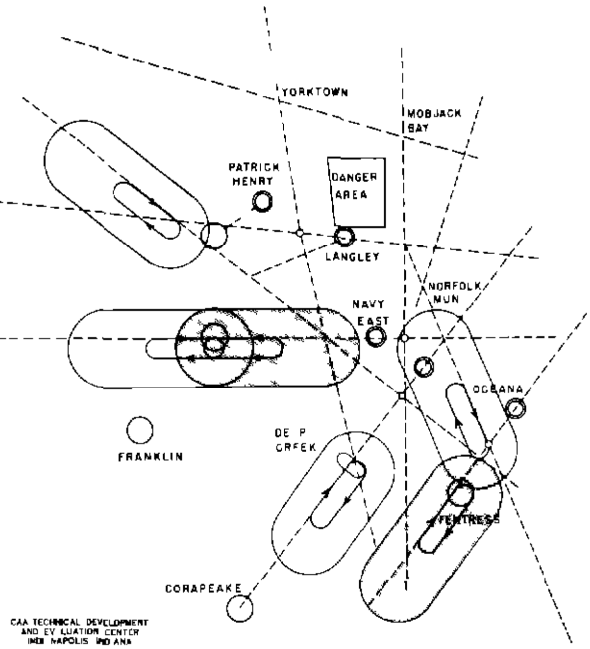


Fig 16 Holding Patterns For Yorktown System (Shading Indicates High-Altitude Jet Patterns)

Terminal-area departure outer-clearance limits used with this system were Charles City, Gwynn, Chincoteague, Aydlette, and Corapeake

D Results

Delays and communications times are shown graphically in Fig 28, systems characteristics are listed in Table III, and recorded arrival paths are shown in Fig 19 Recorded departure paths are shown in Fig 20

E Observations

Departure routes were excellent in this system By-passing of the Patrick Henry area by departing aircraft reduced the amount of co-ordination required between controllers

Addition of the Bacons Castle holding pattern for north-sector arrivals reduced the amount of traffic in the Eclipse stack and eliminated the high holding altitudes required in the Savedge System

Because arrivals on Green Airway 6 from Richmond to the south-sector airports had to cross over the holding stacks at Bacons Castle and Eclipse, traffic delays were caused by the time required for descent from higher altitudes

The Franklin jet-approach procedure did not work as well as had been expected Because the approach path for conventional aircraft from Bacons Castle to Langley was long, it was very difficult to co-ordinate jet approaches with conventional approaches to this airport As a result, a jet approach to Langley restricted approaches to both Patrick Henry and Langley Airports for several minutes if the bottom aircraft in the Bacons Castle stack was holding for a Langley approach Inasmuch as jet approaches had to cross through the Eclipse stack, operations into Navy East Field were interrupted if two jets made successive approaches across Eclipse For these reasons, the Franklin jet approach was unsatisfactory

The Combination System

A Navigational Aids

As a further refinement of the Savedge System, some of the advantageous features of the Yorktown System were applied to make up an arrangement known as the Combination System This arrangement, which is illustrated in Fig 21, included the following changes from the original Savedge arrangement

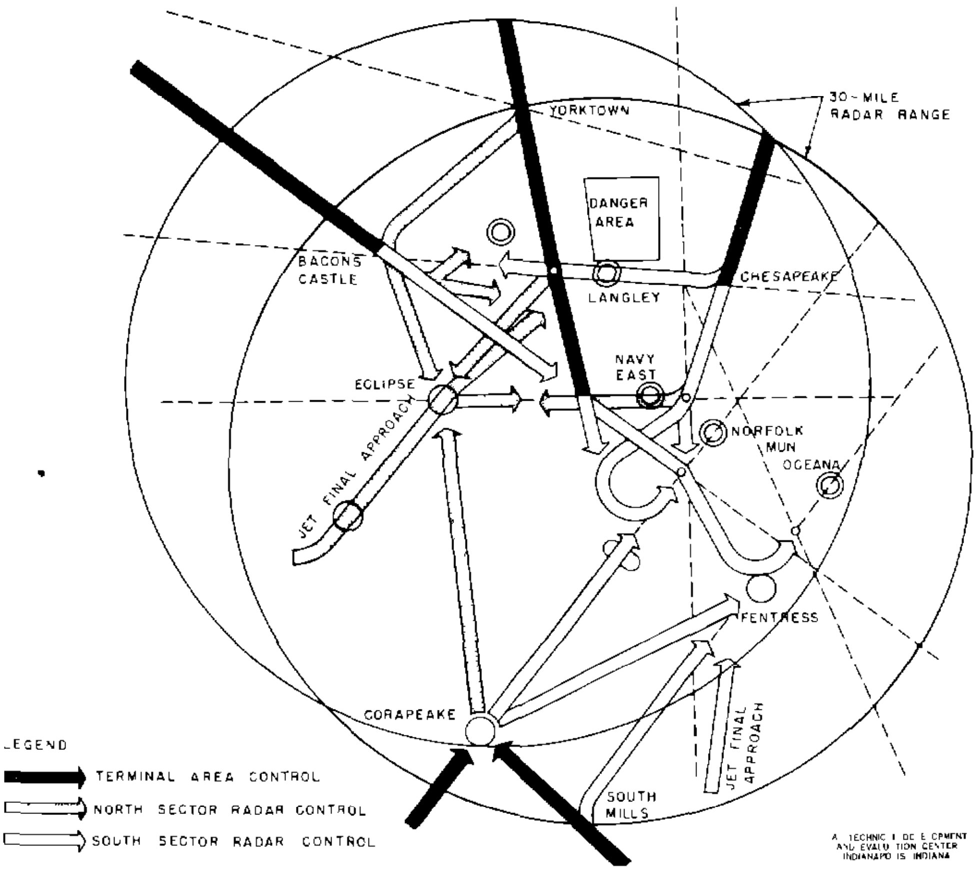


Fig 17 Yorktown System Showing Main Arrival Routes, Desired Radar Coverage, and Division of Control

1 The southeast course of the Richmond range was realigned directly toward the Langley range, enabling aircraft to by-pass Bacons Castle This repositioning permitted use of both the Bacons Castle and the Eclipse holding patterns and reduced high altitude holding at Eclipse

2 A fan marker was established at Yorktown for use as a starting point for jet approaches to Langley

B Arrival-Control Procedures

Arrival routes, radar coverage, and jurisdiction of control are illustrated in Fig 22 The arrival routes were basically similar to those of the Savedge System Holding patterns, shown in Fig 18, were the same as those used in the Savedge System with three exceptions (1) A holding pattern was added at Bacons Castle for arrivals destined for Langley and Patrick Henry Airports, (2) The Langley jet pattern was moved to Yorktown, and (3) The Oceana jet pattern was moved to the Oceana range, as in the Yorktown System

Inasmuch as the north course of the Langley range was no longer used for en route traffic, the Langley jet-approach procedure was changed as follows Jet aircraft held south of the Yorktown fan marker on the north course of the Langley range at 20,000 feet and above When these aircraft were cleared for an approach, they descended in this holding pattern to 16,000 feet and crossed Yorktown headed north After passing Yorktown, the descent was continued and a procedure turn was accomplished When the north course of the range was intercepted again, the aircraft headed south and crossed the Yorktown fan marker at 1500 feet

This procedure was designed to permit jet traffic to utilize as small an area as possible in making descent and to insure that such aircraft would be at 1500 feet when passing the Yorktown fan marker southbound

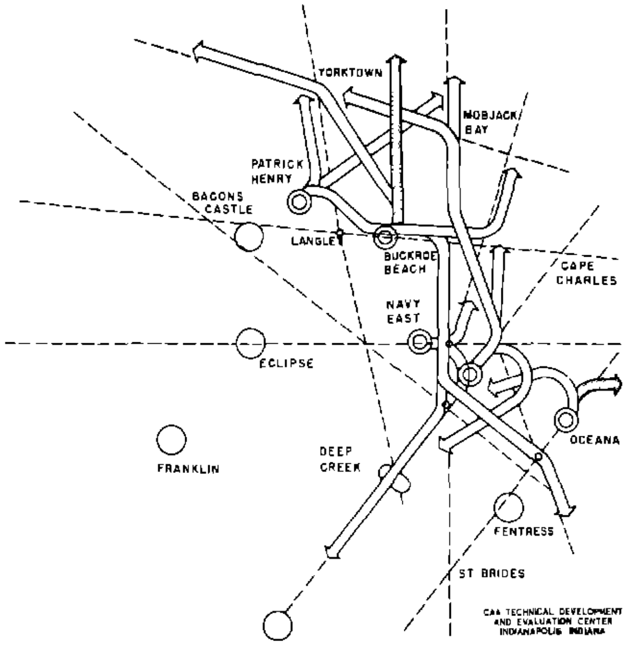


Fig 18 Yorktown System, Departure Routes (Shaded Arrows Indicate Jet Climb-Out Paths)

The Oceana jet-approach procedure was the same as that described in the Yorktown System

In order to provide separation from departures or from other conflicting traffic, arrivals were restricted to the following altitude levels from Tappahannock, 3500, 5500, and 7500 feet over Charles City, from Richmond, 2500, 4500, and 6500 feet over Savedge, from Chincoteague, 5500 feet and above

C Departure-Control Procedures

Departure routes are shown in Fig 23 Departure procedures were similar to those used with the Savedge System, except that the northwest departure route by-passed Bacons Castle and proceeded directly from the Langley range to Richmond

D Results

Delays and communications times are shown graphically in Fig 28 Systems characteristics are listed in Table III No arrival and departure paths were recorded, because the flow routes differed in only minor details from those of the original Savedge System

E Observations

This system had all the advantages of the original Savedge System, plus the following

1 The north-sector controller had two holding stacks, instead of one, for conventional aircraft This feature served to make operations into Patrick Henry and Langley Airports more independent of operations into Navy East Field It was also possible to keep holding aircraft at lower levels and thus to minimize delays due to descent time

2 The more direct northwest departure route reduced the workload somewhat by getting departing aircraft on course more rapidly

3 As in the Yorktown System the Oceana jet approach, starting from the Oceana range, allowed more space for descent As in the Savedge System, the arrival routes were longer in some cases than the corresponding routes of the present and Yorktown Systems

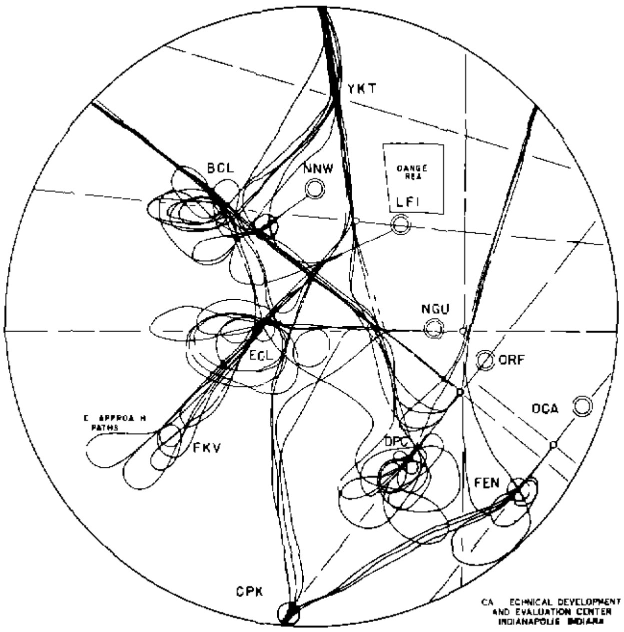


Fig 19 Recorded Simulator Flight Paths, Yorktown System With Radar, Arrivals Only

Berlin VOR System

A Navigational Aids

In order to investigate future operations based on VHF navigational aids, an arrangement known as the Berlin VHF omnirange (VOR) system was tested This system was built around three VHF omniranges which furnished an almost infinite number of possible routes In order to control the traffic and to restrict the number of possible conflicting points, only a relatively few courses were actually used in the simulation tests of the system Figure 25 shows the radial courses which were primarily in use The Berlin VOR system included the following arrangement of simulated facilities

1 VHF omniranges were established at Berlin, Virginia, at the present site of the Oceana range, and three miles east of the present Eclipse marker

2 Complete ILS facilities were established at Patrick Henry

3 A homing facility was established at Morrison, four miles southwest of Langley

4 Fan markers were established at Sharps, Lake Drummond, and Ruthville

5 The former Deep Creek fan marker was moved northeast to Portsmouth in order to place the Norfolk Municipal Airport holding pattern closer to the airport This, in turn, enabled the southwest feeding trough to be moved eastward, shortening the arrival routes

B Arrival-Control Procedures

Arrival routes, jurisdiction of control, and recommended radar coverage are shown in Fig 26 The general arrangement of traffic flow resembled that of the Combination System in most respects However, the Berlin VOR system included two significant improvements

1 Langley jet approaches started from the Berlin VOR and made a straight-in letdown on a radial course to Runway 7 at Langley This very simple procedure enabled jet pilots to have continuous navigational guidance and an unrestricted descent path all the way to the airport It also enabled such approaches to be conducted without interfering with operations at either Patrick Henry or Navy East Airports

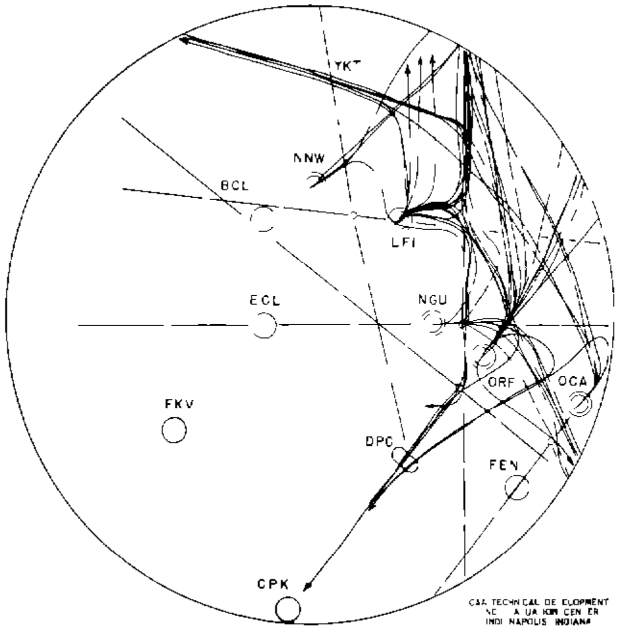


Fig 20 Recorded Simulator Flight Paths, Yorktown System With Radar, Departures Only

2 When traffic permitted, aircraft en route from Tappahannock to Norfolk Municipal or Oceana Airports could use an inner passage from Spring Grove directly to Portsmouth This direct route shortened arrival paths by as much as 20 miles However during periods when jet aircraft were on approach from Berlin or when the holding stack at Eclipse built up to high altitude levels, this inner passage was not used and aircraft were routed around the feeding trough via Berlin

In order to provide separation from departures or from other conflicting traffic, arrivals were restricted to the following altitude levels from Tappahannock, 3500, 5500, and 7500 feet over Ruthville, from Richmond, 2500, 4500, and 6500 feet over Berlin, from Elizabeth City, 3500, 5500, and 7500 feet over Lake Drummond, from Raleigh, 2500, 4500, and 6500 feet over Lake Drummond, from Chincoteague, from 5500 feet and above

C Departure-Control Procedures

Departure routes are shown in Fig 27 Terminal-area outer clearance fixes at Ruthville, Sharps, Chincoteague, Aydlette, and Lake Drummond were used for initial departure clearance limits in order to start aircraft on their flight without prior clearance from the Washington ARTC Center

The arrangement of departure-traffic routes was similar to that of the Yorktown System in that the route to Richmond extended well north of the airport area

D Results

Delay and communications times are shown graphically in Fig 28, and system characteristics are listed in Table III

E Observations

The system furnished continuous VHF navigation courses on nearly all routes This feature simplified control procedures and reduced controller workload by minimizing the need for radar navigational guidance Since the pilots did most of their own navigation, radar was used primarily to monitor the traffic flow Failure of the radar equipment would have a minimum effect on traffic operations

Even though only a small proportion of the total possible routes were used, the system was extremely flexible and delays were the lowest that occurred in all the systems tested

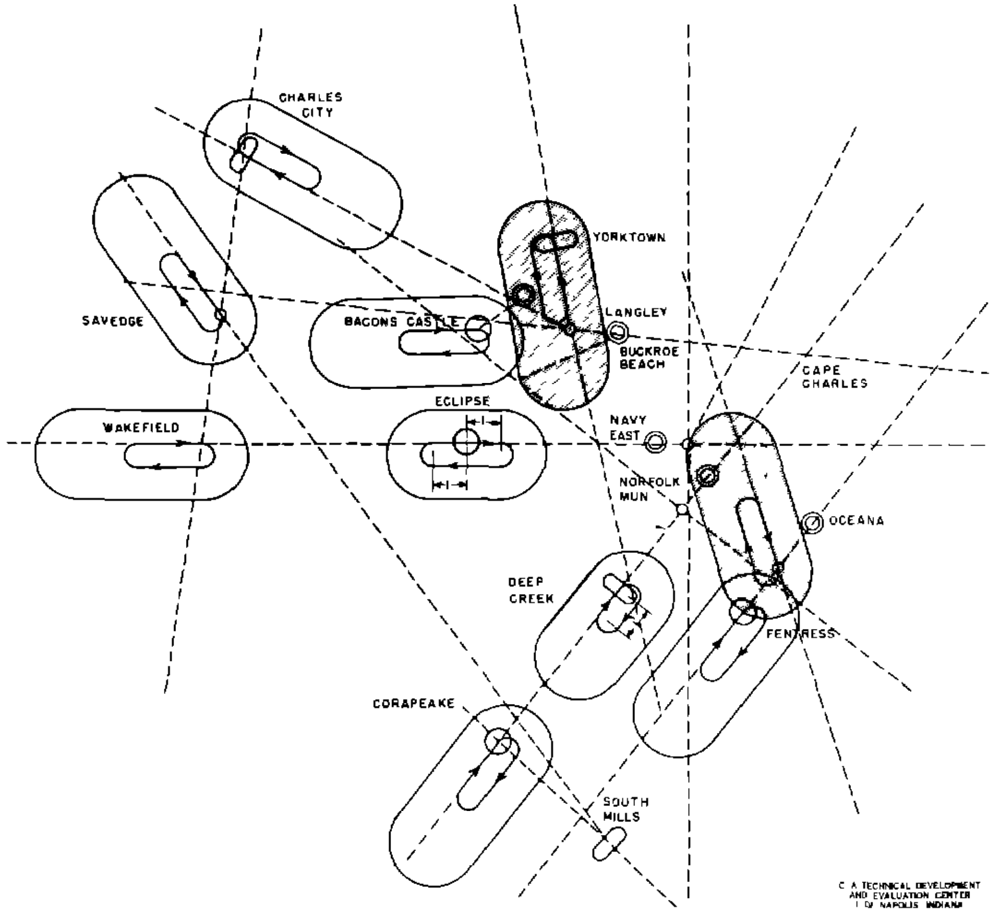


Fig 21 Holding Patterns, Combination System (Shading Indicates High-Altitude Jet Patterns)

One of the most important factors in the reduction of delay times was the use of the short-cut inner passage from Spring Grove direct to Portsmouth

The straight-in jet letdown path to Langley Field functioned very efficiently For the first time during the simulation tests, Langley jet approaches did not interrupt traffic operations at either Patrick Henry or Navy East Fields The location of the Jamestown holding pattern in relation to the jet letdown path made it relatively easy to co-ordinate conventional aircraft with jet aircraft in the Langley approach sequence

It should be emphasized that the Berlin VOR System was the only omnirange system tested and for this reason should be regarded as only one of many possibilities It is believed that a further study of omnirange traffic systems should be made before adopting any omnirange system for the Norfolk terminal area

F Notes on Control Equipment

Four possible arrangements of control equipment to handle Norfolk terminal-area traffic operations are shown in Figs 29, 30, 31, and 32 In designing these arrangements, consideration was given to two factors which the simulation tests had shown to be important

1 Co-ordination between related positions of operation should be accomplished easily
2 Equipment should be so arranged that control positions can be combined easily during periods of low traffic density

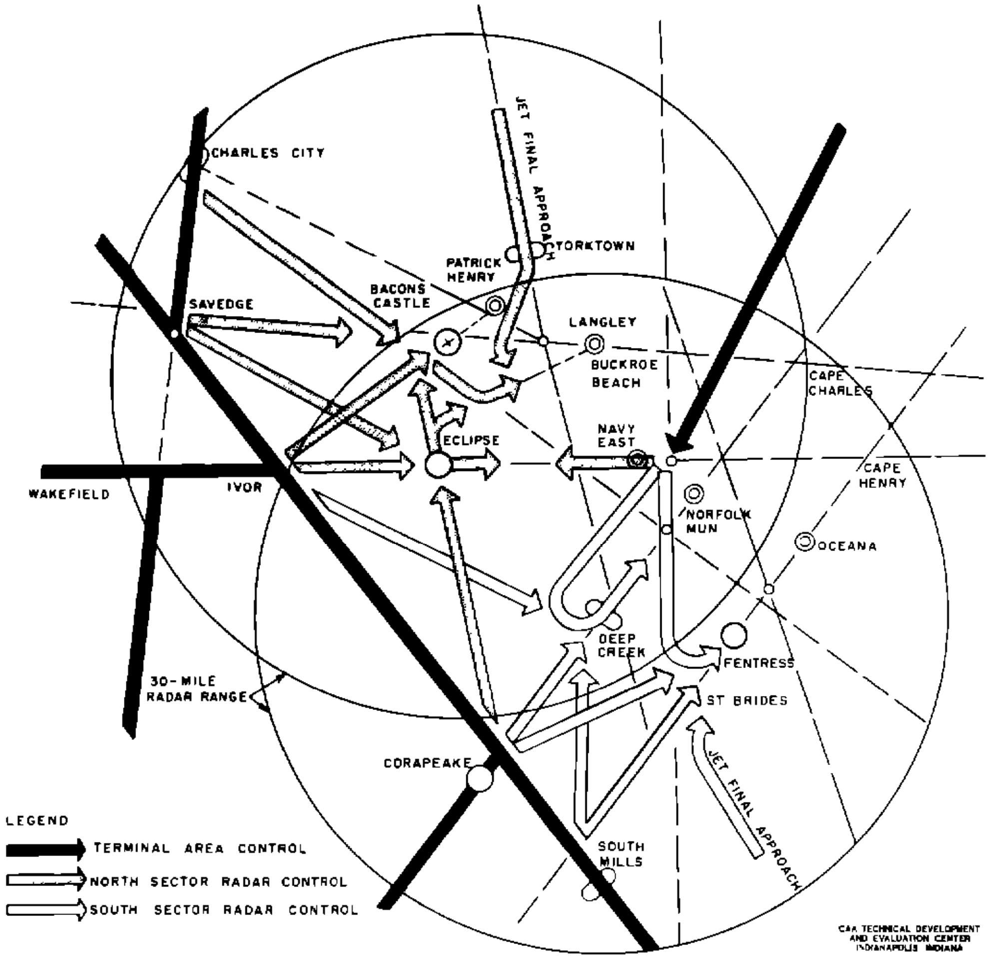


Fig 22 Combination System Showing Main Arrival Routes, Desired Radar Coverage, and Division of Control

Figure 29 shows a semicircular arrangement which permits ready co-ordination between control positions Figure 30 shows essentially the same relationship of control positions, except that positions are arranged in a straight line to reduce external light reflections in the radar scopes

Figure 31 shows the arrival and departure positions separated Co-ordination between the terminal-area arrival and terminal-area departure controllers can be accomplished by the controllers turning around An additional flight-progress board would be required with this arrangement of equipment

Figure 32 shows a layout utilizing a horizontal plotting scope The terminal-area arrival controller may experience some difficulty in passing flight data to the radar controllers unless automatic data transfer is used Co-ordination between radar positions would be excellent, and such positions could be easily combined when necessary

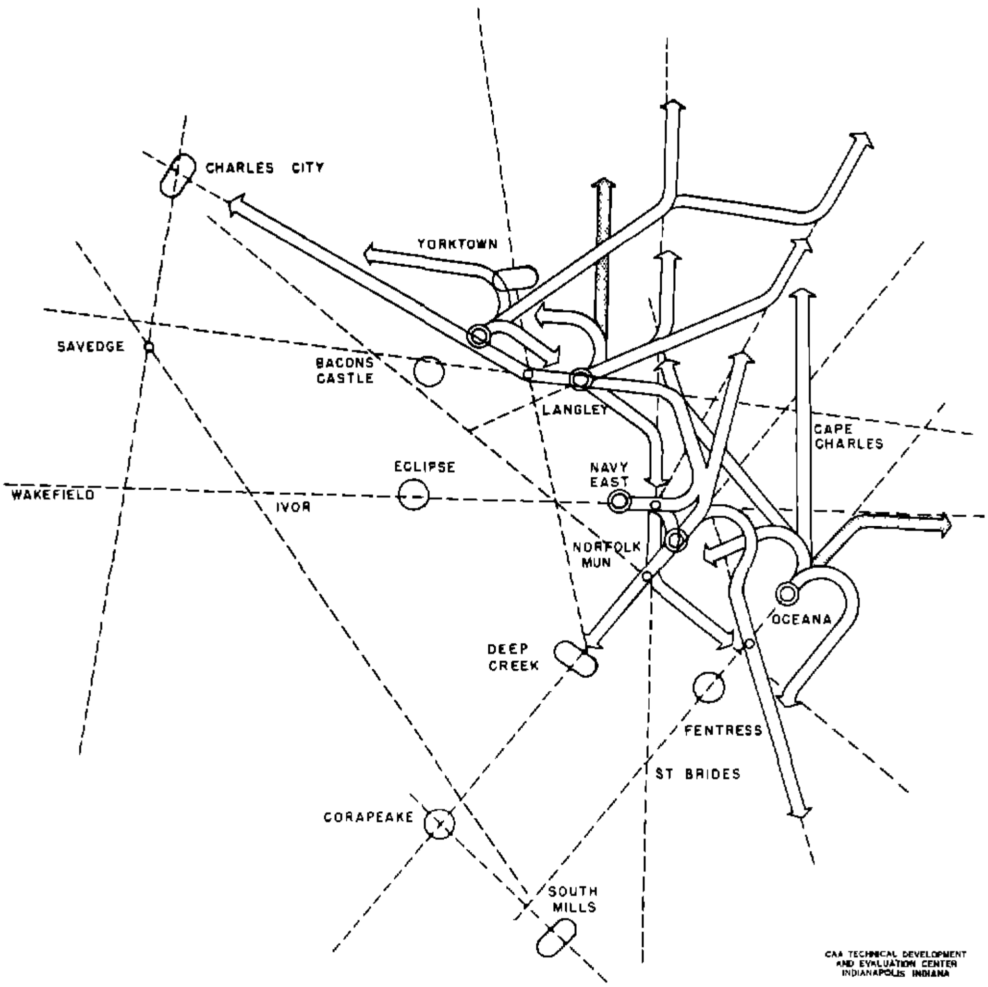


Fig 23 Departure Routes, Combination System (Shaded Arrows Indicate Jet Climb-Out Paths)

CONCLUSIONS

1 Simulation tests indicate that the acceptance rate of the Norfolk terminal area can be increased substantially by the use of radar-control procedures However, unless certain changes are made in the arrangement of navigation facilities in this area, the system will be relatively difficult to operate

2 Controller workload can be substantially reduced with further increases in safety and in traffic acceptance rates, if the navigational facilities are rearranged to (1) provide lateral separation between inbound and outbound routes and (2) provide by-pass routes around holding patterns

3 With the type of system described in paragraph 2 of this section, departure delays can be reduced greatly by the provision of adequate terminal-area departure clearance fixes at strategic points near the perimeter of the terminal area The use of these fixes as departure clearance limits would permit departures to take off without prior clearance from the Washington ARTC Center These flights could then be assimilated into the Washington ARTC area more easily from these holding points close to the heavily travelled airways

4 The configuration of navigational aids described in this report as the Combination System embodied the improvements described in paragraphs 1, 2, and 3 and was the best of the low-frequency systems tested

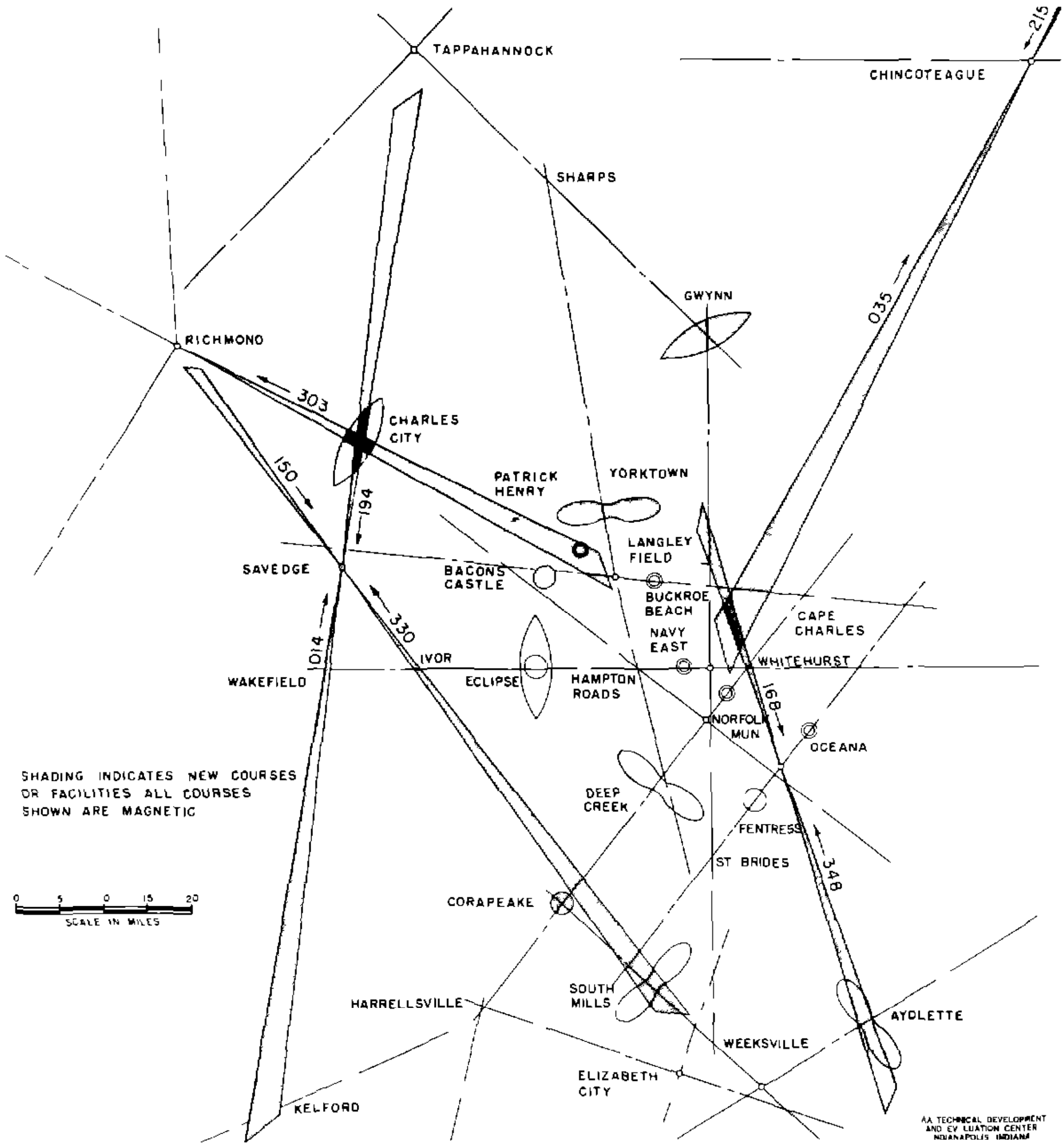


Fig 24 Recommended Changes in Air Navigation Facilities to Implement Combination System

5 The inherent flexibility of navigational aid arrangements based on the use of VHF omniranges promises even greater gains in acceptance rates and in simplicity of control procedures The Berlin VOR System described in this report has potentially the highest acceptance rate of all the systems tested However, it was the only omnirange layout tested during this study, and it is quite possible that further study would develop an even better system

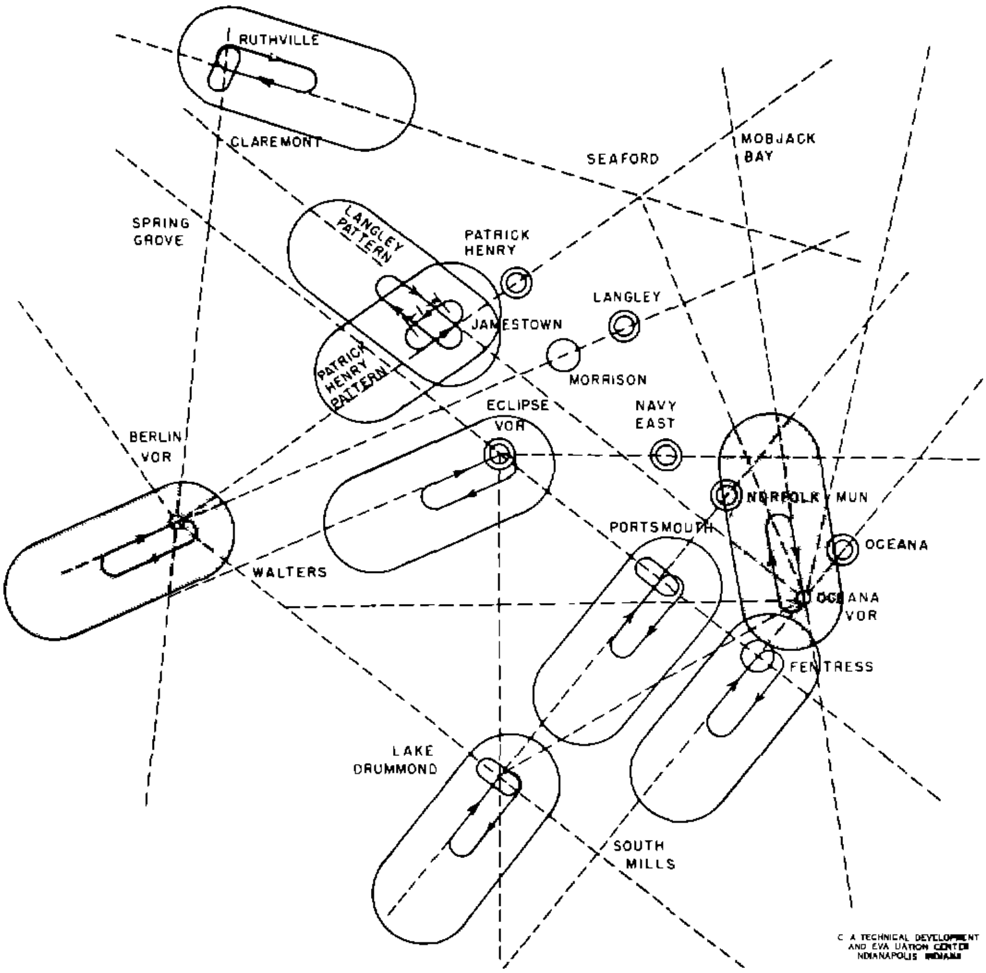


Fig 25 Holding Patterns of Berlin VOR System (Shading Indicates High-Altitude Jet Pattern)

RECOMMENDATIONS

Based on the simulation studies made for the Norfolk terminal area, the following recommendations are made

1 Radar-control procedures should be implemented in the Norfolk terminal area at the earliest practicable date

2 The layout of navigational aids should be modified in order to develop the Combination System described in this report, Fig 24 In the event that it is impossible to procure another low-frequency range for installation at Savedge, consideration should be given to the relocation of the Norfolk range to serve this purpose Reference to Figs 22 and 23 will show that in the Combination System the Norfolk range is used only to provide a range-approach procedure at Norfolk Municipal Airport and to provide guidance from Charles City to Bacons Castle Since Norfolk Municipal Airport has facilities for ILS, ADF, and radar approach procedures and since right-side separation could be utilized between Charles City and the Langley range, it is believed that the Norfolk range station would serve a more useful role if it were installed at Savedge This relocation is recommended if budget and frequency-allocation problems would otherwise prevent installation of an entirely new range facility at Savedge

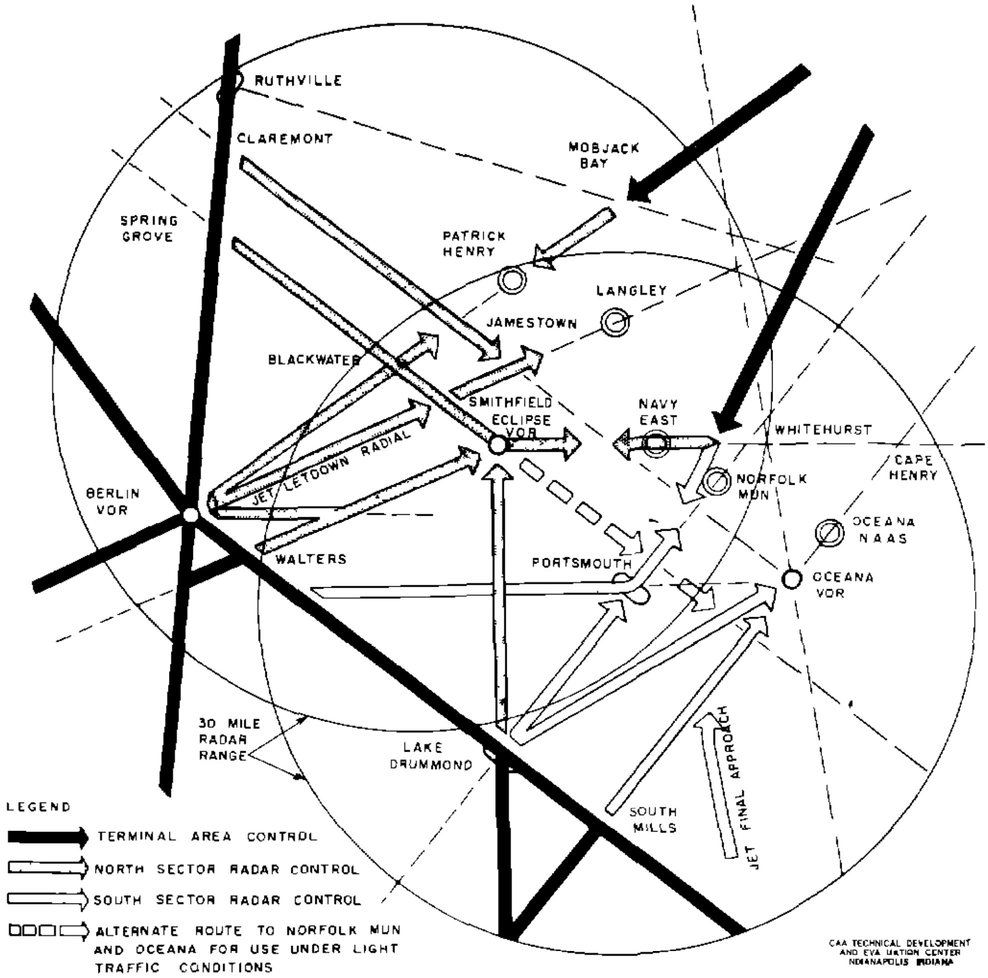


Fig 26 Berlin VOR System Showing Main Arrival Routes, Desired Radar Coverage, and Division of Control

3 Surveillance radar and communications facilities should be installed in a suitable control room, preferably in the Administration Building of the Norfolk Municipal Airport The control room should have adequate space and communication facilities for seven positions of operation and should not require controllers to work under radar tents

4 Depending on the shape of the control room and the type of radar equipment used, it is believed that any of the control equipment layouts described in this report will operate satisfactorily If ASR-2 radar equipment is used, the equipment arrangements shown in Figs 29 or 30 are believed to be preferable to that shown in Fig 31

5 In order to avoid later technical and operational difficulties, it is recommended that any repeater radars procured for use with the ASR-2 equipment should have a synchro system which is compatible with the ASR-2 synchro and is capable of following the high rotational scan rate

6 The traffic-control systems described in this report were predicated on the use of ASR-2 radar If service tests show that this radar does not give adequate range and altitude coverage, immediate consideration should be given to the use of radar information from Air Defense radar installations in the area

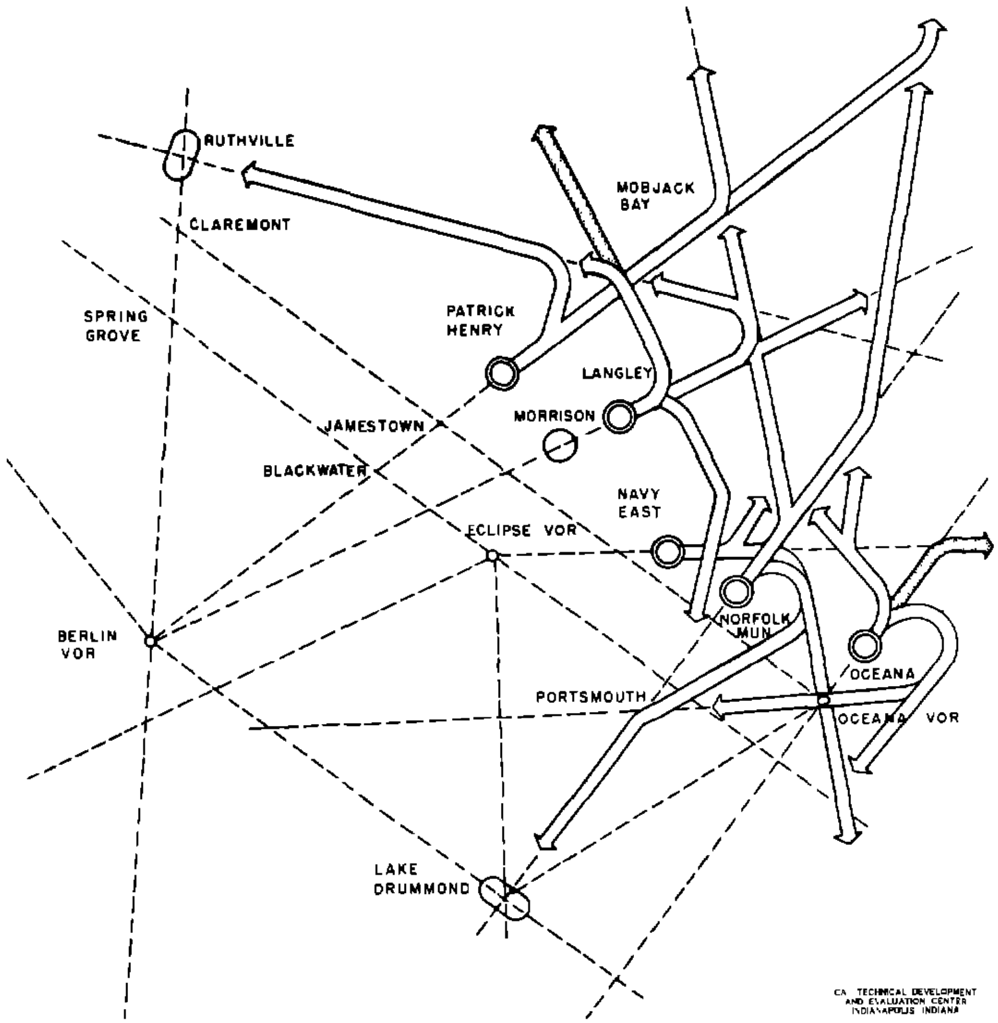


Fig 27 Departure Routes, Berlin VOR System (Shaded Arrows Indicate Jet Climb-Out Paths)

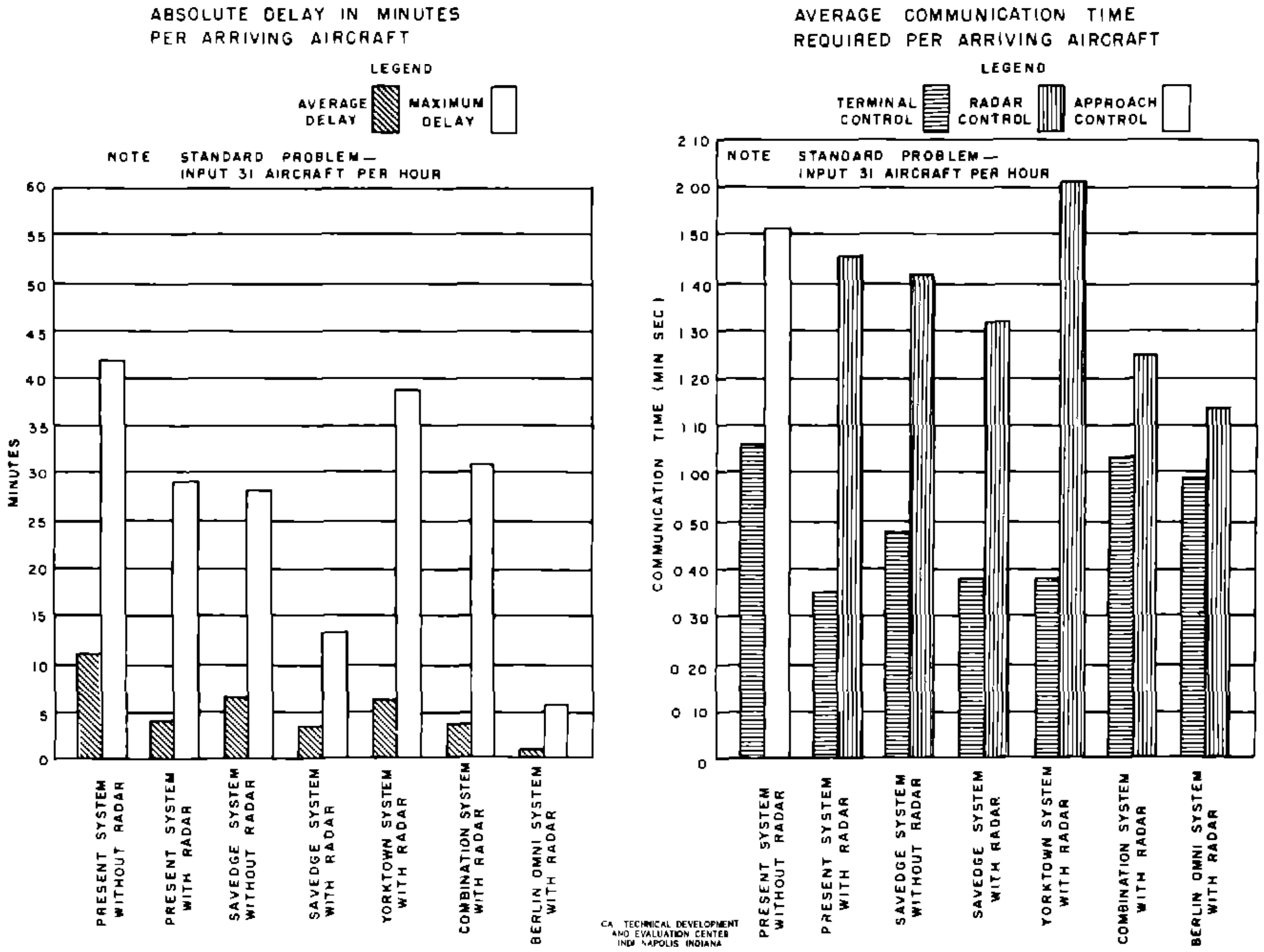
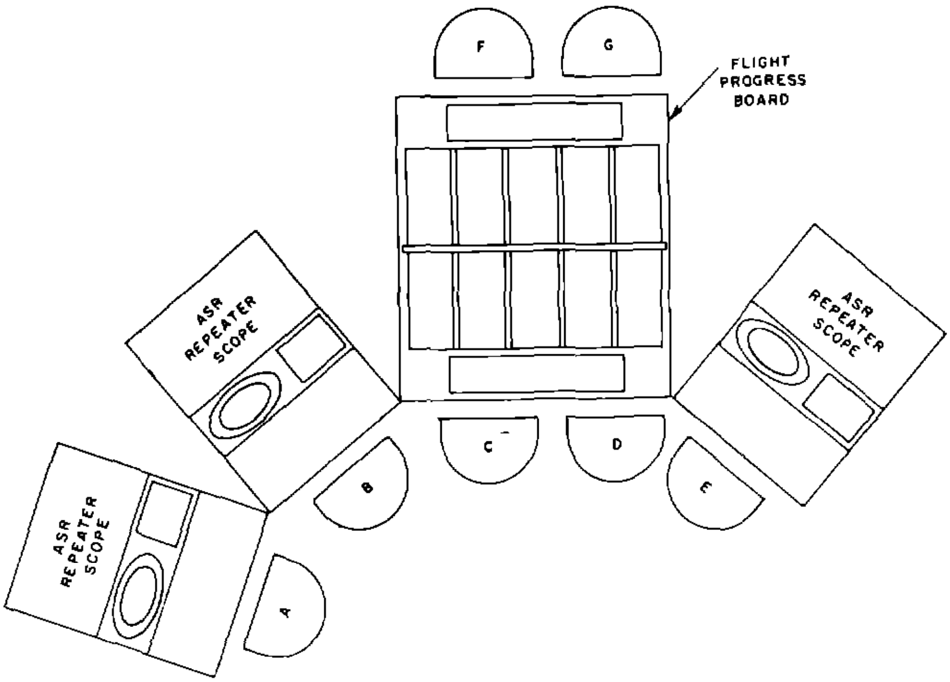


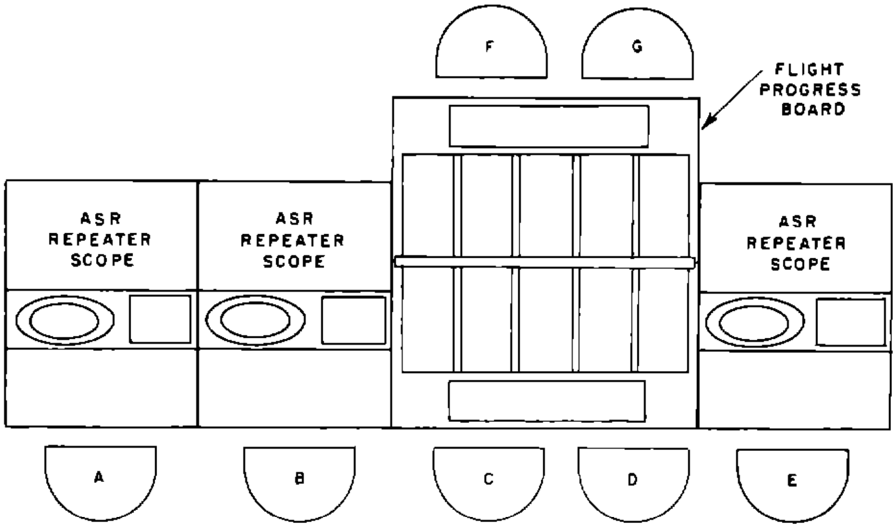
Fig 28 Summary of Simulation Tests of Norfolk Traffic-Control Systems



A SOUTH SECTOR RADAR CONTROLLER
B NORTH SECTOR RADAR CONTROLLER
C TERMINAL AREA CONTROLLER
D DEPARTURE CONTROLLER
E DEPARTURE RADAR CONTROLLER
F ARRIVAL DATA
G DEPARTURE DATA

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

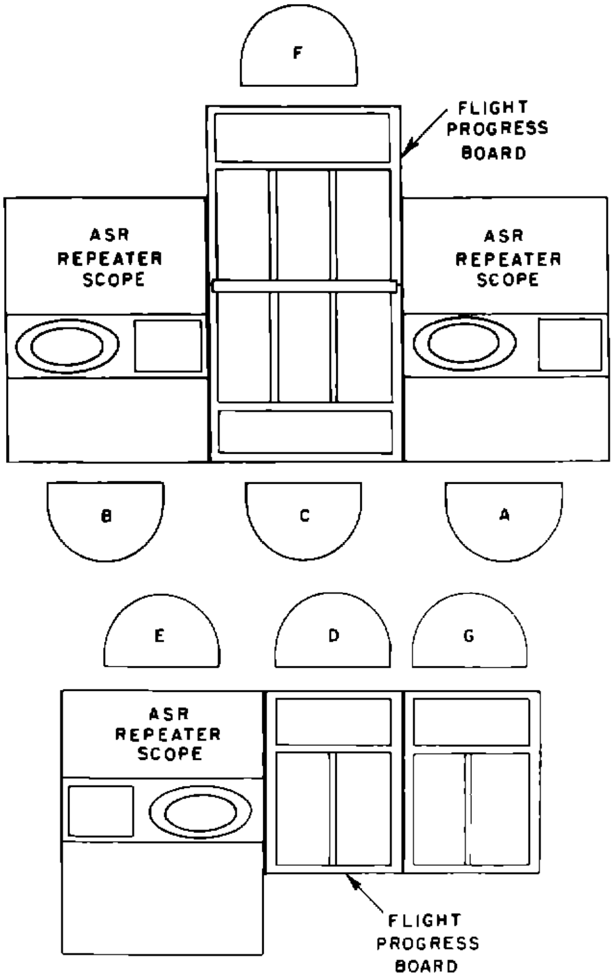
Fig 29 Equipment Arrangement No 1



A SOUTH SECTOR RADAR CONTROLLER
B NORTH SECTOR RADAR CONTROLLER
C TERMINAL AREA CONTROLLER
D DEPARTURE CONTROLLER
E DEPARTURE RADAR CONTROLLER
F ARRIVAL DATA
G DEPARTURE DATA

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

Fig 30 Equipment Arrangement No 2



A SOUTH SECTOR RADAR CONTROLLER
B NORTH SECTOR RADAR CONTROLLER
C TERMINAL AREA CONTROLLER
D DEPARTURE CONTROLLER
E DEPARTURE RADAR CONTROLLER
F ARRIVAL DATA
G DEPARTURE DATA

C A TECHNICAL DEVELOPMENT ND EV LUATION CENTER INDIAN POLIS INDIAN

Fig 31 Equipment Arrangement No 3

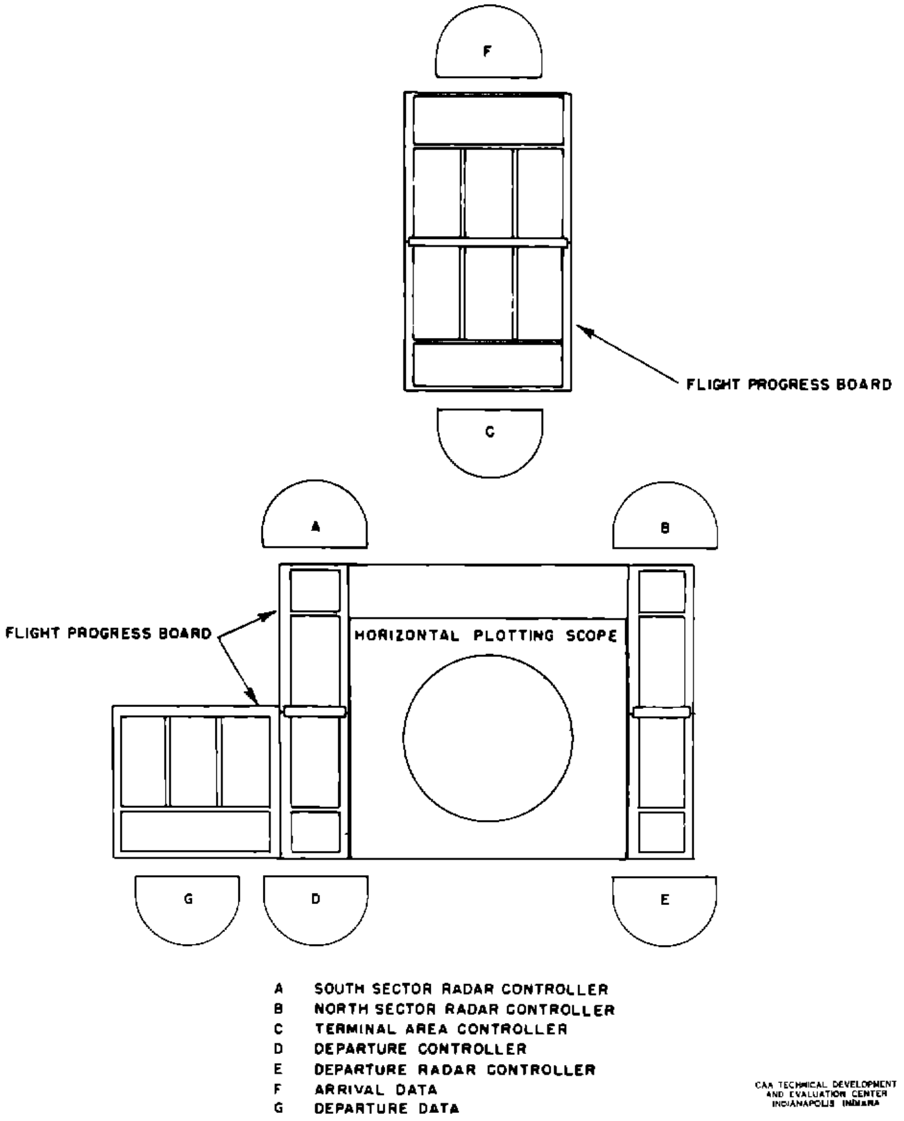


Fig 32 Equipment Arrangement No 4