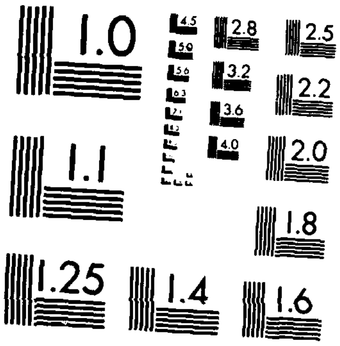
AD-A174 973 HELICOPTER AREA AIR TRAFFIC CONTROL DEMONSTRATION PLAN 1/1
(U) FEDERAL AVIATION ADMINISTRATION WASHINGTON DC
SYSTEMS RESEARC T K VICKERS ET AL JUN 81
UNCLASSIFIED FAA-RD-81-59 DOT-FA79WA-4279 F/G 1/5 NL


1.0
4.5
5.0
5.6
6.3
7.1
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

REPORT NO: FAA-RD-81-59

2

HELICOPTER AREA AIR TRAFFIC CONTROL DEMONSTRATION PLAN

June 1981

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
System Research & Development Service
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. FAA-RD-81-59	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Helicopter Area Air Traffic Control Demonstration Plan		5. Report Date June 1981
		6. Performing Organization Code
7. Author(s) T. K. Vickers, D. J. Freund		8. Performing Organization Report No.
9. Performing Organization Name and Address Federal Aviation Administration Systems Research & Development Service Helicopter Systems Branch Washington, D.C. 20590		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington, D.C. 20590		13. Type of Report and Period Covered Program Plan
		14. Sponsoring Agency Code ARD-330

15. Supplementary Notes

This effort was sponsored by the Systems Research and Development Service, Navigation and Landing Division, Helicopter Systems Branch, under the direction of Raymond J. Hilton, Program Manager

16. Abstract

As part of the Helicopter Operations Development Plan, this document outlines a phased study of area navigation applications in the control of low-altitude IFR helicopter operations, with particular emphasis on methods of reducing controller workload in order to make the use of direct random routes feasible. Each of the four phases of the plan embodies analysis, simulation, and validation. The study is evolutionary; Phase 1 starts with the basic functions of generating conflict-free routes, and maintaining positive separation between aircraft in areas outside of radar coverage. Phase 2 introduces terrain problems in mountainous areas. Phase 3 investigates interactions between fixed and random routes, and between fixed-wing aircraft and helicopters in major terminal areas. Phase 4 provides further complications in the study of off-optimum operations (interruptions in navigation, communications, and surveillance coverage) in which the airborne separation assurance function will be investigated. A broad outline of the entire plan is presented, with a detailed schedule of the first phase. Keywords:

(Random Navigation),

17. Key Words Air Traffic Control, Helicopter, IFR, ~~Random Routes~~, RNAV, ~~Simulation~~. ~~Separation Assurance~~	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENT

The information and effort reflected in this report could not have been achieved without the cooperation and assistance of the Air Traffic Services Headquarters, the Technical Center, the Southwest Regional Office and the Eastern Regional Office of the FAA. In particular, the support and suggestions of Glenn Leister and Karl Trautmann of the Air Traffic Service, Bill Redeen of the Air Traffic and Airways Facilities Service, Andy Sluka of the Technical Center, Keith Rogers of the Houston Center, and Jim Knoetgen of the Eastern Regional Office were essential to this effort.

I wish to express my sincere gratitude to those listed above, and look forward to continued association with them during my continued involvement in the helicopter program.

Raymond J. Hilton
ATC Helicopter Program Manager

A-1

Index

List of Illustrations

Interim Report

HELICOPTER AREA AIR TRAFFIC CONTROL

DEMONSTRATION PLAN

A. Objectives

This interim report outlines a proposed study for the development and evaluation of area navigation applications in the control of low-altitude helicopter operations. The proposed study is a part of the FAA Helicopter Operations Development Plan. The development of the study plan is being performed under the provisions of Contract DOT-FA79WA-4279, Modification No. 12. The specific objectives of the study are to:

(a) Determine the feasibility of controlling IFR helicopter traffic on direct random routes and on offset parallel RNAV route structures;

(b) Determine the benefits and problems involved;

(c) Identify any new procedures and ATC system improvements required to facilitate such flight operations.

B. Justification

Direct Routes. Justification for direct (random-route) helicopter navigation includes the need to save time and fuel, and to reduce exposure of the helicopter to icing and other adverse flight conditions. Also, because of the differences between the performance characteristics of helicopters and fixed-wing aircraft there is a need to segregate the two types of aircraft wherever feasible. In many cases, the use of existing routes, random routes, and offset parallel routes at the lower altitudes will enable helicopters to utilize airspace which is not normally used by fixed-wing aircraft.

Offshore low-altitude operations in the Gulf of Mexico provide an immediate justification for a random route study. The more than 800 helicopters in offshore service here are generating a growing demand for IFR traffic control. The existing need for direct random route operations stems from the fact that there are over 1500 possible offshore flight origin and destination points (helipads) in this area; 238 of these helipads are on drilling rigs, which change their location from time to time.

Dual-Route Operations. The number of altitude levels available to helicopters may sometimes be restricted by the need to stay below the freezing level or to avoid interference with fixed-wing traffic. Under conditions where only two levels are available and two busy helicopter routes cross each other, it should be possible to minimize the number of potential conflictions by placing opposite-direction traffic on laterally separated dual routes at the same altitude, instead of on the same route at odd and even altitude levels.

Placing the opposite-direction, laterally-separated lanes of a busy crossing route at the next useable altitude level, as shown in Figure 1, should simplify ATC workload by precluding conflictions of crossing as well as opposite-direction traffic. For example, a northbound aircraft would not be concerned with southbound, eastbound, eastbound, or westbound traffic, but only with overtaking or merging situations with other northbound traffic. (Actually the two routes could cross at any angle and still be completely independent in all four directions of traffic flow).

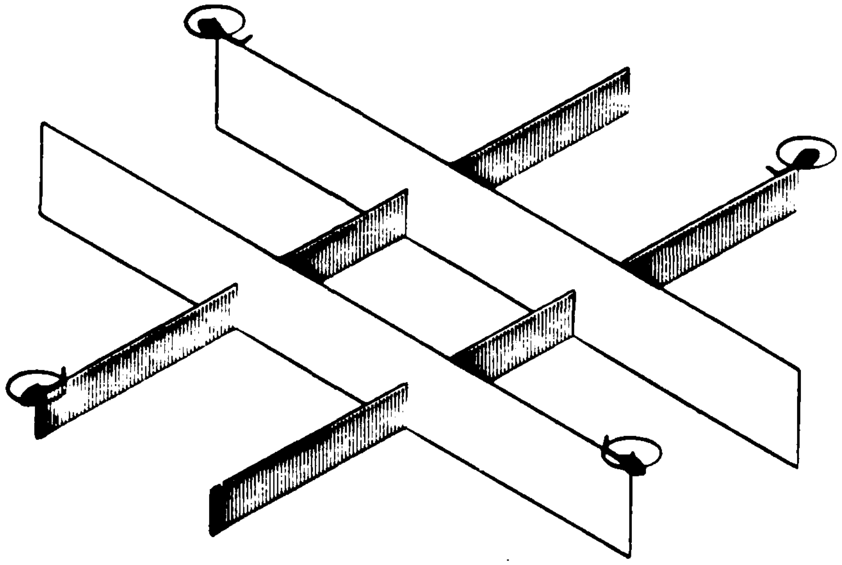


Figure 1 - Dual-Route Intersection Concept

C. Scope

Figure 2 outlines the main areas of interest in the proposed study. Development of the system capability to control traffic on direct random routes involves the operational considerations of navigating the aircraft, and the ATC workload of separating and expediting the traffic. The airborne navigational capability already exists. Consequently the emphasis will be placed on the development of the necessary air traffic control capability. A key to the attainment of this goal will be the development of software to provide the controller with the monitoring and decision aids necessary to perform these functions.

FAA Advisory Circular AC 90-45 is the basic document covering area navigation (RNAV) criteria. Considerable work has been accomplished in RNAV studies, including the subjects listed below:

- Impact on controller productivity and the ATC system: Reference 1, 2, 14.
- Flight technical error: Reference 3, 4, 5, 6, 13, 17.
- Terminal procedures: Reference 7, 8, 9, 10, 14, 15
- High-altitude payoffs: Reference 3, 11.
- Integration with Upgraded 3rd Generation ATC system: Reference 1, 14.
- Waypoint designation: Reference 20.
- Vertical navigation concepts and payoffs: Reference 3, 11.
- Economic Impact: Reference 19, 30.

However, this work was concerned almost exclusively with fixed-wing RNAV operations based on VOR/DME inputs. Maximum use of applicable information from these studies will be made; however, it will still be necessary to address the problems of helicopter IFR operations with Loran C navigation.

D. Phasing of Study Elements

General Plan. The study will be conducted in four phases. Phase I will examine the fundamental problems of random routing in a relatively clean and uncluttered operating environment. Phase II will examine the additional problems introduced by terrain and other obstructions in a mountain-

---

NOTE: Reference numbers are identified in Section H of this report.

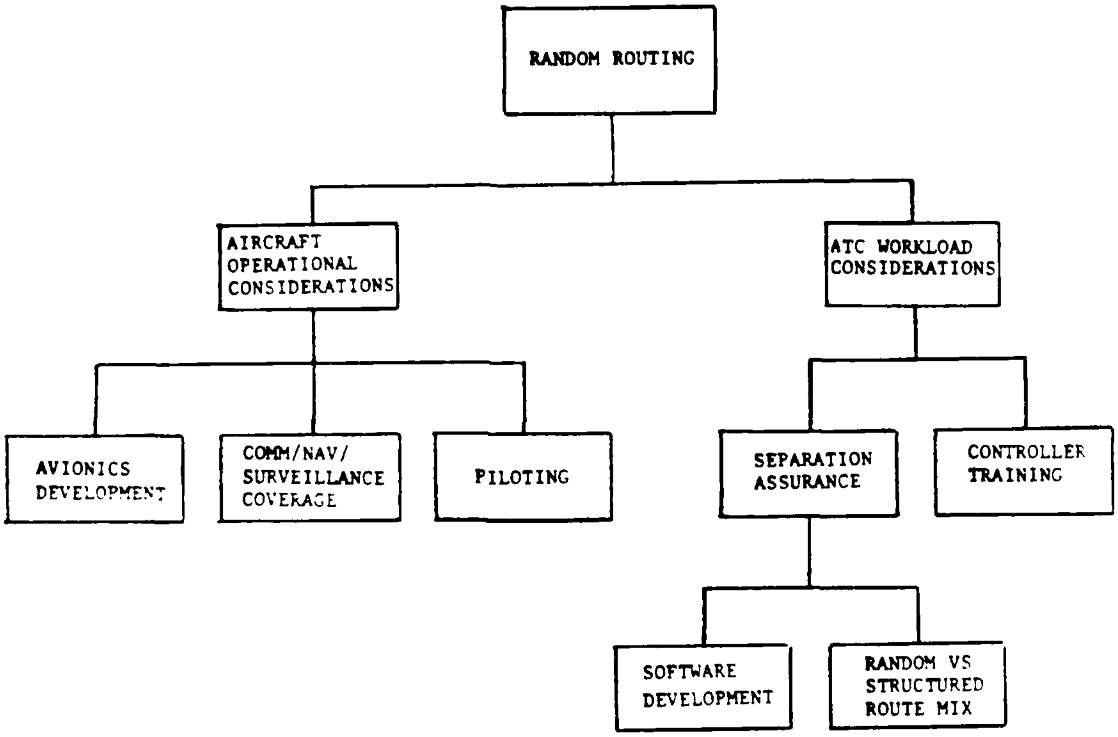


Figure 2. Areas of Interest

ous environment. Phase III will investigate the problems of mixed helicopter and fixed-wing traffic in high-density terminal areas, and the problems of interfacing mixed traffic on random routes and established fixed routes in the enroute area. Phase IV will study the problems introduced by gaps and interruptions in navigation, communications, and surveillance converage; and by high winds, thunderstorms, and icing conditions.

Following is a more detailed discussion of the operational problems to be examined in each phase.

(a) Phase I. Basic Random Routing Problems

(1) Separation Assurance. The fundamental problem of random route operations is the topological problem of an increased number of route intersections, which bring the increased possibility of conflict between aircraft at the points of intersection. A related problem is the difficulty of determining in advance whether the aircraft on such routes will conflict with each other. The key to the solution of such problems may be the development of a software program which, on entry of the navigation waypoints of a proposed flight plan, would define the route of flight on the controller's PPI display. On entry of the flight plan data the computer would check the active and pending flight plans in storage and would determine which ones were on routes which coincided or intersected the route of the flight plan being processed.

If a coincidence or intersection were found, the computer would compare the altitude profile of that flight plan with the altitude profile of the flight plan being processed. If the altitudes coincided at any point where the routes coincided or intersected, the computer would determine the time difference between the ETA's of each aircraft over such points. If sufficient time separation did not exist, the computer would probe another flight altitude in a similar manner, or would delay the proposed takeoff time in order to obtain a conflict-free path to the destination. This process is diagrammed in Figure 3.

Suggested changes to the original plan would be displayed to the controller or FSS operator for coordination with the pilot.

The procedure described above would simplify the control of random route traffic, by eliminating most of the potential conflicts before the aircraft ever left the ground. Theoretically, the goal would be intervention-free operations. The approach toward this goal might well be the key to increased controller productivity and increased ATC system capacity.

Although vagaries in winds aloft and variations in aircraft performance, as well as detours around weather, would tend to affect the benefits of such a procedure, it should be remembered that most helicopter flights are

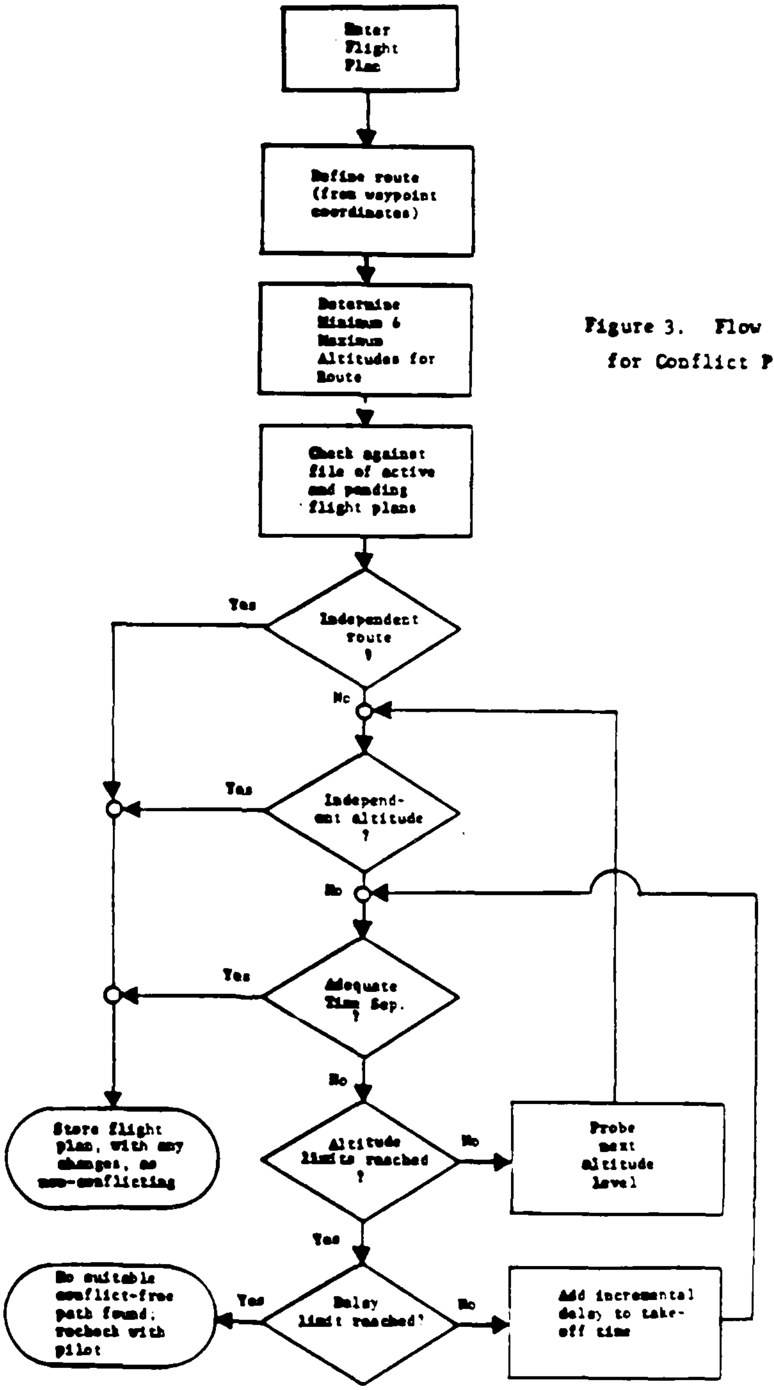


Figure 3. Flow Chart for Conflict Probe

Figure 3. Flow Chart for Conflict Probe

relatively short, and (without the need to wait for a vacant runway), takeoff times could be very close to the proposed departure times. Also, there are many areas where the low density of low-altitude traffic would make such a procedure practical.

The inclusion of a conflict-alert function to monitor the positions of aircraft in flight would be a very useful addition to the computer software, in closing the automation loop.

(2) Separation Standards. The ATC System proposed for the control of low-altitude offshore helicopters in the Gulf of Mexico would use the LOFF (Loran Flight Following) system for the automatic reporting of aircraft positions, in areas beyond and below radar coverage. A block diagram of the LOFF system is shown in Figure 4.

Although procedural separation standards will be used initially, an important task in Phase I will be to develop recommended separations for aircraft using various combinations of navigation and surveillance systems. Such standards must embrace aircraft performance capabilities, flight technical errors, plus the errors of the navigation system, the psoition reporting digital communicaitons and processing system, the tracking system, the ATC display, and the time lag between position reports. Tracking errors could be relatively large during turns, unless the message reporting rate were speeded up temporarily at such times.

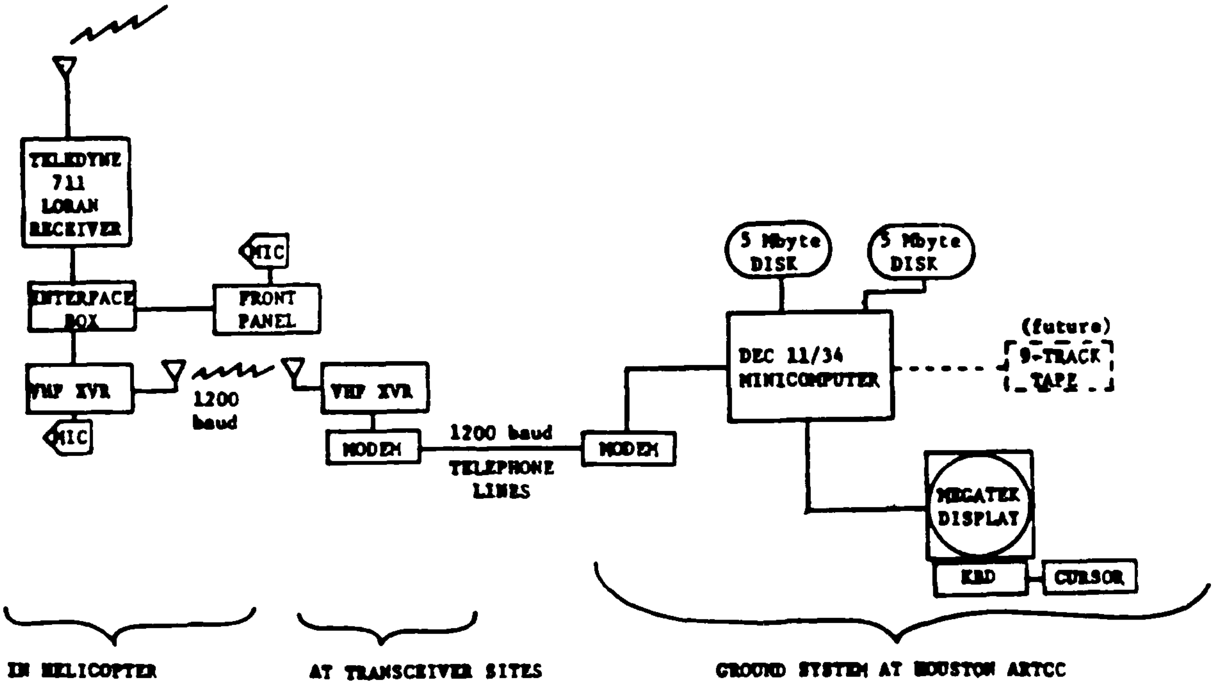


Figure 4. Block Diagram of LOFF System

An important point regarding the capacity of helicopter routes is that the time interval imposed by a fixed distance standard is inversely proportional to the ground speed. For example, if ground speeds are below 120 knots, the existing 20 NM DME separation standard produces spacing intervals of more than 10 minutes.

(3) Waypoint Entry. The operational versatility of helicopters in being able to take off and land in very small areas is their reason for being; but the use of this versatility and flexibility generates the need to specify takeoff and landing points as well as intermediate waypoints in a manner that can be quickly entered and stored in the computer and displayed to the controller on an as-needed basis. This subject has been studied previously for VOR/DME waypoints. The method of coding these geographical points, whether by Lat/Lon coordinates or by some other designation scheme, will be studied for applicability to other types of navigation systems, using present and next-generation ATC computers.

(4) Human Factors. Starting in Phase I and continuing throughout the entire study, the ergonomic aspects of proposed navigation, control and display concepts will be studied from the standpoint of the controller and the pilot. ATC simulation will explore the special display needs and options for handling radom route traffic. Control workload will be measured in terms of the amount of communications necessary as well as the number of interventions required in feeding the same traffic samples through the various route configurations, using various levels of ATC automation. The inherent flexibilty of the LOFF system should enable many of the concepts developed in the analysis and simulation stages to be validated in the flight tests.

Using a helicopter flight simulator, cockpit workload will be investigated for alternate methods of resolving enroute conflicts. In some cases, the simulator may be interfaced with the ATC simulator. Any unique problems or solutions may be further explored during the validation stage.

(5) Training Requirements. Throughout all phases of the study, pertinent training requirements will be examined; appropriate recommendations will be developed to cover the needs of controllers to deal efficiently with the special procedures and display formats which emerge from the demonstration program.

(b) Phase II. Terrain/Obstacle Avoidance

(1) Quick Determination of Minimum Safe Altitudes for Random Routes. After sufficient experience has been gained in random-route ATC operations in the relatively clean and uncluttered offshore area, the complication of terrain problems, typical of mountainous areas, will be introduced.

The ability to operate safely below the majority of fixed-wing operations is a desirable goal for helicopters on short random-route flights. The quick determination of minimum safe altitudes for any specific route will be a necessity. The possible application of the MSAW concept (but using a much smaller grid interval) as well as special charting and plotting facilities will be investigated.

One candidate test environment for this phase of the study is the Appalachian area between Pittsburgh and Knoxville. More than 100 helicopters are based in this area, mainly in support of mining operations. Another candidate area with terrain problems is in Alaska. This area has some unique operating problems not found in the contiguous United States. Both of the candidate areas are well inside existing Loran C coverage.

(2) Approach and Departure Procedures. FAR 91.116(a) requires that when an instrument letdown to an airport is necessary, a standard instrument approach procedure prescribed for that airport must be used.

In a large percentage of helicopter operations, the origin or the destination of the flight is at a heliport where few if any approach aids are available. An IFR flight cannot terminate at such a destination unless the pilot can make a visual approach from the MEA, or from the MDA of an approved instrument approach procedure. However, the use of an existing approach procedure usually involves a significant increase in flight distance over that of a direct route from origin to destination.

An ultimate objective would be the development of a universal approach system which could provide the capability for instrument approaches to any desired heliport site.

Loran C, and ultimately GPS, may provide the capability for low-altitude RNAV, terminating with a non-precision approach to any desired heliport within the system coverage. By providing useable signals from the ground up, these aids would also furnish navigation guidance for instrument departures, in a similar manner.

The Northeast Corridor experiment has demonstrated the value and practicality of point-in-space approaches. Tests have also demonstrated the possibility of using Loran C for guidance on non-precision approaches.

These capabilities establish the foundation for the remaining system elements that would make the use of random direct routes, at altitudes below fixed-wing cruising levels, a viable concept for helicopters.

Another operational need for low-altitude random-route operations particularly in mountainous areas, is a rapid and practical means of checking the surrounding obstructions for the establishment of a safe instrument approach and missed approach procedure. The application of the IAPA program is recommended for this function. IAPA (Instrument Approach Procedures Automation) is presnetly being established for FAA field offices across the country. Prior to using it for the establishment of helicopter approaches, the IAPA data base must be updated with the new helicopter criteria which is now being developed for TERPS Chapter 11.

(c) Phase III. Mixed Traffic and Interactions of Fixed/Random Routes

This phase deals primarily with terminal area operations, where the potential for conflicts between helicopters and fixed-wing aircraft is highest. In areas where the speed differential between the two types of aircraft is greatest, the goal will be to establish helicopter traffic patterns as independent as possible from fixed-wing traffic patterns in order to avoid overtaking problems. Because helicopter takeoffs and landings need not necessarily use runways, the establishment of independent approach and departure paths, which allow simultaneous operations of helicopters and fixed-wing aircraft, can enhance terminal area capacity in some cases.

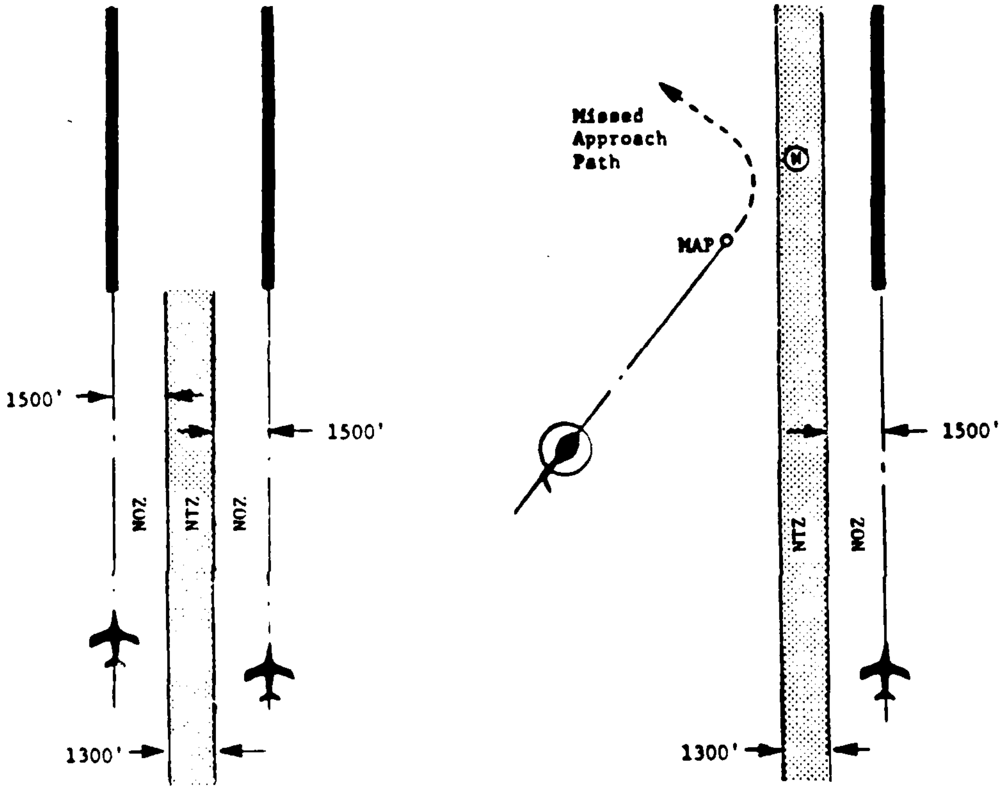
In view of the low approach speed and high maneuverability of helicopters, it may be possible to adapt the existing criteria for dual simultaneous parallel approaches, as shown in Figure 5(a), to permit simultaneous approaches of helicopters and other aircraft, as shown in Figure 5(b).

The transition between direct random enroute paths and terminal area approach and departure paths will be an important object for study, due to the potential for interference between fixed and random routes. Although some general principles may be developed for minimizing such interference through the use of lateral or vertical separation, the final solution for any terminal area will be site specific.

These problems can be studied either in the Northeast Corridor where low-altitude helicopter routes and approach procedures are already established; or in some other candidate area such as the Great Lakes Megapolis (Pittsburgh and Buffalo westward to Chicago and Milwaukee). Industry forecasts indicate that the Great Lakes area will experience a major growth in helicopter traffic in the next few years, and may be the next area for the establishment of low-altitude helicopter corridors.

(d) Phase IV. Intermittent Nav/Comm/Surveillance

(1) System Malfunctions. Navigation requirements for helicopter operations over the horizon and down to the surface of the earth can be met by the use of Loran C over much of the continental United States and in the areas for several hundred miles offshore around the U.S. coastlines. Most of this portion of the study will deal with failures of the airborne equipment.



(a) Existing Criteria (b) Proposed Criteria

Legend:
NOZ = Normal Operating Zone
NTZ = No-Transgression Zone

Figure 5. Adaptation of Existing Criteria for Simultaneous Helicopter/Fixed Wing Approaches

(3) Gaps in Communications Coverage. The air traffic control system cannot function without communications. Because the present communications channels used for air traffic control are limited by VHF line-of-sight, they cannot provide service to helicopters at very low altitudes in many areas -- particularly in mountainous terrain. Thus any low-altitude area ATC concept which relies on the present standard VHF communications facilities will be severely limited if it requires the helicopters to operate in the same airspace and with the same navigational facilities as conventional airplanes. This would eliminate from consideration much of the lower airspace where helicopters normally operate during VMC without the use of additional or alternate communications facilities.

Some studies have already been performed to reassess the possibility of using other frequency bands or other communications techniques[21]. Mostly such studies have reaffirmed the need for using VHF in the near term. Nevertheless, several innovative ideas which have been suggested recently may warrant a new look. These ideas include:

- VHF relay under control of ACARS, by high flying jet aircraft.
- VHF relay through satellites (e.g., Marisat).
- VHF relay through unattended low-cost transceivers.
- Use of data in general, in place of voice communications.
- MF uplink, with extended-range VHF for the downlink. Discontinuance of Loran A has made a portion of the spectrum available for the uplink and a range of 400-500 miles could be achieved. Other techniques such as extended-range VHF would be needed for the downlink.
- HF, using recent technical developments which make this concept much more attractive than it was in the past.

Techniques and procedures to overcome problems of coverage gaps will be sought and evaluated.

(4) Separation Assurance Outside of ATC Surveillance Coverage. Existing primary and secondary radar coverage is limited by line of sight as well as by the normal limits of the antenna pattern. Flight operations over the horizon or behind terrain obstructions from the radar antenna thus are outside of radar coverage. One method of obtaining aircraft position data from such areas would be to use a flight following system such as the LOFF system which is planned for installation at the Houston Center. With LOFF, aircraft position data obtained from the aircraft navigation receiver is transmitted along with aircraft identification and altitude data, via data link to the ATC facility for processing and presentation as a tagged target, on the PPI display.

An airborne collision avoidance system (CAS) designed to use Mode S (the selective address mode of the ATC radar beacon system) is now under development by the FAA and is called BCAS for Beacon Collision Avoidance System. A block diagram of the airborne unit is shown in Figure 6. Designed as a backup system to guard against malfunctions of the ATC system, it is capable of operating outside of radar coverage. Thus it should be applicable to low-altitude helicopter operations, and should be particularly attractive when used in an ATC environment in which the ATC computer selects a tentatively conflict-free path for each aircraft, as described in Phase I above.

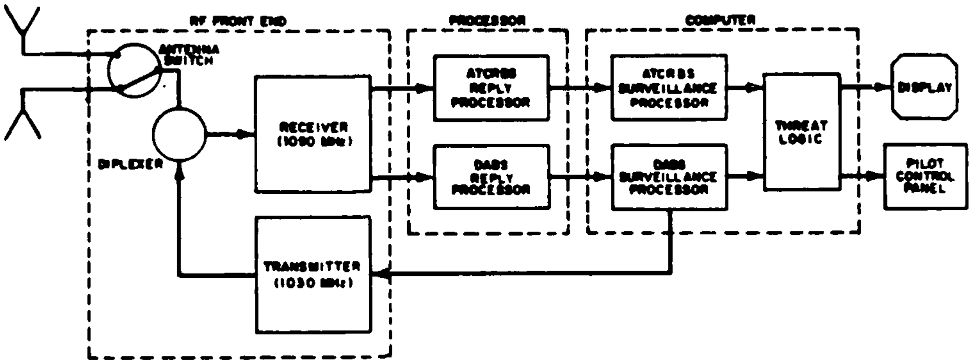


Fig. 6. BCAS Block Diagram

Phase IV of the helicopter study will include applications of airborne separation assurance devices as a backup to the ground ATC system in the event of system malfunction or gaps in coverage. The possibility of cascading interactions of such equipment in different aircraft will be studied.

E. Methodology

As shown in Figure 7, each phase of the study will be conducted in three basic stages:

- Analysis
- Simulation
- Validation

The objective will be to obtain the maximum amount of useful information at the least cost. In some cases, particularly if adequate simulation facilities are not available when needed, it may be necessary to by-pass the simulation stage and go directly into the validation (flight test) stage. Also, it may not be necessary to simulate LOFF operations if the necessary data is readily available from the actual system.

Software will be developed or adapted as required for the simulation and validation stages.

Typical tasks for each stage are listed in the following section.

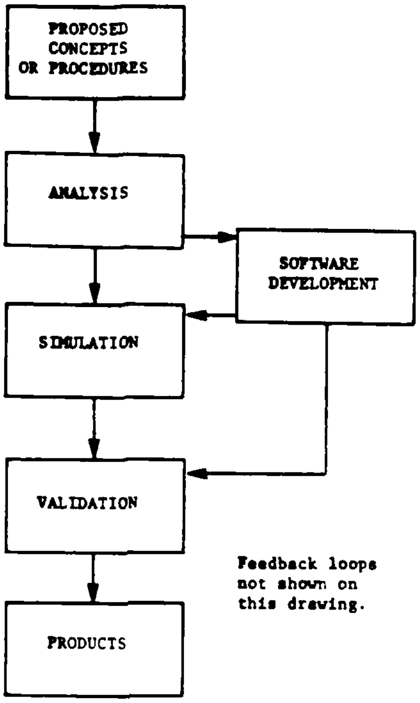


Figure 7. Methodology Flow Chart

Tasks - Analysis Stage

1. Search literature
2. Discuss operations with users
3. Select and define geographical areas for study
4. Study traffic requirements for selected areas
    a. Aircraft performance characteristics
    b. Demand characteristics (loads, distribution, origin/destination data)
5. Set up typical traffic samples
6. Determine minimum altitudes for each area (based on obstruction clearance only) (Phase II and subsequent only)
7. Determine coverage gaps at minimum altitude (Phase IV only)
    a. Navigation
    b. Communications
    c. Surveillance

8. Postulate alternative IFR route structures for areas of existing coverage (Navigation, Communications, Surveillance)

   a. Exisiting IFR routes
   b. Random (direct) routes to approximate VFR routings
   c. Offset parallel routes
   d. Appropriate combinations of the above

9. Determine alternate methods of obtaining desired augmented coverage

   a. Navigation (Phase IV only)
   b. Communications
   c. Surveillance

10. Postulate alternative IFR route structures for expanded areas (i.e., existing and augmented navigation, communications, surveillance coverage) (Phase IV only).

   a. Existing IFR routes
   b. Random (direct) routes to approximate VFR routings
   c. Offset parallel routes

11. Develop ATC procedures for pilots and controllers
12. Determine the availability of simulation facilities
13. Develop detailed test plan of simulation tests for:

   a. Existing navigation, communications, and surveillance facilities using route structures developed in Item 8 above.
   b. Augmented navigation, communications, and surveillance facilities using route structures developed in Item 10 above. (Phase IV only).

14. Determine dynamic simulation requirements for human factors and procedural studies of existing system versus augmented system, in Phase I to IV.

   a. Target generation (number and type of controllable targets)
   b. Data entry, display characteristics
   c. Communications (number of voice channels)
   d. Data recording facilities
   e. Flexibility and adaptability to desired plan (Item 11)

15. Determine hardware and software requirements for fast-time simulation (parametric analysis) of existing system versus augmented system, in all three environments.

16. Determine flight simulation requirements for analysis of pilot workload and procedures, in existing system versus augmented system, in Phases I to III.

Tasks - Simulation Stage

1. Select simulation facilities, based on availability, cost and convenience.
    a. Fast-time
    b. Dynamic (Real-time)
    c. Flight

2. Adapt hardware and software as necessary
3. Update simulation plan
4. Generate traffic samples for test runs
5. Run tests
6. Analyze results
7. Recommend specific items or procedures for flight tests, implementation, or further study

Tasks - Validation Stage

1. Coordinate simulation recommendations with appropriate offices
2. Install necessary ground and airborne equipment for tests
3. Run tests
4. Analyze results
5. Recommend specific items or procedures for implementation or further study.

F. Use of Results

Interim reports will be issued at appropriate intervals to cover the results of completed portions of the analysis, simulation, and flight tests. A final report will be issued to summarize the results and conclusions from the entire program.

Reports will be furnished to ATM and to the appropriate regional offices and field facilities, for comment and coordination regarding special routes, procedures, and other improvements to facilitate the control of helicopter traffic.

G. Schedule

Figure 8 is a preliminary schedule of all four phases of the Demonstration Plan. Figure 9 provides a detailed listing of the tasks to be performed in Phase I. Within three months from the start of the program, the schedule will have to be refined, depending upon the amount of available software which can be adapted for the required functions.

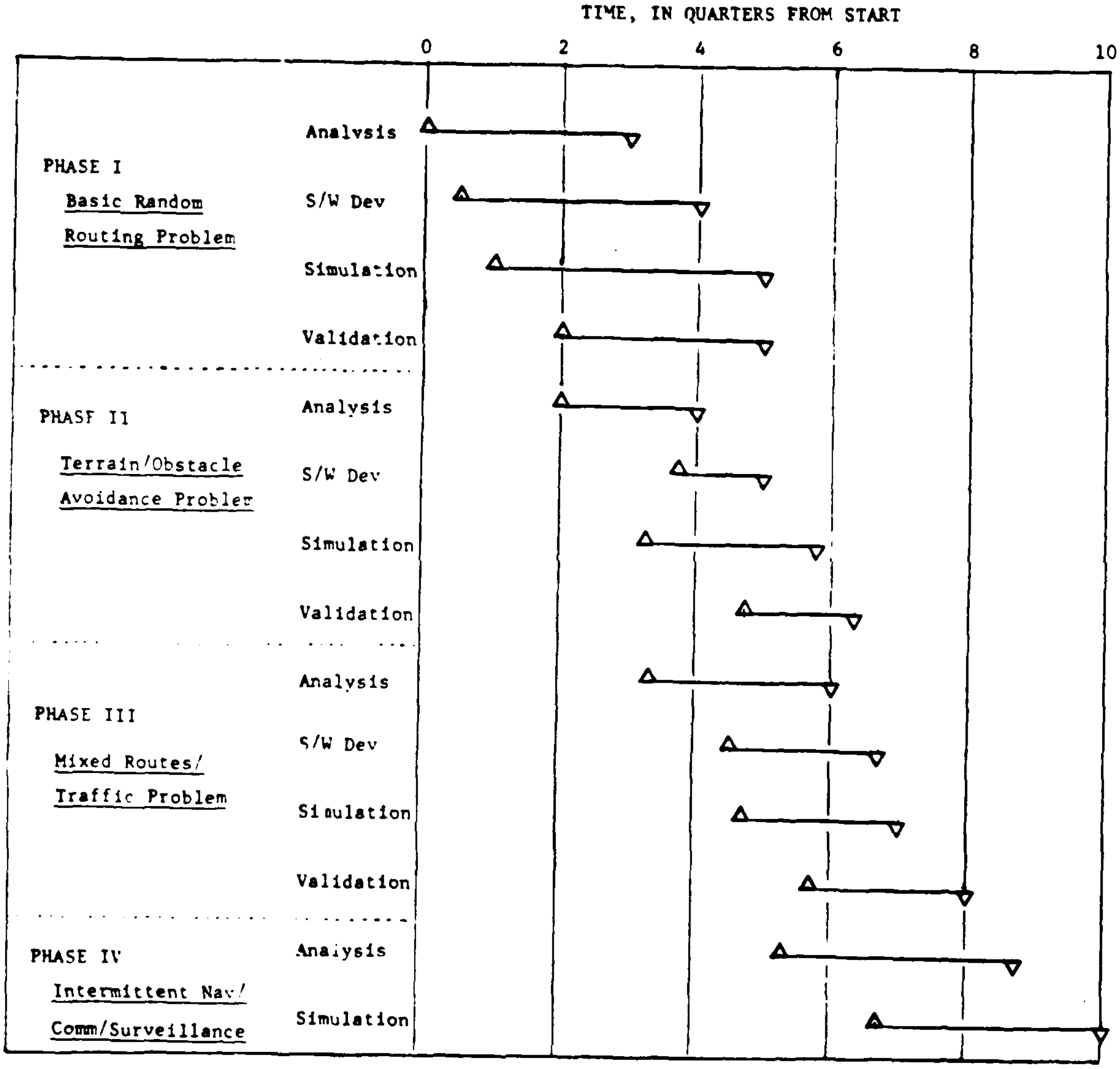


Figure 8. Preliminary Schedule

ANALYSIS

Develop conflict probe algorithm.
Determine priorities for adjustments in altitude, takeoff time, cruising speed and course offset.
Develop conflict alert algorithm.
Determine appropriate separation standards.

SOFTWARE DEVELOPMENT

Determine software requirements.
Review available software.
Adapt or develop software for conflict probe and conflict alert.

SIMULATION

Determine simulation requirements.
Install any special equipment.
Simulate and compare different procedures for obtaining conflict-free paths. Study display, input, communications and decision problems, for controllers and pilots.
Determine sensitivity of system to changes in separation standards.

VALIDATION

Determine data collection requirements. Install any special equipment needed for tests.
Collect and analyze data to determine feasibility and benefits of conflict probe, conflict alert, and various control procedures.
Make appropriate recommendations regarding system requirements, control procedures, separation standards, and human factors including training requirements.

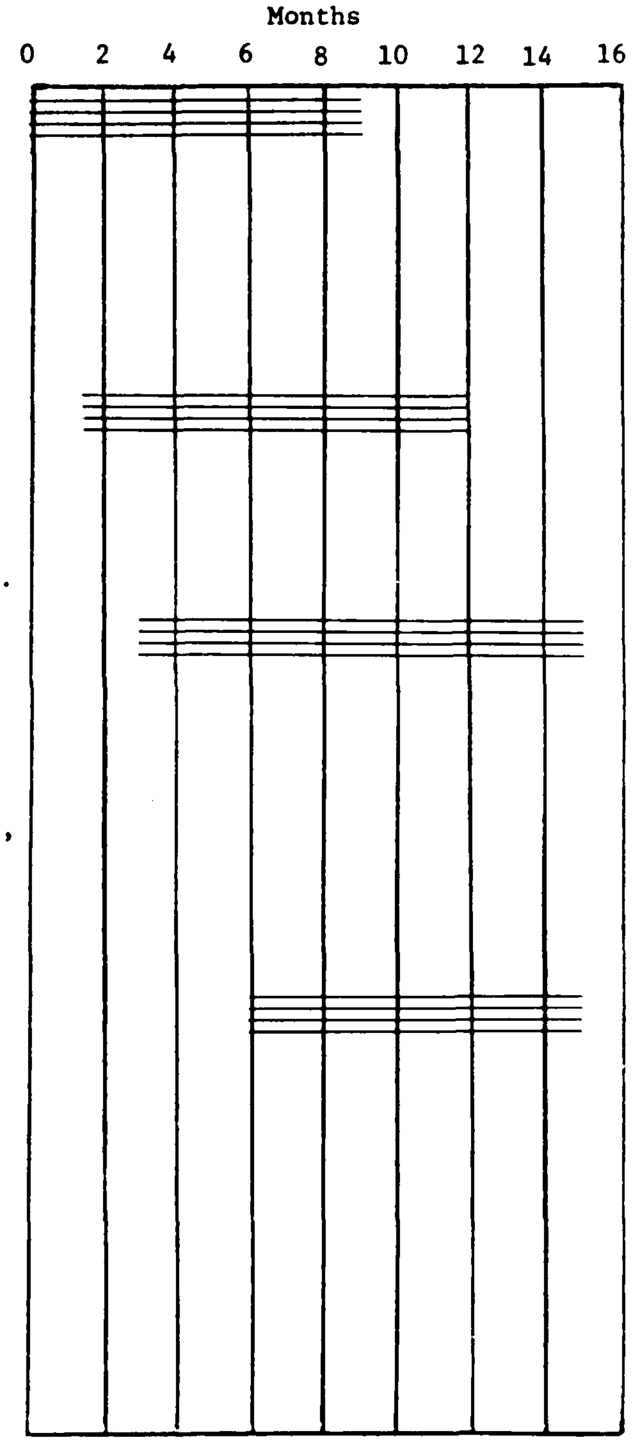


Figure 9. Detailed Tasks for Phase I

H. References

Numbered references appearing in foregoing sections of this document are identified below.

Title	Report No.	FAA Library Shelf No.
1. RNAV Impact on ATC Automation	MTR 6612	74-0626
2. Area Navigation Part 1	NASA LS-38255	78-0380
Part 2	"	78-0381
3. A Flight Investigation of System Accuracies and Operational Capabilities of a General Aviation RNAV System	FAA-RD-77-45	77-0781
4. RNAV Procedure Turn Anticipation Techniques, Exp. No. 2 GAT 2A	FAA-RD-78-110	78-1078
5. Simulation Tests of Pilotage Error in RNAV With Vertical Guidance	FAA-RD-73-202	74-0565
6. Flight Tests of Pilotage Error in RNAV With Vertical Guidance	FAA-RD-72-126	74-0121
7. Automated Metering and Spacing With RNAV	MTR 6431	76-0205
8. RNAV Application to STOL Operations	EAL	76-0300
9. RNAV Route Design, Terminal Procedures, and Transition Area Design Guidelines	FAA-RD-78-[illegible]1	78-1316
10. Real-Time Manned Simulation and Advanced Terminal Area Guidance Concepts for Short-Haul Operations	NASA TN-D-8499	78-1230
11. RNAV High Altitude Payoff Analyses Enroute Fast-Time Sim. Results	FAA-RD-76-26	76-0577
12. Navaid Support of High-Altitude RNAV Routes	FAA-RD-76-210	77-0303
13. RNAV Route Width Requirements	FAA-RD-77-21	77-0585
14. Implementation of RNAV in the NAS	FAA-RD-76-196	77-0546
15. RNAV/VRNAV Terminal Simulation	FAA-RD-76-211	77-0447

16. 4-D Guidance Algorithms for Aircraft Guidance in an ATC Environment NASA TN-D-7829 75-1336

17. Sim. Tests of Pilot Performance in Terminal Area Navigation Operations FAA-RD-76-99 76-1292

18. 4D RNAV Description and Flight Test Results NASA TN-D-7874 75-1337

19. Economic Impact of RNAV FAA-RD-75-20 75-1246

20. RNAV Waypoint Designation Standards FAA-RD-75-122 75-1150

21. Helicopter Communications System Study FAA-RD-80-20

22. Weihe, V., A Comparison of Air and Marine Separation Assurance J. Navigation (US), Vol. 18 No. 1

23. Anderson, E.W., Air Navigation Techniques, J. Navigation (US), Vol. 18 No. 1

24. Van Der Hauten, R.J. and Oprel., A., Navigation on the Use of Helicopters Offshore J. Navigation (UK), Vol. 27 No. 4

25. Villiers, J ., The Automation of Air Traffic Control J. Navigation (UK), Vol. 28 No. 1

26. Anderson, E.W., The Craft of the Navigator J. Navigation (UK), Vol. 28 No. 1

27. Ratcliffe, S., System Problems in Air Traffic Control J. Navigation (UK), Vol. 29, No. 4

28. Kuhar, W.T., and Quinn, G.H., Offshore Operations J. Navigation (US), Vol. 24 No. 4

29. Meyer, D.H., System Requirements for Transition from Enroute to Approach Guidance J. Navigation (US), Vol. 24, No. 4

30. Braff, R., and Joglekar, A.N., Future Domestic Air Navigation System Analyses J. Navigation (US), Vol. 25, No. 1

END

1-87

DTIC