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APPROVAL OF AREA NAVIGATION SYSTEMS FOR USE IN THE U. S. NATIONAL AIRSPACE SYSTEM

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Initiated by: AFS-260

AC NO: 90-45A

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: APPROVAL OF AREA NAVIGATION SYSTEMS FOR USE IN THE U.S. NATIONAL AIRSPACE SYSTEM

1. PURPOSE. This Advisory Circular provides guidelines for implementation of two-dimensional area navigation (2D RNAV) within the U.S. National Airspace System (NAS). It provides for both VOR/DME dependent systems and self-contained systems such as Inertial Navigation Systems (INS), etc. The airborne requirements for three-dimensional area navigation (3D RNAV) are specified. Implementation instructions for 3D RNAV are not included herein. They will be contained in appropriate agency orders. Until such orders are issued, use of airborne 3D-RNAV systems on 2D-RNAV procedures to stabilize flight paths, etc. is permitted provided the minimum/maximum altitudes specified in procedures are observed.

   Additional changes may be expected which reflect elements of the Industry/FAA Task Force Report as they become verified.

2. CANCELLATION. Advisory Circular 90-45, Approval of Area Navigation Systems for Use in the U.S. National Airspace System, dated August 18, 1969, and Change 1 dated October 20, 1970, are canceled.

3. REFERENCES. "U.S. Standard for Terminal Instrument Procedures (TERPs)"; AC 90-28, "Course Changes While Operating under IFR below 18000' MSL"; AC 90-63, "ATC Procedures for Random Area Navigation Routes"; AC 95-1, "Airway and Route Obstruction Clearances"; FAR Parts 21, 23, 25, 27, 29, 43, 71, 75, 91, 95, 97, 121, and 135 as applicable.

4. HOW TO OBTAIN THIS PUBLICATION.

   a. Copies of this circular may be obtained free of charge from:

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Approval of Area Navigation Systems for Use in the U. S. National Airspace System
Dated February 1975

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Acting Director, Flight Standards Service

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1. BACKGROUND AND DEFINITIONS.

a. Present navigational methods, based on the use of VOR/DME/TACAN ground facilities, result in routes or airways which lead either directly toward or away from the station. This results in limitations on the configuration and the number of routes available between two points.

b. These limitations take on even more importance considering that arrival and departure procedures are based, in large measure, on the same ground stations which serve the enroute structure. This means the funneling effect is compounded by altitude changes for traffic transitioning to or from the enroute structure.

c. The employment of airborne area navigation systems (RNAV) permits flight over predetermined tracks within prescribed accuracy tolerances without the need to overfly ground-based VOR/DME (VORTAC) navigation facilities. Area navigation has three principal applications: between any given departure and arrival points along a route structure so organized as to permit reduction in flight distances or reduction in traffic congestion; in terminal areas to permit aircraft to be flown on preorganized arrival and departure flight paths to assist in expediting traffic flow and reduce pilot and controller workload; and to permit instrument approaches within certain limitations.

d. Area navigation allows the use of routes not solely limited by air navigation facility location. These additional routes provide operational advantages for pilots and controllers by increasing route capability and flexibility.

e. Definitions of particular significance.

(1) Along-Track Distance (ATD) Fix - The ATD fix is an along-track position defined with reference to a waypoint and with geographical coordinates.

(2) Along-Track Error - A fix error along the flight track resulting from the total error contributions of the airborne and ground equipment only.

(3) Area Navigation (RNAV) - A method of navigation that permits aircraft operations on any desired course within the coverage of station referenced navigation signals or within the limits of self-contained system capability. In addition, RNAV utilizing capabilities in the horizontal plane only is 2-D while RNAV which also incorporates vertical guidance is 3-D.

(4) Area Navigation (RNAV) Equipment - Airborne equipment that provides for area navigation.

(5) Changeover Point - The point at which navigation reference is shifted from one reference facility to the next reference facility.

(6) Circular Position Error (CPE) - The probable navigation error expressed in terms of the radius of a circle centered on the desired geographic point.

(7) Cross-Track Error - A fix error to the left or right from the desired track to the present position, measured perpendicular to the desired track. This error includes airborne equipment, ground equipment, and FTE.

(8) Designated RNAV Route - An area navigation route, based on the current high altitude or low altitude VOR/DME coverage, as designated by the Administrator and published in FARs 71 and 75.

(9) Established RNAV Route - A predefined enroute segment, arrival, or departure route (including RNAV SIDs and STARs). It also includes enroute segments established with gaps in VOR/DME coverage for use of aircraft equipped with RNAV systems capable of automatic dead reckoning.

(10) Flight Path Angle - A vertical angle defining an ascending or descending path TO a specified altitude (MSL) at a specified waypoint. *

(11) Flight Technical Error (FTE) - Flight Technical Error refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the indicated aircraft position to match the indicated command or desired position. It does not include procedural blunders.

(12) Instrument Approach Waypoints - Fixes used in defining RNAV instrument approach procedures, including the INITIAL APPROACH WAYPOINT (IAWP), INTERMEDIATE WAYPOINT (INWP), the FINAL APPROACH WAYPOINT (FAWP), the MISSED APPROACH WAYPOINT (MAWP), and the RUNWAY WAYPOINT (RWY WP). *

(13) Parallel Offset Route - A desired parallel track to the left or right of the "parent" or designated route specified in whole nautical miles.

(14) Reference Facility - The ground VOR/DME facility used for the identification and establishment of an area navigation route, waypoint, or flight procedure.

(15) RNAV Instrument Approach Procedures - Instrument approach procedures based on RNAV and identified by the prefix RNAV followed by the procedure number; i.e., RNAV Rwy 21 or RNAV-A.

(16) RNAV Transition Routes for Initial Approach - Transition routes, based on RNAV, from the enroute environment to the initial approach waypoint of an instrument approach procedure. RNAV transition routes may be included in conventional approach procedures such as ILS, as well as in complete RNAV approach procedures.

(17) Route Segment - Two subsequently related waypoints (or ATD fixes) define a route segment.

(18) Slant Range - The actual distance between aircraft in flight and certain air navigational aids (radar, DME). This distance is greater than the geographical range because of the altitude of the aircraft.

(19) Slant Range Error - Slant range error is the difference between the distance of an aircraft to a point on the surface and the distance from that point along the surface to a point directly beneath the aircraft.

(20) Tangent Point - The point from which a line perpendicular to the RNAV route centerline passes through a specified VORTAC.

(21) Tangent Point Distance (TPD) - Distance from VORTAC to tangent point.

(22) Track Angle - Settings used in station oriented RNAV systems to identify prescribed routes and tracks over the ground from point to point.

(23) Turn Points - A waypoint which identifies a change from one Great Circle track to another along a given route.

(24) Vertical Navigation (VNAV) - That function of RNAV equipment which provides guidance in the vertical plane.

* (25) Vertical Path Angle - (See Flight Path Angle). *

(26) Waypoint - A predetermined geographical position used for route definition and/or progress reporting purposes that is defined relative to a VORTAC reference facility.

(27) Waypoint Displacement Area - The rectangular area formed around the plotted position of the waypoint. The rectangle is oriented along the desired track with the waypoint at its center. Its dimensions are two times (plus-and-minus) the appropriate along-track and cross-track fix displacement error values.

f. Application of area navigation equipment and procedures in the National Airspace System requires that they be compatible with the VOR/DME system on which route structure and air traffic control are based. Implementation, therefore, requires that area navigation devices employed assure proper positioning with respect to the VOR/DME route structure by reference to the geographic locations of VOR/DME ground facilities. Such systems must further permit navigation along, and within the protected airspace of, conventional VOR routes, airways, and terminal procedures.

g. 2-D Systems - To assure compatibility with existing ATC routes and procedures, 2-D area navigation systems typically compute distances, bearings, and/or command guidance signals relative to "waypoints" that are used to define RNAV route segments in relation to VOR/DME station locations. A succession of these waypoints defines the centerline of the route to be flown.

h. 3-D area navigation systems include the functions of 2-D systems with vertical guidance added. Vertical guidance includes computed deviation from desired ascending or descending path to a specified altitude at the waypoint, which is included in the route definition.

i. The advantages of area navigation are applicable to VFR as well as IFR operations. For VFR operations, straight line point-to-point navigation, bypassing of congested and restricted area, and elimination of air navigational facility overhead requirements are the principal advantages gained, and each contributes to the reduction of pilot workload and to flight safety. Installation requirements for VFR use only are shown in Appendix A, Page 13, Paragraph 4.

j. For IFR operations, area navigation offers similar benefits, but must be conducted in accordance with standards and procedures designed to ensure the safe, expeditious, and orderly movement and control of air traffic within prescribed airspace dimensions.

k. Introduction of an area navigation capability into the National Airspace System provides a means for overcoming many of the disadvantages of the VOR structure. By eliminating the requirement to fly along radials that lead directly to or from the ground station, it is possible to design routes and procedures that better facilitate the movement of traffic. Typical of the benefits that result are:

(1) Congested area bypass routes.

(2) Multiple routes to allow segregation of traffic according to speed or other operating characteristics.

(3) Pilot navigation of commonly flown radar vector paths.

(4) Improved alignment of routes.

(5) Dual routes for one-way traffic.

(6) Increased instrument approach capability.

(7) Optimum location of holding patterns.

(8) Procedures designed for STOL and helicopter operations.

l. FAA encourages the installation of area navigation equipment and has established routes and terminal procedures that are specifically designed for, and are beneficial to, properly equipped users.

m. Previous action was directed to the development of transcontinental and major hub connecting routes along with terminal procedures to serve these routes. Development of other routes and terminal procedures will be consistent with user needs whenever possible.

2. WHERE TO APPLY FOR APPROVAL.

a. Application for approval of an area navigation equipment installation other than those relating to an application for a Supplemental Type Certificate (STC) may be made to any FAA Air Carrier, General Aviation District Office, or Flight Standards District Office.

b. Application for a Supplemental Type Certificate covering an area navigation equipment installation may be made to any FAA Regional Engineering and Manufacturing Office.

c. Application for approval of new area navigation routes and instrument approach procedures should be made to the appropriate FAA regional office. Air carrier/air taxi requests should be forwarded to the appropriate Flight Standards District Office.

d. Air Carriers should advise the certificate-holding office of any application made to other offices.

3. AREA NAVIGATION EQUIPMENT. Equipment that meets the performance specifications outlined in Appendix A is suitable for use within the NAS. A single system will be considered suitable to meet these requirements. Equipment may include doppler radar, inertial, pictorial display/course line computers, or any other technique/device that will ensure compatibility with the operational procedures, route widths, vertical separation, and obstacle clearance requirements prescribed. Pictorial displays or course line computers provide one of the typical methods of operating on an area basis. This method is predicated on utilizing the signals from VOR/DME ground stations, or other facilities offering equivalent accuracy. The airborne equipment standard is the minimum for IFR. However, the NAS will recognize various levels of equipment sophistication. The more sophisticated equipment will include track

smoothing, turn anticipation, parallel offset capability, and at least a 6 waypoint storage for 2-D and at least a 10 waypoint storage capability for 3-D. They will normally use ARINC quality components which are more accurate than the minimum standards require and often utilize more than DME/VOR inputs. They typically use heading and air data or even inertial and ILS information to improve on the basic accuracy. The minimum equipment will use the published reference facility. It normally does not employ track smoothing and rarely utilizes more than two waypoints. It is the minimum for IFR approval. This level of equipment is expected to be limited ultimately in the NAS, particularly in the terminal area where the cockpit workload is such that 6 to 10 waypoint storage, parallel offset and turn anticipation features will be very desirable.

RNAV will be used in all phases of the NAS. Although current use is primarily enroute, it is expected to become increasingly important in terminal airspace. Sophisticated RNAV systems -- especially when supplemented with airborne 3-D capability -- are expected to provide the user with significantly improved instrument approach capability when compared with the non-precision approaches currently used. The minimum RNAV systems on the other hand will be of limited usefulness in the terminal area. The minimum system cannot supplant VOR/DME and localizer for use as an approach aid except under special conditions where certain geometrics can show an advantage for this level of RNAV. RNAV approach procedures which cater to the minimum equipment levels will normally not be developed in high density terminal areas except where a definite operational advantage can be the result as at an airport located over 10 miles from the reference facility or where circling minimums only apply, or where a localizer back course is unflyable; etc., or to satisfy a specific user need.

4. PROCEDURES. In order to prolong the usefulness of the minimum equipment systems, procedures will be developed, where possible, with only two required waypoints. It must be noted, however, that procedures in complex terminals may require the use of up to 6 waypoints in rapid succession for 2-D and up to 10 for 3-D. The minimum equipment systems, although sufficiently accurate to meet present RNAV requirements, will find these complex procedures unflyable because of the extremely high cockpit workload.

5. TURN ANTICIPATION. Pilots flying the system are expected to initiate a turn prior to reaching the turning point in order to intercept the next segment without overshoot. Pilots flying systems which do not automatically anticipate the turn should use a method which involves "leading" the turn by approximately one mile for each 100 knots true airspeed. Automatic coupled systems must have the capability of similar methodology.

6. GROUND FACILITIES. Throughout the text of this Advisory Circular, ground
* facility references are to VOR/DME. Where TACAN service is provided in the NAS, any TACAN user whose equipment meets the minimum system performance characteristics of the U.S. National Aviation Standard for VORTAC (AC 00-31) may apply TACAN to all VOR/DME references herein. *

APPENDIX A. AIRBORNE AREA NAVIGATION SYSTEMS: ACCEPTABLE MEANS OF COMPLIANCE WITH AIRWORTHINESS REGULATIONS

1. INTRODUCTORY REMARKS.

a. Area navigation systems based on VORTAC stations have four sources of error: (1) ground VOR/DME radiated signal; (2) airborne VOR/DME equipment; (3) flight technical (pilotage); and (4) the air navigation equipment itself. It is assumed further that these are independent errors having such distribution that they may be combined root-sum-square (RSS) fashion. See Appendix C.

b. The means of compliance presented herein apply to systems that use VOR/DME sensor signals either for direct aircraft position determination or for updating aircraft position derived from other sources such as air data computers and magnetic compasses, inertial navigation systems, and doppler radar navigation systems. However, RNAV systems may employ sensor inputs other than VOR/DME without VOR/DME updating if equivalent accuracies can be demonstrated by means suitable to such systems.

c. The problem of slant range error takes on particular significance under the area navigation concept because of a direct effect upon the intended route of flight. Airborne systems that are dependent upon ground station signals for course guidance are subject to this error, while self-contained systems are not. Of the former, some systems are designed to compensate for slant range error and others are not. The problem is even more significant above FL 180, where airspace buffers are not planned.

2-D airborne systems affected by slant range error are accommodated through procedural compensation by the airspace planning and air traffic control systems outside the terminal area below FL 180. Route design compensations will take the form of limitations of the proximity of route centerlines to the reference facility, increased lateral dimensions for routes that must pass in proximity to reference facilities and increased lateral spacing of dual or parallel routes.

Air traffic control compensation is in the form of longitudinal and lateral separation criteria that encompasses the extremes of slant range error possibilities.

3-D Systems are expected to incorporate slant range correction because the input data for the correction is normally available, therefore, 3-D route planning and traffic control will NOT allow for slant range error.

Elimination of slant range error and its attendant compensating procedures is prerequisite to the development of optimum routes and separation criteria. FAA plans to initiate rulemaking action in the near future requiring slant range correction in terminal hubs and at FL 180 and above. This level may be lowered as operational experience is gained.

2. ACCETPABLE MEANS OF COMPLIANCE (FOR USE UNDER INSTRUMENT FLIGHT RULES) An acceptable means of compliance with Section -.1301, -.1309, -.1431, and -.1581, of Part 23, 25, 27 or 29 (as applicable), with respect to area navigation systems, provided for use under IFR conditions, is to satisfy the criteria set forth in this paragraph.

a. Accuracy.

(1) 2-D RNAV System using Reference Facility for continuous navigation information. The total of the error contributions of the airborne equipment (receivers plus area navigation - including desired track setting as well as waypoint setting errors) when combined RSS with the following specific error contributions should not exceed the error values shown in Table 1, Appendix A

VOR ground station	± 1.9°
DME ground station	± 0.1 NM

(2) 2-D RNAV systems which use VOR/DME information from other than the Reference Facilities must show that the algorithm used will always select a station that will provide cross track/along track errors equal to or less than the greater of the RNAV system errors of the reference facility for any RNAV track (Table 1) or the errors shown in paragraph 2.a.(3).

(3) 2-D RNAV System not using VOR/DME for continuous navigation information. The total of the error contributions of the airborne equipment (including update, aircraft position and computational errors), when combined with appropriate flight technical errors listed in 2.a.(4) below, should not exceed the following with 95% confidence (2-sigma) over a period of time equal to the update cycle:

	Cross Track	Along Track
Enroute	2.5 NM	1.5 NM
Terminal	1.5 NM	1.1 NM
Approach	0.6 NM	0.3 NM

(4) 2-D Flight Technical Errors (FTE) when combined RSS with the errors discussed in (1) and/or (a) above determine the Total

System error. The Total System error is used by airspace planners and includes the following specific FTE values for determining cross-track position accuracies. Values larger than these must be offset by corresponding reduction in other system errors. (See Appendix C) No FTE is used in determining the along-track accuracy.

Enroute	± 2.0 NM
Terminal	± 1.0 NM
Approach	± 0.5 NM

(5) 3-D RNAV Systems. The total of the error contributions of the airborne equipment, including sensors and area navigation:

(a) Should not contribute any new horizontal error, and

(b) When combined RSS with the specific vertical error contributions for "Flight Technical" listed in Table B of this Appendix, should not exceed the total RSS accuracy requirements of Table B, Appendix A.

(c) Vertical Navigation Equipment (VNAV)

Total vertical navigation system accuracy criteria are based largely on the satisfactory experience of many years with the present separation standard of 1000 feet, while also anticipating the probable needs of the air traffic system in the future.

The total 3-D system accuracy requirements for level flight are stated in Table A. The requirements are based on final approach, terminal area, and enroute operations in level flight. The specific requirements are based on the obstacle clearance standards for final approach and on airspace protection standards up to FL 290. The requirements for operations above FL 290, where separation standards change, are based on performance levels typical of altimetry systems meeting accuracy requirements for final approach and enroute operations up to FL 290.

The 3-D system accuracy for other than level flight varies with the ascent/descent angle. This variance is due to the flight technical error which has been shown to vary with the angle of ascent or descent. These variations are shown in Table B.

MINIMUM ACCURACY REQUIREMENTS FOR VERTICAL GUIDANCE EQUIPMENT EMPLOYED IN AIRBORNE VERTICAL NAVIGATION SYSTEMS

Level Flight

Flight Segment	Altitude Region	Total Vertical Error in Feet (3σ) (99.7% confidence)	Remarks
Final Approach	At or below 5000' MSL	200	Meets the obstacle clearance requirements of 250'.
Terminal Area	At or below 10000' MSL	350	Meets the 1000' level flight vertical separation requirement.
Enroute	All altitudes	350	Meets the 1000' level flight vertical separation requirement.

TABLE A

Table B illustrates typical error budgets where errors are assumed to be independent and are combined by the root-sum-square (RSS) method. These accuracy requirements provide an adequate buffer zone to accommodate all normally encountered atmospheric anomalies and reference discrepancies without jeopardizing the validity of the 1000 foot vertical separation standard in level flight.

The table lists vertical position error budgets without regard for horizontal position uncertainty. In a dynamic situation, additional vertical errors must be considered during ascending and descending flight because the aircraft may be either ahead of or behind its assumed position along track. For systems meeting minimum horizontal position accuracy requirements, this additional error is generally larger than the non position-dependent vertical position errors shown. The airborne computer calculates the descent angle and commands an altitude for the assumed position. If the aircraft is behind the assumed position, the aircraft is below the intended track by an amount proportional to the along-track error. This error must be added (RSS) to the basic vertical position errors shown when calculating airspace protection and obstacle clearance during descent.

SUMMARY OR REPRESENTATIVE VERTICAL GUIDANCE ERROR BUDGET IN FEET 99.7% (3σ)						
Error Source	*Final Approach 5000 feet MSL and below		*Terminal 10,000 feet MSL and below		Enroute (1) All altitudes	
	Level Flight	Ascent or Descent	Level Flight	Ascent or Descent	Level Flight	Ascent or Descent
Altimetry (3)	90	140	200	265	250	350
VNAV Equipment (4)	100	100	150	150	0 (2)	220
Flight Technical (5)	150	200	250	300	250	300
TOTAL RSS (3σ)	200	265	350	430	350	510

TABLE B

NOTE 1. Maximum operating altitudes to be predicated on compliance with total accuracy tolerance.
*When final approach and terminal area procedures are developed above altitudes shown, error is increased proportionately in the altimetry and RNAV parameters to provide airspace and obstacle clearance protection.

NOTE 2. In the event that VNAV guidance is used in level flight enroute the incremental error component contributed by the VNAV equipment must be offset by a corresponding reduction in other error components, such as flight technical error, to ensure that the total error budget is not exceeded.

NOTE 3. <u>Altimetry Error</u>. Refers to the electrical output and includes all errors attributable to the aircraft altimetry installation including position effects resulting from normal aircraft flight attitudes. <u>In high performance aircraft, it is expected that altimetry correction will be necessary to meet these requirements. Such correction should be done automatically. In lower performance aircraft, upgrading of the altimetry system may be necessary</u>. The larger errors shown for ascent/descent are typical of automatically corrected altimeter systems which meet the level flight error budget.

NOTE 4. <u>VNAV Equipment Error</u>. Includes all errors resulting from the vertical guidance equipment installation. Does not include errors of altimeter system but does include any additional errors resulting from the addition of the VNAV equipment. This error component may be disregarded in level enroute flights if the operation is limited to guidance by means of the altimeter only. It should not be disregarded in the terminal and approach operations, where the pilot is expected to follow the VNAV indications.

NOTE 5. Flight Technical Error. Includes errors in pilot interpretation of vertical guidance instrumentation, pilot activation of aircraft vertical controls, and deviations caused by aircraft response characteristics. Consideration is given to the relatively high pilot proficiency and good aircraft characteristics expected to be found in most operations at the higher altitudes. These values represent consensus estimates based upon experience and some limited testing; and for cases in which there is no relevant experience, they are conservative estimates. It is recognized that there are several design and operational parameters that could affect those values including display configuration, autopilot coupling versus manual control, pilot workload, and variation of aircraft response with increasing gross weight and altitude. As operational experience and experimental data are accumulated and analyzed, the values will be suitably adjusted.

(6) All RNAV equipment approved for use under Instrument Flight Rules (IFR) must meet the appropriate accuracy criteria. Should it not meet these criteria, a placard must be installed in the aircraft which reads "IFR Operation Not Authorized."

(7) Equipment presented will be approved by issuance of an STC or, upon prior approval from the appropriate regional office, may be approved by a properly processed Form 337 in the field.

b. Area Navigation System Design.

(1) General. The systems will normally use VOR/DME input sensor signals (or use combinations of VOR and DME for updating purposes) and indicate aircraft positions relative to the RNAV route and selected waypoint. Systems may be designed to utilize other

sensor inputs if equivalent accuracy can be demonstrated. Installations intended for final approach should use position information that is essentailly continuous with interruptions no longer than would result from switching from one preprogramed waypoint to another. The system should give no operationally significant misleading information.

(2) Vertical Guidance Input Controls.

In the absence of pre-stored or automatically inserted flight profile parameters, pilot controls shall provide for at least the following inputs:

(a) Station Elevation. For systems employing slant range error correction, elevation of the VOR/DME ground station in increments not greater than 100 feet if used during final approach, and for other phases in increments not greater than 1000 feet.

(b) Waypoint. Waypoint altitude in increments not greater than 10 feet if used during final approach, and for other phases in increments not greater than 100 feet. Waypoint horizontal position shall be entered in increments not greater than 0.1 nautical mile or 0.2 degree bearing from the station or the equivalent.

(c) Flight Path Angle. Vertical gradient from a zero degree origin in increments not greater than 0.1 degree or the equivalent.

(3) Checking of Input. Provisions should be made to enable the pilot to check the correctness of the inputs.

(4) Altimeter Setting. The system shall be so designed that there is no requirement to insert separate barometric correction inputs into the vertical guidance computer. Adjusting one of the barometric pressure altimeters in the cockpit should automatically provide the corrected input to the vertical computer. In order to avoid the abrupt irregularity in the computer vertical flight path at the transitional level, the pilot will make altimeter setting changes between local and standard 29.92" Hg. above the transitional level. Airspace will be buffered above this level to account for the discontinuities in the vertical flight path and the pilot will be expected to make the change gradually so as not to introduce unacceptably abrupt flight path requirements.

(5) Vertical Guidance Display. The equipment shall provide a vertical guidance presentation compatible with the aircraft's flight instrumentation such that the pilot is continuously furnished vertical deviation of the aircraft with respect to a pre-programed ascent/descent or level flight profile.

(6) Failure Warning. Provision should be made to alert the crew upon occurrence of any probable failure of major system functions or loss of inputs, including those that would affect aircraft position, heading, command course, command heading, altitude, or vertical guidance indications.

(7) Performance Check. Provision should be made for checking the system's performance on the ground and in flight. This may be a built-in check, an auxiliary test system or a procedural check.

(8) Response Time. The navigation display should indicate aircraft position, to the accuracy specified in Paragraph 2.a., assuming that navigation sensor outputs are available:

(a) During flight in any direction at the maximum ground speed declared by the equipment manufacturer, and

(b) During ascent or descent at the maximum rates declared by the equipment manufacturer, and

(c) Within five seconds after any normal maneuver, assuming sensor inputs are not lost during the maneuver.

(d) The time lag between time of data input and guidance derived from the display of the data should not be operationally significant.

NOTE: Terminal area speed limitations are taken into account in connection with this provision. Moving elements of the navigation display may be damped.

(9) Coordination of Displays. In installations incorporating both horizontal and vertical guidance, there should be no operationally significant difference between the various displays used by the flight crew. For example, if a descent is programmed to end at a waypoint, the command to level off should be operationally coincidental with the waypoint indication. This is not intended to preclude maneuver anticipation.

(10) Environmental Conditions. The area navigation equipment should be capable of satisfying the criteria set forth in Paragraph 2.a. and 2.b. above over the environmental ranges expected to be encountered in actual aeronautical operations. In demonstrating compliance, the environmental conditions outlined in Radio Technical Commission for Aeronautics Document DO-138 titled "Environmental Conditions and Test Procedures for Airborne Electronic/Electrical Equipment and Instruments" dated June 27, 1968, or other appropriate environmental standards may be used.

(11) Auto Tune Systems. Systems which automatically tune/select VOR/DME facilities for navigation or update should be limited to a search range of 130 NM for high altitude facilities and 40 NM at 18,000 feet and below for low altitude facilities in keeping with the NAS frequency protection criteria unless through computer logic or a 'reasonableness test' faulty information is rejected.

(12) Turn Anticipation and Parallel Offset.

(a) RNAV systems which provide for parallel offset tracks must also limit the turning maneuver. Turns shall be anticipated and flown in such a way as to cause the aircraft to remain within $\pm$ 2.5 NM of the desired track centerline enroute and $\pm$ 1.5 NM of the centerline in the terminal area. Pilots flying systems which do not automatically anticipate the turn are expected to lead a turn by 1 NM per 100 knots true airspeed.

(b) 3-D systems shall not require additional controls to assure that the offset route is in the same horizontal plane as the parent route at the waypoint. The plane is measured on the bisector angle between centerlines of the adjacent route segments.

c. Area Navigation Equipment Installation.

(1) Location of the RNAV display. Each display element to be used as a primary flight instrument in the guidance and control of the aircraft should be located where it is clearly visible to the pilot with the least practicable deviation from his normal position and from his line of vision when he is looking forward along the flight path.

(2) Failure protection. Any probable failure of the airborne area navigation equipment should not derogate the normal operation of required equipment connected to it, nor cause a flight hazard.

(3) Radio frequency interference. The area navigation equipment should not be the source of objectionable radio frequency interference,nor be adversely affected by radio frequency emissions from other equipment in the aircraft.

(4) Manufacturer's instructions. The area navigation equipment should be installed in accordance with instructions and limitations provided by the manufacturer.

d. Aircraft Flight Manual. If an aircraft flight manual is provided by the aircraft manufacturer, its FAA approved portion may contain the following information on the area navigation equipment:

(1) Normal procedure for operating the equipment;

(2) Equipment operating limitations; and,

(3) Emergency operating procedures (if applicable).

If not contained in the aircraft flight manual, information on equipment operating limitations should be provided to the pilot by means of placards. The aircraft flight manual or placard should state "RNAV Instrument Approaches Not Authorized" if the instrumentation is such that FTE cannot be resolved to meet appropriate criteria. Revisions or supplements to the flight manual must be approved by the Regional Chief of the Engineering and Manufacturing Branch.

3. TESTING PROCEDURE (FOR EQUIPMENT PROVIDED FOR USE UNDER INSTRUMENT FLIGHT RULES)

a. General. An applicant for approval of an area navigation system installation in an aircraft may show that he has satisfied the criteria in Paragraph 2 by a combination of bench tests of the individual components (including VOR and DME) and ground/flight tests of the entire installed area navigation system. The bench tests may have already been performed by the individual component manufacturer (during design and construction) or by the installer (on behalf of a previous customer). Such bench test data, if certified by the manufacturer or installer are acceptable. In addition, the applicant may refer to applicable TSO standards, if the manufacturer of the equipment certifies that his equipment meets those standards.

b. Bench Tests. The following tests may be performed on the bench or with the navigation system installed in the aircraft:

(1) Test equipment. Bench test equipment should be capable of simulating the input signals from VOR/DME and/or the altimeter or other sensors and of varying those signals over the ranges for which the equipment is designed.

(2) Accuracy testing.

(a) Variables to be considered. Each variable that has a significant effect on position error should be investigated over its entire range, and the error analysis should show the effects of reasonably probable variations of these variables on total system accuracy. The statistical technique described in RTCA Document No. DO-153 entitled "Minimum Performance Standards -- Airborne VOR Receiving Equipment Operating Within the Radio Frequency Range of 108-118 Megahertz" dated August 18, 1972, may be used as a guide.

(b) Static test. Horizontal and/or vertical position accuracy should be measured statically as the error in displayed position relative to the theoretical position obtained from perfect signal inputs (range and bearing from a known station location and/or altitude). Simulated range and bearing and/or altitude signals are introduced into the area navigation equipment. Combinations of ranges from zero up to the maximum distance for which the equipment is designed, bearings from zero to 360 degrees, and altitudes up to the maximum certificated altitude for the aircraft should be inserted as input signals. For each set of input signals, the corresponding display output should be compared to the theoretical position and recorded as an RNAV system error. The errors for each test point are then combined statistically to determine the 2σ (95%) probable error. When this value exceeds the RNAV system error element shown on Table 1, the total horizontal system error must be computed by adding the RNAV system error RSS to the other system errors. See Appendix C. They should be within the values shown in Table 1 if the system is to be used in IFR flight. Note that only one error table is provided. This represents the required accuracy for IFR of VOR/DME equipment using the reference facility. The only variable between enroute, terminal, and approach is FTE (shown in 2.a.(4) above). Separate tables are redundant.

The vertical system error is computed by adding RSS the values for FTE (Table B) and altimetry appropriate to the installation. The values shown in Table 1 and the RSS totals in Table B should not be exceeded.

(c) Dynamic test. In addition to the static test, a dynamic accuracy test should be performed utilizing simulated VOR/DME and/or altimeter inputs varied in range, bearing and/or altitude in order to assess the ability of the system to smooth variable input signals without incurring excessive lag. These tests should be performed with representative simulated airspeeds throughout the range for which the equipment is designed. During these tests the measured RNAV equipment error should be consistent with the total system accuracies specified in Paragraph 2. Alternatively, an in-flight demonstration of satisfactory dynamic characteristics may be accepted.

(d) Systems having map type displays. If the system uses a map type pictorial display of aircraft position as a primary means of steering guidance, the accuracy determination should take into account any error contribution by the cartography.

(e) Altimetry tests. The accuracy of the installed altimetry system should be determined by tests, evaluation of previously approved data, or both, to assure that the altimetry error budget of Table B is not exceeded. Static system error determined during aircraft certification or determined by currently recognized means may be combined RSS with scale error data for the altimeter.

c. Ground/flight tests.

(1) Ground tests. After the area navigation system has been installed, but before the aircraft is flown, an operational/functional check should be performed to ensure that the system has been installed in accordance with the installation criteria in Paragraph 2.c. (and with all applicable airworthiness regulations) and that it functions properly and safely.

(2) Determination of when flight tests are necessary. At least one flight test for accuracy in the approach case is necessary. Additional flight tests for accuracy are necessary if the system accuracy is not adequately determined by signal simulation as described in 3.b. above, or if it appears that the resolution of the pilot display is such

That the assumed FTE of 2.0 NM (enroute), 1.0 NM (terminal) or 0.5 NM (approach), will be exceeded.

NOTE: The "Approach" mode is defined as the flight operation between the final approach waypoint and the airport. The "Terminal" mode is defined as the ingress/egress flight operation between Enroute and Approach, normally below FL 180 within 50 miles of the airport. The "Enroute" mode is defined as the cruising flight operation between Terminal areas.

(3) Accuracy tests in flight. When the bench check data required by paragraph 3.b. above are not available, flight tests are necessary. Therefore, in addition to ground tests, to demonstrate satisfactory performance of the area navigation equipment, the airplane should be flown solely by reference to the RNAV display and other standard flight instruments, at a relatively low altitude under VFR conditions, with a safety pilot, and if practicable under ground radar surveillance as follows:

(a) Along the length of an FAA approved RNAV route segment.

(b) In accordance with an FAA approved RNAV terminal area procedure; and

(c) In accordance with an FAA approved RNAV approach procedure.

(d) During ascent and descent flight in terminal and/or final approach operation with theodolite observation or equivalent to check vertical angle performance of 3-D RNAV. Final approach performance may be compared against ILS signals.

In each case, the area navigation system is satisfactory if the equipment meets the accuracy requirements of Paragraph 2.a. as determined by direct visual reference or other suitable methods to identifiable ground check points and a large scale map of the area on which are shown route segment centerlines and boundary widths applicable to the distance from the reference facility.

(4) Functional test in flight. The area navigation system should be checked out in flight to determine whether the design and installation criteria in Paragraph 2.b. and 2.c. are satisfied.

4. ACCEPTABLE MEANS OF COMPLIANCE (FOR EQUIPMENT PROVIDED FOR USE UNDER VISUAL FLIGHT RULES ONLY)

a. An acceptable means of compliance with Sections -.1301, -.1309, -.1431 and -.1581, of Part 23, 25, 27, or 29 (as applicable), with respect to area navigation systems provided for use under VFR conditions only, is to satisfy the criteria in Paragraphs 2.c. and 3.c.(1) above, and to placrad the aircraft to limit the use of the area navigation system to VFR only.

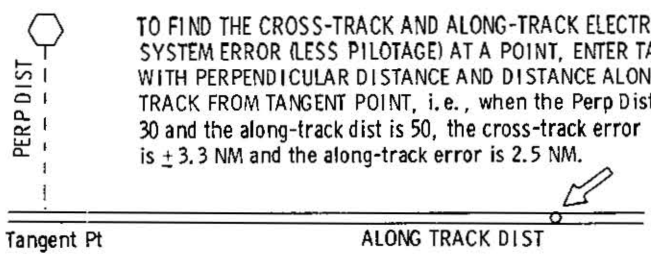
b. Airborne area navigation equipment installed under Paragraph 4.a. may be approved by means of a Form 337 or Supplemental Type Certificate.

5. MILITARY MEANS OF COMPLIANCE. Military RNAV equipment approval procedures, the means for designating equipment for use under VFR flight conditions only, and methods by which pilots are to be informed of equipment limitations will be accomplished by the individual military services. Military use of TACAN azimuth and distance information is assumed where VOR/DME is required.

VOR/DME/TACAN STATION REFERENCED AREA NAVIGATION ERROR TABLE (95% PROBABILITY)

DISTANCE ALONG TRACK FROM TANGENT POINT

PERPENDICULAR DIST TO TANGENT POINT	0	5	10	15	20	25	30	35	40	50	60	70	80	90	100	110	120	130	150	200
0(x trk)		.6	.8	1.1	1.3	1.6	1.9	2.2	2.5	3.1	3.7	4.4	5.0	5.6	6.2	6.8	7.4	8.1	9.3	12.4
(alg trk)		.7	.7	.7	.8	.9	1.0	1.2	1.3	1.6	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.9	4.5	6.0
5(x trk)	.7	.7	.8	1.1	1.4	1.6	1.9	2.2	2.5	3.2	3.8	4.4	5.0	5.6	6.2	6.8	7.5	8.1	9.3	12.4
(alg trk)	.6	.7	.8	.8	.9	1.0	1.1	1.2	1.4	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.6	6.1
10(x trk)	.7	.8	.9	1.1	1.4	1.7	2.0	2.3	2.6	3.2	3.8	4.4	5.0	5.6	6.2	6.9	7.5	8.1	9.3	12.4
(alg trk)	.8	.8	.9	.9	1.0	1.1	1.2	1.4	1.5	1.7	2.0	2.3	2.6	2.9	3.1	3.4	3.7	4.0	4.6	6.1
15(x trk)	.7	.8	.9	1.2	1.4	1.7	2.0	2.3	2.6	3.2	3.8	4.4	5.0	5.6	6.3	6.9	7.5	8.1	9.3	12.4
(alg trk)	1.1	1.1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.9	2.1	2.4	2.7	3.0	3.2	3.5	3.8	4.1	4.7	6.2
20(x trk)	.8	.9	1.0	1.2	1.5	1.8	2.1	2.3	2.6	3.2	3.8	4.4	5.1	5.7	6.3	6.9	7.5	8.1	9.4	12.5
(alg trk)	1.3	1.4	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.3	2.6	2.8	3.1	3.4	3.6	3.9	4.2	4.8	6.2
25(x trk)	.9	1.0	1.1	1.3	1.6	1.8	2.1	2.4	2.7	3.3	3.9	4.5	5.1	5.7	6.3	6.9	7.5	8.1	9.4	12.5
(alg trk)	1.6	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.1	2.3	2.5	2.7	3.0	3.2	3.5	3.8	4.0	4.3	4.9	6.3
30(x trk)	1.0	1.1	1.2	1.4	1.7	1.9	2.2	2.5	2.7	3.3	3.9	4.5	5.1	5.7	6.3	6.9	7.6	8.2	9.4	12.5
(alg trk)	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.5	2.7	2.9	3.2	3.4	3.7	3.9	4.2	4.5	5.0	6.4
35(x trk)	1.2	1.2	1.4	1.5	1.8	2.0	2.3	2.5	2.8	3.4	4.0	4.6	5.2	5.8	6.4	7.0	7.6	8.2	9.4	12.5
(alg trk)	2.2	2.2	2.3	2.3	2.3	2.4	2.5	2.5	2.6	2.8	3.0	3.2	3.4	3.6	3.9	4.1	4.4	4.6	5.2	6.5
40(x trk)	1.3	1.4	1.5	1.6	1.9	2.1	2.3	2.6	2.9	3.4	4.0	4.6	5.2	5.8	6.4	7.0	7.6	8.2	9.5	12.5
(alg trk)	2.5	2.5	2.6	2.6	2.6	2.7	2.7	2.8	2.9	3.0	3.2	3.4	3.6	3.8	4.0	4.3	4.5	4.8	5.3	6.7
50(x trk)	1.6	1.6	1.7	1.9	2.1	2.3	2.5	2.8	3.0	3.6	4.1	4.7	5.3	5.9	6.5	7.1	7.7	8.3	9.5	12.6
(alg trk)	3.1	3.2	3.2	3.2	3.2	3.3	3.3	3.4	3.4	3.6	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.2	5.7	7.0
60(x trk)	1.9	1.9	2.0	2.1	2.3	2.5	2.7	3.0	3.2	3.7	4.3	4.8	5.4	6.0	6.6	7.2	7.8	8.4	9.6	12.6
(alg trk)	3.7	3.8	3.8	3.8	3.8	3.9	3.9	4.0	4.0	4.1	4.3	4.4	4.6	4.8	5.0	5.2	5.4	5.6	6.0	7.3
70(x trk)	2.2	2.2	2.3	2.4	2.6	2.7	2.9	3.2	3.4	3.9	4.4	5.0	5.5	6.1	6.7	7.3	7.9	8.5	9.7	12.7
(alg trk)	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.6	4.6	4.7	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.5	7.7
80(x trk)	2.5	2.5	2.6	2.7	2.8	3.0	3.2	3.4	3.6	4.1	4.6	5.1	5.7	6.2	6.8	7.4	8.0	8.6	9.8	12.8
(alg trk)	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.2	5.2	5.3	5.4	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.9	8.0
90(x trk)	2.8	2.8	2.9	3.0	3.1	3.2	3.4	3.6	3.8	4.3	4.8	5.3	5.8	6.4	6.9	7.5	8.1	8.7	9.9	12.9
(alg trk)	5.6	5.6	5.6	5.6	5.7	5.7	5.7	5.8	5.8	5.9	6.0	6.1	6.2	6.4	6.5	6.7	6.8	7.0	7.4	8.5
100(x trk)	3.0	3.1	3.1	3.2	3.4	3.5	3.7	3.9	4.0	4.5	5.0	5.5	6.0	6.5	7.1	7.6	8.2	8.8	10.0	12.9
(alg trk)	6.2	6.2	6.2	6.3	6.3	6.3	6.3	6.4	6.4	6.5	6.6	6.7	6.8	6.9	7.1	7.2	7.4	7.5	7.9	8.9
110(x trk)	3.3	3.4	3.4	3.5	3.6	3.8	3.9	4.1	4.3	4.7	5.2	5.6	6.2	6.7	7.2	7.8	8.3	8.9	10.1	13.0
(alg trk)	6.8	6.8	6.9	6.9	6.9	6.9	6.9	7.0	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.8	7.9	8.1	8.4	9.4
120(x trk)	3.6	3.7	3.7	3.8	3.9	4.0	4.2	4.4	4.5	4.9	5.4	5.8	6.3	6.8	7.4	7.9	8.5	9.0	10.2	13.1
(alg trk)	7.4	7.5	7.5	7.5	7.5	7.5	7.6	7.6	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.5	8.6	9.0	9.9
130(x trk)	3.9	4.0	4.0	4.1	4.2	4.3	4.5	4.6	4.8	5.2	5.6	6.0	6.5	7.0	7.5	8.1	8.6	9.2	10.3	13.2
(alg trk)	8.1	8.1	8.1	8.1	8.1	8.1	8.2	8.2	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.2	9.5	10.4
140(x trk)	4.2	4.3	4.3	4.4	4.5	4.6	4.7	4.9	5.0	5.4	5.8	6.3	6.7	7.2	7.7	8.2	8.8	9.3	10.5	13.3
(alg trk)	8.7	8.7	8.7	8.7	8.7	8.8	8.8	8.8	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	10.0	10.9
150(x trk)	4.5	4.6	4.6	4.7	4.8	4.9	5.0	5.2	5.3	5.7	6.0	6.5	6.9	7.4	7.9	8.4	9.0	9.5	10.6	13.5
(alg trk)	9.3	9.3	9.3	9.3	9.4	9.4	9.4	9.4	9.5	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.6	11.4



TO FIND THE CROSS-TRACK AND ALONG-TRACK ELECTRONIC SYSTEM ERROR (LESS PILOTAGE) AT A POINT, ENTER TABLE WITH PERPENDICULAR DISTANCE AND DISTANCE ALONG TRACK FROM TANGENT POINT, i.e., when the Perp Dist is 30 and the along-track dist is 50, the cross-track error is ± 3.3 NM and the along-track error is 2.5 NM.

ERROR ELEMENTS	
GROUND	
VOR	1.9°
DME	0.1 NM
AIRBORNE	
VOR	3.0°
DME	3% or 0.5 NM
RNAV SYSTEM	0.5 NM
PILOT	ZERO

TABLE 1

APPENDIX B. PROCEDURE FOR OBTAINING FAA DATA APPROVAL BY SUPPLEMENTAL TYPE CERTIFICATE (STC) OR MAJOR REPAIR AND ALTERATION (FORM 337) (FOR EQUIPMENT PROVIDED FOR USE UNDER INSTRUMENT FLIGHT RULES)

1. APPROVAL OF TECHNICAL DATA BY SUPPLEMENTAL TYPE CERTIFICATE (STC).

a. What the STC applicant does:

(1) Makes an application for STC at the FAA Regional Engineering and Manufacturing office. Early contact is wise, since scheduling may be critical. FAA evaluates the data submitted by the applicant (see Paragraph 1.b.), issues a Type Inspection Authorization (TIA), and participates in ground/flight tests outlined in Appendix A, Paragraph 3.c. An STC is issued when all airworthiness requirments are met. If the submitted data is adequate, the STC authorizes similar installations in the same aircraft type.

(2) Designs and constructs his area navigation system installation to the criteria set forth in Appendix A, Paragraph 2.

(3) Obtains, from the equipment manufacturer or the installer, the bench test data described in Appendix A, Paragraph 3.b., or an appropriate certification of accuracv per Paragraph 3.a., or conducts these bench tests himself.

(4) Makes available an aircraft (with the area navigation system installed) for ground inspection and flight test. The applicant is responsible for furnishing a qualified flight crew for conducting the required flight tests.

b. Data submitted by the STC applicant. The following kinds of data be submitted for FAA airworthiness evaluation:

(1) Equipment data, such as:

(a) Equipment schematics.

(b) Equipment manufacturer's operating instructions and installation instructions.

(c) Equipment manufacturer's quality control procedures.

NOTE: Equipment data is submitted for original installation only.

(2) Fault analysis covering installation.

(3) Installation information and/or photographs.

(4) Any needed structural substantiation.

(5) Electrical schematics.

(6) Any needed flight manual revision or supplement, or placard drawings.

(7) Evidence of previously approved data.

c. What the Equipment Manufacturer Can Do.

(1) Assist the STC applicant by supplying the data specified in Paragraphs 1.a.(3) and 1.b.(1).

(2) Perform the bench tests described in Appendix A, Paragraph 3.b. and certify (to the applicant and FAA) that the accuracy criteria in Appendix A, Paragraph 2.a., are satisfied.

2. APPROVAL OF TECHNICAL DATA BY FORM 337, Major Repair and Alteration (Airframe, powerplant, propeller or appliance) OMB 04-R060.1 (FOR USE UNDER INSTRUMENT FLIGHT RULES).

a. Data Submitted by the Applicant. The following alteration data for the equipment installation will be submitted with a properly executed Form 337.

(1) Data to confirm that the requirements of Appendix A, Paragraph 2, have been met.

(2) Data to confirm that the requirements of Appendix A, Paragraphs 3.b. and 3.c. have been met.

b. Additional Data Which May be Required. If required for FAA Airworthiness evaluation by the FAA District Office approving the technical data, the applicant may also be required to furnish a copy of the equipment schematics, manufacturer's operating and installation instructions, fault analysis for installation, installation details and/or photographs, substantiation of structural changes, electrical schematics, and any appropriate proposed flight manual revision and/or placards.

c. Inspection of Aircraft. Make the aircraft available for data conformity inspection.

APPENDIX C. SOURCES OF NAVIGATION SYSTEM ERROR

1. GENERAL. The establishment of relationships between navigation system accuracy and IFR aircraft separation criteria or route widths is a complex process. The first problem is to determine a reasonably achievable level of navigation system accuracy. This must be based not only on analysis of the measurable system error elements for state-of-the-art equipment but also on a series of intangibles judged primarily on the basis of experience.

Current separation criteria, based on such analysis and experience, provide aircraft under IFR control a high degree of protection against collision with other aircraft or obstructions. These criteria take into account the measured accuracies of the VOR/DME ground facilities and airborne equipment and judgments as to how pilots actually fly their airplanes. Accumulating evidence shows that VOR/DME information, when used with area navigation computing and display devices and presented properly to the pilot, offers the potential for an even more efficient utilization of the airspace while maintaining current standards of in-flight safety.

2. CURRENT RELATIONSHIP BETWEEN NAVIGATION ACCURACY AND ROUTE WIDTH. The system of airways and routes used in the United States has widths of route protection used on a VOR system use accuracy of ± 4.5 degrees on a 95 percent probability basis. The ± 4.5 degrees for VOR justifies the application of ± 4 nautical mile route width out to a distance of 51 NM from the facility and a widening of route protection on the ± 4.5 degree basis beyond 51 miles.

3. CURRENT RELATIONSHIP BETWEEN VERTICAL NAVIGATION ACCURACY AND SEPARATION STANDARDS. The system of airways used in the United States allow for altimetry systems errors and atmospheric errors of various amounts dependent on mode of flight and altitude of the flight operations. Altimeter standards for accuracy (TSO C 10b) requires certain demonstrations of accuracy over a wide range of conditions including temperature, vibration and pressure. These accuracies combined with the expected changes in atmospheric pressure over the distances used and pilotage factors do not exceed a value which would interfere with other IFR aircraft operating with 1000' vertical separation below FL 290 and with 2000' vertical separation above FL 290. These are the vertical separation standards currently used. Efforts have been made to improve altimeter performance above FL 290 in order to permit application of 1000' vertical separation above, as well as below, this flight level. The accuracy requirements of the current altimeter standards are not stringent enough to meet this goal but the minimum accuracy requirements of Appendix A, Tables A and B are intended to support 1000' vertical separation at all flight levels.

4. SOURCES OF ERROR.

a. Horizontal Errors. The basic assumption is that four sources of error - ground VOR and DME radiated signal, airborne VOR receiver equipment, area navigation equipment, and pilotage - contribute independent errors of such distribution that they may be combined in RSS fashion. This is the normal assumption used traditionally by the FAA and is required by the method recommended by ICAO Annex 10 for the determination of VOR system use accuracy (ICAO Annex 10, Second Edition, April 1968, Attachment C to Part I, Paragraph 3.6, VOR System Accuracy). All errors are based on a 95 percent probability basis.

Errors from the four major sources listed above are actually composite values including error contributions from various factors. For example, "Errors in radiated signals" include propagation errors as well as errors in the transmitted signals arising from geographical siting and magnetic alignment of the ground station.

(1) "Airborne VOR equipment errors," in accordance with common practice include not only errors in the receiver outputs, but also errors contributed by the converter and the conventional course selector and deviation indicator. In those cases in which an area navigation system accepts inputs directly from the receiver, the error components normally included for the converter and indicator are not incurred and, therefore, the appropriate value for "airborne VOR equipment error" can be correspondingly reduced. (NOTE: This factor is considered subsequently as one type of error compensation that may be afforded by area navigation equipment.) The errors for DME receivers to be used in conjunction with area navigation equipment, although small compared to the total system use error, are taken into account in Tables 1, 2, and 3, Appendix A.

(2) "Area navigation equipment error" includes error components contributed by any input, output, or signal conversion equipment used, by any computing element employed, by the display as it presents either aircraft position or guidance commands (e.g., course deviation or command heading), and by any course definition entry devices employed. For systems in which charts are incorporated as integral parts of the display, the "area navigation equipment error" necessarily includes charting errors to the extent that they actually result in errors in controlling the position of the aircraft relative to a desired path over the ground. To be consistent, in the case of symbolic displays not employing integral charts, any errors in waypoint definition directly attributable to errors in reference charts used in determining waypoint positions should be included as a component of "area navigation equipment error." This type of error is virtually impossible to handle and in general practice highly accurate published waypoint locations are used to the greatest extent possible in setting up such systems to avoid such errors (and to reduce workload).

(3) The 'flight technical error' refers to the accuracy with which the pilot controls the aircraft as measured by his success in causing the indicated aircraft position to match the indicated command or desired position on the display. Manual insertion errors are due to the human interface with the control and display units that affect the performance of an RNAV operation. The resulting error causes a deviation from the defined RNAV flight plan. These errors are usually recognized and corrected before developing in magnitude to a point where they may be considered blunders. However, "manual" errors also include undetected errors such as inaccuracies in track setting and in setting waypoint bearing information in some types of systems.

Blunder errors are gross errors in human judgment or attentiveness that cause the pilot to stray significantly from his area navigation flight plan, and are not included in the area navigation system error budget. Blunder tendency is, however, an important system design consideration.

Pilotage error will vary widely, depending on such factors as pilot experience, pilot workload, fatigue, and motivation. Equipment design and ambient environment variables also affect pilotage directly and measurably, such as:

Processing of the basic display inputs (i.e., smoothing and quickening), whether or not heading is presented integrally with position and/or command guidance indications, display scale factors, numerous display configuration variables, aircraft control dynamics, air turbulence, and many more. Strictly speaking, with autopilot coupling, "flight technical error" becomes "autopilot error." These factors must be taken into account in arriving at empirical values for pilotage contribution to system use accuracy.

Evaluation of area navigation equipment to the present time indicates that the flight technical error, using such equipment, is linear in nature. A value of $\pm$ 2.0 NM is typical for the enroute case and $\pm$ 0.5 is typical for final approach operations.

"Manual" errors, however, are not linear in nature. Track setting error, for example, is angular, and its effect on cross-track error is a function of distance from the waypoint.

The term "pilotage error" in the RNAV equipment error budget Appendix A includes ONLY the FLIGHT TECHNICAL ERROR element described above, and "manual" errors must be considered in the AIRBORNE EQUIPMENT ERROR BUDGET.

b. Vertical Errors. The sources of vertical error are listed in Appendix A, paragraph 2a(5)(c) Table B, of this advisory circular.

5. COMBINING THE ERROR ELEMENTS. Based on the assumptions that the variable errors from the various sources are normally distributed and independent, they may be combined in RSS (root-sum-squares) fashion. Thus, the standard deviations obtained from the various contributing sources may be combined geometrically rather than arithmetically by taking the square root of the sum of their squares:

$$\sigma\ \text{total} = \sqrt{\sigma 1^2 + \sigma 2^2 \ldots + \sigma n^2}$$

6. ERROR BUDGETING.

a. In optimizing a navigation system design, it is generally desirable to avoid having the error from one source much larger than those from the other sources since, by the RSS method of combination, it contributes disproportionately to the total error. However, it may be technically easier, cheaper, or operationally more desirable to reduce the error from one source rather than another in order to meet a total system use accuracy requirement.

b. In establishing an error budget, a system designer may trade off reduction in the errors from one or more sources against increases in the errors from others. Thus, in adding an area navigation computing and display capability to the basic VOR/DME system, it is necessary and possible to compensate for the errors introduced by the new equipment by means of reductions in errors from other sources. Any of the airborne error elements, including Flight Technical Error, may be traded provided the total system accuracy reflected in Appendix D, Tables 2, 3 and 4 are met.

(1) Assume that a company sells an airborne VOR system designed to fly within a ± 4 NM route width to a distance of 51 NM from a ground facility on the basis of the following error budget:

(2)

Ground VOR Station Error	±1.9° @ 51 NM = 1.7 NM cross-track error
Airborne VOR Equipment Error	±3.0° @ 51 NM = 2.7 NM cross-track error
Ground DME Error	±0.1 NM on radial = 0.0 NM cross-track error
Pilotage Error	±2.5° @ 51 NM = 2.2 NM cross-track error

(3) The error elements combine to make:

$$\text{Total Error} = \pm\sqrt{1.7^2 + 2.7^2 + 2.2^2}$$

$$= \pm 3.88$$

(4) In designing a new system containing area navigation devices contributing an error element of ±2 NM (equivalent to ±2.3° at 51 NM), the system engineer finds that the total error of the new system would not satisfy the requirement of a ±4 NM route width at 51 NM range if the other error elements remained the same. However, he also finds that he can compensate for the added error component in two ways:

(a) By picking off signals directly from the VOR receiver and using a digital course selector in the RNAV equipment the usual converter and indicator errors are not incurred so that the airborne VOR equipment error is reduced from 3° to 2° thus the cross-track error becomes ±1.8 NM.

(b) By employing a linear RNAV display which permits an assumed pilotage error of ±2.0 NM which is consistent with values shown in Appendix A, Paragraph 2.a.(4).

(5) The system engineer now recomputes the total system error on the basis of the following error budget:

$$\text{Total Error} = \pm \sqrt{1.7^2 + 1.8^2 + 2.0^2 + 2.0^2}$$

$$= \pm\ 3.76 \text{ NM at 51 NM from the facility (95\% probability)}$$

The new system meets the design accuracy requirement with an increased margin of safety. In this example, the DME errors did not contribute to cross-track error. With track orientation other than along a radial, an increase in DME contribution will be offset by a decrease in VOR effect.

APPENDIX D. INSTRUMENT FLIGHT PROCEDURES

1. GENERAL. This appendix contains obstacle clearance requirements for RNAV instrument flight procedures. Section I provides guidelines which are applicable to all RNAV procedures. Section II discusses the concept of 3-D RNAV only. Obstacle clearance requirements will be included in the U. S. Standard for Terminal Instrument Procedures (TERPs).

   a. Approval of RNAV procedures will be based on FAA capability to provide service, anticipated volume of traffic, and compatibility of the procedure with existing airways, routes, traffic and procedures.

   b. All approved area navigation routings and procedures will be assured adequate signal coverage and frequency protection. Those approved for public use will be published in the United States government flight information publication enroute and terminal charts, FAR's and/or Airman's Information Manual (AIM).

   c. Pilots should refer to AC 90-63, "Air Traffic Control Procedures for Random Area Navigation Routes" to insure correct use of off-airways routes.

   d. RNAV routes which require VOR/DME inputs will be provided uninterrupted VOR/DME signal reception as opposed to Victor airways which may incorporate signal gap areas.

   e. RNAV waypoints will be identified by lat/long (nearest 1/10 min.) and a radial and distance from the ground facility on which they are based. Additionally, geographical names (5 letter pronounceable words) will be assigned to waypoints if required for flight planning or ATC purposes. Along-Track Distance (ATD) fixes are normally used in lieu of a final approach waypoint when no lateral course change is required at that point. It is used to simplify pilot workload. An ATD fix may be used in lieu of a missed approach waypoint when the runway waypoint is NOT the MAP. Changeover points on RNAV routes will be defined using distance from an established waypoint.

   f. Terminal area routes are normally flown 'to' the waypoint, and are compatible with 3-D concepts. However, simplified procedures designed for the minimum equipment 2-D system may be flown 'to' or 'from' the waypoints. Changeover points will not be used unless more than one facility is required to support the procedure.

   g. RNAV route segments are numbered in a manner similar to VOR airways and jet routes. The suffix 'R' identifies the route as an RNAV route. For example, J 830 R indicates a high altitude RNAV route while V 762 R indicates a low altitude RNAV route. RNAV standard

Instrument Departures (SID) and Standard Terminal Arrival Routes (STAR) will be identified by the term RNAV immediately preceding the words "departure" and "arrival." For example: Brooks One RNAV Departure, Richards Three RNAV Arrival.

h. Terminal RNAV instrument procedures will be developed as requested by the users and required by the NAS. They may be of two types as follows:

(1) Simplified procedures will be developed at small airports, typically with less than 4000' runways, or in areas where air traffic problems are minimal. They will use at the most two waypoints and will be supplemented with ATD fixes. The runway threshold will be one of the waypoints. The other will provide transitions to the Final Approach course. They will be flyable with minimum equipment systems.

(2) Standard procedures will be developed in large terminals based upon air traffic requirements, and to the extent possible, the desires of the users. These procedures will use up to six or even ten waypoints in rapid succession. They will be flyable in aircraft with sufficient waypoint storage, but are expected to generate a high cockpit workload to the extent that they will be unflyable with minimum equipment.

i. RNAV instrument approach procedures will be identified as follows:

(1) Straight-in Approach. Procedures which meet criteria for authorization of straight-in landing minimums will be identified by the word RNAV and the runway to which the straight-in approach is made; for example, RNAV Rwy 21.

(2) Circling Approach. When a procedure does not meet criteria for straight-in landing minimums authorization, it will be identified alphabetically in sequence; for example: RNAV A, RNAV B, etc.

j. Units of Measurement. Units of measurement in RNAV procedures shall be expressed as follows:

(1) Radials and bearings in degrees magnetic.

(2) Altitudes in feet.

(3) Distances in nautical miles except visibility which shall be expressed in statute miles and RVR which shall be expressed in feet.

(4) Aircraft speeds in knots.

(5) Track angles shall be expressed in degrees.

SECTION I
2D RNAV CONSIDERATIONS

2. ENROUTE CRITERIA. Enroute procedures shall be evaluated using existing flight inspection facility performance data, or by flight inspection of the procedure when facility data is lacking.

a. RNAV Routes Protected Areas. The area to be protected is shown in Figure 1, the Area Navigation Route Width Summary, and is described as follows:

(1) Four miles each side of routes in which the tangent point distance of the route centerline is within 102 miles of the ground station. The route boundaries splay at 3.25° beginning at the point where the route centerline exits the eight-mile zone.

(2) When the tangent point distance is beyond the 102 mile limit, the minimum width of the protected area each side of the route at the tangent point distance is increased at the rate of 0.25 miles for each 10 miles increase in distance from the ground station. The route boundaries splay 3.25° from this minimum width at the tangent point distance.

(3) Parallel offset routes are not charted in flight information publications. When a pilot is cleared to fly a parallel offset route, he is expected to fly it in precisely the same fashion as the parent route. Parallel offsets will be used to separate overtaking traffic and other similar applications. Enroute, it will not always be possible to develop a parallel offset route on both sides of the parent route due to signal loss on the side of the parent route farthest from the reference station. When developing parallel offset routes consideration must be given to MOCA and MRA on both sides of the parent route. In the event that the MEA is higher than the parent route, offset parallel operations will normally not be authorized on the side to which the higher MEA applies.

(4) Enroute vertical separation will be provided as prescribed in Air Traffic Control procedures handbooks where climb or descent is made using 3-D RNAV airborne equipment.

(5) When using reference facilities not on the route the track angle must be computed relative to the reference facility being used. These track angles may change when using different reference facilities due to meridian divergence/convergence.

b. Obstacle Clearance Requirements. Obstacle clearance will be provided as described in Advisory Circular 95-1, paragraphs 4, 5, and 7, except that the primary obstacle clearance areas will be as specified in paragraphs 2.a.(1) and 2.a.(2) above.

(1) Secondary obstacle clearance areas extend laterally 2 miles on each side of the primary area and splay at 4.9° where the primary area splays at 3.25°.

(2) Obstacle clearance areas are expanded as specified in paragraph 3.c of AC 95-1 and as illustrated in Figure 3 to accommodate turns of more than 15 degrees.

c. Enroute Waypoint Displacement Area. The enroute waypoint displacement area is a rectangular or square area formed around the plotted position of the waypoint. The dimensions of this area are derived from the appropriate along-track and cross-track error values. See Table 2, Appendix D. The enroute waypoint displacement area shall be considered for each waypoint when developing RNAV enroute procedures.

3. TERMINAL CRITERIA. Terminal routes provide access to the enroute structure for aircraft departing an airport and routing to enter an instrument approach procedure for arriving aircraft. Parallel offset terminal routes will be used where practical for spacing and to separate overtaking aircraft. Terminal routes shall be evaluated by flight inspection concurrently with associated instrument approach and departure procedures.

Terminal arrival routes will be designed for efficient traffic flow to the final approach aid - normally ILS. To the extent possible the altitudes specified on the arrival routes will provide for a 300' per mile rate of descent from the enroute environment to the runway or the point where the final approach aid is intercepted. To facilitate the transition and to standardize the terminal route structure, the last waypoint on the arrival route will be established approximately 8 miles from the runway at the intermediate fix. The altitude at the eight mile waypoint should agree with the glide slope or provide an approximate 300'/mile gradient to the runway as appropriate to the type of final approach utilized.

Terminal departure routes will be designed from the departure end of the runway to the enroute structure. The first waypoint will be shown at the departure end of the runway. Immediate turns at the end of the runway are discouraged. Insofar as possible from the standpoint of airspace management the second waypoint will be established on the runway centerline extended.

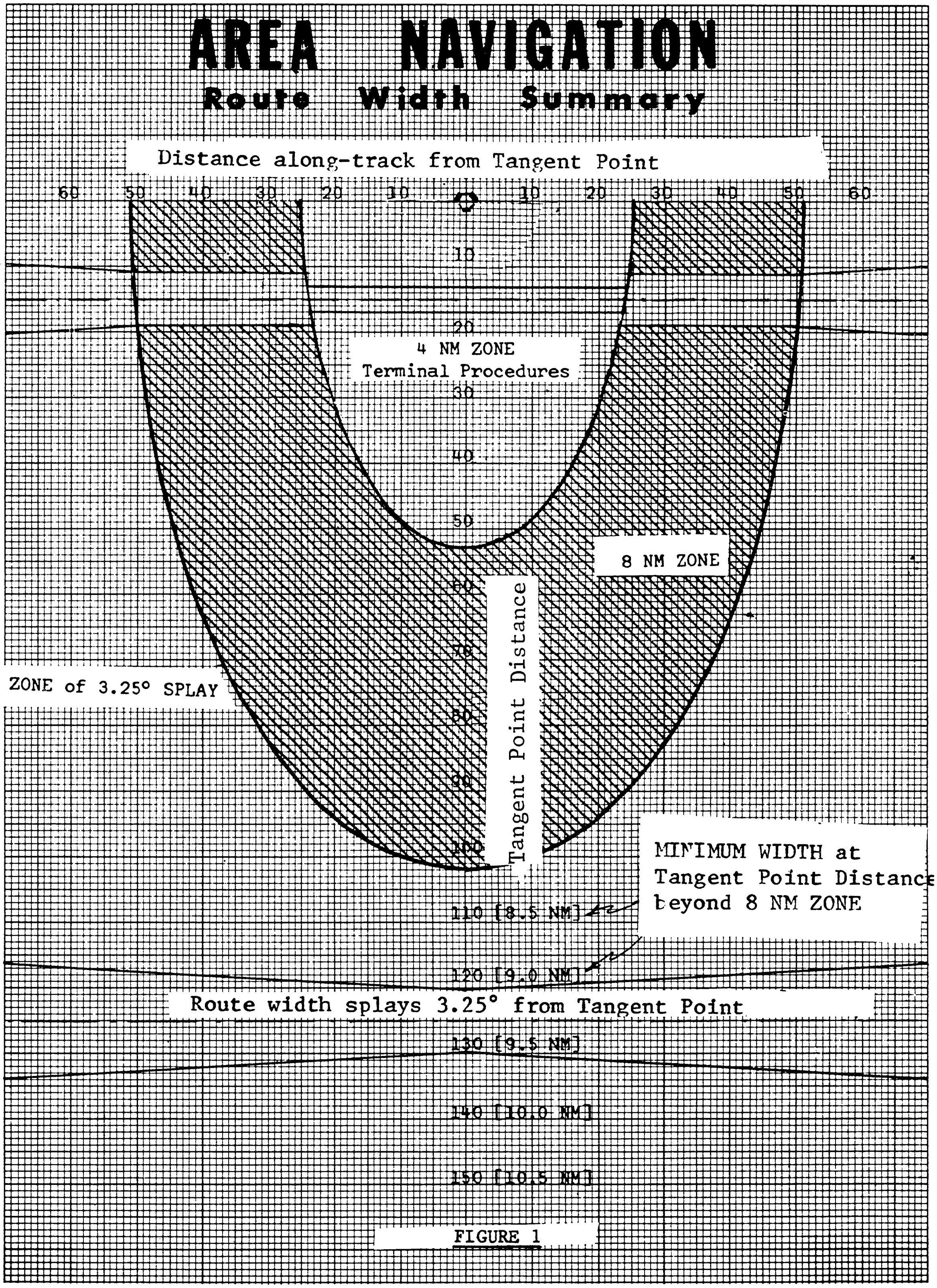

AREA NAVIGATION
Route Width Summary
Distance along-track from Tangent Point
60 50 40 30 20 10 0 10 20 30 40 50 60
10
20
4 NM ZONE
Terminal Procedures
30
40
50
8 NM ZONE
60
70
80
90
100
Tangent Point Distance
ZONE of 3.25° SPLAY
MINIMUM WIDTH at
Tangent Point Distance
beyond 8 NM ZONE
110 [8.5 NM]
120 [9.0 NM]
Route width splays 3.25° from Tangent Point
130 [9.5 NM]
140 [10.0 NM]
150 [10.5 NM]

FIGURE 1

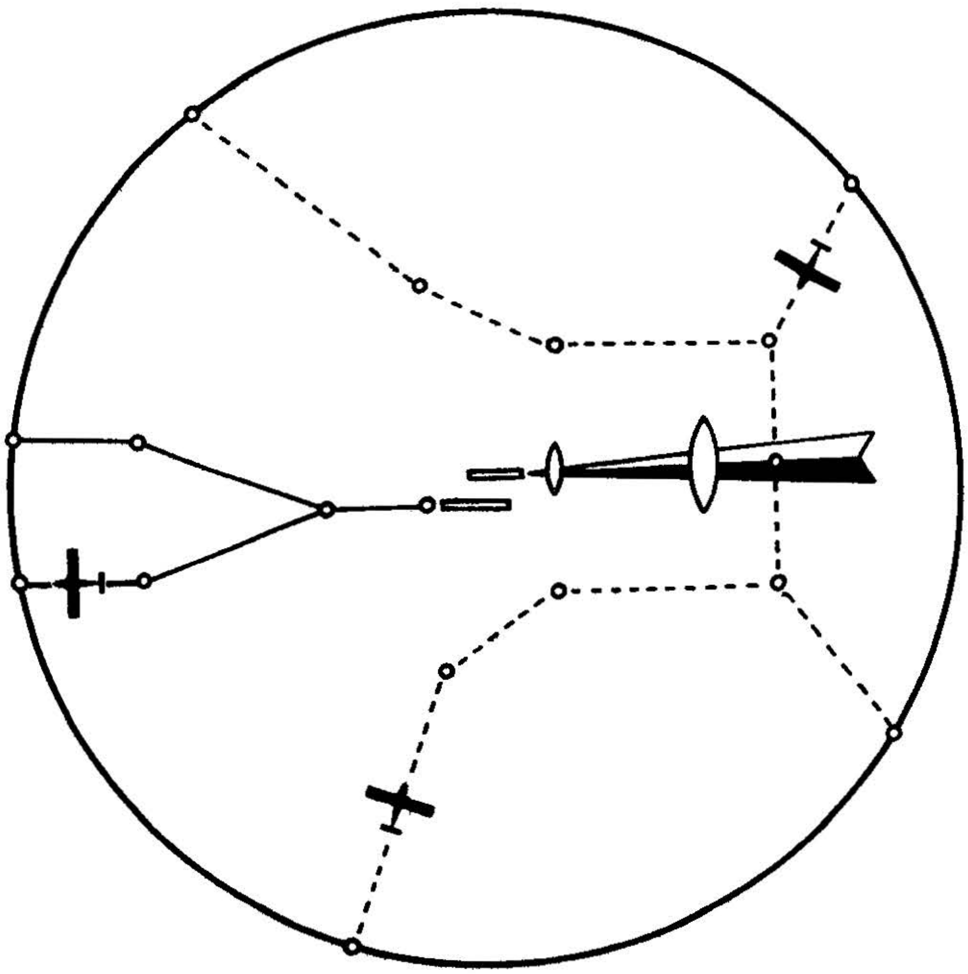
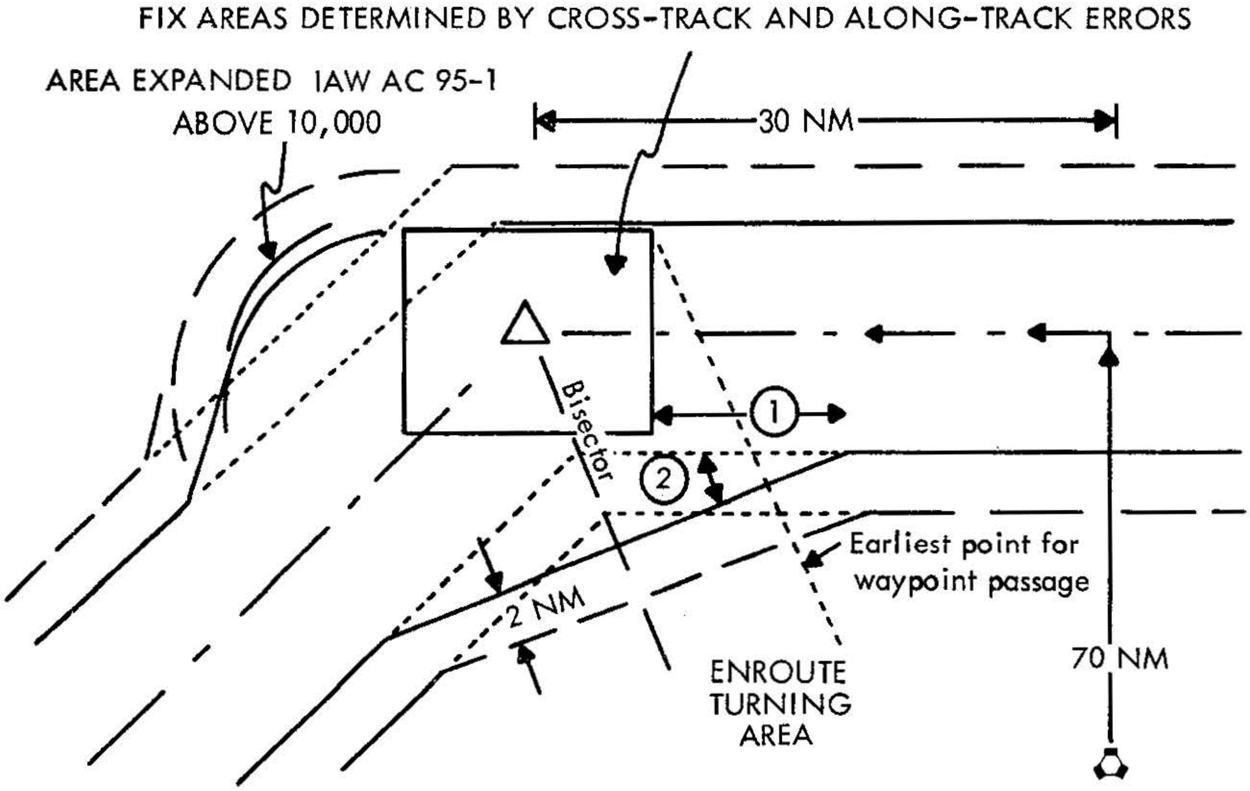


FIGURE 2. TYPICAL RNAV ARRIVAL AND DEPARTURE ROUTE CONFIGURATION

*



(1.) Expansion for "corner cutter" begins at a distance prior to the earliest point the waypoint can be received:
3 NM below 8000' - 7 NM 8000-18000' - 12 NM above FL 180.

(2.) Angle of splay for expanding area is 1/2 the amount of the course change.

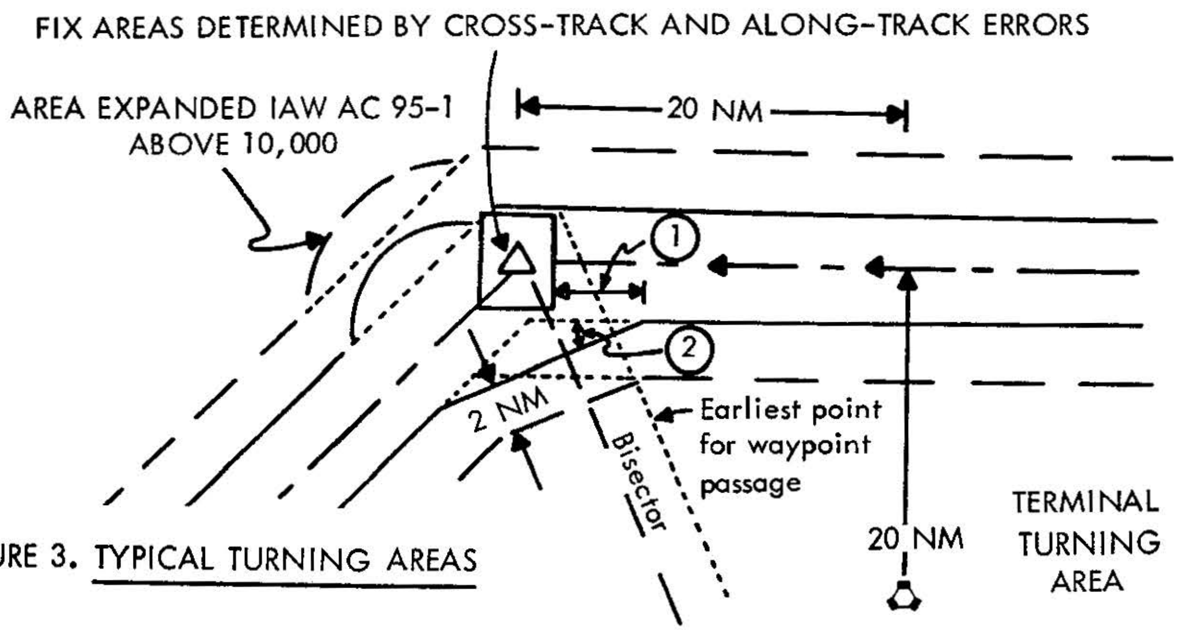


FIGURE 3. TYPICAL TURNING AREAS *

a. RNAV Routes Protected Areas. The area to be protected is as shown in Figure 1 and is described as follows:

(1) Primary obstacle clearance areas extend laterally two miles each side of routes in which the tangent point distance of the route centerline is within 53 miles of the ground station. The route boundaries splay 3.25° beginning at the point where the route centerline exits the four-mile zone. *

(2) Secondary obstacle clearance areas extend laterally 1 mile each side of the primary area and splay 4.9° where the primary area splays at 3.25°. *

(3) Obstacle clearance areas are expanded as specified in paragraph 3.e in AC 95-1 and as illustrated in Figure 3 to accommodate turns of more than 15 degrees.

(4) Paragraphs 2.a(3) and 2.b(2) above which concern parallel offsets and turning areas also apply.

b. Obstacle Clearance Requirements. Obstacle clearance will be provided as described in FAA Handbook 8260.3A (TERPS), paragraph 232.c.

c. Terminal Waypoint Displacement Area. The terminal waypoint displacement area is a rectangular or square area formed around the plotted position of the waypoint. The dimensions of this area are derived from the appropriate along-track and cross-track error values. See Table 3, Appendix D. The terminal waypoint displacement error shall be considered for each waypoint when used in RNAV departures and arrivals, including initial and intermediate approach waypoints.

d. Holding Pattern Area Determination. The holding pattern is a race-track pattern flown at a waypoint or an ATD fix and at an IAS appropriate to the aircraft and altitude. The holding IAS for helicopters is 90 knots. The RNAV holding area will have the outbound leg length specified in nautical miles. Minimum leg length for helicopters is 2 NM. Determination of required area is made using Table 2 or Table 3, Appendix D, appropriate IAS, an omnidirectional wind of 50 knots increasing 3 knots per 2000' above 4000 AGL, pattern entry direction, ICAO standard atmosphere plus 15°C and fix passage tolerance of 5 seconds. Turning radii are based on a standard rate turn or a 25° angle of bank whichever is less. The following example is for helicopters holding at a sea level terminal area, but the method applies to all aircraft by using the appropriate IAS, altitude, and table for the mode of flight; i.e., enroute (Table 2) or terminal (Table 3). *

* Example: IAS = 90 KTS | ATD = 30 NM
Alt = 6000' MSL & AGL | TPD = 30 NM
OAT = 3° + 15° = 18°C | xwind = 50 + 3 = 53 KTS

From Table 3, Appendix D; cross-track error (x trk) = 2.4 NM, along-track error (alg trk) = 2.2 NM.

(1) The cross-track area is determined as follows.

(a) Holding side. The area on the holding side is determined by the cross-track navigation system errors, the effect of wind and the area required for a standard rate turn (max 25°) from entries along-track or the reciprocal and including all directions from the nonholding side.

The contribution due to winds will be .88 NM during the 180° turn outbound (assume crosswind for worst case).

The cross-track error value and the wind contribution are root-sum-squared, yielding:

$$RSS = \sqrt{2.4^2 + .88^2} = \underline{2.55\ NM}$$

The angle of bank at 90 KTS (95 KTS, TAS) for a standard rate turn is determined by the following:

$$\tan \phi = .00275V,\ V = KTS,\ TAS$$

$$= .00275(95) = .26125$$

$$\text{then } \phi = 14.64° = \underline{15°}$$

The turning radius (r) at TAS = 95 KTS and bank angle (ϕ) of 15° is determined by the following:

$$r = \frac{1.4589 \times 10^{-5}\ V^2}{\tan \phi},\ \text{where } V = KTS,\ TAS$$

$$r = \frac{1.4589 \times 10^{-5}\ (95)^2}{.2679}$$

$$r = \underline{.49\ NM}$$

The cross-track contribution due to the turn is:
2r = .98 NM.

Hence, the total cross-track displacement on the HOLDING side is:

cross-track RSS + 2r: 2.55 + .98 = 3.53 NM. *

* (b) Nonholding side. The cross-track displacement on the NONHOLDING side is either one-half of the route width at the ATD fix, as discussed below, or the area required to make an entry from the holding side, whichever is greater. One-half of the route width in the terminal area (50 NM or less) is 2.0 NM. In the enroute area (more than 50 NM but less than 102 NM) one-half of the route width is 4 NM. At distances greater than 102 NM, one-half of the route is 4 NM plus a 3.25° splay. (See Figure 1). For parallel entry at the 70° sector line (worst case), cross-track displacement is determined as follows (see Figure 3-1):

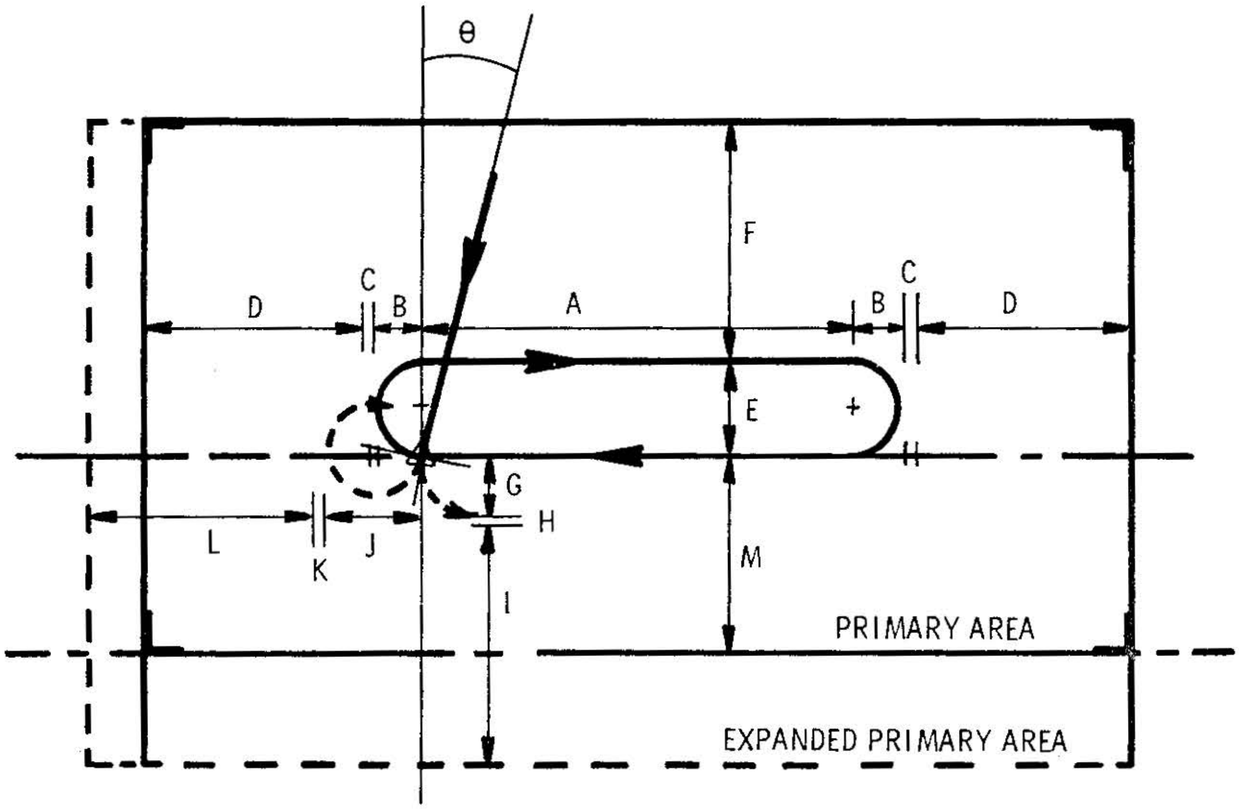


FIGURE 3-1. HOLDING AREA DETERMINATION

A - DME leg distance
B - Turn radius
C - Fix passage tolerance
D - Direct entry RSS
E - 2(Turn radius)
F - Cross-track RSS
G - Turn radius (1 + sin θ)
H - Fix passage tolerance (sin θ)
I - Nonholding side entry RSS
J - Turn radius (1 + cos θ)
K - Fix passage tolerance (cos θ)
L - Holding side entry RSS
M - 1/2 Route width *

* The wind contribution during the 110° turn to parallel the outbound is .54 NM.

When RSS'd with the cross-track error:

$$RSS = \sqrt{(2.4)^2 + (.54)^2} = \underline{2.46\ NM}$$

The turn contribution is r(1 + sin θ): (here θ = 20°)

$$.49(1.3420) = \underline{.66\ NM}$$

The fix passage tolerance is:

$$(5 \text{ secs @ } 95 \text{ KTAS}) \sin 20° = .05 \text{ NM}$$

The cross-track displacement on the NONHOLDING side is then:

parallel entry RSS + r(1 + sin θ) + fix passage tolerance (sin θ):

$$2.46 + .66 + .05 = \underline{3.17\ NM}$$

Since this exceeds 2.0 NM half route width, it is the width to be protected.

(2) The along-track area for a direct (or reciprocal) entry or an entry from the nonholding side is determined as follows.

The contribution due to winds during the 180° turn outbound is .44 NM (assume direct entry and tailwind for worst case).

When RSS'd with the along-track error:

$$RSS = \sqrt{(2.2)^2 + (.44)^2} = \underline{2.24\ NM}$$

fix passage tolerance (5 secs) @ 95 KTAS = .13 NM.

The total along-track displacement is:

2 (nonholding side entry RSS) + 2(r) + 2 fix passage tolerance + DME leg

$$2(2.24) + 2(.49) + 2(.13) + 2 = \underline{7.72\ NM}$$ *

* (3) The along-track error for an entry from the holding side (70° sector line for worst case) will elongate the entry end and is determined as follows.

The wind contribution during the 160° turn to fly the pattern is .79 NM.

When RSS'd with the along-track error:

$$RSS = \sqrt{(2.2)^2 + (.79)^2} = \underline{2.33\ NM}$$

The turn contribution is $r(1 + \cos \theta)$: (here $\theta = 20°$)

$$.49(1.9397) = \underline{.95\ NM}$$

The fix passage tolerance is:

$$(5\ secs\ @\ 95\ KTAS)\cos 20° = \underline{.12\ NM}$$

The total along-track displacement is the sum of the entry, leg distance and inbound turn displacements:

holding side entry RSS + $r(1 + \cos \theta)$ + fix passage tolerance ($\cos \theta$) + DME leg + direct entry RSS + r + fix passage tolerance:

$$2.33 + .95 + .12 + 2.0 + 2.24 + .49 + .13 = \underline{8.26\ NM}$$

A secondary area of one-half of the cross-track error or 2 NM, whichever is greater, is added to the perimeter of the pattern for obstacle clearance. *

4. INSTRUMENT APPROACH PROCEDURE CRITERIA. FAA Handbook 8260.3A, The United States Standard for Terminal Instrument Procedures (TERPS), prescribes criteria for the design of instrument approach procedures. Although it does not at the present time contain special criteria for the design of RNAV procedures, most of the TERPS criteria are applicable to RNAV procedures with minor modifications. This appendix will therefore provide only the criteria necessary to modify TERPS for RNAV procedure application. In applying TERPS to RNAV procedures, the term "fix" is equivalent to "waypoint," thus, "Final Approach Fix (FAF)" becomes "Final Approach Waypoint (FAWP)."

a. Procedures Construction. An RNAV instrument approach procedure may have four separate segments. They are the initial, the intermediate, the final and the missed approach segments. In addition, an area for circling the airport under visual conditions shall be considered. The approach segments begin and end at waypoints or along-track distance (ATD) fixes which are identified to coincide with the associated segment. For example, the intermediate segment begins at the intermediate waypoint (INWP) and ends at the Final Approach Waypoint (FAWP) or ATD fix.

(1) Descent Gradients. TERPS descent gradients will apply to all RNAV procedures except where an uninterrupted descent gradient of 300 feet per mile (+20', -50') can be established from the initial approach through the final approach. It shall be done to provide stabilized descent throughout the arrival procedures.

* (2) Runway Waypoint and Flight Path Angle. Both standard and simplified procedures should incorporate a waypoint at the runway threshold. This waypoint will be used as the point from which the Flight Path Angle is computed. On ILS runways, the Flight Path Angle shall be computed using the runway waypoint elevation equal to the ILS threshold crossing height. Where no ILS glide path is present, the Flight Path Angle shall be computed from the runway waypoint elevation 50 feet higher than the runway threshold elevation for runways 4,000 feet and longer. It may be established as low as 37 feet for runways less than 4,000 feet in length. The procedure shall specify the runway waypoint elevation under additional flight data. Example: Rwy W/P elevation 1827'. *

b. Transition Routes. When transition routes are required from the en route structure to the initial approach waypoint, they should be designed to coincide with the local air traffic flow. En route RNAV obstacle clearance criteria (paragraph 2.b. above) shall apply to transition routes in which the tangent point distance (TPD) of the route centerline is more than 53 miles from the ground station. When the TPD is within 53 miles of the ground station, RNAV terminal route obstacle clearance criteria (paragraph 3.b. above) shall apply.

c. Initial Approach Segment. The RNAV instrument approach procedure commences at the Initial Approach Waypoint (IAWP). In the initial approach, the aircraft has departed the en route phase of flight and is maneuvering to enter the intermediate segment. Standard RNAV procedures -- as opposed to simplified procedures -- may utilize several initial approach segments to accommodate the traffic flow requirements. En route RNAV obstacle clearance criteria (paragraph 2.b. above) shall apply to initial approaches in which the TPD of the initial approach course is more than 53 miles from the ground station. When the TPD is within 53 miles of the ground station, RNAV terminal route obstacle clearance criteria (paragraph 3.b. above) shall apply.

(1) Initial approach segments based on a procedure turn shall not be established. Where course reversal is required, a holding pattern shall be established in lieu of a procedure turn. Standard holding pattern obstacle clearance shall apply.

d. Intermediate Approach Segment. The purpose of the intermediate segment is to blend the initial approach into the final approach and provide an area in which aircraft configuration, speed and positioning adjustments are made for entry into the final approach segment. The intermediate segment begins at the Intermediate Waypoint (INWP) and ends at the FAWP or ATD fix.

(1) Alignment. The course to be flown in the intermediate segment should be the same as the final approach course whenever possible. When it is not practical for the courses to be identical, the intermediate course may not differ from the final approach course by more than 60 degrees.

(2) Distance from runway. For Standard procedures the intermediate waypoint shall be established approximately 8 miles from the runway. For the Simplified procedure the intermediate fix will be established as necessary to accommodate a procedure which utilizes only two waypoints. See paragraph 1.h.

(3) Length. The minimum length is 3 miles with standard procedures.

e. Final Approach Segment. This is the segment in which alignment and final descent for landing are accomplished. The final approach segment begins at the final approach waypoint or Along-Track Distance (ATD) fix and ends at the missed approach point, normally the runway threshold waypoint. When it is not at the runway threshold, it is an ATD fix based on a distance to the runway waypoint. Final approach may be made to a runway for straight-in landing, or to an airport for a circling approach. Only one final approach shall be specified for a procedure.

(1) Alignment. Whenever possible, the final approach course shall be aligned with the straight-in landing runway. When the alignment exceeds 15^{o}, straight-in minimums are not authorized.

(2) Final Approach Area. The area considered for obstacle clearance starts at the earliest point the Final Approach Waypoint (FAWP) or ATD fix can be received and ends at the latest point the Missed Approach Waypoint (MAWP) can be received or at the runway threshold whichever occurs last. See Table 4, Appendix D, for fix errors. When the final approach course is a continuation of the intermediate course, an ATD fix shall be used instead of a FAWP. Additional ATD fixes may be established as step-down fixes.

(a) Length. The OPTIMUM length of the final approach segment is 5 miles. The MAXIMUM length is 10 miles. The MINIMUM length of the final approach segment shall provide adequate distance for an aircraft to make the required descent, and to regain course alignment when a turn is required over the final approach waypoint. Table 1, Appendix D, shall be used to determine the minimum length needed to regain the course.

MINIMUM LENGTH OF THE FINAL APPROACH SEGMENT (MILES)						
APPROACH CATEGORY	Magnitude of turn over the Final Approach Waypoint (FAWP)					
	10°	20°	30°	40°	50°	60°
A	1.0	1.5	2.0	3.0	4.0	5.0
B	1.5	2.0	2.5	3.5	4.5	5.5
C	2.0	2.5	3.0	4.0	5.0	6.0
D	2.5	3.0	3.5	4.5	5.5	6.5

Table 1

(b) Width. The final approach primary area is centered longitudinally on the final approach course. The primary area is ± 2 miles wide either side of the final approach course at the final approach fix. It narrows to the width of the fix displacement area at the runway threshold. See Table 4, Appendix D. A secondary area one mile in width is established on each side of the primary area. Figure 4 illustrates a typical final approach area.

*

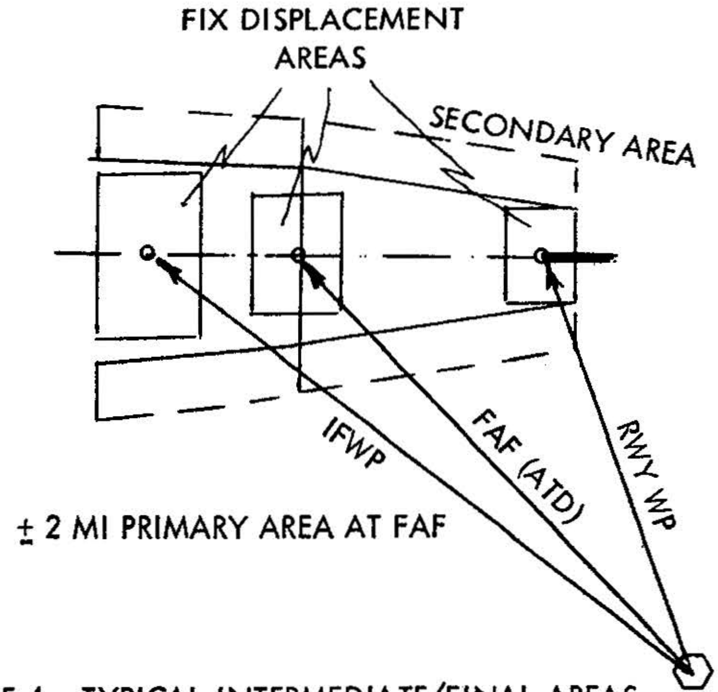


FIGURE 4. TYPICAL INTERMEDIATE/FINAL AREAS

*

(c) Obstacle Clearance. The minimum obstacle clearance in the primary area is 250 feet. In the secondary area the full obstacle clearance of the adjacent primary area is provided at the inner edge, tapering uniformly to zero at the outer edge of the secondary area.

f. Missed Approach Segment. A missed approach procedure shall be established for each instrument approach procedure. The missed approach shall be initiated no later than the runway threshold waypoint. The missed approach should be simple and shall specify an altitude and a clearance limit. The missed approach altitude specified in the procedure shall be sufficient to permit holding or enroute flight.

(1) Straight Missed Approach Area. The straight missed approach area may be used when the missed approach track does not differ more than 15 degrees from the final approach track. The area starts at the plotted position of the missed approach waypoint and has the same width as the final approach primary and secondary areas at the MAWP. The primary missed approach area splays at 15 degrees each side of the missed approach track until it reaches the width of the appropriate terminal or enroute obstacle clearance area. The secondary areas expand uniformly from one mile to the width of the appropriate enroute secondary areas. See Figure 5. *

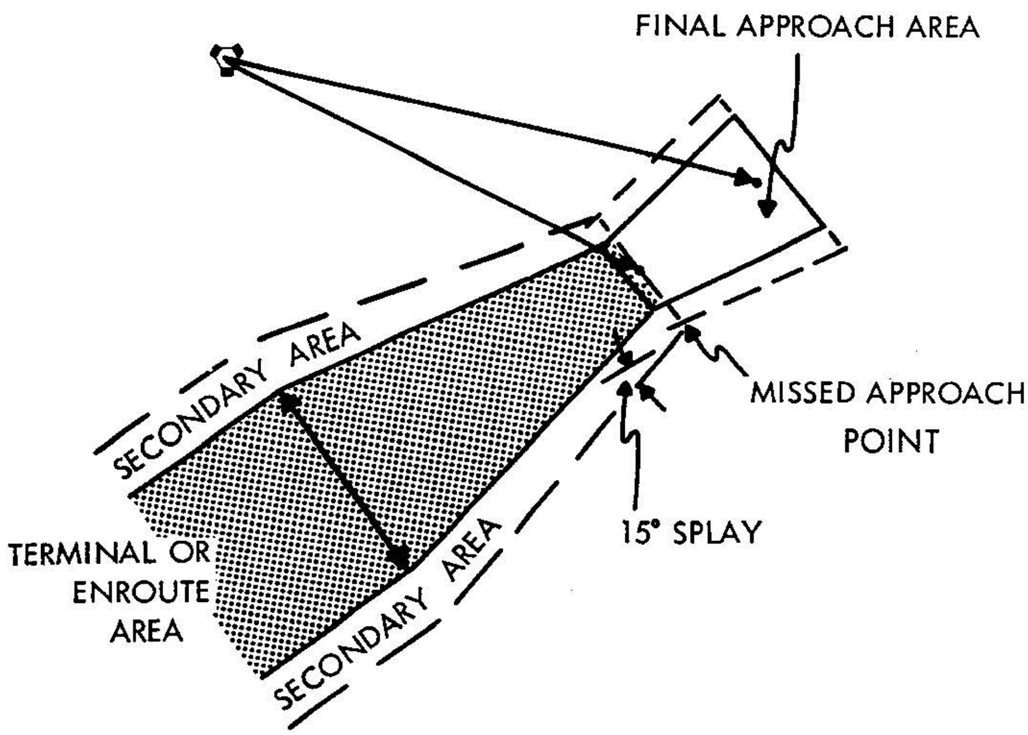


FIGURE 5. STRAIGHT MISSED APPROACH AREA *

(2) Straight Missed Approach Obstacle Clearance. Within the primary missed approach area no obstacle may penetrate the 40:1 missed approach surface. This surface begins at the plotted position of the MAWP when the along-track error at the MAWP is one mile or less. When the along-track error (Table 4, Appendix D) at the MAWP exceeds one mile, the surface begins at a distance past the plotted position of the MAWP equal to the amount of along-track error in excess of one mile. The missed approach surface beginning height is determined by subtracting the required final approach obstacle clearance from the minimum descent altitude. In the secondary area, no obstacle may penetrate a 12:1 slope which extends upward and outward from the 40:1 surface at the inner boundaries of the secondary area. See Figure 5.

* NOTE: Helicopter procedures use a 20:1 missed approach surface with 4:1 slopes in the secondary areas. (Ref. TERPS 1119 & 1120)

(3) Turning Missed Approach. The turning missed approach will be as prescribed in FAA Handbook 8260.3A (TERPS) except that * the starting point for the 40:1 obstacle clearance surface will be prescribed in the preceding paragraph (4.f.(2)).

g. Approach Minimums. Published civil RNAV approach minimums shall meet the criteria for nonprecision approach systems as specified * in FAA Handbook 8260.3A (TERPS). Table 6 criteria which relates * minimum visibility to distance from station shall be applied as a variation of cross-track displacement area (Table 4, Appendix D) as follows:

Cross-track	area	0.6 - 0.8 NM	use	Column	0-10
"	"	"	0.9 - 1.0 NM	"	"	10-15
"	"	"	1.1 - 1.2 NM	"	"	15-20
"	"	"	1.3 - 1.6 NM	"	"	20-25
"	"	"	Over 1.6 NM	"	"	Over 25

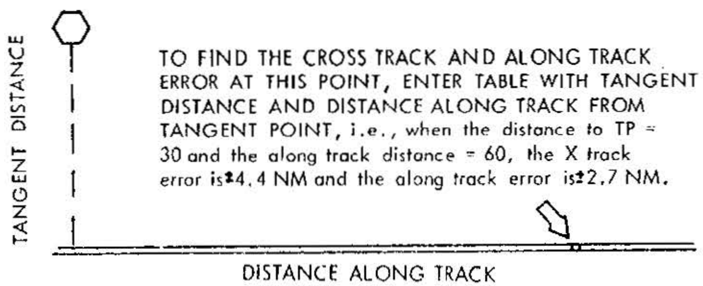
h. Approach Waypoint Displacement Area. The approach waypoint displacement area is a rectangular or square area formed around the plotted position of the waypoint. The dimensions of the area are derived from the appropriate along-track and cross-track error values. See Table 4, Appendix D. The approach waypoint * displacement area shall be considered for each waypoint used in developing RNAV final approach procedures including the FAWP, MAWP, and any stepdown WP or ATD fixes used on final. *

ENROUTE AREA FIX DISPLACEMENT ERROR (95% Probability)

DISTANCE ALONG TRACK FROM TANGENT POINT

DISTANCE FROM TANGENT POINT TO VORTAC

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	200
0(x trk)	2.5	2.5	2.5	2.8	3.2	3.7	4.2	4.8	5.4	5.9	6.5	7.1	7.7	8.3	8.9	9.5	12.6
(alg trk)	1.5	1.5	1.5	1.5	1.5	1.6	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.9	4.2	4.5	6.0
10(x trk)	2.5	2.5	2.5	2.8	3.3	3.7	4.3	4.8	5.4	6.0	6.6	7.1	7.7	8.3	8.9	9.5	12.6
(alg trk)	1.5	1.5	1.5	1.5	1.5	1.7	2.0	2.3	2.6	2.9	3.1	3.4	3.7	4.0	4.3	4.6	6.1
20(x trk)	2.5	2.5	2.5	2.9	3.3	3.8	4.3	4.9	5.4	6.0	6.6	7.2	7.8	8.4	9.0	9.6	12.6
(alg trk)	1.5	1.5	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.4	3.6	3.9	4.2	4.5	4.8	6.2
30(x trk)	2.5	2.5	2.6	3.0	3.4	3.9	4.4	4.9	5.5	6.1	6.6	7.2	7.8	8.4	9.0	9.6	12.6
(alg trk)	1.9	2.0	2.1	2.2	2.3	2.5	2.7	2.9	3.2	3.4	3.7	3.9	4.2	4.5	4.7	5.0	6.4
40(x trk)	2.5	2.5	2.7	3.1	3.5	4.0	4.5	5.0	5.6	6.1	6.7	7.3	7.9	8.5	9.1	9.7	12.7
(alg trk)	2.5	2.6	2.6	2.7	2.9	3.0	3.2	3.4	3.6	3.8	4.0	4.3	4.5	4.8	5.0	5.3	6.7
50(x trk)	2.6	2.6	2.9	3.2	3.6	4.1	4.6	5.1	5.7	6.2	6.8	7.4	7.9	8.5	9.1	9.7	12.7
(alg trk)	3.1	3.2	3.2	3.3	3.4	3.6	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.2	5.4	5.7	7.0
60(x trk)	2.7	2.8	3.1	3.4	3.8	4.2	4.7	5.2	5.8	6.3	6.9	7.4	8.0	8.6	9.2	9.8	12.8
(alg trk)	3.7	3.8	3.8	3.9	4.0	4.1	4.3	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0	7.3
70(x trk)	2.9	3.0	3.2	3.6	3.9	4.4	4.8	5.4	5.9	6.4	7.0	7.5	8.1	8.7	9.3	9.9	12.9
(alg trk)	4.4	4.4	4.4	4.5	4.6	4.7	4.8	5.0	5.1	5.3	5.5	5.6	5.8	6.0	6.3	6.5	7.7
80(x trk)	3.2	3.3	3.5	3.8	4.1	4.5	5.0	5.5	6.0	6.5	7.1	7.7	8.2	8.8	9.4	10.0	12.9
(alg trk)	5.0	5.0	5.1	5.1	5.2	5.3	5.4	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	6.9	8.0
90(x trk)	3.4	3.5	3.7	4.0	4.3	4.7	5.2	5.6	6.2	6.7	7.2	7.8	8.3	8.9	9.5	10.1	13.0
(alg trk)	5.6	5.6	5.7	5.7	5.8	5.9	6.0	6.1	6.2	6.4	6.5	6.7	6.8	7.0	7.2	7.4	8.5
100(x trk)	3.6	3.7	3.9	4.2	4.5	4.9	5.3	5.8	6.3	6.8	7.4	7.9	8.4	9.0	9.6	10.2	13.1
(alg trk)	6.2	6.2	6.3	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.1	7.2	7.4	7.5	7.7	7.9	8.9
110(x trk)	3.9	4.0	4.2	4.4	4.7	5.1	5.5	6.0	6.5	7.0	7.5	8.0	8.6	9.1	9.7	10.3	13.2
(alg trk)	6.8	6.9	6.9	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.8	7.9	8.1	8.2	8.4	9.4
120(x trk)	4.2	4.2	4.4	4.6	5.0	5.3	5.7	6.2	6.6	7.1	7.6	8.2	8.7	9.3	9.8	10.4	13.3
(alg trk)	7.4	7.5	7.5	7.6	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.5	8.6	8.8	9.0	9.9
130(x trk)	4.4	4.5	4.7	4.9	5.2	5.5	5.9	6.4	6.8	7.3	7.8	8.3	8.9	9.4	10.0	10.5	13.4
(alg trk)	8.1	8.1	8.1	8.2	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9	9.0	9.2	9.3	9.5	10.4
140(x trk)	4.7	4.8	4.9	5.1	5.4	5.8	6.1	6.6	7.0	7.5	8.0	8.5	9.0	9.5	10.1	10.6	13.5
(alg trk)	8.7	8.7	8.7	8.8	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.9	10.0	10.9
150(x trk)	5.0	5.0	5.2	5.4	5.7	6.0	6.4	6.8	7.2	7.7	8.2	8.7	9.2	9.7	10.2	10.8	13.6
(alg trk)	9.3	9.3	9.4	9.4	9.5	9.5	9.6	9.7	9.8	9.9	10.0	10.1	10.2	10.3	10.5	10.6	11.4



TO FIND THE CROSS TRACK AND ALONG TRACK ERROR AT THIS POINT, ENTER TABLE WITH TANGENT DISTANCE AND DISTANCE ALONG TRACK FROM TANGENT POINT, i.e., when the distance to TP = 30 and the along track distance = 60, the X track error is ±4.4 NM and the along track error is ±2.7 NM.

TABLE 2

ERROR ELEMENTS

GROUND
- VOR 1.9°
- DME 0.1 NM

AIRBORNE
- VOR 3.0°
- DME 3% or 0.5 NM

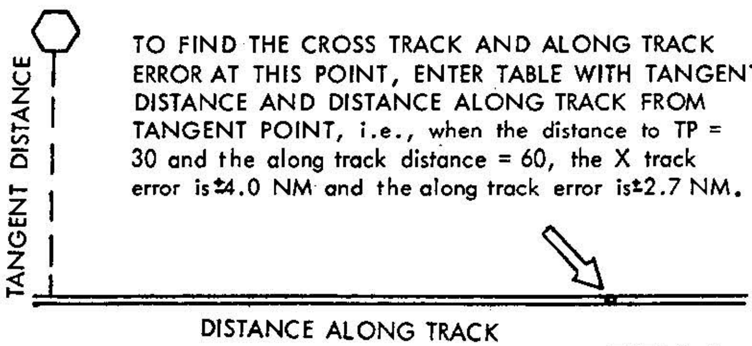
RNAV SYSTEM 0.5 NM

PILOT
- CROSS-TRACK 2.0
- ALONG-TRACK ZERO

*

TERMINAL AREA FIX DISPLACEMENT ERROR (95% PROBABILITY)

DISTANCE FROM TANGENT POINT TO VORTAC	DISTANCE ALONG TRACK FROM TANGENT POINT: 0	10	20	30	40	50	60	70	80	90	100
0(x trk)	1.5	1.5	1.7	2.2	2.7	3.3	3.9	4.5	5.1	5.7	6.3
(alg trk)	1.1	1.1	1.1	1.1	1.3	1.6	1.9	2.2	2 5	2.8	3,0
10(x trk)	1.5	1.5	1.7	2.2	2.8	3.3	3.9	4.5	5.1	5.7	6.3
(alg trk)	1.1	1.1	1.1	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.1
20(x trk)	1.5	1.5	1.8	2.3	2.8	3.4	4.0	4.6	5.2	5.8	6.4
(alg trk)	1.3	1.4	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3.1	3.4
30(x trk)	1.5	1.6	1.9	2.4	2.9	3.5	4.0	4.6	5.2	5.8	6.4
(alg trk)	1.9	2.0	2.1	2.2	2.3	2.5	2.7	2.9	3.2	3.4	3.7
40(x trk)	1.6	1.8	2.1	2.5	3.0	3.6	4.1	4.7	5.3	5.9	6.5
(alg trk)	2.5	2.6	2.6	2.7	2.9	3.0	3.2	3.4	3.6	3.8	4.0
50(x trk)	1.9	2.0	2.3	2.7	3.2	3.7	4.2	4.8	5.4	6.0	6.6
(alg trk)	3.1	3.2	3.2	3.3	3.4	3.6	3.7	3.9	4.1	4.3	4.5



TO FIND THE CROSS TRACK AND ALONG TRACK ERROR AT THIS POINT, ENTER TABLE WITH TANGENT DISTANCE AND DISTANCE ALONG TRACK FROM TANGENT POINT, i.e., when the distance to TP = 30 and the along track distance = 60, the X track error is ±4.0 NM and the along track error is ±2.7 NM.

ERROR ELEMENTS	
GROUND	
VOR	1.9°
DME	0.1 NM
AIRBORNE	
VOR	3.0°
DME	3% or 0.5 NM
RNAV SYSTEM	0.5 NM
PILOT	
CROSS-TRACK	1.0
ALONG-TRACK	ZERO

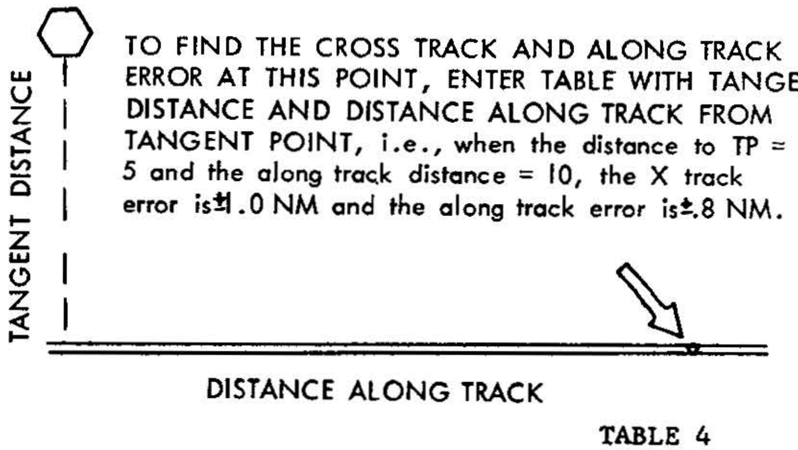
TABLE 3

Terminal waypoint displacement errors apply to waypoints used in arrival and departure procedures including Initial and Intermediate approach waypoints. (para 3c) *

* **FINAL AREA FIX DISPLACEMENT ERROR (95% PROBABILITY)**

DISTANCE ALONG TRACK FROM TANGENT POINT

DISTANCE FROM TANGENT POINT TO VORTAC	0	5	10	15	20	25	30
0 (x trk)		.8	.9	1.2	1.4	1.7	2.0
(alg trk)		.7	.7	.7	.8	.9	1.0
5 (x trk)	.9	.9	1.0	1.2	1.4	1.7	2.0
(alg trk)	.6	.7	.8	.8	.9	1.0	1.1
10 (x trk)	.9	.9	1.0	1.2	1.5	1.7	
(alg trk)	.8	.8	.9	.9	1.0	1.1	
15 (x trk)	.9	.9	1.1	1.3	1.5	1.8	
(alg trk)	1.1	1.1	1.1	1.2	1.2	1.3	
20 (x trk)	.9	1.0	1.1	1.3	1.6		
(alg trk)	1.3	1.4	1.4	1.4	1.5		
25 (x trk)	1.0	1.1	1.2	1.4			
(alg trk)	1.6	1.6	1.7	1.7			
30 (x trk)	1.2	1.2					
(alg trk)	1.9	1.9					



TO FIND THE CROSS TRACK AND ALONG TRACK ERROR AT THIS POINT, ENTER TABLE WITH TANGENT DISTANCE AND DISTANCE ALONG TRACK FROM TANGENT POINT, i.e., when the distance to TP = 5 and the along track distance = 10, the X track error is ±1.0 NM and the along track error is ±.8 NM.

ERROR ELEMENTS

- GROUND
  - VOR 1.9°
  - DME 0.1 NM
- AIRBORNE
  - VOR 3.0°
  - DME 3% or 0.5 NM
- RNAV SYSTEM 0.5 NM
- PILOT
  - CROSS-TRACK 0.5
  - ALONG-TRACK ZERO

TABLE 4

Final waypoint displacement errors apply to the waypoints used in the Final approach segment. (para 4h) *

SECTION II

3D RNAV CONSIDERATIONS

5. BACKGROUND. Adding a third dimension of vertical guidance to the two dimensional RNAV system can achieve significant operational advantages. Briefly, a 3D RNAV capability permits altitude change by following vertical routes (tubes) of known dimensions thus vertical guidance is available for stabilized descent in instrument approach procedures using computed glide path information. In some cases, the computed glide path can make it possible to safely eliminate obstacles from consideration. This section discusses the operational problems and capabilities of 3D RNAV and provides criteria for vertical instrument flight procedures.

a. Level Flight RNAV Longitudinal and Vertical Errors.

(1) In level flight, the plus or minus vertical position error is due to altimetry and flight technical errors. Current standards for aircraft separation and obstacle clearance allow for these errors, and in addition, provide an allowance for atmospheric anomalies.

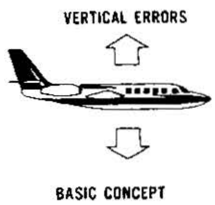


FIGURE 6. LEVEL FLIGHT VERTICAL ERROR

(2) Also, in level flight the combination of ground station, airborne equipment, and computer errors produce a plus-or-minus longitudinal position error called along-track error. No flight technical error is involved.

FIGURE 7. ALONG-TRACK ERROR

(3) Thus, providing airspace for aircraft in level flight using RNAV is simply a matter of containing the plus-or-minus vertical and longitudinal position errors as the aircraft progresses along the intended flight path.

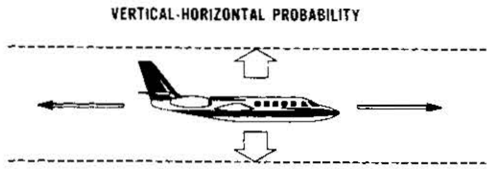


FIGURE 8. AIRSPACE IN LEVEL FLIGHT

b. Vertical Flight RNAV Errors. To provide vertical guidance during ascent or descent, the 3D RNAV equipment compares the indicated altitude with the desired altitude and presents the computer correction instrumentally; typically in the form of fly up/fly down cross pointer information. The computation and comparison process produces vertical position errors which are additional to those affecting the aircraft in level flight.

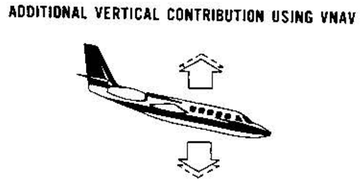


FIGURE 9. ADDITIONAL ERROR ALLOWANCE FOR ASCENDING/DESCENDING FLIGHT.

(1) The along-track error also has significance in vertically guided flight. When an aircraft is ahead or behind its assumed position, it will be either above or below its intended path.

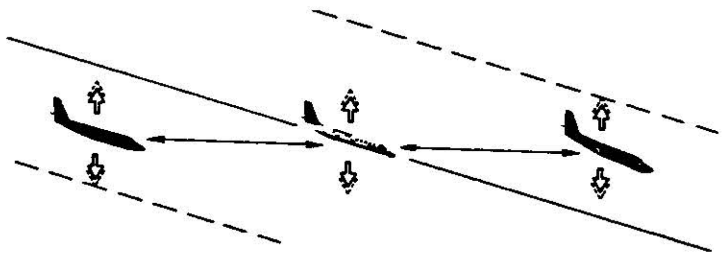


FIGURE 10. EFFECTS OF ALONG-TRACK ERROR.

(2) The angle at which climb or descent is made also affects the required obstacle clearance because as the vertical angle increases, there is a corresponding increase in the effect of the along-track error on the thickness of the tube.

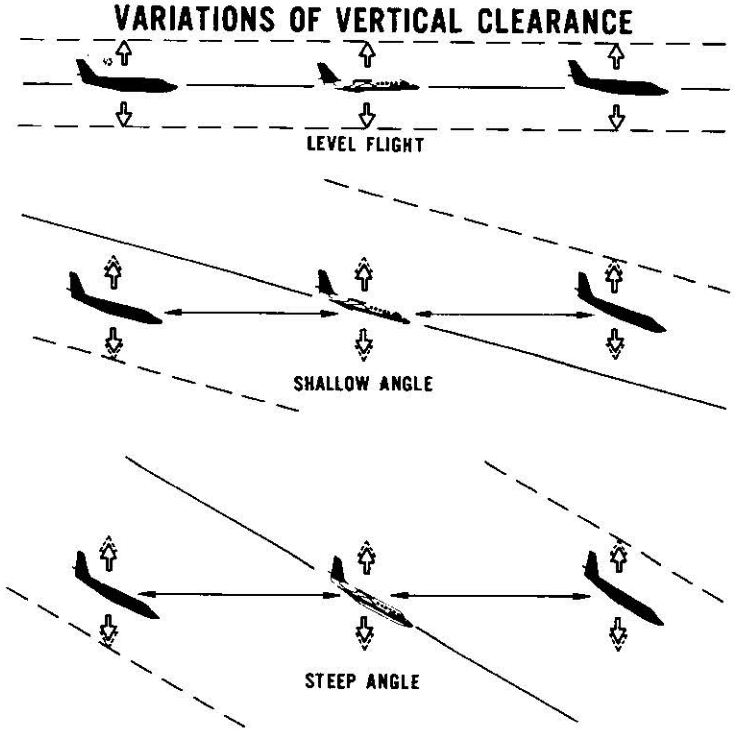


FIGURE 11. VARIATIONS OF TUBE SIZE TO CONTAIN POSITION ERRORS AS VERTICAL ANGLE INCREASES.

6. <u>CONCEPT OF VERTICAL OBSTACLE CLEARANCE</u>. In prescribing obstacle clearance for 3D RNAV, it is useful to think of the vertical route as being the center of a tube of airspace. The lateral dimension of the tube is the width of the RNAV route as described in Section I of this appendix. The vertical dimension of the tube is sufficient to contain the combined 3D RNAV vertical errors. The longitudinal dimension of the tube is limited only by its operational use; for example: The distance required to climb 10,000 feet at a climb angle of 2°, or the descent from the final approach waypoint to the missed approach waypoint at a descent angle of 3°. For obstacle clearance, it is necessary to consider only that portion of the tube which is at and below the designed vertical flight path. An aircraft is protected from obstacles when no obstacles penetrate the tube from below.

7. OBSTACLE CLEARANCE REQUIREMENTS. 3D obstacle clearance requirements will be included in FAA Handbook 8260.3A, "U.S. Standard for Terminal Instrument Procedures (TERPs).

NOTE: Use of 3D RNAV on 2D RNAV procedures is not prohibited. 2D RNAV procedures are annotated with Flight Path Angles measured from the TCH at the runway threshold waypoint to the altitude at the Final Approach ATD. These FPA may be flown as may any other FPA generated by the airborne equipment PROVIDED that the minimum and maximum altitudes specified in the flight procedures or in Air Traffic Control clearances are not violated.

APPENDIX E. MAINTENANCE

1. MAINTENANCE. All maintenance will be performed in accordance with FAR 43 and the manufacturer's instructions, or in accordance with a manual under an approved maintenance procedure. Records of maintenance should be entered in the airplane maintenance records required by FAR 43.9, or in the records required by the operator's approved maintenance procedures. Following repair or alteration, the system should be checked before predicating any operation on its use. Compatibility of the airborne area navigation system replacement components should be assured unless the replacement is of the same make and model as those upon which original approval was based.

2. INSPECTION AND TEST PROCEDURES. Operators using aircraft under IFR with an airborne area navigation system and not under an approved maintenance procedure should establish procedures which will be used to inspect and test the equipment periodically to determine that it is operating in accordance with at least the accuracy specified in Appendix A for minimum equipment. Such procedures should include a method for analyzing malfunctions and defects to determine that the established inspections and tests give reasonable assurance that the equipment is maintaining its accuracy. Test and inspection procedures and intervals should be adjusted in accordance with the results of the analysis.

APPENDIX F. AIR CARRIERS/AIR TAXI AND COMMERCIAL OPERATORS OF LARGE AIRCRAFT/TRAVEL CLUBS*

1. TRAINING PROGRAM. This type of operator should outline the training program he plans to set up to comply with the referenced FAR 121 parts. Under these rules, the training program is acceptable if:

   a. It encompasses all phases of the operation and fully covers all responsibilities of flight crewmembers, dispatchers and maintenance personnel.

   b. Its technical content for pilots covers:

      (1) Theory and procedures, limitations, detection of malfunctions, preflight and inflight testing, cross-checking methods, etc., relating to the operations; and,

      (2) An operational explanation of all systems, together with a review of navigation and flight planning.

   c. Its recurrent training program includes area navigation training.

   d. Each pilot assigned as an operating crewmember completes as many trips over a route or area (either in actual operation or, in part in an approved simulator or approved procedural trainer or training device) under the supervision of an appropriate instructor or a check airman, as may be necessary to:

      (1) Ensure his qualification in the system; and,

      (2) Enable certification of his proficiency in the system, as required by Section 121.401(c).

   e. The training program conforms with the above and is approved by a representative of the Administrator.

   *Travel Clubs will conform to the applicable parts of the above training program.

2. OPERATIONS MANUAL. Revisions to the operations manual should be provided outlining all procedures and emphasizing the methods for preflight and inflight test and step-by-step operation of the area navigation equipment. The manual should contain procedures for continuing the flight with partial or complete area navigation equipment failure.

3. MINIMUM EQUIPMENT LIST (MEL). For those components of the area navigation equipment required for area navigation operations, MEL revisions will be needed and operations specifications will so specify. The MEL should permit single system operation in dual system installations.

4. AUTHORIZATION. The operations specifications will contain the authorization to use an area navigation system and identify the airborne equipment.

5. APPROACH MINIMUMS. For the initial six months of RNAV operations, approach minimums may be approved with an additional margin of 200 feet and 1/2 mile above the MDA and visibility minimums published on the standard instrument approach procedure. At the end of that period, the minimums published on the standard instrument approach procedure may be approved on a permanent basis if the operational reliability has been satisfactorily demonstrated during the initial six month period.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

OPERATIONS SPECIFICATIONS - EN ROUTE FLIGHT PROCEDURES

Form Approved
Budget Bureau No. 04-R083.1

ROUTE OR ROUTE SEGMENT	VIA	OPERATION AUTHORIZED				TYPE OF AIRCRAFT AUTHORIZED				SPECIAL REQUIREMENTS				
		DAY		NIGHT										
		VFR	IFR	VFR	IFR	DC-9 B-707				MOCA	MEA	MAA	OTHER	TYPE NAVIGATION[1]
							Note: Both pilots will be RNAV qualified in accordance with approved training programs, except that when navigation is being performed under the supervision of an approved RNAV-qualified check pilot, the pilots performing such supervised navigation need only have satisfactorily completed the approved RNAV ground school curriculum.							RNAV

EFFECTIVE DATE	NAME OF AIR CARRIER
	ABC Airlines, Inc.

[1] Where a navigator or special cockpit navigation and equipment is required, so specify; ie Navigator, Cockpit (Doppler - Loran), (Inertial).
RNAV

FAA Form 8400-1 (10-68)

APPENDIX G. GENERAL AVIATION

1. TRAINING PROGRAM. The operator should become thoroughly familiar with the operation of his area navigation equipment before he uses this equipment in an IFR environment. A recommended training program should:

   a. Encompass all phases of the operation of the area navigation system.

   b. Cover the theory of operation, setting procedures, familiarization, detection of malfunctions, preflight and inflight testing and cross-checking methods.

   c. Include procedures for continuing the flight with partial or complete area navigation equipment failure.

   d. Provide that each operator of area navigation equipment will complete a sufficient number of simulated IFR approaches, missed approaches, departures and en route operations to ensure that he is competent to operate the equipment.

2. APPROACH MINIMUMS. The accuracy of RNAV equipment which meets only the minimum operational characteristics is such that a straight-in landing cannot always be assured. Therefore, general aviation pilots should not use lower than circling minimums unless they insure their RNAV systems are capable of consistently placing their aircraft within the final approach alignment tolerance.

   The lowest minimums that may be authorized for operations that meet the above performance are those published on the standard instrument approach procedure.

APPENDIX H. AIR TAXI

1. AIR TAXIS USING SMALL AIRCRAFT.

   a. TRAINING PROGRAM. This type operator should outline the training program he plans to establish in compliance with the training requirements of his operations specifications. A training program is acceptable if:

      (1) It encompasses all phases of the operation and fully covers all responsibilities of flight crewmembers and maintenance personnel.

      (2) Its technical content, for pilots, covers:

         (a) Theory and procedures, limitations, detection of malfunctions, preflight and inflight testing, cross-checking methods, etc., relating to the operation; and,

         (b) An operational explanation of all systems, a review of navigation and flight planning.

      (3) Its recurrent training program includes area navigation training.

      (4) Each pilot assigned as an operating crewmember completes as many trips over a route or area (either in actual operation or, in part, in an approved simulator or approved procedural trainer or training device) under the supervision of an instructor or a check airman, as may be necessary to:

         (a) Ensure his qualification in the system; and,

         (b) Enable certification of his proficiency in the system, as required by Section 135.131.

   b. OPERATIONS MANUAL. Revisions to the operations manual should be provided outlining all procedures and emphasizing the methods for preflight and inflight test and step-by-step operation of the area navigation equipment. The manual should contain procedures for continuing the flight navigation with partial or complete area navigation equipment failure.

   c. AUTHORIZATION. The operations specifications will contain the authorization to use an area navigation system and identify the airborne equipment.

2. APPROACH MINIMUMS. For the initial six months of RNAV operations, approach minimums may be approved with an additional margin of 200 feet and 1/2 mile above the MDA and visibility minimums published on the standard instrument approach procedure. At the end of that period, the minimums published on the standard instrument approach procedure may be approved on a permanent basis if the operational reliability has been satisfactorily demonstrated during the intial six-month period.

APPENDIX I. COMPUTATION OF CROSS-TRACK AND ALONG-TRACK ERROR COMPONENTS.

1. TRACK ERROR.

The track error table is developed by combining the appropriate cross-track and along-track error vector derived from VOR, DME, RNAV equipment and pilotage error values. The value printed out in the table is the larger of the two possible vectors (left or right, fore or aft). The mathematics used in these computations for distance greater than five miles are shown in subsequent paragraphs.

NOTE: This appendix is presented for information purposes and for use by manufacturers who wish to develop tables for certification of equipment.

2. CROSS-TRACK.

a. Definitions.

D_1 = Distance from facility to the tangent point.

D_2 = Distance from aircraft to the tangent point.

D = Distance from facility to the aircraft.

θ = The angle formed by the tangent point, facility and the aircraft (facility at Vortex).

α = Ground VOR error.

β = Airborne VOR error.

$\gamma = \sqrt{\alpha^2 + \beta^2}$

DGE = DME ground error.

DAE = DME air error χ % or Υ NM whichever is greater.

DTE = $\sqrt{DGE^2 + DAE^2}$

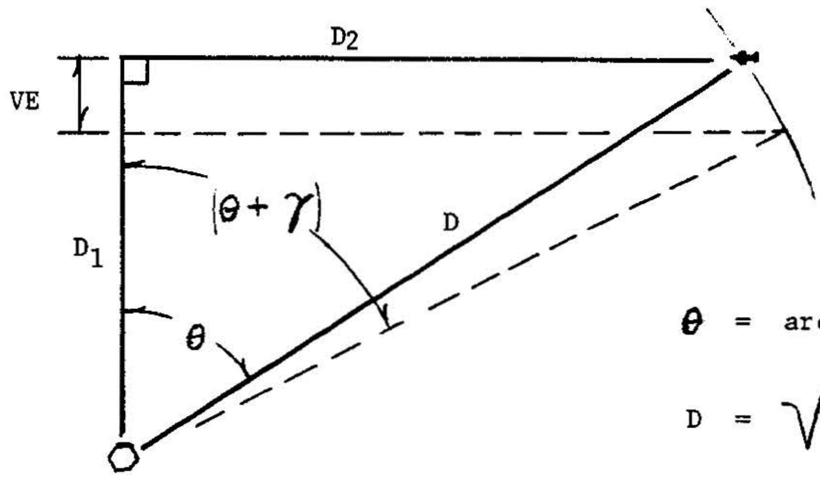
VE = Cross track component of errors due to α and β.

DE = Cross track component of errors due to DAE and DGE.

Pilot = Pilot error.

Comp. = Computer error.

b. VOR Component (VE)

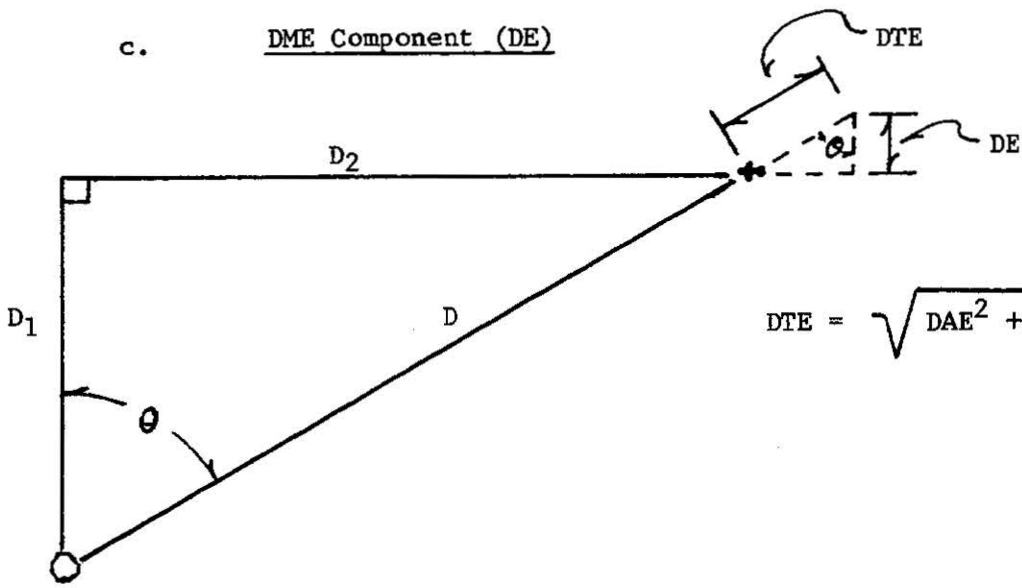


$$\theta = \arctan \frac{D_2}{D_1}$$

$$D = \sqrt{D_1^{\,2} + D_2^{\,2}}$$

$$VE = D_1 - D \cos(\theta + \gamma)$$

c. DME Component (DE)



$$DTE = \sqrt{DAE^2 + DGE^2}$$

$$DE = DTE \cos \theta$$

d. Total expected cross-track error (95%) probability

All cross-track components are combined by the "root-sum-square" method as follows:

$$\text{cross-track error} = \pm\sqrt{VE^2 + DE^2 + Comp^2 + Pilot^2}$$

3. ALONG-TRACK.

a. Definitions

D_1 = Distance from facility to tangent point.

D_2 = Distance from aircraft to the tangent point.

D = Distance from aircraft to the facility.

θ = The angle formed by the tangent point, facility and the aircraft (facility at Vortex).

α = Ground VOR error.

β = Airborne VOR error.

$\gamma = \sqrt{\alpha^2 + \beta^2}$

DGE = Ground DME error.

DAE = DME air error X % or Y NM whichever is greater.

DTE = $\sqrt{DGE^2 + DAE^2}$

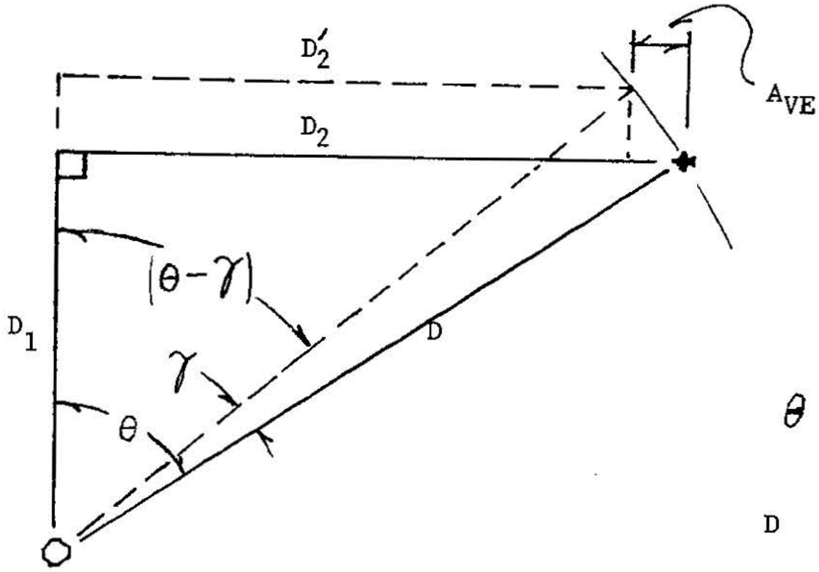
A_{VE} = Along-track component of errors due to α and β.

A_{DE} = Along-track component of errors due to DAE and DGE.

Pilot = Pilot error.

Comp. = Computer error.

b. VOR Component (A_{VE})



$$\theta = \arctan \frac{D_2}{D_1}$$

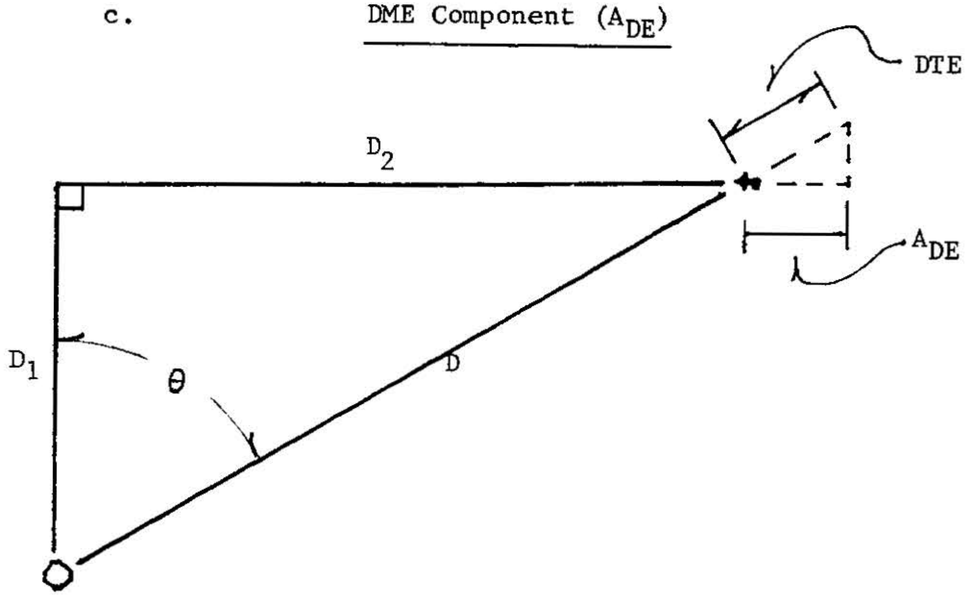
$$D = \sqrt{D_1^2 + D_2^2}$$

$$\frac{D_2'}{D} = \sin(\theta - \gamma)$$

$$D_2' = D \sin(\theta - \gamma)$$

$$A_{VE} = D_2 - D_2'$$

c. DME Component (A_{DE})



$$\text{Sin } \theta = \frac{A_{DE}}{DTE}$$

$$A_{DE} = DTE \text{ Sin } \theta$$

d. Total expected along-track error (95%) probability.

All along-track components are combined by the "root sum square" method.

$$\text{Along-track error} = \sqrt{A_{VE}^2 + A_{DE}^2 + \text{Comp}^2 + \text{Pilot}^2}$$

APPENDIX J. COMPUTATION OF GEODESIC INFORMATION

1. METHOD. Mathematical formulas used for geodetic computations are derived from a procedure developed by Sodano (U.S. Army Engineer; Geodesy, Intelligence and Mapping Research and Development Agency; Fort Belvoir, Virginia.) The method provides very good direct and inverse computational compatibility; it is used by the FAA for all Route development.

NOTE: This appendix is presented for information purposes and for use by manufacturers who wish to compare airborne computational processes. All angles are expressed in degrees and distances in Nautical Miles.

2. COMPUTATION OF A GEODESIC LINE GIVEN TWO GEODETIC POINTS.

Given: B_1, L_1 Geodesic Lat., Long. of P_1

B_2, L_2 Geodesic Lat., Long. of P_2

And

$F = 3.3901 \times 10^{-3}$

$A_o = 3443.95594$ (Semimajor Axis of the Earth)

Required:

A_{12}: Azimuth of Geodesic from P_1 to P_2

A_{21}: Azimuth of Geodesic from P_2 to P_1

S: Geodesic Length

Compute S (Geodesic Length in Nautical Miles):

$$S = (1-F)\ A_o\ S_1$$

Where:

$$S_1 = \Psi + \frac{(F^2 + F)}{2} \left[\Psi(2-M) + \alpha(2A-M\phi)\right]$$

$$+ \frac{F^2}{16\alpha} \left\{8\Psi^2 (M-1)\left[A + \alpha \text{ Cot } \frac{180\Psi}{\pi}\right] + \alpha^2 \phi \left[8A (M\phi-A)+(1-2\phi^2)\right] + \alpha\Psi\right\}$$

$$\Psi = \frac{\pi}{180} \text{ Arc Tan } \frac{\alpha}{\phi}$$

$$M = \frac{\alpha^2 - \text{Sin}^2 L \text{ Cos}^2 \beta_1 \text{ Cos}^2 \beta_2}{\alpha^2}$$

$$\alpha = \left[\text{Sin}^2 L \text{ Cos}^2 \beta_2 + (\text{Sin } \beta_2 \text{ Cos } \beta_1 - \text{Sin } \beta_1 \text{ Cos } \beta_2 \text{ Cos } L)^2\right]^{1/2}$$

$$\phi = \text{Sin } \beta_1 \text{ Sin } \beta_2 + \text{Cos } \beta_1 \text{ Cos } \beta_2 \text{ Cos } L$$

$$L = \begin{cases} L' \text{ if } |L'| \leq 180^\circ \\ L' + 360 \frac{|L'|}{L'} \text{ if } |L'| > 180^\circ \end{cases}$$

$$L' = L_1 - L_2$$

$$A = \text{Sin } \beta_1 \text{ Sin } \beta_2$$

$$\beta_i = \text{Arc Tan } \left[(1-F) \text{ Tan } B_i\right] \text{ for } i = 1, 2$$

Compute A_{12} (Azimuth of Geodesic from P_1 to P_2)

$$A_{12} = \begin{cases} \sigma \text{ if } L \geq 0 \\ \sigma + 180^\circ \text{ if } L < 0 \end{cases}$$

Where:

$$\sigma = \begin{cases} \text{Arc Tan } \frac{a}{b} + 180^\circ \text{ if Arc Tan } \frac{a}{b} < 0 \\ \text{Arc Tan } \frac{a}{b} \quad \text{if Arc Tan } \frac{a}{b} \geq 0 \end{cases}$$

$$a = \text{Sin } H \text{ Cos } \beta_2$$

$$b = \text{Sin } \beta_2 \text{ Cos } \beta_1 - \text{Cos } H \text{ Sin } \beta_1 \text{ Cos } \beta_2$$

$$H = \frac{180}{\pi} \left[\frac{\text{Sin } L \text{ Cos } \beta_1 \text{ Cos } \beta_2}{\alpha} \right] \left[x \right] + L$$

$$x = \Psi (F+F^2) - \frac{AF^2}{2\alpha} \left[\alpha^2 + 2\Psi^2 \right] + \frac{MF^2}{4} \left[\alpha\phi - 5\Psi + 4\Psi^2 \text{ Cot } \frac{180\Psi}{\pi} \right]$$

Compute A_{21} in degrees (Azimuth P_2 to P_1)

$$A_{21} = \begin{cases} V & \text{if } L \leq 0 \\ V + 180^\circ & \text{if } L > 0 \end{cases}$$

Where:

$$V = \begin{cases} 180^\circ + \text{Arc Tan } \frac{c}{d} & \text{if Arc Tan } \frac{c}{d} < 0 \\ \text{Arc Tan } \frac{c}{d} & \text{if Arc Tan } \frac{c}{d} \geq 0 \end{cases}$$

$$c = \text{Sin } H \text{ Cos } \beta_1$$

$$d = \text{Sin } \beta_2 \text{ Cos } \beta_1 \text{ Cos } H - \text{Sin } \beta_1 \text{ Cos } \beta_2$$

Computation of the Geodetic Description of a True Bearing and Distance From A Given Geodetic Point.

Given: B_1 Geodesic Latitude of a P_1

L_1 Geodesic Longitude of a P_1

S Geodesic Length

A_{12} Azimuth of Geodesic from P_1 to P_2

And:

$F = 3.3901 \times 10^{-3}$

$A_o = 3443.95594$

Required: B_2 Geodesic Latitude of P_2

L_2 Geodesic Longitude of P_2

A_{21} Azimuth of Geodesic from P_2 to P_1

Compute B_2 Geodesic Latitude

$$B_2 = \text{Arc Tan}\left[\frac{\text{Tan}\,\beta_2}{1-F}\right]$$

Where:

$$\text{Tan}\,\beta_2 = \frac{\text{Sin}\,\beta_1\,\text{Cos}\,\rho + \text{Cos}\,\beta_1\,\text{Cos}\,A_{12}\,\text{Sin}\,\rho}{\left[\text{Cos}^2\,\beta_o + (\text{Cos}\,\rho\,\text{Cos}\,\beta_1\,\text{Cos}\,A_{12} - \text{Sin}\,\beta_1\,\text{Sin}\,\rho)^2\right]^{1/2}}$$

$$\rho = r - \frac{90A_1E_2}{\pi}\,\text{Sin}\,r - \frac{M_1E_2}{8}\left(2r - \frac{180}{\pi}\,\text{Sin}\,2r\right) + \frac{225}{4\pi}A_1^2E_2^2\,\text{Sin}\,2r$$

$$+ \frac{M_1^2E_2^2}{128}\left[22r - \frac{2340}{\pi}\,\text{Sin}\,2r - 16r\,\text{Cos}^2\,r + \frac{1800}{\pi}\,\text{Cos}^2\,r\,\text{Sin}\,2r\right]$$

$$+ \frac{A_1M_1E_2^2}{16}\left[\frac{1080}{\pi}\,\text{Sin}\,r + 4r\,\text{Cos}\,r - \frac{900}{\pi}\,\text{Cos}\,r\,\text{Sin}\,2r\right]$$

$$A_1 = h\left[\text{Sin}^2\,\beta_1\,\text{Cos}\,r + \text{Cos}\,\beta_1\,\text{Cos}\,A_{12}\,\text{Sin}\,\beta_1\,\text{Sin}\,r\right]$$

$$r = \frac{180S}{\pi\,(1-F)A_o}$$

$$M_1 = h\,(1 - \text{Cos}^2 \beta_o)$$

$$h = 1 + \frac{E_2}{2} \text{Sin}^2 \beta_1$$

$$\beta_1 = \text{Arc Tan}\left[(1-F) \text{ Tan } B_1\right]$$

$$\text{Cos } \beta_o = \text{Cos } \beta_1 \text{ Sin } A_{12}$$

$$E_2 = (1-F)^{-2} - 1$$

Compute L_2 (Geodesic Longitude)

$$L_2 = \begin{cases} L_2' - \dfrac{360\,L_2'}{|L_2'|} & \text{if } |L_2'| > 180 \\ L_2' & \text{if } |L_2'| \leq 180 \end{cases}$$

$$L_2' = L_1 - V \text{ Cos } \beta_o - L_c'$$

$$V = \frac{270\,A_1F^2}{\pi} \text{ Sin } r - Fr + \frac{3M_1F^2}{4}\left(r - \frac{90 \text{ Sin } 2r}{\pi}\right)$$

$$L_c' = \begin{cases} L_c - 180 & \text{if Sin } \rho \geq 0 \text{ and Sin } A_{12} < 0 \\ L_c + 180 & \text{if Sin } \rho < 0 \text{ and Sin } A_{12} \geq 0 \\ L_c - 360 & \text{if Sin } \rho < 0 \text{ and Sin } A_{12} < 0 \\ L_c & \text{Otherwise} \end{cases}$$

$$L_c = \text{Arc Tan} \frac{\text{Sin } \rho \text{ Sin } A_{12}}{\text{Cos } \beta_1 \text{ Cos } \rho - \text{Sin } \beta_1 \text{ Sin } \rho \text{ Cos } A_{12}} \quad \text{where } -90 \leq L_c \leq 90$$

Compute <u>Geodesic Azimuth A_{21}</u> in degrees

$$A_{21} = \begin{cases} (A_{21}' + 180^\circ) & \text{if Sin } A_{12} \geq 0 \\ A_{21}' & \text{if Sin } A_{12} < 0 \end{cases}$$

$$A'_{21} = \begin{cases} \bar{A} + 180^\circ & \text{if } \frac{N}{D} < 0 \\ \bar{A} & \text{if } \frac{N}{D} \geq 0 \end{cases}$$

$\bar{A}$ = Arc Tan $\frac{N}{D}$ where $-90^\circ \leq \bar{A} \leq 90^\circ$ (Principle Arc Tan)

$N = \text{Cos } \beta_o$

$D = \text{Cos } \beta_1 \text{ Cos } A_{12} \text{ Cos } \rho - \text{Sin } \beta_1 \text{ Sin } \rho$