DOT/FAA/CT-82/48

Microwave Landing System/ Area Navigation Curved Path Approach Flight Tests

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Test Plan

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Federal Aviation Administration
Technical Center
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1. INTRODUCTION.

1.1 OBJECTIVES.

The objectives of these flights are to test the accuracy and suitability of a modified area navigation (RNAV) system to perform Microwave Landing System (MLS) guided curved path approaches in support of the MLS Service Test and Evaluation Program (STEP), and to develop the data base and background experience required to formulate instrument approach and obstacle clearance criteria. The curved path approach concept offers significant benefits for noise abatement and obstacle clearance problems. The equipment, a Jet Electronics and Technology (J.E.T.™) DAC-2000 RNAV system will be installed and flown in one of the Federal Aviation Administration (FAA) Technical Center's Boeing 727's, N-40. An onboard data collection system will collect aircraft state and navigation system data, and telemetered aircraft position data from ground tracking equipment. Additional ground tracking data will be merged with airborne data postmission. Among the parameters to be examined are system accuracy, path repeatability, aircraft dynamics, and level of pilot workload. Specific criteria to be applied are found in current Advisory Circulars (AC's) pertaining to RNAV systems and Category I and II flight control systems.

Conclusions and recommendations will address the adequacy of this level of equipment sophistication to perform this task, and identification of and proposed solutions to, any system or operational problems encountered.

The specific objectives are as follows:

1.1.1 Accuracy.

a. To determine if the J.E.T. MLS RNAV system meets the requirements of AC-90-45A, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System," when processing MLS signals in lieu of very high frequency omnirange/distance measuring equipment (VOR/DME) signals.

b. To determine if the lateral and vertical guidance provided by the J.E.T. MLS/RNAV system is as accurate as the guidance provided by localizer (LOC) and glide slope (GS) systems when flying to a noninstrumented runway within MLS coverage.

c. To determine if the J.E.T. MLS/RNAV guidance is as accurate as MLS receiver raw deviation when on centerline approach to an MLS equipped runway.

1.1.2 Dynamic Performance.

a. To determine if the lateral and vertical guidance provided by the J.E.T. MLS/RNAV signals to the B-727 autopilot are sufficient to keep the aircraft within Category I and II automatic approach criteria.

b. To determine if the J.E.T. MLS/RNAV signals provide as good autopilot tracking on runway centerline and on selected glide slope as the MLS receiver raw deviation signals.

c. To determine if the J.E.T. MLS/RNAV system causes any significant overshoot or undershoot of final approach course and to determine if these deviations are a function of final intercept angle, final segment length, or manual versus coupled autopilot flight.

d. To determine the extent of dispersion of ground path and vertical path on repeated approaches over the same route and to find, if possible, the cause of any excessive dispersion encountered.

e. To determine if the J.E.T. MLS/RNAV system can navigate over a multi-segmented three-dimensional curved path approach and bring the aircraft into the threshold zone with the proper position, attitude, and energy for a normal manual touchdown.

f. To determine if the J.E.T. MLS/RNAV system can transition from navigation on inaccurate VOR/DME signals to navigation on MLS signals without excessive path dispersion.

g. To determine if the J.E.T. MLS/RNAV can transition from vertical guidance using less accurate barometric altitude information to MLS derived vertical guidance with no excessive altitude loss or gain.

h. To determine the extent to which any MLS/RNAV system errors are particular to this equipment and aircraft or if they would be expected to occur in other installations.

i. To determine if the J.E.T. MLS/RNAV system can provide adequate guidance to execute a multisegmented missed approach procedure in those circumstances where the normal straight ahead and climb maneuver is inappropriate.

j. To determine if the J.E.T. MLS/RNAV system can provide adequate guidance to perform delay and speedup maneuvers such as parallel offsets and direct-to-waypoint paths in response to air traffic control (ATC) requests, and to determine if any special problems exist in performing these maneuvers under MLS guidance.

k. To compare, in a broad sense, the quality of guidance provided by this slightly modified off-the-shelf RNAV computer with the performance offered by state-of-the-art aircraft and systems, particularly the U.S. Air Force (USAF) MLS equipped T-39 and the National Aeronautics and Space Administration's (NASA's) Terminal Configured Vehicle (TCV).

1.1.3 Human Factors Objectives.

a. To determine what differences exist in blunder tendency and magnitude of flight technical error between fully automatic RNAV system operation and manual system operation.

b. To determine if any aspect of operation of this MLS/RNAV system presents the possibility for repeated or serious pilot blunders and whether these are particular to the J.E.T. system or might be endemic to MLS/RNAV systems in general.

c. To determine if the J.E.T. MLS/RNAV system, through the presentation of a unified set of guidance displays, can keep the pilot better oriented to his present location and intended direction and if this better orientation can improve his navigation and aircraft control performance during complicated go-around procedures or after navigation equipment failure.

d. To determine the level of pilot acceptance of, or resistance to, the high dynamics (versus long stabilized) final approach to landing.

e. To determine the pilot acceptance of, or resistance to, the steep descent and short final type of approach in scheduled passenger service.

f. To determine what relationship, if any, exists between course width sensitivity and the magnitude of flight technical error.

1.2 BACKGROUND INFORMATION.

The concept of using MLS in an area navigation mode has been demonstrated by several government organizations including FAA, NASA, and the USAF. These demonstrations, for the most part, used highly specialized computers and some used advanced display concepts.

However, airlines and aircraft operators will be understandably reluctant to invest in new guidance systems and advanced display equipment for existing aircraft. The concept of an MLS curved path approach will be more readily accepted if it can be performed with conventional displays and comparatively low cost guidance equipment.

During the MLS worldwide demonstrations, 1977 and 1978, Technical Center personnel, including this author, adapted a conventional RNAV system, a Collins Radio Corporation ANS-70 installed aboard the Center's Convair 880 aircraft to use MLS azimuth and DME signals electronically modified to simulate the outputs of standard VOR/DME airborne equipment. Several flight-tests showed moderate success in flying the Canarsie approach at New York's John F. Kennedy (JFK) Airport, but there were serious drawbacks to the scheme: (a) vertical guidance came strictly from barometric instruments, not MLS elevation signals; (b) the RNAV computer was unmodified and could not take advantage of MLS's greater accuracy; and (c) the cockpit workload was very high, requiring a fourth crew-member in the cockpit.

Recognizing the need to gain experience in MLS curved path approaches based on existing technology, the FAA Systems Research and Development Service (SRDS) embarked upon a program to obtain information about MLS/RNAV so that preliminary avionics standards can be formulated. A contract was initiated with Systems Control Technology (SCT) of West Palm Beach, Florida, to consider the application of MLS/RNAV and it's impact upon terminal area operations. Subsequently, a subcontract was issued to Jet Electronics and Technology of Grand Rapids, Michigan, to modify one of their DAC-2000 VOR/DME RNAV systems in such a way that MLS/RNAV operations could be performed, with none of the shortcomings of earlier efforts.

In January 1980, J.E.T. demonstrated this capability at the FAA Technical Center on runway 31 in their company aircraft, a Cessna 421. The JET MLS/RNAV equipment was substantially modified to provide selectable lateral course sensitivity and a capability to output certain test parameters for flight test recording purposes.

1.3 RELATED PROJECTS.

A similar project is being conducted jointly by NASA and FAA at NASA's Langley Research Center, Hampton, Virginia. The objective of the program is to build an aircraft and equipment data base to be used in developing terminal instrument procedures (TERPS) criteria. The aircraft used is a USAF T-39 transport (Saberliner) and is equipped with digital flight computers and conventional cockpit displays. The navigation computations to direct the aircraft along an MLS guided curved path approach are also done in the flight control computers. One of the significant differences in computational techniques between this aircraft's guidance and the J.E.T. RNAV guidance, is that in the T-39 the desired path is described as straight line segments joined by fixed radius arc-segments. An analysis of the difference in computation power required and available will be included in the final report.

The joint FAA/NASA flights will be conducted at NASA's Wallops Flight Center, Wallops Island, Virginia. First flights were planned for December 1981, with project completion in late 1982. One of the first tasks undertaken will be to determine the minimum distance the aircraft must be stabilized on centerline and on glide slope prior to decision height. Once the minimum stabilized segment (MSS) has been determined, the maximum intercept angle to final approach course will be determined. The test plan originally conceived for the J.E.T. MLS/RNAV project by SCT included approximately 30 hours of flight time to test MSS and intercept angle. This portion of testing would have been an unnecessary and costly duplication of effort, and has been greatly reduced in scope. The MSS and maximum intercept angle determined in the FAA/NASA T-39 flights will be tested to ensure that it can be flown in the B-727, or if not, what longer segment length or shallower intercept angle is necessary. This is expected to take no more than 10 flight hours.

1.4 RELATED DOCUMENTATION.

a. Report FAA-RD-76-32 dated May 1976, "A Flight Investigation of System Accuracies and Operational Capabilities of an Air Transport Area Navigation System," describes the flight evaluation of an advanced area navigation system, the Collins Radio Corporation ANS-70. Of particular relevance are those sections dealing with parallel offset maneuvers and direct to waypoint maneuvers to implement speedup and delay for traffic spacing.

b. Report FAA-RD-79-120 dated February 1980, "A Flight Investigation of System Accuracies and Operational Capabilities of a General Aviation/Air Transport Area Navigation System," describes the flight evaluation of a medium capability area navigation system, the Edo Corporation TCE-71A. This system was almost identical in operation to the J.E.T. RNAV in its high workload mode.

c. AC 120-28A dated December 14, 1971, "Criteria for Approval of Category IIIa Landing Weather Minima," describes the required capabilities of an autopilot for Category III approach and landing operations and describes the lateral and vertical limits within which the aircraft must remain on final approach.

d. AC 120-29 dated September 25, 1970, "Criteria for Approving Category I and Category II Landing Minima for FAR 121 Operators," describes the required capabilities of an autopilot for Category II approach and landing operations and the lateral and vertical limits within which the aircraft must remain on final approach.

e. AFFDL-TR-76-43 dated January 1970, "Flight Test Demonstration of Selected Segmented Approach Paths Based on Microwave Landing System Guidance," describes flight tests of an MLS curved approach and auto-land system onboard a USAF T-39 transport. Directly comparable to the J.E.T. MLS/RNAV tests are short final approach and segmented glidepath flight evaluations.

f. NASA TM 78745 dated May 1978, "Flight Demonstration of Curved Descending Approaches and Automatic Landings Using Time Reference Scanning Beam Guidance," describes flight demonstrations of the NASA Boeing 737 TCV flying MLS guided curved path approaches and automatic landings. This aircraft employed state-of-the-art computing power and cockpit displays in its guidance system.

g. FAA Handbook OAP 8200.1, "U.S. Standard Flight Inspection Manual," describes accuracy requirements for Category I, II, and III Instrument Landing Systems.

h. AC 90-45A dated February 21, 1975, "Approval of Area Navigation Systems for Use in the U.S. National Airspace System," describes the accuracy requirement for both VOR/DME and non-VOR/DME RNAV systems. It also delineates individual error limits and their contribution to the overall error budget.

i. "Microwave Landing System Service Test and Evaluation Program (STEP)," dated September 12, 1978, is an overview document of the MLS program.

j. Report MTR-6951 dated July 1975, "Benefits of MLS Guidance for Curved Approaches," proposes several curved approach paths for use in the Newark/ La Guardia/Kennedy terminal area to resolve airspace conflict and provide noise abatement benefits.

k. Report FAA-RD-71-84 dated September 1971, "Measurement and Analysis of Noise from Four Aircraft During Approach and Departure Operations (727, KC-135, 707-320B, and DC-9)," reports noise measurements of various approach techniques, including two-step glide slopes.

l. "MLS/RNAV Integration Program" dated February 1, 1980, Final Report, Phase 1, prepared by J.E.T. Electronics and Technology, Inc., 5353 52nd Street, Grand Rapids, Michigan, 49508, describes the development and operation of the J.E.T. MLS/RNAV system.

m. "MLS/RNAV Flight Test Evaluation Plan" dated April 1, 1980, Systems Control Technology, Incorporated, contract No. DOT-FA78WA-4138, original test plan for this project. This document is a source for some of the flight test routes to be used in this evaluation.

2. SYSTEM/EQUIPMENT DESCRIPTION.

2.1 TEST AIRCRAFT.

The test aircraft is the Technical Center's Boeing 727-100QC, registration N-40. This is a representative short-to-medium haul aircraft with a maximum gross weight of 160,000 pounds, 94 to 131 passenger capacity, cruising speed of 450 knots, and approach speeds in the range of 120 to 140 knots. There are about sixteen hundred 727's in service worldwide.

The airframe and engines are standard Boeing issue, but this aircraft's electrical and avionics systems have been extensively modified and upgraded to support project tasks. Sensors and systems added include:

Dual Litton LTN-51 Inertial Navigation Systems

Bendix RDR 1400 Color Weather Radar

Dual KDM-7000 DME Interrogators

60 Hz 110 V power; 3.5 kVA available

Flight control position sensors: aileron, elevator, rudder, flaps, No. 3 throttle

Angle of attack and sideslip sensors

Digital Airdata Computer

Wind shear detection equipment

Project signal inputs to the pilot's Attitude and Direction Indicator (ADI), pilot's Horizontal Situation Indicator (HSI), Collins FD-109 Flight Director System, and Sperry SP-50 autopilot

Data collection system (described later in this document)

The Technical Center's other transport aircraft, Convair 580's, were considered for the tests but were deemed unsuitable for several reasons. Technical Center pilots report two problems, both related to the age and lack of sophistication of the autopilot.

a. The system will not track a VOR (and, thus, not the RNAV) properly in a crosswind, instead, "standing off" from course by several degrees.

b. The altitude hold function (and, thus, vertical navigation (VNAV)) becomes unstable and oscillatory at cruise speeds.

A data collection system is already installed on N-40 which will require very little upgrading to collect all required data.

2.2 MLS/RNAV SYSTEM.

In addition to standard VOR and barometric altitude instruments, the 727 will be equipped with a Bendix STEP MLS receiver, an MLS Precision DME interrogator, and the J.E.T. DAC-2000 RNAV computer modified to accept and use MLS azimuth and elevation inputs in addition to VOR, DME, and barometric altitude. A block diagram of the navigation system is shown in figure 1. This system is a conventional RNAV/VNAV setup except for the MLS receiver shown at the left of the diagram.

2.2.1 VOR-DME/RNAV Operation.

The J.E.T. RNAV is a station referenced system in which the waypoint is defined by specifying a range and radial from a reference VOR/DME station. The deviation output displays are referenced to: (a) the selected inbound course to the waypoint, and (b) a selected climb or descent angle to cross the waypoint at a selected altitude. Bearing and distance displays are direct to the waypoint.

The system displays lateral and vertical deviation from desired path, to/from, bearing and distance to waypoint, and selected course on conventional instruments. The aircraft ADI and HSI which display this information are shown in figure 2. The system is capable of storing up to 100 routes of 1 to 20 waypoints each and has a total capacity of 187 waypoints. The following data associated with each waypoint can be stored:

- Waypoint range
- Waypoint radial
- Waypoint altitude
- Frequency of the VOR/DME facility
- Inbound course to the waypoint
- Vertical descent angle to the waypoint
- Elevation of the reference facility (for slant range correction)
- Total flight distance (for flight management purposes)

The control display unit (CDU) for the J.E.T. system is shown in figure 3. The top of the CDU is a two-line gaseous discharge display which is used for viewing and verifying computer data. The two lefthand columns on the keyboard are used to store and recall waypoint parameters. The righthand column is used to select specific waypoints and routes. The numeric keys are used to input data. A detailed description of the CDU operation is contained in appendix A.

Two additional RNAV controls are available to the pilot. One is the control annunicator. This panel, shown in figure 4, is used to display and control the functions of the RNAV system. The other panel is the offset control, shown in figure 5. This control permits parallel, lateral offsets, and along-track offsets to be input into the computer guidance computations. This results in a modified flightpath which can be useful for responding to ATC requests or storm avoidance. The J.E.T. RNAV system to be used in these tests has the following additional features not found in other DAC-2000 RNAV systems but used in the DAC-7000 series computer:

- Automatic course slewing on the HSI
- Automatic waypoint advance
- Improved ground speed computation for turn anticipation

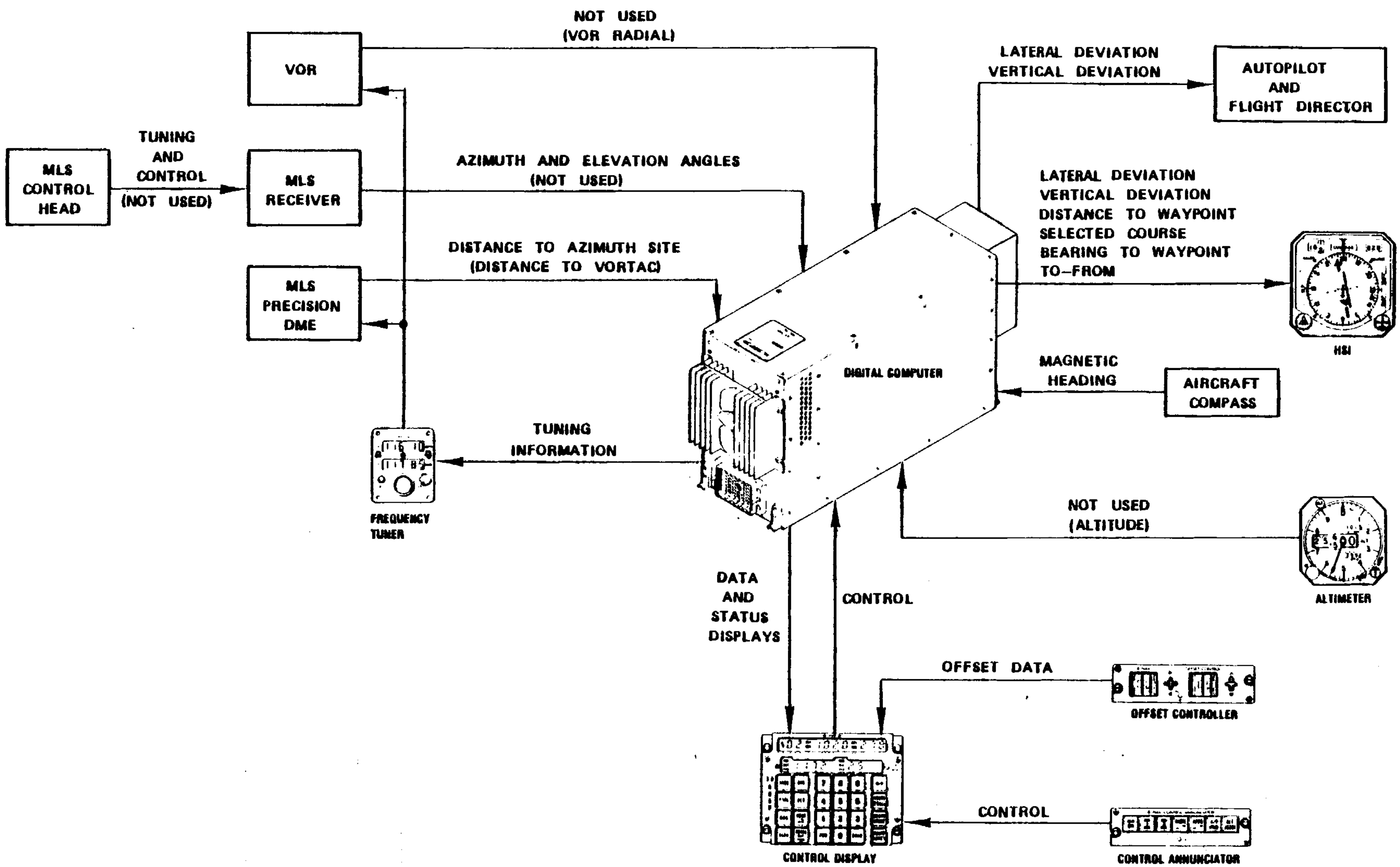

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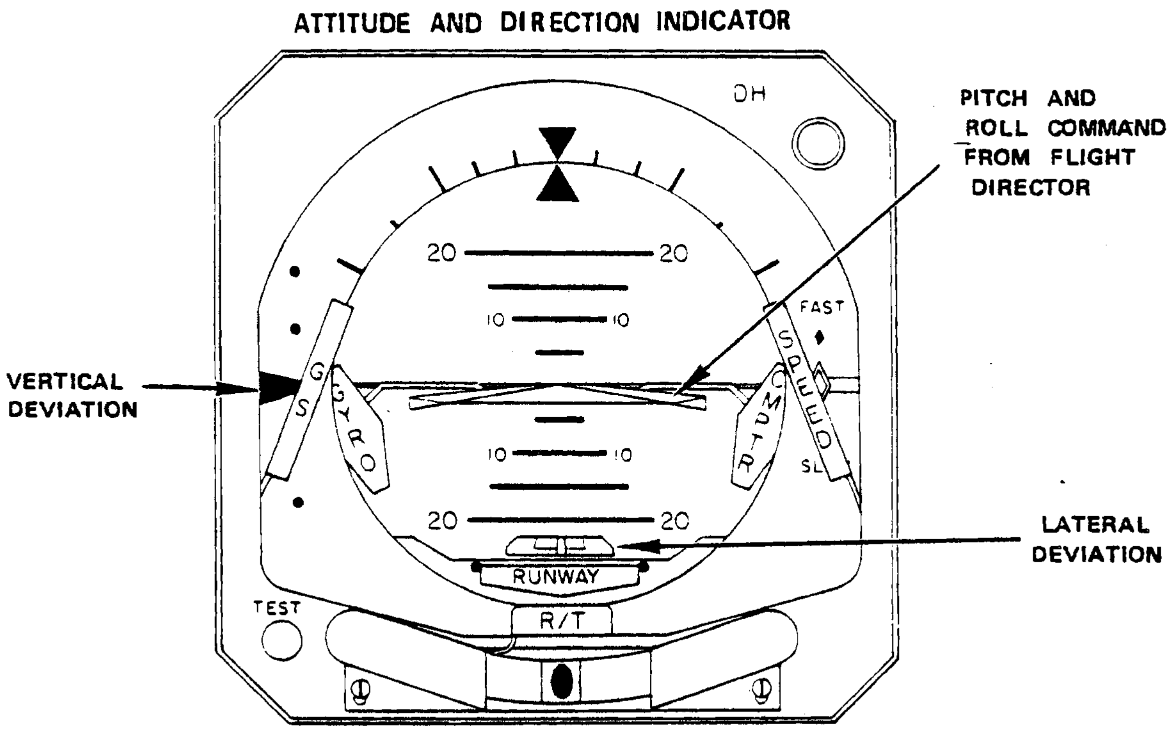
FIGURE 1. DAC-2000 MLS/RNAV SYSTEM BLOCK DIAGRAM



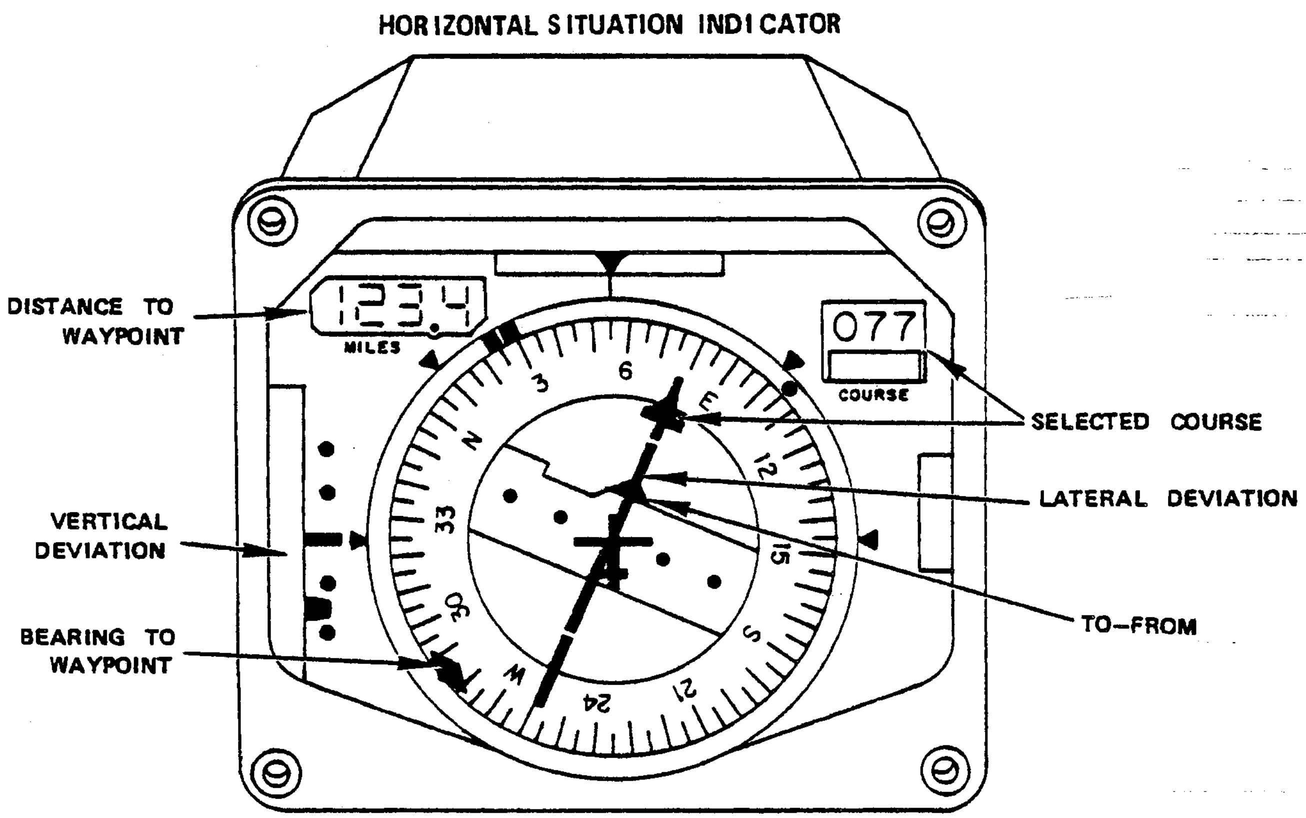


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FIGURE 2. AIRCRAFT ADI AND HSI

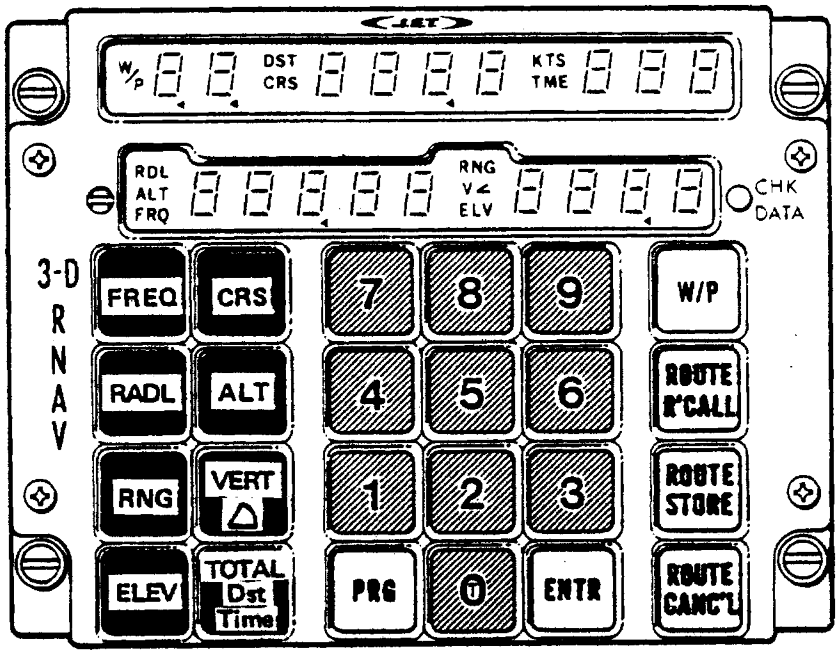

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FIGURE 3. J.E.T. SYSTEM CDU

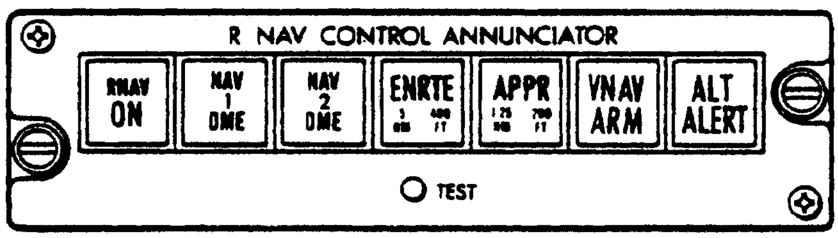

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FIGURE 4. J.E.T. SYSTEM CONTROL ANNUNCIATOR PANEL

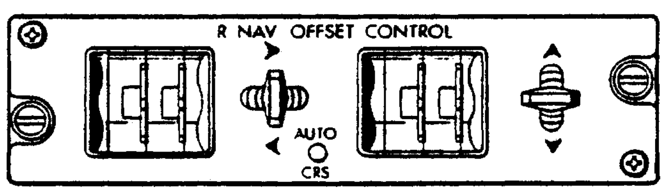

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FIGURE 5. J.E.T. SYSTEM OFFSET CONTROLLER

These features allow virtually "hands off" approaches to be made in autopilot coupled operations and aircraft control inputs only in uncoupled operations. This, plus the capability to store all waypoint parameters, greatly reduces the pilot's navigation workload.

2.2.2 MLS/RNAV OPERATIONS.

In the MLS/RNAV configuration, the computer uses both DME and MLS azimuth information for lateral guidance and DME azimuth and elevation information for vertical guidance. The algorithm by which this is achieved is described in detail in the J.E.T. report "MLS/RNAV Integration Program" listed in section 1.4 of this test plan. The incorporation of this capability in the J.E.T. system is provided by a direct input of MLS azimuth and elevation digital data from the MLS receiver into the navigation computer. The computer responds in the following manner:

a. If the active waypoint is 1 through 10, the computer ignores the MLS information and operates in the VOR/DME/baro-altitude RNAV mode.

b. If the active waypoint is 11, the computer decodes MLS azimuth and builds confidence in the signal but remains in the VOR/DME/baro-altitude RNAV mode.

c. If the active waypoint is 12, the computer uses DME and MLS azimuth, modified by runway heading, for lateral guidance. The computer begins looking at MLS elevation and building confidence in that signal. Vertical guidance is provided by baro-altitude.

d. If the active waypoint is 13 and if the elevation data is valid, the vertical guidance transitions from using baro-altitude to using the computed MLS altitude. The vertical path angle is recomputed by using MLS altitude, the altitude of the waypoint, and the distance to the next waypoint. Therefore, no altitude discontinuity should occur. If elevation data are not valid, an annunciator is lighted and the vertical guidance remains on baro-altitude.

e. If the active waypoint is 14 through 20, the aircraft remains on MLS and DME guidance. The loss of any of these guidance signals will cause a flag to drop on the HSI indicating that the approach should be terminated.

f. A missed approach using VOR/DME/RNAV may be initiated by selecting a waypoint number from 1 to 10.

Thus, waypoints 1 through 10 may, but need not, be used for conventional RNAV (e.g., en route, missed approach). Waypoint 11 is normally the initial approach fix (IAF) and must be within azimuth signal coverage. Waypoint 12 is normally the intermediate fix (IF) and must be within azimuth and elevation coverage. Waypoints 13 to 20 (as necessary) are fixes along the final approach course, including final approach fix and missed approach point. These must also be within azimuth and elevation coverage.

The computation of MLS azimuth and MLS altitude requires the use of MLS site related data. These site constants are broadcast by the MLS ground station as part of the auxiliary data message. In operational use these constants would be obtained from this MLS auxiliary data. However, the J.E.T. MLS/RNAV equipment is an engineering development type of system and the site constants for six MLS equipped runways are permanently stored in the DAC-2000's memory.

FAA Technical Center runway 31
Washington National Airport runways 18 and 33
Philadelphia International Airport runway 17
Benedum Airport, Clarksburg, W. Va., runway 21
One Spare

The required numbering for waypoints and the lack of auxiliary data input are two limitations of this specific equipment. These limitations do not affect the operational capability or the accuracy of the guidance computations. It does, however, remove the potential for evaluating auxiliary data inputs to the computer.

2.2.3 MLS/RNAV to Analog MLS Transition.

In addition to the logic and program modifications to provide MLS/RNAV guidance, the J.E.T. system can cause guidance to be switched from MLS/RNAV to analog MLS azimuth and elevation. The MLS/RNAV mode functions to bring the aircraft within a specified envelope around the selected MLS azimuth/elevation and DME distance. When these conditions are met, a relay is energized which switches the MLS analog outputs from the Bendix receiver directly to the pilot's HSI and flight director, or autopilot, thus eliminating the navigation computer from the system. This feature may be deselected by a switch on the rack containing the computer.

At the time this test plan was drafted, a software problem in the DAC-2000 computer prevented navigation on baro-altitude in the event the elevation signal was not valid. This condition will remain during the initial checkout phase, but is expected to be rectified before the data collection is begun.

3. TESTING AND DATA COLLECTION.

3.1 FLIGHT TEST PROFILES.

A series of profiles has been developed to test the capabilities of the J.E.T. MLS/RNAV system and to simulate realistic operational scenarios.

3.1.1 Lateral Profile Tests.

Figure 6 shows the lateral profile to be flown to test the minimum stabilized segment length and maximum intercept angle. The initial approach segment (IAS) is flown at level altitude. Lateral guidance is by MLS and vertical guidance transitions from baro-altitude to MLS elevation on this segment. The intermediate segment (IS) and final approach segment (FAS) are flown at a 3° descent angle under full MLS guidance. The length of the final approach segment and the intercept angle will be the values determined by the concurrent joint FAA/NASA project previously mentioned in this test plan.

The patterns will be flown manually and on autopilot down to Category II decision height (100 feet). On some of the autopilot flights the final approach segment will use MLS receiver raw deviation signals instead of MLS/RNAV computer outputs to test the autopilot's ability to capture and track properly on short final segment.

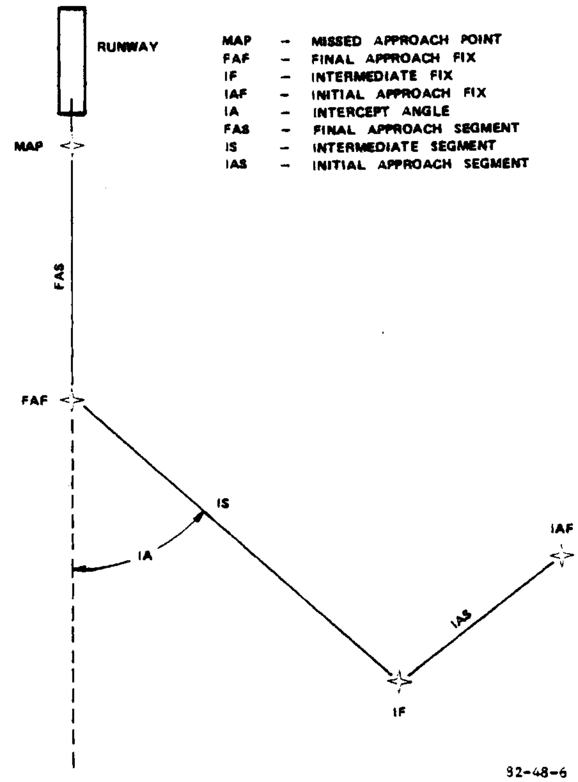

FIGURE 6. LATERAL PROFILE TESTS

Category I, II, and III refer to differing bad weather visibility requirements for landing and are determined by, among other things, instrument landing system (ILS) airborne and ground equipment accuracy.

For Category I, ILS accuracy is specified down to 200 feet above the runway. Below this "decision height" (DH), the pilot must have the runway, runway markings, or approach lights in sight to land, or else must discontinue the approach, i.e., "a missed approach".

Category II accuracy is specified down to 50 feet, and decision height is as low as 100 feet.

Category III accuracy is specified down to and along the surface of the runway for zero visibility operations. Other factors determining category of operations are airborne and ground equipment redundancy, runway lighting, pilot training, visibility measuring equipment, and terrain clearance.

3.1.2 Vertical Profile.

The vertical navigation (VNAV) capability of the MLS/RNAV system can be used to perform the two-step glide slope approach. In this profile the aircraft descends on a steep glidepath and joins the normal 3° glidepath at a point several miles from threshold. This maneuver keeps the aircraft higher on final approach, and reduces the noise impact on areas under the final approach path.

The vertical profile to be flown is shown in figure 7. The initial approach segment is flown at level altitude, the intermediate segment is flown at 4.5° or 6°, and the final approach is flown at 3°. The lateral profile is a straight-in centerline approach. The distance from threshold at which the steep descent transitions to shallow descent has not yet been determined, pending further study by project personnel on the reduction in noise impact offered by various descent angles and intercept distances.

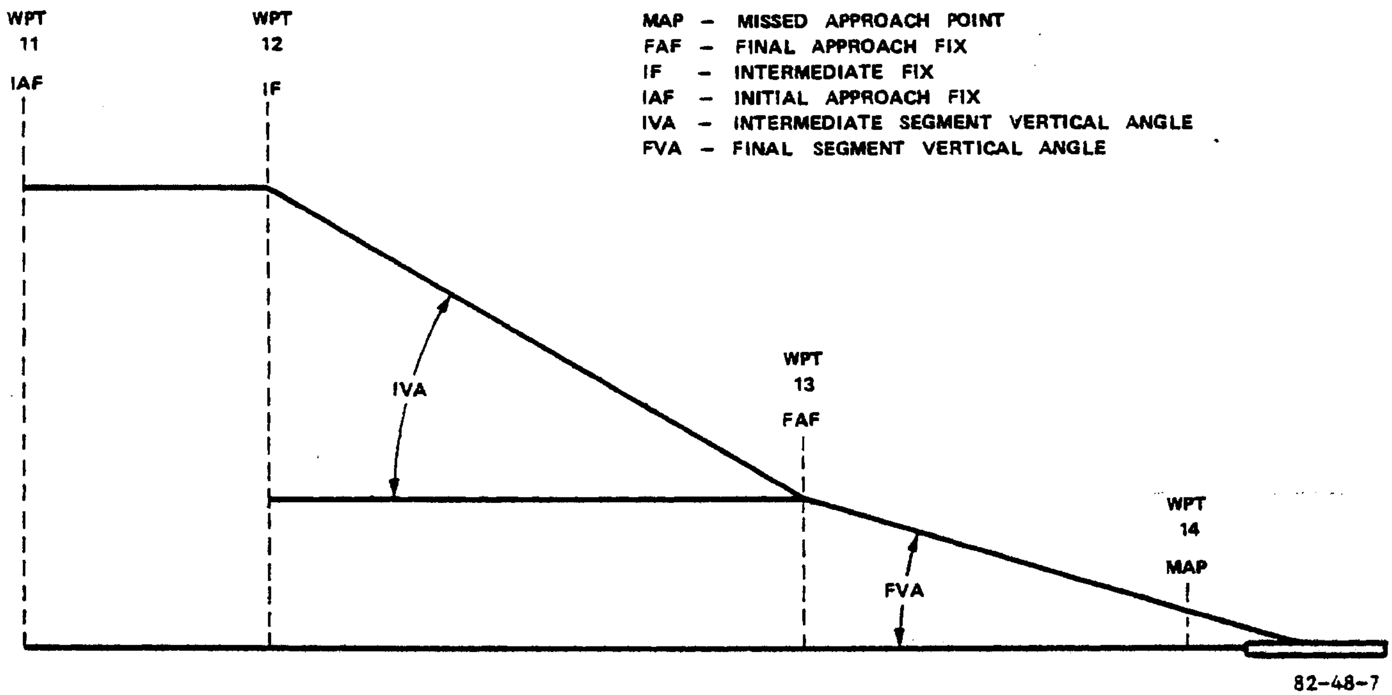

FIGURE 7. VERTICAL PROFILE TESTS

The project manager will make use of computer models of aircraft noise profiles available from the FAA Office of Environment and Energy (AEE-100) and from the NASA Langley Research Center in defining the exact flight profiles. The project pilot reports that the Technical Center's B-727 has been flown on a 6° glidepath down to 300 feet above threshold, or approximately 1-mile ground distance, with no problems recovering from a high sink rate. These profiles will require precise coordination with Atlantic City Airport tower controllers and approach controllers because on the steep descent segments, the aircraft will be above the normal descent path and the wake vortices will be descending into the path of following aircraft on final approach.

3.1.3 Special Applications.

The MLS/RNAV system can be useful at airports with particular operational problems. Washington National Airport is a case in point. A straight-in approach to runway 18 is illegal because it traverses the prohibited zone around the White House and the Washington Monument. The river approach, which follows the course of the

Potomac River from the northwest, is currently approved for visual flight rules (VFR) only. The required weather minimums are: (a) 3-mile visibility, and (b) 3,500-foot ceiling. The MLS Basic Narrow equipment installed on runway 18 has the coverage and accuracy to enable this approach to be flown entirely under instrument flight rules (IFR). A plan view of the Washington National river approach overlaid on the Technical Center's runway 31 is shown in figure 8. Waypoints 11 and 12 are flown at constant altitude; 12 to 15 are flown at a constant 3° glide slope.

In order to demonstrate the validity of simulating approaches to other airports at the Technical Center, the flight tests will include 1 day of flying the actual river approach at Washington National. The exact location in the test sequence is not rigidly defined, but it will be shortly after the special applications section of the testing has begun. This will give the project team time to resolve and correct any discrepancies that may arise between the simulated and actual operations before too much flight time has been expended. Weather, traffic density, and system confidence will all be determining factors in choosing an actual date.

3.1.4 Noninstrumented Parallel Runway.

The wide coverage volume of MLS provides the capability to fly an approach to a noninstrumented parallel runway within the MLS service volume. A simulated runway, 31R, located 3,000 feet northeast of the Technical Center's runway 31, has it's missed approach point (MAP) at a 100-foot DH within azimuth (AZ), elevation (EL), and DME coverage. The plan view of the approach to 31R is shown in figure 9. The vertical profile is a constant 3° glidepath to DH. A set of large, visible signboards will be placed on the airfield surface to mark the first 2,000 feet of a simulated 150-foot wide runway. This will permit the cockpit observer to assess the progress of the approach and enable the pilot to determine whether a successful landing could have been made.

3.1.5 AZ Only Approach to Runway 26.

The approach to the Technical Center's runway 26 is within the AZ coverage of the MLS system installed on runway 31. The J.E.T. MLS/RNAV computer is capable of navigating laterally on MLS signals and vertically on baro-altitude in the absence of elevation signals. This capability will be used to conduct AZ only approaches to runway 26. The lateral guidance is expected to be more accurate than a conventional VOR/DME RNAV approach. Due to a reduction in along-track errors, the vertical guidance is expected to be slightly better than a conventional VNAV approach. A plan view of the approach is shown in figure 10. The vertical profile is a constant 3° glidepath.

3.1.6 Delay and Speedup Maneuvers.

The J.E.T. MLS/RNAV system is capable of guiding the aircraft through maneuvers in response to ATC requests to advance or delay arrival time over threshold. To advance the arrival time, the pilot would be requested to proceed direct to a waypoint on final approach from downwind or base leg, thus shortening the path length and decreasing the approach time. A plan view of this direct-to-path is shown as figure 11. After passing waypoint 11, the pilot would be requested to proceed direct to waypoint 14, shortening his approach track by as much as 3 nautical miles (nmi) and advancing his arrival up to 1.5 minutes.

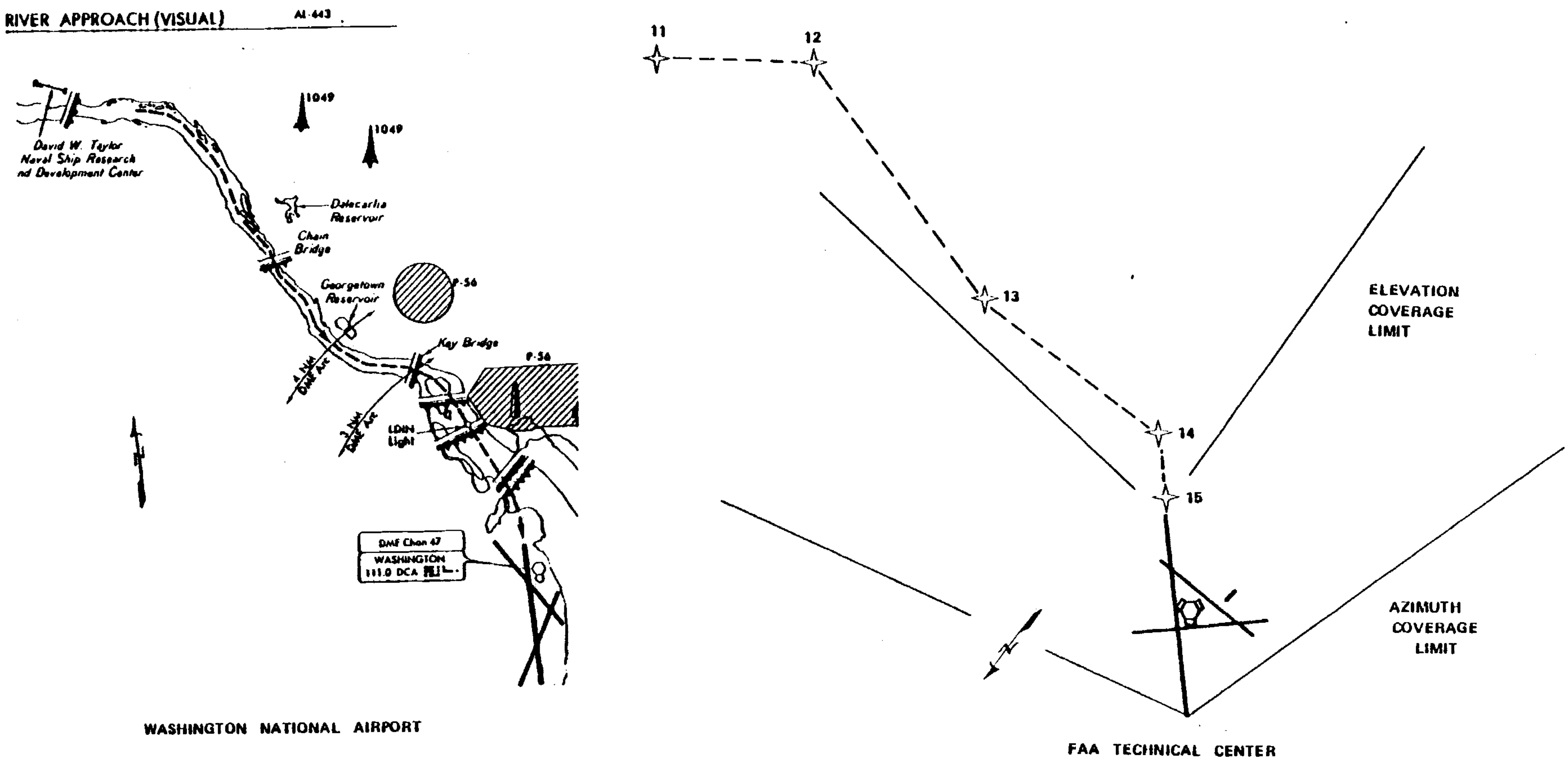

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FIGURE 8. WASHINGTON NATIONAL RIVER APPROACH TO RUNWAY 18 AND OVERLAY OF RIVER APPROACH ON FAA TECHNICAL CENTER'S RUNWAY 31

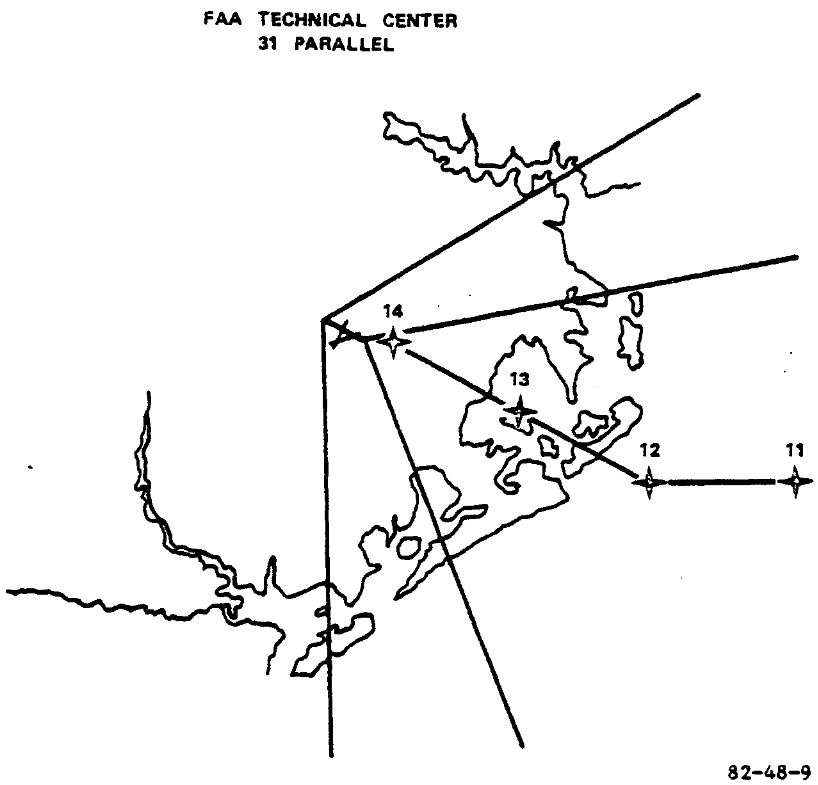

FIGURE 9. APPROACH TO A SIMULATED RUNWAY 31R

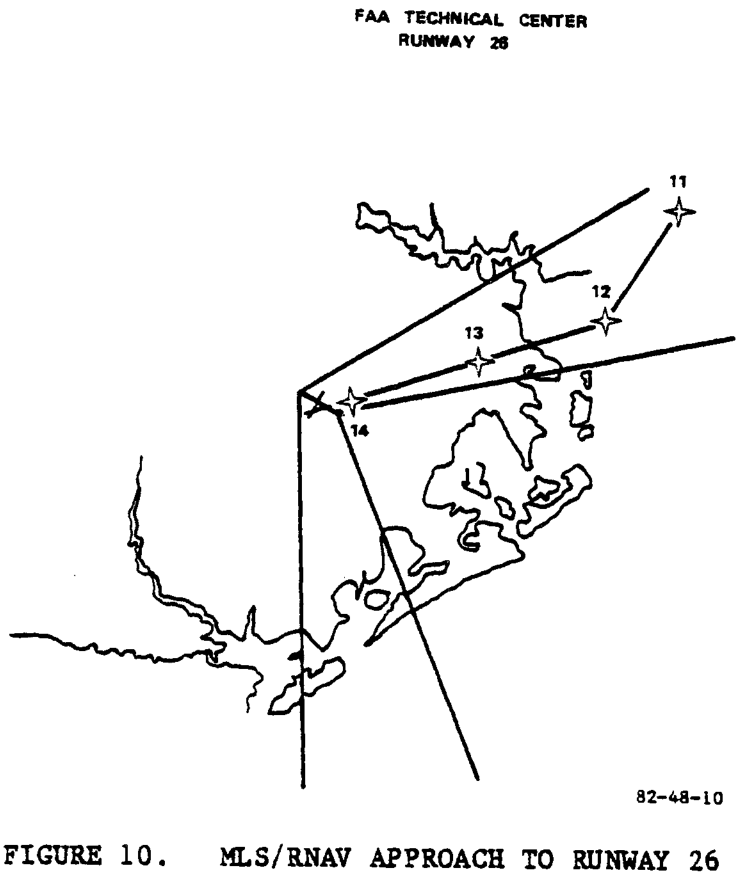

FIGURE 10. MLS/RNAV APPROACH TO RUNWAY 26

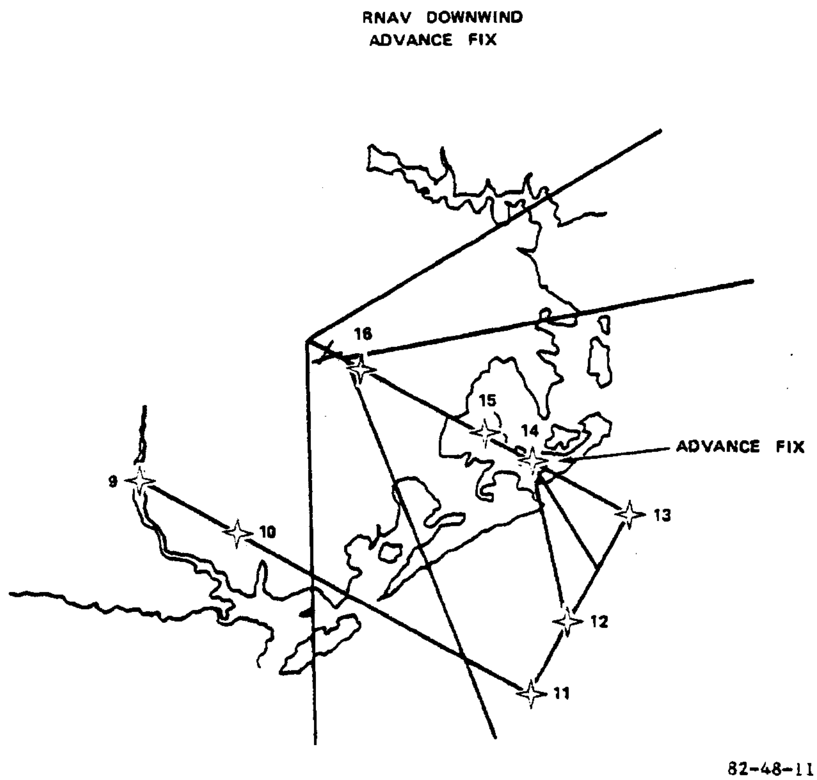

FIGURE 11. DOWNWIND LEG ADVANCE FIX OPERATION

A parallel offset maneuver can be requested to stretch the approach path and delay the arrival at threshold. This is shown in figure 12. The offset will increase the path length by 5 to 10 nmi and delay arrival by 2 to 5 minutes. In both approaches, the glidepath is a constant 3° descent.

In order to provide a realistic scenario for these impromptu maneuvers, the subject pilot will not be informed in advance which approaches will include direct to or parallel offsets.

3.1.7 High Workload Case.

The automatic features of the J.E.T MLS/RNAV computer provide a hands-off navigation capability from en route cruise to touchdown. To simulate a lower capability MLS/RNAV system, the high workload mode will be exercised. This mode requires the pilot to manually tune the VOR/DME equipment, advance the waypoints, and set the inbound course on the HSI. No new approach paths will be used in this mode. Instead, the minimum stabilized segment and Washington National river approaches will be used.

3.1.8 Missed Approach.

The design of a missed approach procedure will vary, depending on the reason for the missed approach. A go-around due to lack of visibility would be initiated at DH. The usual procedure would be to climb straight ahead above the

RNAV PARALLEL OFFSET

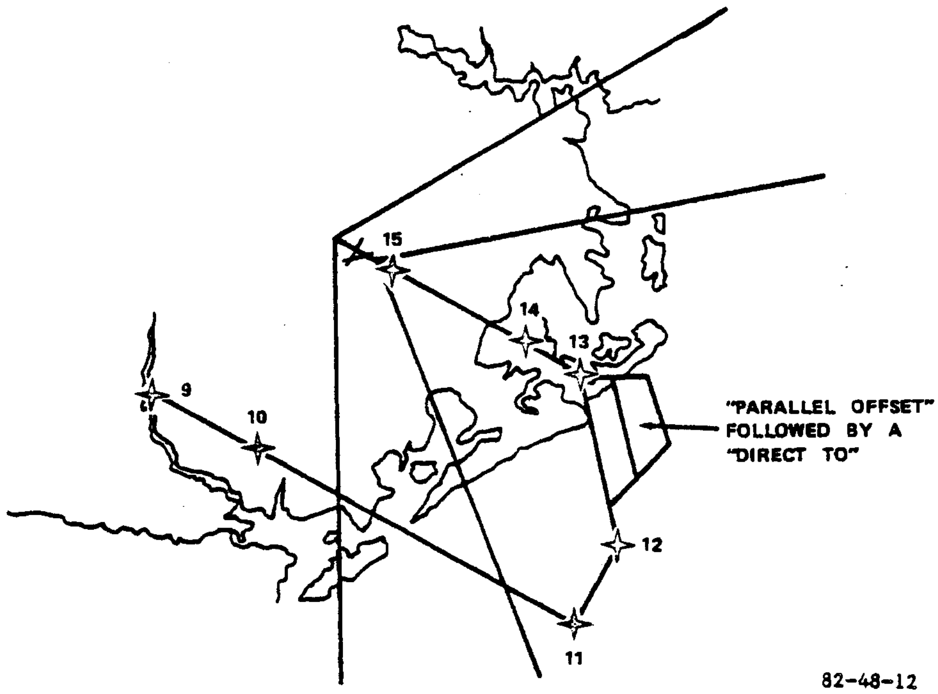

FIGURE 12. DOWNWIND LEG OFFSET DELAY PATTERN

runway and then turn to follow a specific track for obstacle clearance. Since the aircraft will be out of MLS coverage shortly after passing the runway threshold, the lateral navigation would be by conventional VOR/DME RNAV, and no specific vertical profile would be used. This is a normal RNAV task and is not within the scope of this project.

The task becomes much more difficult if the go-around must be initiated during a curved path approach. On a Washington National river approach, a straight-ahead-and-climb procedure could carry the aircraft right through the prohibited airspace over the White House and Washington Monument. In the event of MLS ground or airborne equipment failure, or aircraft problems not related to navigation (engine out, flap/gear problems, etc.), a usable go-around procedure would be to climb along the original ground track, using RNAV. A number of approaches will be terminated in just this manner, with a missed approach requested by the flight test observer.

If the onboard navigation computer should fail, the problem is much more difficult. The pilot is left in the middle of a complex, multisegmented approach with nothing more than raw receiver data and his mental recognition of his location with respect to the runway. Hopefully, the presence of an integrated navigation display, as presented by the MLS/RNAV, can keep the pilot more fully aware of his location and intended track prior to the failure. The project manager will consult with the Atlantic City Flight Inspection Field Office, Flight Procedures and Airspace Branch, AFO-730, and Standards Development Branch, AFO-560, to design realistic missed approach procedures.

It will be possible to execute a missed approach on a large proportion of the runs since it will not be necessary to land the aircraft to fulfill the data collection requirements. Therefore, the missed approach tests impose no additional flight time requirements.

3.2 DEGRADED RNAV AND DEGRADED ALTIMETRY.

Not all airports have a VOR/DME facility on the airfield (e.g., Philadelphia International), and good signal coverage and accuracy on approach is not always guaranteed. Also, altimeters may have errors in calibration, or a recent accurate barometric pressure setting may not be available. To test the capability of the J.E.T. MLS/RNAV system to transition from less than optimum RNAV/altimetry guidance to accurate MLS guidance, the location of the last VOR/DME waypoint (waypoint 11) will be altered so that it does not lie on the inbound course to waypoint 12. Similarly, the desired altitude at waypoint 12 will be changed to a value above or below the desired vertical profile. Approximately 40 approaches will begin with this degraded guidance situation.

3.3 VARIABLE COURSE SENSITIVITY.

The HSI crosstrack deviation sensitivity (the ratio of aircraft path deviation to steering command deflection) is independently variable on a leg-by-leg basis in the J.E.T. MLS/RNAV system. It will be possible to test for variations in magnitude of flight technical error (the closeness with which a pilot follows steering commands) as a function of crosstrack sensitivity. It is initially intended to use sensitivities which approximate the increase in sensitivity of a tailored localizer (a tailored localizer course width gives full scale course deviation indicator (CDI) deflection at a 350-foot offset from centerline at runway threshold) as the aircraft nears threshold, and experiment with 50 percent higher and lower scale factors. Three of the subject pilots will be given successive runs over the same flight profiles with differing crosstrack scale factors.

3.4 SUBJECT PILOTS.

In order to minimize the effects of pilot technique on the data, a selection of pilots will be used for these flights. The Technical Center currently has six 727 rated test pilots. They will be randomly selected to fly various test routes; each route will be flown by at least two different pilots. The project pilot will be onboard for all flights, as subject pilot or safety pilot. He will designate an alternate safety pilot for his flights as subject pilot or in case of illness, schedule conflict, etc.

In order to provide a broad data base, subject pilots from other government agencies and from the airlines will be asked to participate once the program is successfully under way. The Airline Pilot's Association (ALPA), Air Transport Association (ATA), and Allied Pilot's Association will be asked to solicit test subjects willing to participate. The subjects must be type-rated, current in the 727-100, and should have flown at least 10 hours within the last 6 months using conventional RNAV equipment for navigation. The responsibility for and availability of travel funds has not yet been determined. It is currently planned to use four subject pilots, other than Technical Center pilots, each flying six to ten approaches in one or two flight periods.

Pilot training is expected to be minimal for this project as the J.E.T. system operates almost identically to a normal three-dimensional (3-D) RNAV system and uses conventional cockpit displays. All of the 727-rated Technical Center pilots have participated in RNAV flight tests in the past and the recent RNAV experience requirement for the airline subject pilots should ensure their familiarity as well. It is expected that a 1- to 2-hour briefing and a ground demonstration in the aircraft should suffice.

3.5 AIRCRAFT AND WEATHER REQUIREMENTS.

In addition to project equipment, the SP-50 autopilot and FD-109 flight director system installed in N-40 must be fully functional. This includes altitude hold, heading select, and navigation signal capture and track with no overshoot, drift, or oscillations. The system must also be capable of guiding the aircraft on a coupled approach down to Category II (100 feet) DH.

The Nike-Hercules radar and the laser tracker or phototheodolite system must be fully functional.

Since optical tracking will be used in the final stages of an approach, weather minimums will be 5-mile visibility and a 2,000-foot ceiling.

4. DATA REDUCTION AND ANALYSIS.

4.1 DATA ANALYSIS CRITERIA.

The data will be analyzed to determine whether criteria of AC 90-45A are met. This document sets forth the accuracy requirements for area navigation systems used off-airways for en route, terminal, and nonprecision approach guidance. The necessary total system accuracies for non-VOR/DME based RNAV systems are summarized as follows:

Error Limits, Mean + 2 Sigma

	En Route (nmi)	Terminal (nmi)	Nonprecision Approach (nmi)
Along-Track	1.5	1.1	0.3
Crosstrack	2.5	1.5	0.6

RNAV system errors come from three sources: sensor errors, computer errors, and flight technical errors (FTE's). Sensor errors are the inaccuracies in VOR/DME, altimetry, and MLS equipment. Computer errors are those generated in the process of determining position from sensor inputs, and calculating and displaying steering commands to the pilot. FTE's are caused by a pilot or autopilot not closely following steering commands due to aircraft dynamics or workload and distraction factors. The root sum square (rss) addition of sensor error and computer error is referred to as airborne equipment error. AC 90-45A does not specify separate limits for sensor and computer error for non-VOR/DME RNAV systems. It does specify particular values of FTE which must be added to airborne equipment error to determine total system error. The rss subtraction of FTE from total system error yields required airborne equipment accuracy. Specified FTE and calculated airborne equipment accuracies are as follows:

	En Route (nmi)	Terminal (nmi)	Nonprecision Approach (nmi)
FTE	2.0	1.0	0.5
Airborne Equipment Crosstrack Accuracy	1.5	1.1	0.3

AC 90-45A also lists representative error budgets and required accuracy for the vertical navigation components of a 3-D RNAV system. These are summarized as:

Vertical Guidance Error Budget

Below 5,000 feet MSL ascent or descent, mean +3 sigma

Altimetry (sensor error)	140 ft
VNAV equipment	100 ft
FTE	200 ft

Minimum Accuracy Requirement

Mean +3 sigma Total system vertical error	265 ft

The data will also be analyzed to determine if it can meet the criteria for precision approach guidance. The accuracy requirements for current ILS are found in FAA Handbook OAP 8200.1. Airborne equipment error values of the MLS/RNAV system will be compared to these ILS standards. The maximum errors in the handbook are given as cross-pointer deflections in microamps, but are shown here in equivalent angular error limits. (Assumed runway length is 10,000 feet; assumed glidepath angle 3.0°.)

Instrument Landing System Error Limits Category II

	Localizer	Glide Slope
Beyond 4 nmi from threshold	±0.4°	±0.14°
4 nmi to 3,500 ft from threshold	linear decrease from ±0.4° to ±0.07°	linear decrase from ±0.14° to ±0.09°
Within 3,500 ft of threshold	±0.07°	±0.09°

4.2 DATA PROCESSING.

Each day's flight data will be reduced and fully analyzed following the flight; no further flights will be undertaken until failures and anomalies have been identified and corrected.

The data tapes will first be scanned for "events." The time of occurrence of the following events will be printed:

- MLS signals becoming valid or invalid
- VOR and DME signals becoming valid or invalid
- RNAV system failure
- Waypoint switching
- Tracking telemetry becoming valid or invalid
- Aircraft sensors becoming valid or invalid
- Initiation of go-around
- Beginning and end of run

Two or four sensor parameters at a time will be plotted on a time- or distance-to-go axis, and the airborne sensed (VOR/DME altimetry or MLS, as appropriate) ground track and vertical profile will be plotted.

Not all of the data will be plotted during this phase. Different parameters will be sampled at different points in the flight to ensure data reliability. Only parameters of particular interest will be plotted for the entire flight. A conventional engineering-units line-printer listing will be developed to examine individual data points, but will not be used to check data integrity as it is nearly impossible to discern short duration data anomalies when scanning large quantities of numerical data. Subsequently, the ground tracking data and airborne data will be merged. In this process, each airborne data sample is time aligned with its corresponding tracking position sample and transcribed as a single record.

MLS/RNAV system errors will be determined in the following manner:

The recorded values of MLS azimuth, elevation, and DME will be resolved into the same X, Y, Z coordinate system used for the tracking data. The difference between this sensed position and actual position is sensor error. It will be resolved into components parallel to, perpendicular to, and above or below the desired flightpath. These are along-track, crosstrack, and vertical sensor errors, respectively. Bearing-to-waypoint and distance-to-waypoint will be resolved to determine computed along-track distance. J.E.T. MLS/RNAV computer error will be determined by comparing crosstrack and vertical distances with their respective sensor errors. FTE is merely crosstrack and vertical deviation as displayed on the pilot's instruments.

Total system error is the actual deviation of the aircraft from its intended path, as determined from tracking data. The rss combination of sensor, computer, and FTE's should equal total system error. Total system crosstrack, along-track, and vertical errors will be computed from both tracking data and as the rss combination of contributing errors. This will provide a cross-check of the data reduction processing.

Errors will be computed on a leg-by-leg basis; mean, standard deviation, skewness and kurtosis (peakedness) will be determined for each leg. Since the J.E.T. RNAV merely anticipates the turn to the next desired track, the problem arises of how to determine the desired track in a turn. At present, it is planned to compute a fixed radius arc segment joining the two intersecting ground tracks at a turn and tangent to the inbound track at the nominal waypoint advance point.

Errors will be computed, summed, and compared to the requirements of AC 90-45A for the following parameters:

Sensor Error

Along-track
Crosstrack
Vertical

Computer Error

Along-track
Crosstrack
Vertical

FTE

Crosstrack
Vertical

Total System Error

Along-track
Crosstrack
Vertical

Only total system errors computed from tracking data will be reported for turn segments.

The position of the aircraft relative to runway centerline and glidepath at the DH will be calculated. The mean and standard deviations of these positions over many approaches will be determined and compared to the Category II "window." Additionally,the means and standard deviations of ground speed, airspeed, ground track, pitch and roll, and sink rate at the DH will be computed and reported.

A stepwise linear regression analysis will be performed on the data grouped by flight profile. Regression analysis is a technique to determine the relationships (general relationships, not necessarily cause and effect) between sets of independent variables. The independent variables to be considered are sensor error, computer error, and FTE.

Statistical data will be presented as tables and possibly histograms. Graphical data will be presented as overlays of ground track and vertical profile of repeated runs over the same route. In addition, single flights of particular interest will be presented in plan and profile.

Data on path dispersion and overshoot in turns will be calculated and presented as maximum observed value, mean, and standard deviation of total system crosstrack error. Total system vertical error (altitude loss) on transition from steep to shallow glidepath will also be presented as maximum observed value, mean and standard deviation.

Any pilot action in operating the RNAV system which causes the aircraft to deviate from its desired track or which requires the intervention of the flight test observer to prevent a deviation will be considered a blunder.

Mistakes which are noticed and/or corrected by the safety pilot will not be considered blunders unless they are repeated. However, the safety pilot will not coach the subject pilot. Blunders will be recorded by the flight test observer and their number, type, and circumstances of occurrence will be reported.

The data reduction effort will require four major computer programs:

a. Event scan and plot or print raw data in engineering units.
b. Merge airborne and ground tracking data.
c. Error analysis and computation of statistics.
d. Stepwise linear regression analysis.

4.3 DATA ANALYSIS SUMMARY.

Objective	Data to be Collected	Method of Analysis or Interpretation
System accuracy on curved path approach	Ground tracking data	To specifications in AC 90-45A
System accuracy on centerline approach	Ground tracking data	To specifications in FAA OAP-8200.1 and comparison with raw MLS receiver data
Individual contributions to overall error budget	Ground tracking data, MLS receiver data and RNAV computer data	To specifications in AC 90-45A and discussion of anomalies
Autopilot performance under RNAV computer guidance	Ground tracking data, RNAV computer data, aircraft state parameters	To specifications in AC 120-29
Ground path dispersion and overshoot during maneuvering	Ground tracking data	Interpretation of graphical data, discussion of anomalies
Aircraft state over threshold proper for landing	Ground tracking data, aircraft state data	Interpretation of graphical data, discussion of anomalies
Transition from inaccurate conventional RNAV to MLS/RNAV	Ground tracking data, aircraft state data	Interpretation of graphical data, discussion of anomalies
Adequacy of guidance displays	Pilot questionnaires	(To be determined)

Objective	Data to be Collected	Method of Analysis or Interpretation
Measurement of pilot performance and blunder tendancy	RNAV display data, observer logs	Analysis of FTE
Measurement of pilot workload	(To be determined)	(To be determined)
Pilot acceptance of curved path procedures	Pilot questionnaires	(To be determined)

5. INSTRUMENTATION AND FACILITIES.

5.1 DATA COLLECTION SYSTEM.

The data acquisition system for these tests will consist of data from the following sources:

Ground based position tracking system
Airborne data collection system
Observer logs and recorded audio commentary
Pilot questionnaires

The flight test observer (usually the project manager) will keep a written log of each flight containing, as a minimum, the following information:

Local weather observation from Automated Terminal Information Service
Time and brief description of system or equipment anomalies
Flight number
Date
Approach start/stop times
Crew members
Manual or automatic flight control
Low or moderate workload case
Computed or analog guidance in final segment
ATC problems (type and time)

A data collection system engineer will also be onboard for all flight tests. He will be responsible for the operation of the data collection system and will monitor its performance. He will also, using the real-time display capabilities of the data collection system, monitor for any aircraft sensor or system failures, and, as the need arises, assist the flight test observer in analyzing and correcting any equipment or system failures or anomalies.

An audio cassette recorder will be installed onboard as part of the data collection system to record aircraft intercom audio. Thus, flight crew and project team members can record any comments or observations as they arise. This will provide greater depth of subjective data than would written notes, especially in high workload situations.

With the assistance of Technical Center engineering psychologists, a pilot questionnaire will be developed to solicit and collect subjective data. Topics discussed will include, but not be limited to:

Difficulty of the approach procedure
Navigation workload
Flight control difficulty
Acceptability of the procedure for regular operations
Comments

5.2 AIRBORNE DATA EQUIPMENT.

The airborne data collection system (figure 13) is based on a Norden Division of United Technologies PDP-11/34M ruggedized minicomputer. The computer is equipped with 32 kilowords of programmable memory, floating point arithmetic hardware, floppy disc controller, RS-232 serial line interface, and a programmable real-time clock.

An in-house fabricated aircraft systems coupler takes aircraft sensor data in analog, synchro, serial digital, and discrete form and converts it into a format compatible with the computer's internal data bus. It also interfaces the time code generator and the 9-track digital tape recorder. Dual ruggedized floppy disc drives are used to store and transport the data collection software. The airborne data is recorded on a 9-track, 800 bits per inch, digital magnetic tape transport. A ruggedized graphics terminal provides user interaction and a real-time data display in engineering units in pseudo strip-chart form. A hard copy unit makes dry-silver process recordings of any data displayed on the graphics terminal. For aircraft tracking purposes, the time code generator is capable of being synchronized to an external time source. The line conditioner eliminates noise and power transients from the aircraft input power.

The data collection software performs several tasks. Under interrupt control of the real-time clock, it collects and formats data to be recorded. The data are collected every 200 milliseconds and recorded every second. In addition, any two parameters, operator selected, are plotted in engineering units on a time axis. The data are plotted twice a second over a 6-minute time span. A list of recorded parameters is shown in table 1.

5.3 GROUND TRACKING.

Ground based position tracking will be done by one of the Technical Center's Nike-Hercules radars and by laser or phototheodolite systems.

The Nike-Hercules are highly accurate, modified missile tracking radars, operating in X band, and located approximately 1/2 mile west of the stop end of runway 31. They measure the aircraft's position in azimuth, elevation, and range and can resolve that position into other coordinate systems as required. The data will be resolved into X, Y, Z coordinates referenced to the MLS azimuth antenna site and runway 31 centerline, and recorded with the time of sample on magnetic tape. This data will also be telemetered to the aircraft to be recorded with the airborne data. The tracking data will be acquired and recorded at a 5-Hertz sample rate. The 1-sigma accuracy of the Nike-Hercules radar, at the ranges encountered in these tests, is about 5 meters.

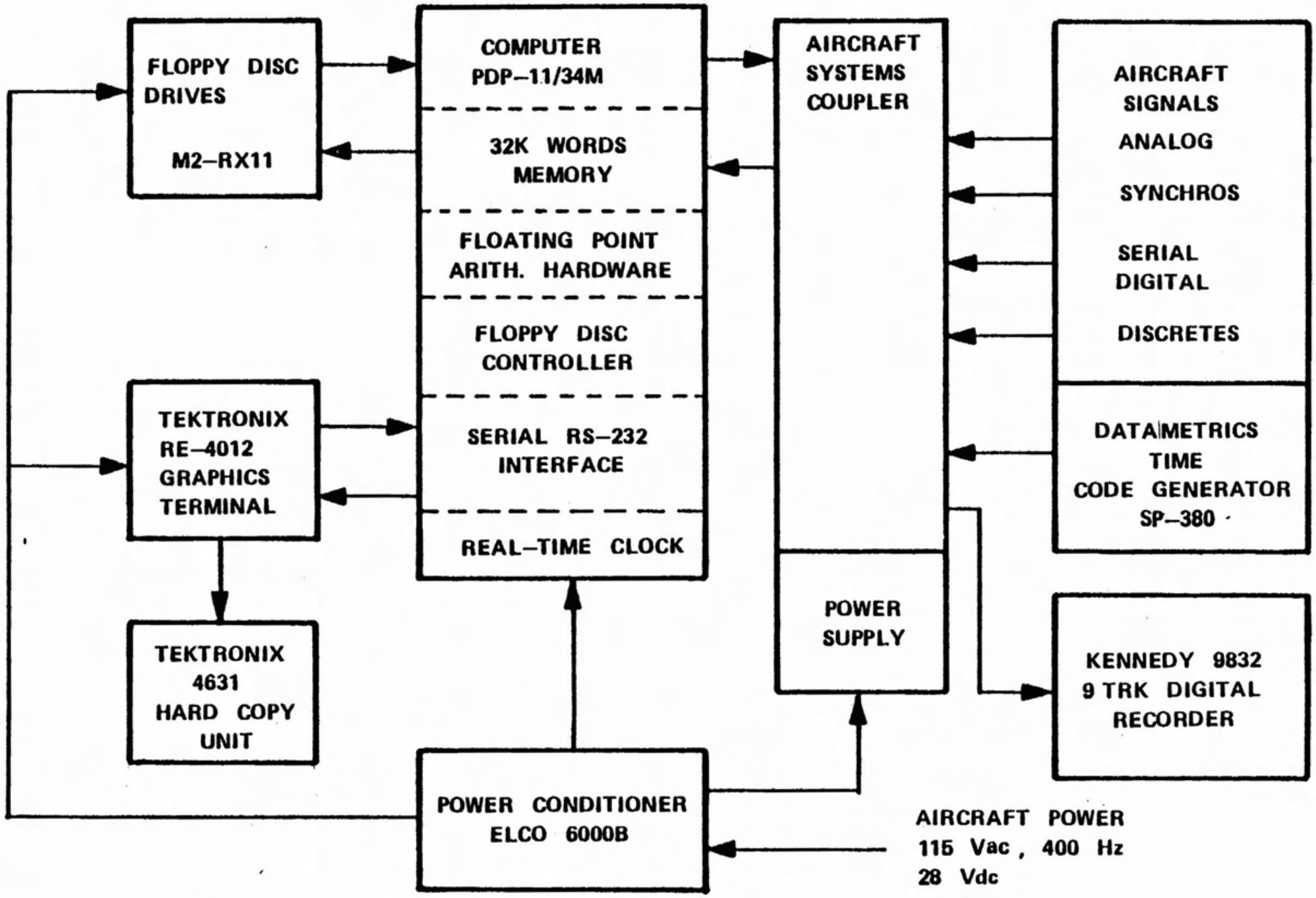

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FIGURE 13. AIRBORNE DATA COLLECTION SYSTEM

TABLE 1. DATA PARAMETERS

Parameter	Input Signal Format	Range	Resolution	Input Data Rate	Signal Source
MLS EL Deviation	Analog d.c.	±150 μA	0.5 μA	*	MLS Receiver
MLS AZ Deviation	Analog d.c.	±150 μA	0.5 μA	*	MLS Receiver
Radio Altitude	Analog d.c.	-10 to 2,500 ft	1 ft	*	Radio Altimeter
Pitch	Synchro	±180°	0.02°	*	No. 1 LTN-51 Inertial Navigation System (INS)
Roll	Synchro	±180°	0.02°	*	No. 1 INS
Ground Speed	Serial Digital	0 to 3276.7 kts	0.1 kt	0.6 Hz	No. 1 INS
True Heading	Serial Digital	0 to 360°	0.02°	0.6 Hz	No. 1 INS
Ground Track	Serial Digital	0 to 360°	0.02°	0.6 Hz	No. 1 INS
Baro Corrected Altitude	Dual Synchro	-1,000 to 50,000 ft	1 ft	*	Pilots Altimeter
Drift Angle	Synchro	±180°	0.02°	0.6 Hz	No. 1 INS
True Airspeed	Serial Digital	130 to 599 kts	1.0 kt	2 Hz	Sperry Digital Central Air Data Computer (CADC)
Computed Airspeed	Serial Digital	30 to 450 kts	0.25 kt	*	Sperry CADC
Pressure Altitude	Serial Digital	-1,000 to 50,000 ft	1.0 kt	*	Sperry CADC
Altitude Rate	Serial Digital	±20,000 ft/min	20 ft/min	*	Sperry CADC
DME Distance	Serial Digital	0 to 399 nmi	0.001 nmi	*	MLS DME Interrogator
Status	RS-232	N/A	N/A	4 Hz	J.E.T. RNAV System
Smoothed MLS Azimuth	RS-232	±60°	0.005°	4 Hz	J.E.T. RNAV System
Smoothed MLS Elevation	RS-232	0 to 15°	0.005°	4 Hz	J.E.T. RNAV System
Smoothed DME	RS-232	0 to 20 nmi	0.024 nmi	4 Hz	J.E.T. RNAV System
Smoothed Baro-Altitude	RS-232	0 to 60,000 ft	3 ft	4 Hz	J.E.T. RNAV System
MLS Altitude	RS-232	0 to 20,000 ft	3 ft	4 Hz	J.E.T. RNAV System
Crosstrack Deviation	RS-232	±5 nmi	0.024 nmi	4 Hz	J.E.T. RNAV System
Vertical Deviation	RS-232	±800 ft	3 ft	4 Hz	J.E.T. RNAV System
RMI-Bearing to Waypoint	RS-232	0 to 360°	0.0055°	4 Hz	J.E.T. RNAV System
Ground Distance to Waypoint	RS-232	0 to 10 nmi	148 ft	4 Hz	J.E.T. RNAV System
VOR angle	RS-232	0 to 360°	0.0055°	4 Hz	J.E.T. RNAV System
Vertical Angle	RS-232	±10°	0.0055°	4 Hz	J.E.T. RNAV System
MLS Azimuth Input	Serial Digital	±60°	0.005°	*	MLS Receiver
MLS Elevation Input	Serial Digital	+2° to +20°	0.005°	*	MLS Receiver
Magnetic Heading	Synchro	0 to 360°	0.02°	*	Aircraft Compass
VOR Radial	Resolver	0 to 360°	0.02°	*	VOR Receiver
RNAV Lateral Deviation	Analog DC	±150 μA	0.5 μA	*	J.E.T. RNAV System
RNAV Vertical Deviation	Analog DC	±150 μA	0.5 μA	*	J.E.T. RNAV System
RNAV Vertical Steering Command	Analog DC	±5 V	2 mV	*	J.E.T. RNAV System
RNAV Course Command	Synchro	0 to 360°	0.02°	*	J.E.T. RNAV System
Waypoint Number	RS-232	N/A	N/A	**	J.E.T. RNAV System
Waypoint Radial	RS-232	0 to 360°	0.1°	**	J.E.T. RNAV System
Waypoint Range	RS-232	0 to 99 nmi	0.1° nmi	**	J.E.T. RNAV System
Waypoint Altitude	RS-232	0 to 50,000 ft	10 ft	**	J.E.T. RNAV System
Facility Elevation	RS-232	0 to 50,000 ft	10 ft	**	J.E.T. RNAV System
Facility Frequency	RS-232	108 to 117.95 MHz	100 kHz	**	J.E.T. RNAV System
Inbound Course	RS-232	0 to 360°	1°	**	J.E.T. RNAV System
Vertical Angle	RS-232	±10°	0.1°	**	J.E.T. RNAV System
Range Time	Parallel Digital	0 to 24 Hz	1 ms	*	Time Code Generator

*Input data rate does not apply, or higher than 5 Hz data collection rate.
**At each waypoint change.

Due to obstruction constraints, the coverage from the Nike-Hercules radar extends down to about 500 feet above ground level on an approach to runway 31. Below this altitude, tracking will be by the Technical Center's laser tracker or phototheodolites.

The pulsed infrared laser tracker is positioned approximately one-half mile north of the threshold of runway 31. A multifaceted mirror reflector is mounted on the forward lower fuselage of the aircraft for good laser beam return. The laser tracking data, like the radar data, will be translated and rotated to the runway coordinate axis and telemetered to the aircraft. It will also be recorded on digital magnetic tape on the ground. The 1-sigma accuracy of the laser tracker over runway 31 threshold is approximately 0.3 meters.

The phototheodolite system tracks the aircraft optically from two or three towers located around the airfield. The azimuth and elevation angles are converted to aircraft position in X, Y, Z coordinates, using the same origin and axes as other trackers. These data will also be telemetered and recorded. The 1-sigma accuracy over threshold is approximately 2 meters. Postmission film reading to correct for operator tracking errors will not be used.

As of the writing of this test plan, the Technical Center's Range Programming and Analysis Branch, ACT-750, is developing procedures and software to integrate the Nike-Hercules radar with the laser tracker system. The laser will begin tracking the aircraft on approach before it is lost by the radar. The tracking data from both sources will be combined so that it is recorded and telemetered as a single data stream with a smooth transition from radar tracking to laser tracking. This system will be utilized as soon as it becomes available.

6. COORDINATION AND AREAS OF RESPONSIBILITY.

ACT-100 will:

Fabricate and test project equipment rack.

Provide flight test observer and data collection system operator for all flights.

Upgrade and maintain airborne data collection equipment.

Develop all required data reduction software.

Be responsible for all data reduction and analysis and report preparation.

Provide Technical Center program management.

Coordinate with other organizations as necessary.

Brief Air Traffic Service (ATS) of proposed scenarios and project requirements.

ACT-600 will:

Furnish aircraft N-40 and flightcrew to conduct project flights.

Provide engineering and manpower to install project equipment and interface project equipment to aircraft systems.

ACT-60 will:

Provide photography, technical illustrations, and printing services for this project.

ACT-700 will:

Be responsible for operation of tracking systems and data processing of tracker tapes.

ATS will:

Be responsible for providing air traffic control service for project flights.

ACT-54C will:

Provide surveying of ground reference checkpoints on the airfield surface.

ACT-230 will:

Assist in preparation of pilot questionnaire.

7. SCHEDULE.

Projected flight time requirements:

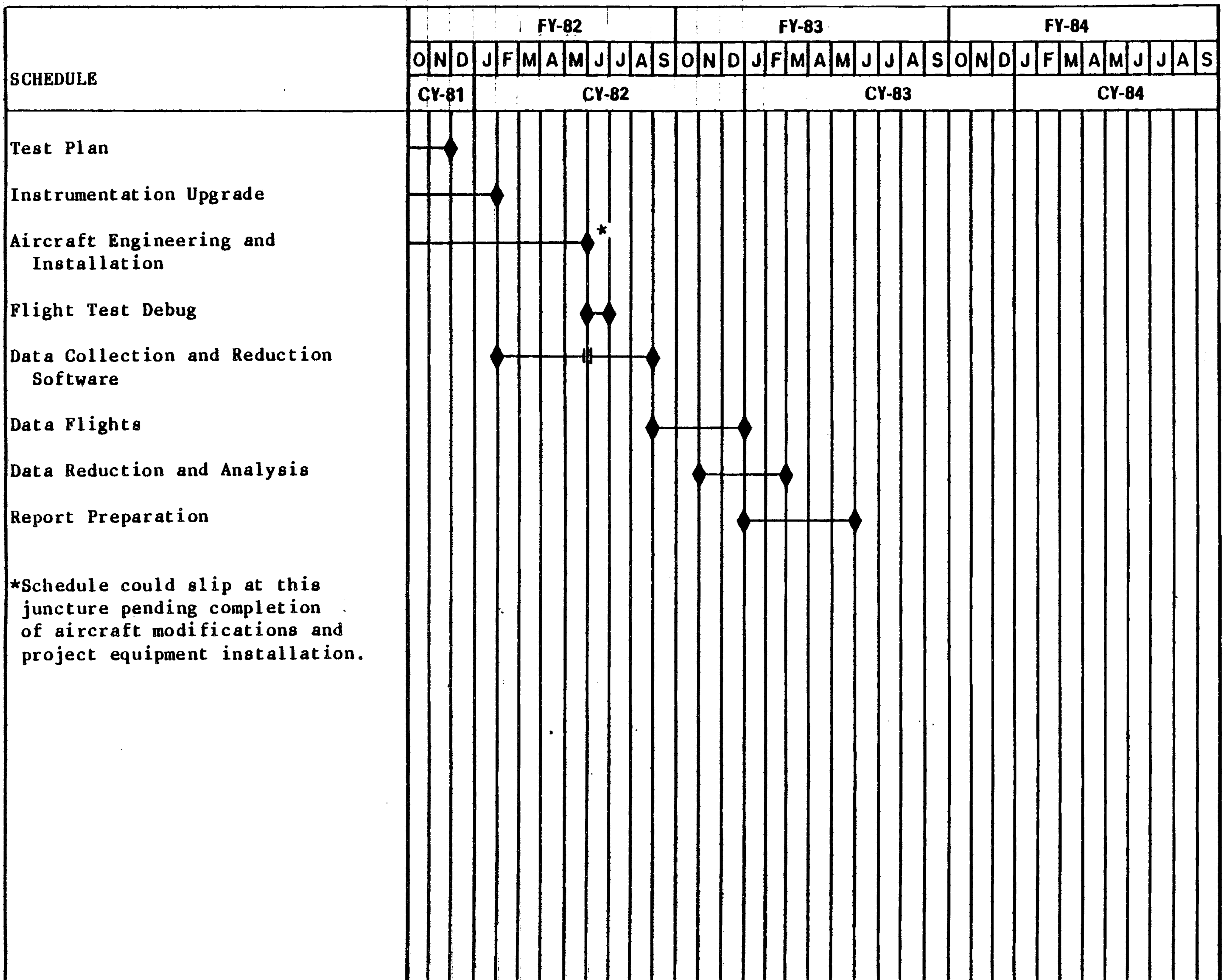
Each profile will be flown three times by each of two subject pilots, plus three times on autopilot, for a total of nine runs over each profile. Considering ATC delays, equipment problems, etc., a yield of three usable approaches per flight hour is projected.

	Approaches	Flight Hours
Minimum stabilized segment/intercept angle: 3 patterns (possibly 1 or 2)	27	9
Vertical profiles: 2 patterns	18	6
Special applications (DCA, 31R, 26)	27	9
High workload: 2 patterns	18	6

	Approaches	Flight Hours
ATC delay and speedup maneuvers: 2 patterns	18	6
System test, debug, and crew training: various patterns	30	10
Flights at Washington National: 1 pattern plus en route	6	4
	144 approaches	50 flight hours

Remaining action items for project planning:

1. Design missed approach procedures.
2. Determine exact profiles for two segment glide slope flights.


SCHEDULE
FY-82
FY-83
FY-84
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
CY-81
CY-82
CY-83
CY-84
Test Plan
Instrumentation Upgrade
Aircraft Engineering and Installation
*
Flight Test Debug
Data Collection and Reduction Software
Data Flights
Data Reduction and Analysis
Report Preparation
*Schedule could slip at this juncture pending completion of aircraft modifications and project equipment installation.

APPENDIX A

J.E.T. SYSTEM OPERATION

The material in this appendix has been reproduced from the J.E.T. DAC-2000 Pilot's Guide.

PURPOSE OF GUIDE

This guide is for information purposes only and is not intended for flight operations. Refer to the applicable Flight Manual Supplement for flight procedures.

A-2

SECTION I
SYSTEM DESCRIPTION

GENERAL

The DAC-2000 RNAV consists of a Control Display unit, a Digital Computer, and the following options for added capability: Frequency Tuner Unit, Control Annunciator, Offset Control, and Instrument Switching Relay.

The Control Display provides a logical, uncluttered means of navigation data control through backlighted force activating keys and a numeric display.

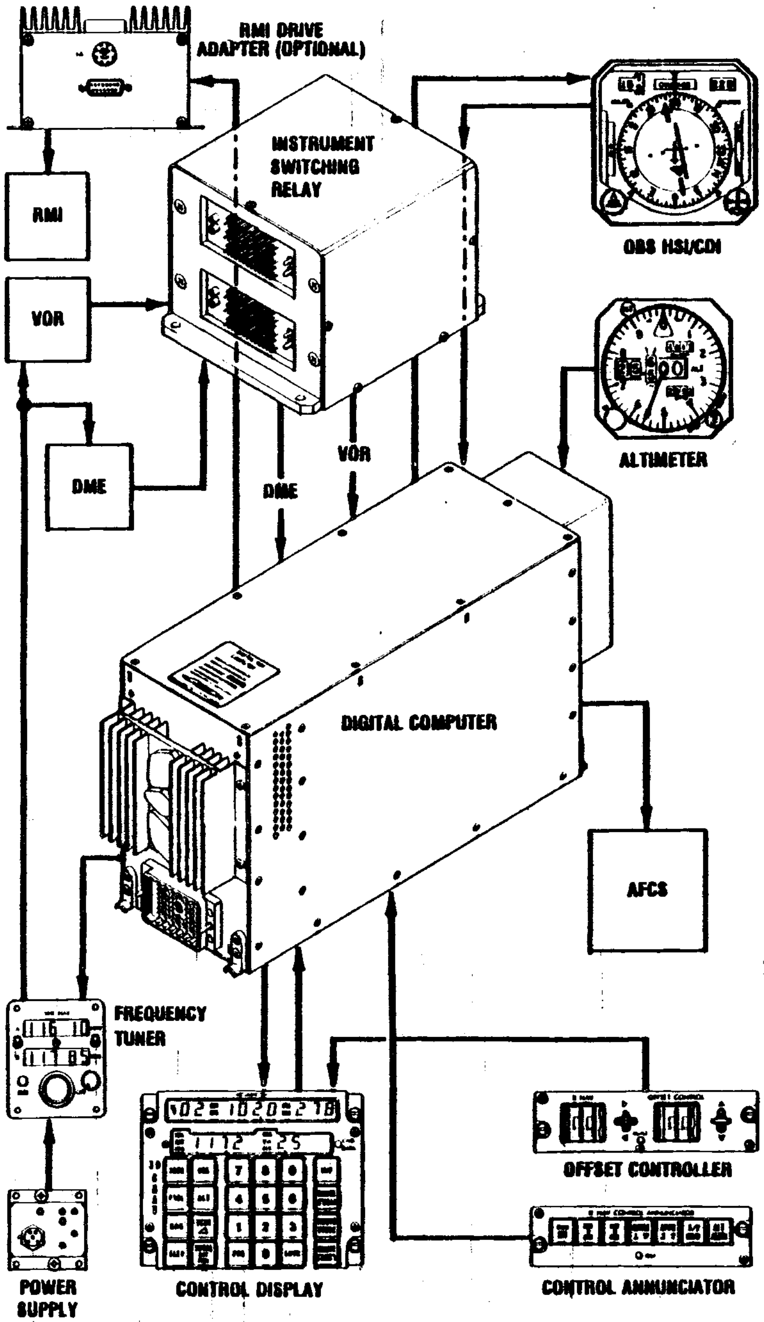
The Digital Computer is a general purpose airborne computer based on the microprocessor design concept with flexibility and capacity for future growth.

The Frequency Tuner enables automatic tuning of the navigation receiver by command of the RNAV Computer. The Frequency Tuner can operate alone as a normal manual NAV head with two frequency capability or provide automatic tuning for the RNAV system. The Frequency Tuner Power Supply provides independent voltage to operate the Frequency Tuner.

The Control Annunciator consists of seven switch/annunciators that control the various functions of the RNAV. A switch also initiates a self-test of the RNAV system.

The Offset Control provides the means of inserting track offsets 0-99 miles left or right and 0-99 miles fore or aft. An AUTO CRS button provides direct course to the waypoint from any point along the offset track that the aircraft is flying.

The Instrument Switching Relay controls switching functions between the RNAV system and the regular navigation system.



DAC-2000 RNAV SYSTEM BLOCK DIAGRAM

Specifications

Unit	Dimensions (In.)	Weight (lb)	Power Requirement (DC)*
CD-2001A	5.750" Wide 4.500" High 7.820" Length Std. Dzus Rail Mtg.	3.7	28 Vdc
DC-2001A	4.900" Wide 7.660" High 15.785" Length (1/2 ATR Short)	10.1 to 10.5	28 Vdc
FC-2001A/ 2001B	2.460" Wide 2.900" High 8.603"/5.500" Length Std. Gables Head Spacer Mtg.	1.7	28 Vdc 5 Vdc
CA-2001A	5.750" Wide 1.500" High 5.360" Length Std. Dzus Rail Mtg.	0.7	28 Vdc
OC-2001A	5.750" Wide 1.500" High 3.280" Length Std. Dzus Rail Mtg.	0.7	
RC-2001A 2001B	5.505" Wide 4.055" High 4.720" Length	2.4 3.8	28 Vdc
PS-2001A	2.030" Wide 2.077" High 1.870" Length	0.4	28 Vdc

*All accept 28 Vdc and 5 Vdc or 5 Vac for bezel lighting.

CD-2001A CONTROL DISPLAY

The Control Display unit is used to program the waypoint parameters into the Digital Computer and to display the programmed data. The Control Display unit enables the pilot to enter, display, store and recall navigation data for 20 operating waypoints and 200 waypoints of routes in storage. The electroluminescent backlighted keyboard consists of force actuating keys with rigid barriers between the keys to prevent inadvertent actuation.

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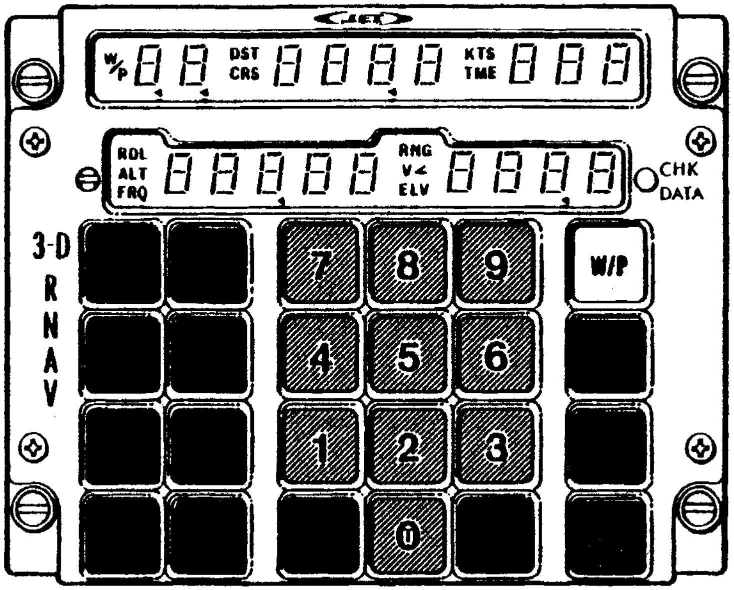
The following figure shows the Control Display unit.



CD-2001A Control Display

KEYBOARD

The Control Display keyboard is color coded and human factor engineered for operational simplicity. The force actuating keys are used to enter navigation data into the Digital Computer and to recall stored navigation data to be displayed on the Control Display.

CAUTION

Do not use a ball point pen or other sharp object to depress a key as this will damage the key face.

Input Keys

FREQ This key is used to program and call-up the frequency of the referenced VORTAC facility that each of the waypoints is offset from. With the optional FC-2001 Frequency Tuner, the RNAV system will automatically tune the NAV receiver to the displayed VOR frequency.

RADL This key is used to program and call-up the radial (bearing) of the desired W/P with respect to its reference VORTAC facility.

RNG This key is used to program and call-up the radial distance in nautical miles between the W/P and its reference VORTAC facility.

ELEV This key is used to program the mean sea level (MSL) altitude of the reference VORTAC facility to the nearest 10 feet.

CRS This key is used to program and call-up the ground track for each leg of the course being flown between waypoints. Therefore, the pilot does not have to refer to a chart or data sheet to set the omni-bearing selector (OBS) or horizontal situation indicator (HSI) course pointer to the desired course.

ALT This key is used to program the W/P altitude to the nearest 10 feet. Altitude is used in the Digital Computer for slant range correction and computation of the aircraft deviation from the desired programmed ascent or descent angles. This deviation is normally displayed by the glideslope deviation pointer on the flight-director indicator (FDI). Additionally, it provides sensory information for the altitude alert function.

VERT ∆ In reference to the waypoint being flown to, the VERT ∆ key will:

1. Allow programming in a desired angle for letdown; then provides deviation about that angle.

2. Allow reading the present angle.

3. Allows freezing any angle, then displaying deviation about that angle on the vertical output.

The deviation signal is designed to drive a glideslope pointer. An optional autopilot drive is available that is gain compensated to provide optimum autopilot control at all altitudes.

TOTAL DST TIME This key is used to program in the total flight distance. The Digital Computer stores this distance and then computes distance and time remaining at any point in flight. When the key is depressed the remaining distance and time is displayed on the Control Display for a period of 5 seconds. The total time/distance records for one flight only and must be reinserted for additional flights.

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0 THROUGH 9 The ten black numerical keys designated 0 through 9 are arranged in a calculator order and are used to enter or recall from the Digital Computer waypoint parameters such as bearing, range, altitude and flight angle. The "0" key will also command the Control Display to display the time to the forward waypoint for a period of 5 seconds.

PRG The blue program key is depressed when programming the Digital Computer. The W/P display on the Control Display will flash when the Digital Computer is in the programming mode. Each parameter input key (eight orange keys) is depressed prior to keying in the waypoint data with the numerical keys. Depressing the ENTR key will store the data in the Digital Computer and cause the entered data to be displayed steadily on the Control Display.

ENTR The blue enter key is depressed to store the entered waypoint parameters in the Digital Computer memory. The Control Display indication stops flashing when the data has been entered.

W/P Waypoint selection is achieved with this key. Direct W/P selection is possible by depressing W/P and the waypoint number desired (0-20). Waypoint incrementing is also possible. The waypoint is incremented (advanced) one waypoint for each press. The incrementing is continuous (ring counting).

ROUTE R'CALL Pressing this key will recall a prestored RNAV route from the Digital Computer's permanent (non-battery powered) memory. This route is inserted into the 20 W/P scratch pad memory of the Digital Computer for current RNAV flight. The stored routes are tabulated in a small notebook by the pilot and are referenced by a three-digit number between 101 and 199. The pilot can retrieve any route stored in the permanent memory by entering the desired three-digit number with the numerical keys and depressing the ROUTE R'CALL key.

ROUTE STORE This key is used to store an RNAV route in the Digital Computer's permanent memory subject to retrieval when needed. A memory bookkeeping system is displayed. It indicates the amount of memory being used and the amount of memory required by the route to be stored. This bookkeeping prevents unknown memory status.

ROUTE CANC'L This key is used to cancel an RNAV route from the Digital Computer's permanent memory when additional storage is needed in the memory for another route or if the route is no longer used.

CHK DATA This switch is used to review waypoint data without disrupting the waypoint being navigated on. Depress the CHK DATA switch and then select the two digit numerical code for the desired waypoint to be reviewed. When in the check data mode, the W/P display will flash and two decimals will illuminate in the W/P window. The Control Display will revert from the CHK DATA display back to the W/P display when the W/P key is depressed.

Vortac Radial/Distance Check

Depressing the AUTO/CRS pushbutton (on Offset Control) will cause the RDL display to show the VORTAC radial (bearing) and the RNG display to show the distance to the VORTAC facility for 5 seconds before reverting back to its previous display. This feature enables the pilot to report the aircraft's position to the air traffic control center without interrupting a navigation mode.

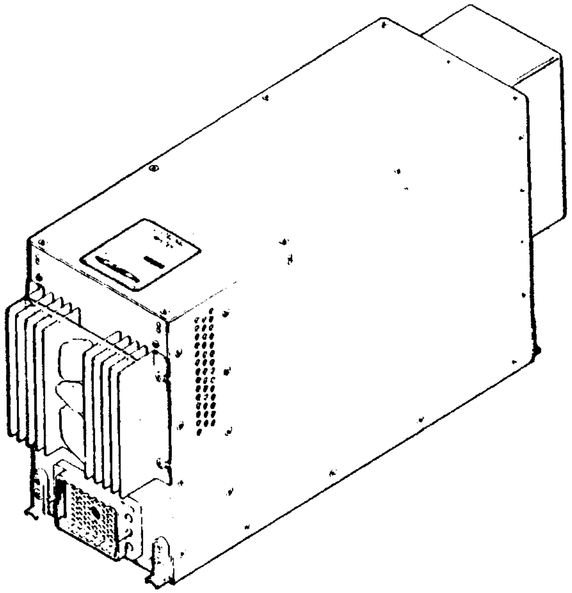
DC-2001A DIGITAL AIRBORNE COMPUTER

The Digital Computer contains electronic circuitry for interfacing with most existing aircraft navigational sensors and existing flight directors and autopilots. Data processing and all computations are accomplished in pure digital form. The "intelligence" center of the Digital Computer is a 16-bit microprocessor. The microprocessor design allows extensive flexibility. All navigational computations performed by the Digital Computer are checked for validity and the Control Display indicates the results to the pilot. Eight plug-in printed circuit cards simplify maintenance of the Digital Computer shown in the following figure.

Test

Two test programs exist within the computer. One is running at all times; checking memory and supporting circuitry for proper check-sum count. Consecutive sum errors will cause a failure annunciation.

The second test is pilot initiated, and in addition to the check-sum count, all 8's are displayed in the windows to check all digits, and the vertical and horizontal deviation meters are deflected half scale up and to the right respectively.



DC-2001A Digital Airborne Computer

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DIGITAL COMPUTER SECTIONS

Input/Output and Logic Section

This plug-in circuit card interfaces the computer with the peripheral equipment. The special circuitry allows digital communications to and from the Digital Computer on just 5 wires.

Analog To Digital, Digital To Analog, And RMI Section

This plug-in circuit card converts incoming analog signals into digital words for processing in the Digital Computer. It also converts the resultant processed signals back to analog signals for driving meter movements and RMI's.

VOR, OBS Synchro Interface RNAV Section

This plug-in circuit card receives the VOR signal from the navigation receiver and processes it to provide VOR bearing to the Digital Computer. This section also generates the output signal to the HSI/OBS.

Processor/Timing Section

This plug-in circuit card performs all the navigational computation for the RNAV system. The time base (clock frequency) for the Digital Computer originates on this board.

Memory Section

This plug-in circuit card contains all the memory circuits required for the various RNAV functions. The memories consist of random access memories (RAM) and read-only memories (ROM).

RNAV Route Memory Section

This plug-in circuit card contains 1024 words of permanent, but alterable memory (E-ROM) that cannot be erased unless the pilot deliberately initiates a change. In the RNAV application this memory enables the pilot to permanently store (without batteries) ~~200~~ waypoints consisting of radial, range, VOR frequency, VOR elevation, altitude, course, and vertical angle information for each waypoint.

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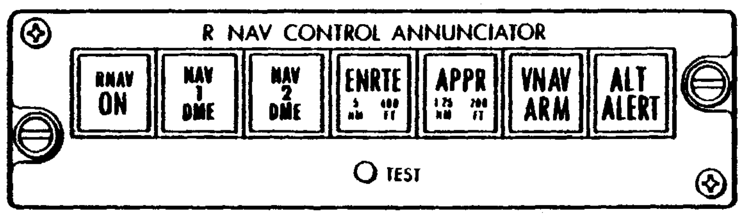
P.C. Board No. 8

This plug-in circuit card section provides computation requirements, additional memory, or additional interface circuitry as required for growth. The ARINC 568 option is on this board.

CA-2001A CONTROL ANNUNCIATOR. (Option)

The Control Annunciator unit consists of seven switch annunciators that control the various functions of the RNAV system. The following figure shows the Control Annunciator. Standard switch nomenclature is shown in the figure, but optional nomenclature is available.



CA-2001A Control Annunciator

Switches/Annunciators

The function of each RNAV switch is as follows. Annunciation of the switch indicates that function has been selected.

RNAV ON This push on/off switch controls an Instrument Switching Relay which switches all navigation information between normal navigation instruments and RNAV.

NAV 1 DME This push on/off switch allows the selection of the NAV 1 system to be used with the RNAV system.

NAV 2 DME This push on/off switch allows the selection of the NAV 2 system to be used with the RNAV system.

ENRTE This switch selects the enroute mode VORTAC beam sensitivity of the RNAV system.

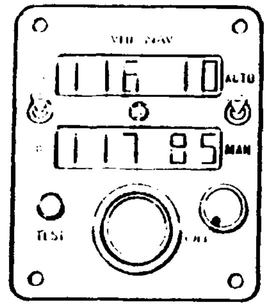
APPR This switch selects the approach mode VORTAC beam sensitivity of the RNAV system.

VNAV ARM This switch informs the RNAV computer that vertical navigation (VNAV) control is desired to the autopilot. The computer furnishes a 28 Vdc signal when a zero vertical beam deviation is present. This signal engages a relay that removes the autopilot input of altitude hold and replaces it with the VNAV signal from the computer. The autopilot must be in the altitude hold mode for VNAV control. An option is available that provides autopilot scaling compatible with altitude hold for either DC or AC deviation signals.

ALT ALERT This switch selects the altitude alert mode. An alert output is provided when in enroute (or in approach) if the aircraft approaches within 1000 feet (300') of the selected altitude. The alert is given until the aircraft is within 300 feet (100') of the alert altitude. If the aircraft should deviate more than 300 feet (100') from the alert altitude, the visual and aural warning will occur. When the deviation exceeds 1000 feet (300'), the altitude alert logic is reset and the visual and aural warning circuits are deactivated. Altitude alert is selectable even if the RNAV ON switch is off.

O TEST When the TEST switch is depressed the Control Annunciator switches will light. See paragraph 3. on page 3-1 for additional test indications.

FC-2001A FREQUENCY TUNER



FC-2001A Frequency Tuner

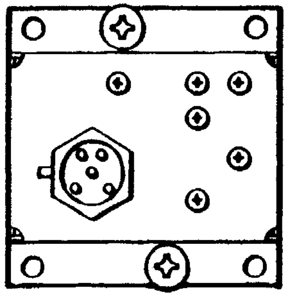
Frequency Tuner Operation

Interface between the Frequency Tuner and the Digital Computer takes place through the Control Display unit. The Frequency Tuner has a manual and an automatic mode. In the AUTO mode the Digital Computer commands the tuner to select the VORTAC frequency relative to the waypoint being displayed regardless of which position the A/B switch is in. This frequency is displayed in the upper A window.

When the AUTO/MAN switch is in the MAN position, the pilot must tune the NAV receivers to the VORTAC frequency. The "B" window displays the standby frequency which the pilot can set up when the A/B switch is in the "A" position. The opposite is true when the switch is in the "B" position. The "B" frequency window can be preset while in AUTO as long as the A/B switch is in position "A".

The frequency tuner operates on a concentric rotation slew principle. The controls are spring loaded to center and by rotating the control knobs counterclockwise will cause the frequency to slew down, whereas a clockwise rotation will cause the frequency to slew up. The large control knob selects the tens and units. The small control knob selects the tenths and hundreths. The Frequency Tuner has its own built-in automatic light dimming control.

PS-2001A POWER SUPPLY

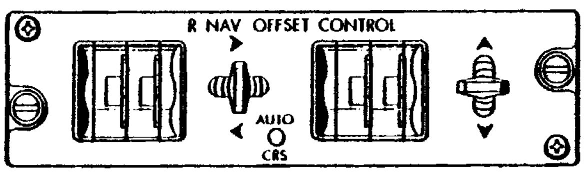


PS-2001A Power Supply

Frequency Tuner Power Supply Operation

The Power Supply provides +5 Vdc to operate the Frequency Tuner and to provide independent operation of the Frequency Tuner.

OC-2001A OFFSET CONTROL



OC-2001A Offset Control

Cross Track Offset Operation

The Offset Control allows the pilot to offset the desired track 0-99 nautical miles to the left or right of the original track. This feature is useful in circumnavigating congested areas and turbulence. The cross track offset function is accomplished as follows:

1. Set the thumbwheels to the desired offset distance.

2. Position the cross track toggle switch in the desired track offset direction as indicated by the symbolic arrows. The offset can be cancelled by placing the thumbwheel controls in the zero position or by placing the toggle switch in the center position.

Along Track Offset Operation

The along track offset feature operates in a manner similar to the cross track offset function except the waypoint is shifted fore or aft of the original location. This feature is useful for vertical navigation when it is desired to let down prior to or after the scheduled letdown point.

The along track offset can be used in conjunction with the cross track offset to relocate the waypoint to the desired location. The along track offset function is accomplished as follows:

1. Set the thumbwheels to the desired offset distance.

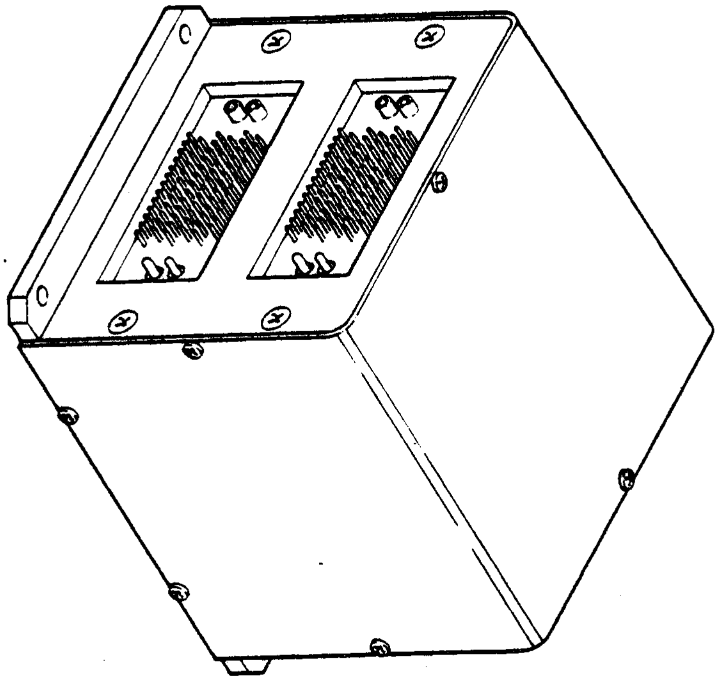
2. Position the along track toggle switch in the desired track offset direction as indicated by the symbolic arrow. The offset can be cancelled by placing the thumbwheel controls in the zero position or by placing the toggle switch in the center position.

AUTO/CRS Pushbutton Operation

This switch provides the direct course readout in the DST window to the programmed waypoint from any point along the offset track. The AUTO/CRS also provides a readout of VORTAC bearing and distance in the RDL and RNG windows respectively. The displays will show for 8 seconds and then revert back to normal.

RC-2001 INSTRUMENT SWITCHING RELAY

The Instrument Switching Relay controls the switching functions between the RNAV system and the navigation systems. The relay is a sealed, highly reliable, service proven instrument used liberally in aerospace applications for over a decade. Each relay has 24 double throw poles. The RC-2001A relay is a single relay. The following figure shows the dual RC-2001B Instrument Switching Relay.



RC-2001B Instrument Switching Relay

LIGHTS

The RNAV Frequency Tuner and Control Display unit digits are automatically adjusted by photoelectric sensors for optimum viewing of the control switches and display characters. Dimmer override provisions are also provided.

DAC - 2000 RNAV System Troubleshooting Guide

Symptom	Possible Cause	Action
1. Normal NAV and RNAV have more than 2 degrees of course difference on a co-located W/P. (As when flying to or from a VORTAC facility.)	VOR and OBS zeroing out of adjustment on the Control Display Unit (CDU). VOR, OBS Synchro Interface Circuit Card in Digital Computer or Offset Trim Interface Circuit Card in Control Display Unit defective.	See DAC-2000 RNAV Installation Manual TP-258 or Maintenance Manual TP-269. Replace defective board. (One at a time.)
2. Considerable random flagging in flight.	VORTAC signal not adequate. **Note** The RNAV system is more critical of poor quality VORTAC signals than the normal NAV system. (Due to compliance with AC-90-45A.)	Select another VORTAC station (preferably above 112.00 mHz). The operator will learn that there are known clean VORTACS and known noisy ones.