

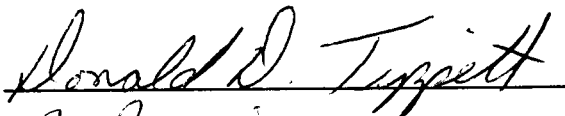
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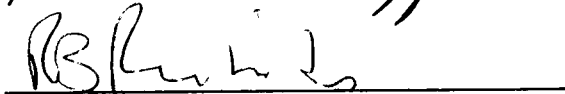
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Date 26 APRIL 1990

**TECHNICAL EVALUATION OF THE
NAVIGATION SYSTEM
INSTALLED IN THE EF-111A AIRPLANE**

**A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville**

Scott J. Howe

May 1990

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The technical data included in this thesis are actual flight test data collected during a limited scope technical evaluation of a United States Air Force EF-111A airplane. However, all deficiencies attributed to this aircraft, the aircraft systems, and/or the aircraft subsystems are the sole opinion of the author and do not necessarily represent the official position of the Naval Air Test Center, the Naval Air Systems Command, or the United States Navy. Similarly, the recommended corrections to the documented deficiencies are presented by the author for the sole purpose of fulfilling the requirements of this thesis, and are not attributable to any of the aforementioned authorities.

ABSTRACT

The purpose of this thesis was to evaluate the navigation system installed in the EF-111A airplane for the stand-off, close-in, and penetration/escort jamming missions and to determine what specific improvements to the existing systems would be required to meet current operational requirements. The evaluation was conducted during one two hour ground evaluation period, two simulator flights (4.0 hours), and two flights totaling 3.9 flight hours. Testing was conducted at Mountain Home Air Force Base, Idaho. A total of twelve deficiencies were identified and analyzed for their impact on the mission. As a result of that analysis it is recommended that the Inertial Navigation System be replaced and that modifications be made to the Navigation Radar System and Terrain Following Radar.

Within the scope of this evaluation, the navigation system installed in the EF-111A demonstrated limited potential for the stand-off, close-in, and penetration/escort jamming missions, but will be satisfactory upon correction of the deficiencies cited.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Due to recent cutbacks in funding for new development programs, the Department of Defense has conducted investigations into upgrading the capabilities of existing weapons systems rather than buying new ones. Examples include; improved power plants for the F-14 and E-2C, a new wing for the A-6E and a new weapons system for the S-3.

The advent of high performance carrier based attack aircraft capable of high speed ingress at both high and low altitudes highlights the need for an electronic countermeasures aircraft capable of meeting the existing threat as well as that expected to be developed in the next decade. A study of current weapons systems capable of meeting these requirements is under way to identify a system to replace that installed in the EA-6B Prowler.

This thesis examines the navigation system installed in the U.S. Air Force EF-111A airplane for possible incorporation into such a replacement system. The basis for this thesis is the authors final flight test evaluation for graduation from the United States Naval Test Pilot School, "Phase IIA Developmental Testing (DT-IIA) of the Weapons System Installed in the EF-111A Airplane, 3 June 1988, Final Report".

1.2 PURPOSE

The purpose of this thesis was to evaluate the navigation system installed in the EF-111A airplane for the stand-off, close-in, and penetration/escort jamming missions and to determine what specific improvements to the existing systems would be required to meet current operational requirements. The decisions to modify the systems were based on application of current technology, acceptable risk assessments, and cost effectiveness in meeting the mission requirements.

1.3 DESCRIPTION OF TEST AIRPLANE

The EF-111A is a two place electronic countermeasures airplane manufactured by the Gruman Aerospace Corporation for long range, all-weather, supersonic operations at both high and low altitudes. The airplane is powered by two afterburning TF-30 turbofan engines. The wing may be varied in area, camber and aspect ratio by adjusting its sweep from 16 to 72.5 degrees. The unique crew module escape system, which encompasses the pressurized cabin and forward portion of the wing glove, is designed to separate the crew from the airplane during catastrophic emergencies and to protect the occupants from post-ejection environmental hazards on either land or water. A detailed description of the EF-111A is contained in the Flight Manual, reference A. The test

airplane, serial number 67-042, was a production model maintained in the custody of the 390th Electronic Countermeasures Squadron based at Mountain Home AFB, Idaho.

1.4 MISSION DESCRIPTIONS

1.4.1 Stand-off Jammer

The stand-off jammer mission is a medium to high altitude mission which involves station keeping using a figure 8 flight path oriented perpendicular to the threat axis. Bank angles of 45 to 60 degrees are commonly used in the turns to minimize the amount of time that the airplane is positioned outside of the favorable geometric relationship with the target. The length of the level legs is relative to the specific mission requirements, but a nominal figure of 20 miles is mission representative for the purposes of this paper.

1.4.2 Close-in Jammer

The close-in jammer mission demands station keeping at low to middle altitudes near the threat positions. A triangle flight path is used to maintain the preferred geometric relationship to the targets. Bank angles of 60 degrees are commonly used in this pattern. The length of the legs are again determined by mission specific parameters, but this paper will assume a nominal length of 10 miles.

1.4.3 Penetration/Escort Jammer

The penetration/escort jammer mission involves low altitude ingress to the target area in company with strike aircraft. Precision low-level navigation is required not only to locate the target, but also to avoid anti-aircraft weapons enroute.

1.5 SCOPE OF TESTS

The evaluation was conducted during one two hour ground evaluation period, two simulator flights (4.0 hours), and two flights totaling 3.9 flight hours. Testing was conducted at Mountain Home Air Force Base, Idaho. The flight test envelope is presented in Table I. All limits were in accordance with the EF-111A flight manual, reference A. Specific tests conducted are detailed in appendix A, tables I,II, and III.

Table I
TEST ENVELOPE LIMITS

Parameter	Limit Values
Altitude	200 ft AGL to 20,000 ft MSL
Airspeed	0 to 1.0 Mach
Load Factor	-1.0 to +5.0 g's

1.6 METHOD OF TESTS

Individual tests were conducted in accordance with the standard Naval Air Test Center systems test methods described in the VAX Test Plan, reference B, with the exceptions noted in the specific Results and Discussion paragraphs in chapter 2. Low-level navigation flights were conducted in military restricted airspace. Time measurements were made using a hand-held stopwatch. Data were recorded on kneeboard cards. Test results were discussed with squadron personnel to determine the relationship of potential problems to the conduct of the mission. Deficiencies were assigned to the test systems based upon their impact on the mission and safety of flight in accordance with the NATC Report Writing Handbook, reference C.

CHAPTER 2

RESULTS AND DISCUSSION

2.1 INERTIAL NAVIGATION SYSTEM

2.1.1 Equipment Description

2.1.1.1 General

The AN/AJQ-20A Inertial Navigation System (INS) is a self-contained dead reckoning analog inertial system consisting of a stabilized platform, navigation computer, and remotely located flux valve. The INS is designed to provide computed airplane position, range and bearing to navigation steering waypoints and destinations, airplane navigation and attitude parameters, automatic steering signals to the autopilot, attitude indicator and horizontal situation indicator, and interface with the navigation radar set. Position updating may be accomplished through direct over-flight of a known position or via radar fixing. As many as three intermediate destinations may be stored in the system and changed at any time by the operator. A self-test feature is designed to isolate system troubles to aid in maintenance and repair.

2.1.1.2 Components

2.1.1.2.1 Stabilized platform The stabilized platform is a four-gimbal, all-attitude inertially stabilized platform located in the forward electronics bay of the airplane. Two precision gyroscopes and three accelerometers are mounted on the platform. Once aligned and operating the Stabilized Platform is designed to supply outputs of pitch, roll, true heading, vertical acceleration, and north and east components of ground speed to the navigation computer.

2.1.1.2.2 Navigation computer The navigation computer is a self-contained navigation steering and radar sighting computer located in the cockpit center instrument panel. Input data from the Stabilized Platform is combined with true airspeed and pressure altitude from the central air data computer and with magnetic heading from the flux valve as a basis for computing the various output parameters. The navigation computer is designed to provide position, attitude, and range and bearing data using either planar (two dimensional) or great circle calculations as selected by the operator. An auxiliary flight reference system is designed to provide the necessary inputs to the Navigation Computer in the event of a failure of the Stabilized Platform. In this mode of operation the Navigation Computer will continue using the last computed wind or an operator inserted wind in its calculations.

2.1.2 Ground Tests

2.1.2.1 Preflight and Alignment

The preflight and alignment procedures for the INS were evaluated during ground operations for thoroughness, clarity, logical sequencing and time to complete. Alignment required entry of airplane position, field elevation, and local magnetic variation. System warm-up required two to three minutes followed by approximately seven minutes for full alignment. A flashing ALIGN lamp and an ERROR lamp provided the operator with system status cues and allowed attention to be directed to other preflight duties during the alignment cycle. Completion of system preflight and alignment within ten minutes will enable the airplane to meet launch times with reliable INS platform and navigation performance. Within the scope of this test, the INS preflight and alignment procedures are satisfactory for the stand-off, close-in, and penetration/escort jamming missions.

2.1.2.2 Controls and Displays

2.1.2.2.1 General. All INS controls and displays were evaluated for location, tactile cueing, operative sense and utility. All were found to be satisfactory, with the exception of those noted below.

2.1.2.2.2 Position Set knobs. Individual latitude and longitude adjustment knobs were provided to set present position and destination coordinates. The four identical knobs were each located adjacent to the display window which they controlled. Latitude entries were increased by turning the proper knob clockwise while increases in longitude values were made by turning the proper knob counterclockwise. This convention is in contradiction to that prescribed in paragraph 5.4.1.2.1 of MIL-STD-1472C, reference D. The knobs were invariably operated in the wrong direction during the course of waypoint entry. Caution was required to avoid data entry errors of one degree in latitude and longitude due to improper rotation of the knobs. A squadron Electronic Warfare Operator indicated that delays in the proper entry of navigation checkpoints due to the confusing operative sense of the position set knobs often results in low-level navigation course errors.¹ The functioning of the INS latitude and longitude set knobs with opposing operative senses is a deficiency which should be avoided in future designs.

2.1.2.2.3 Position Display Windows. The INS position and destination display windows were arranged as shown in appendix B, figure 1 (items 2 and 22). The destination

1. Interview with Captain Paul Walton, USAF, Mountain Home AFB, ID, May 1988.

reading was briefly confused with the present position reading on several occasions. Misreading of the INS position windows will induce erroneous jamming orbit positioning and result in reduced jammer effectiveness. The close proximity of the INS Present Position and Destination display windows is a deficiency which should be avoided in future designs.

2.1.3 Flight Tests

2.1.3.1 INS Dynamic Accuracy

2.1.3.1.1 General. Both maneuvering and non-maneuvering position accuracy were evaluated by recording INS latitude and longitude upon low-level fly-over of selected surveyed checkpoints at intervals of approximately 20 minutes during each flight. Fly-over altitudes were between 300 and 1000 feet AGL at 510 KIAS. The effects of pitch and roll maneuvers used to test radar system stabilization were also evaluated for the INS. Post maneuver points were so annotated on data cards.

2.1.3.1.2 Position accuracy. The INS North-South and East-West position error data are presented in appendix B, figure 2. Radial position error data are presented in appendix B, figure 3. Throughout the mission the INS consistently indicated within a mile of the charted

position. A squadron pilot indicated that the INS provides sufficient position accuracy to consistently locate navigation checkpoints visually or with radar thereby enabling accurate and timely arrival on station for jamming operations.² Within the scope of this test the position accuracy of the INS is satisfactory for the stand-off, close-in, and penetration/escort jamming missions. Further testing is recommended to build a data sample size sufficient to establish statistical confidence in INS performance.

2.1.3.1.3 Drift rates. INS cumulative and instantaneous drift rate data are presented in appendix B, figures 4 and 5, respectfully. The small error rates observed produced no noticeable degradation to navigation. Acceptable INS drift rates will allow jamming orbits to be maintained in position to optimize jammer effectiveness. Within the scope of this test, the INS drift rates are also satisfactory.

2.1.3.2 Mission Utility

The utility of the INS was evaluated during a simulated strike escort mission featuring a low-level ingress to a close-in jamming orbit. The route consisted of seven

2. Interview with Major Dennis DeLuca, USAF, Mountain Home AFB, ID., May 1988.

checkpoints and was flown at 300 ft AGL and 510 KIAS. The INS provided for the storage of only three waypoints. Future waypoints could not be inserted without removing steering advisories for the current waypoint. Squadron operators generally preferred to insert the coordinates of each checkpoint as the preceding point was overflown rather than attempting to update stored waypoint data.³ Entering waypoint coordinates consistently detained the evaluator from attending to visual and radar navigation duties until well into each leg of the route. Time consuming coordinate entry procedures will cause the crew to lose awareness of the navigation situation resulting in misidentified turnpoints and gross course and time errors. The delay inducing limited capacity for INS waypoint entry and storage is a deficiency which must be corrected prior to incorporation of the system into Naval aircraft.

3. Walton, interview.

2.2 NAVIGATION RADAR SYSTEM

2.2.1 Equipment Description

2.2.1.1 General

The AN/APQ-160 radar is designed to provide all-weather navigation, air-to-ground, and air-to-air tracking capabilities. The set may be controlled from either crew station. The system interfaces with other airplane navigation systems as shown in appendix B, figure 6.

2.2.1.2 Components

The Navigation Radar System (NRS) is comprised of an antenna assembly, a Modulator-Receiver-Transmitter, and an electrical synchronizer. The antenna assembly is located in the nose radome and is stabilized by inputs from the Inertial Navigation System. An antenna roll unit provides a roll-stabilized platform for antenna mounting and the antenna control unit provides drive power to position the antenna as commanded. The modulator generates the high voltage pulses for generating high power RF energy. The transmitter portion then pulses this energy at a random or set frequency between 16.0 and 16.4 GHz. The return echo enters the receiver, is amplified and displayed in a Plan Position Indicator (PPI) format in the cockpit. System timing, display range markers and cursors, receiver

automatic gain control, and inflight system monitoring are all provided by the electrical synchronizer. Inflight malfunctions are designed to be detected and isolated by the synchronizer through a self-test operation.

2.2.1.3 Operating Modes

2.2.1.3.1 Air-to-air mode. The air-to-air mode is designed to detect and track air targets to provide both threat and collision avoidance. A pencil beam antenna pattern performs a box scan during the search and detection phase. Upon target detection the cursors must be manually positioned near the target to engage the range gate tracking function. Once lock-on has been obtained tracking is designed to continue automatically until manually disengaged or the target moves beyond the antenna limits.

2.2.1.3.2 Air-to-ground modes. Three air-to-ground modes are designed to enable surface target identification for radar navigation and fixing. In each of these modes, the antenna scans a 90 degree azimuth sector ahead of the airplane using a four beam vertical scan pattern. The Ground Auto (GA) mode is the primary navigation and fixing mode. The antenna position and display crosshairs are designed to be automatically adjusted by inputs from the INS to locate pre-inserted destinations, fix points, and targets. Position updates may be accomplished by manually repositioning the

cursors with the tracking control handle. The Ground Velocity (GV) mode is designed to operate in the same manner as the GA mode. The GV mode display is centered at the selected target or waypoint position and may be expanded to aid in identification and accurate fixing. The Ground Manual (GM) mode is designed as a back-up to the other ground modes. All antenna positioning and navigational functions must be performed manually in this mode.

2.2.2 Ground Tests

2.2.2.1 Preflight Procedures

The Navigation Radar System preflight procedures were evaluated for clarity, timeliness, and logical sequencing during ground operations. The procedures consisted of a warm-up period followed by a series of antenna checks. The sequence was completed within five minutes of placing the radar and display controls to the standby positions. Observing the anticipated responses to control inputs on the NRS display gave an indication of the status of the system. The operator will be able to complete the NRS preflight procedures in a thorough manner within the time allowed for normal start-up and pre-taxi checks. The NRS preflight procedures are satisfactory.

2.2.2.2 Cursor Slew Control

The NRS cursor slew control was evaluated for operative sense and sensitivity in all air-to-ground modes of operation. Movement of the stick with the trigger switch depressed moved the cursors at a rate proportionate to the amount of stick deflection in the GA and GV modes. In the GV mode, the cursors remained centered on the display while the radar video was displaced with control stick movement. There was no difference in the slew rate with stick deflection schedule between modes. Small inputs that had produced only moderate slew rates on the PPI display consistently produced slew rates much too high for use in the expanded GV mode. Unpredictably rapid slew rates will result in turnpoint video being driven off the display, causing missed turnpoints and navigation errors. The oversensitivity of the cursor slew control in the GV mode is a deficiency which should be corrected as soon as practicable.

2.2.3 Flight Tests

2.2.3.1 Qualitative Characteristics

2.2.3.1.1 General. The qualitative characteristics of the NRS were evaluated during level flight at 14,500 ft MSL and during low-level flight at 500 KIAS and 1000 ft AGL.

2.2.3.1.2 Mapping quality. In the GA mode mountain ridges were well defined and the differences between level, rolling and mountainous terrain were apparent. Urban development and lines of communication could be identified from distances beyond 40 nmi at altitude. The radar display could be quickly correlated to a chart of the area and significant landmarks identified. Accurate radar representation of the terrain and development along the route of flight will enable quick and accurate navigational fixing. Within the scope of this test, the mapping quality of the NRS is satisfactory for the stand-off, close-in, and penetration/escort jamming missions.

2.2.3.1.3 Display consistency. In the GA mode with the antenna tilt optimized for coverage in a ten mile selected range scale, close-in targets became difficult to distinguish. The returns within the lower third of the display area were subject to a bright blossoming that could not be adequately smoothed using the Sensitivity Time Controls. Adjusting the antenna tilt and gain to remove the blossoming resulted in the loss of returns beyond 5 nmi. The operator will be required to devote extra attention to the NRS to maintain an accurate display of targets near the airplane as well as the terrain changes lying ahead at the expense of attention to other systems and duties. The

blossoming and brightening of near returns on the PPI display is a deficiency which should be avoided in future designs.

2.2.3.2 Scan Limits

2.2.3.2.1 General. The scan limits of the NRS antenna were determined in level flight at 14,500 ft MSL. Scan angle was determined by placing a clearly identifiable target on radar centerline and noting airplane heading. A slow turn of less than twenty degrees angle of bank was initiated and maintained until the target reached the edge of the radar display. Airplane heading was again noted. The turn was repeated in the opposite direction and the full scan angle determined by adding the differences in airplane heading produced from each maneuver. The scan rate of the NRS antenna was determined by timing ten complete sweeps of the antenna across the display and dividing the average time for one sweep into the computed scan angle value.

2.2.3.2.2 Scan angle. The scan angle of the NRS was determined using a clearly identifiable hydroelectric dam as a reference target. The full scan angle was 94 degrees centered on the nose of the airplane while the sector scan angle was 22 degrees centered on the azimuth cursor. The scan angle provided adequate coverage of the area ahead of the aircraft to allow identification of navigational points

of reference. The sector scan could be used in the GV mode to highlight a target of interest. The full and sector scan angles will be sufficient to navigate at low and mid altitudes. The NRS scan angles are satisfactory.

2.2.3.2.3 Scan rate. The scan rate of the NRS was evaluated using a hand held stopwatch. A scan rate of 70 degrees per second was determined in both full and sector scans. The scan rate provided an adequate refresh time to update the display in all modes and phases of operation. The scan rate will be sufficient to navigate at low and mid altitudes. The NRS scan rate is also satisfactory.

2.2.3.3 System Stabilization

2.2.3.3.1 General. The stabilization of the NRS antenna system was evaluated by maneuvering the airplane in pitch and roll, one axis at a time until the display became unusable or until an airframe limit had been reached. Various rates of pitch and roll were used to determine the ability of the system to perform under various load factors.

2.2.3.3.2 Pitch stabilization. The pitch stabilization of the NRS was evaluated by performing a variety of pull-up maneuvers from an altitude of 14,500 ft MSL. No degradation to radar performance occurred in maneuvers of up to 2.5 g's until a 40 degree nose-up attitude had been attained.

Maneuvers up to 4.0 g's caused noticeable display degradation no sooner than reaching 25 degrees nose-up. Pitch inputs throughout the course of representative station keeping maneuvers produced no ill effect on radar performance. The pitch stabilization of the NRS will allow continued radar use throughout ingress and station keeping phases of flight. The pitch stabilization of the NRS is satisfactory.

2.2.3.3.3 Roll stabilization. The roll stabilization of the NRS was evaluated using a variety of roll rate commands at an altitude of 14,500 ft MSL. At all tested roll rates the radar display was unusable beyond 45 degrees of bank. As the bank angle exceeded 45 degrees, the display video was compressed to a bright, unidentifiable band within ten degrees of the airplane heading. A squadron pilot indicated that during turns required to maintain masking in mountainous terrain, situational awareness is sometimes lost due to the unavailability of radar video.⁴ This type of disorientation could result in the loss of the airplane and crew. The severe degradation of radar performance at bank angles in excess of 45 degrees is a deficiency which must be corrected prior to incorporation of the system in Naval aircraft.

4. DeLuca, interview.

2.2.3.4 Maximum Detection Range

The maximum air-to-ground detection range of the NRS was evaluated at an altitude of 11,500 ft AGL by flying toward two small civil aircraft hangars located on open level terrain. The target buildings began to stand out from background video at 57 nmi. Target video was observed on every sweep of the antenna inside that range with no apparent false alarms. Navigation reference points will be detectable at distances sufficient to maintain precise control of course and time enroute. Within the scope of this test, the maximum air-to-ground detection range of the NRS is satisfactory for the stand-off, close-in, and penetration/escort jamming missions.

2.2.3.5 Minimum Range

The minimum range of the NRS was evaluated during overflight of a river intersection at 800 ft AGL using the GV mode. The approach to the target was made so as to provide the optimum radar return from the point of land between the two rivers. The target was tracked to within 1/4 nmi before being lost at the bottom of the display. Visual identification of the target was easily attained prior to loss of radar contact. Radar returns from navigational checkpoints will be available to well within visual detection ranges during low altitude ingress. The minimum range of the NRS is satisfactory.

2.2.3.6 Air-to-Air Mode

The air-to-air mode of the NRS was evaluated at 14,500 ft MSL and 510 KIAS for its ability to assist in air traffic location and collision avoidance. Traffic reported by Air Traffic Control to be level at one o'clock and ten miles was immediately detected and tracked by the radar. Contact was maintained through a shallow climb to give a small look-down angle. Traffic was tracked to well within visual range without loss of contact or the presence of false alarms. The air-to-air mode will provide adequate detection and tracking capability to assist in traffic avoidance. Within the scope of this test, the air-to-air mode of the NRS is satisfactory for the stand-off, close-in, and penetration/escort jamming missions. Further testing is recommended to determine the weather avoidance capability of the air-to-air mode of the NRS.

2.2.3.7 Mission Utility

2.2.3.7.1 General. The utility of the NRS was evaluated by flying a high-low-high profile simulating an attack escort to a close-in jamming orbit. Both level and mountainous terrain were included in the low-level portion of the flight. The air-to-air, GA, and GV modes were used to assist in air traffic avoidance, navigation and turnpoint identification respectively.

2.2.3.7.2 Mode changes. When the GA mode was selected after operating in the air-to-air mode, the pencil beam antenna pattern used in the air-to-air mode was maintained for several sweeps of the antenna. A narrow band of video was available for display under this condition, but an accurate ground representation could not be produced. The test flight pilot stated that delays in developing a reliable ground picture often result in delayed checkpoint identification and navigation errors.⁵ The failure of the antenna to revert to a fan beam when switching from air-to-air to air-to-ground modes is a deficiency which must be corrected as soon as practicable.

2.2.3.7.3 Range scale changes. With the 30 nmi range scale selected in the GA mode, a navigation checkpoint was tracked to within ten miles with the controls optimized to display that point. Selection of the ten mile range scale required adjustment of the antenna tilt, intermediate frequency and video gain controls to regain a usable display of the checkpoint. Similar adjustments were needed upon selection of the five mile range scale. Recommendations for course corrections were delayed by the need to regain a usable display after each scale change. Squadron operators

5. Deluca, interview.

often experience confusion when selecting smaller range scales which induces errors in course and speed corrections during radar navigation operations.⁶ The failure of the NRS to maintain a usable display following changes in range scales is a deficiency which must be corrected as soon as practicable.

2.3 TERRAIN FOLLOWING RADAR

2.3.1 Equipment Description

2.3.1.1 General

The AN/APQ-110 Terrain Following Radar (TFR) is designed to provide low-altitude terrain following, obstacle avoidance, and blind let-down capabilities. The system consists of redundant left and right antenna receivers, synchronizer transmitters, power supplies and computers in a dual channel configuration. Each channel may be operated independently of the other in any of the operating modes. The TFR receives inputs from the radar altimeter, navigation radar, INS, flight control system, and central air data computer as shown in appendix B, figure 7.

6. Walton, interview.

2.3.1.2 Operating Modes

2.3.1.2.1 Terrain following mode. The terrain following (TF) mode is designed to maintain a selected terrain clearance in either the manual or automatic flight control modes of flight. When in manual flight, pitch steering commands are displayed on the pilot's attitude indicator. Pitch steering commands are coupled to the automatic flight control system when in that mode of flight. The TF mode is also designed to allow manual or automatic let-down to a selected clearance level. The maximum dive angle is limited to 12 degrees for this function. Only one channel may be operated in the TF mode at a time. Selecting TF with the second channel will put it in the standby condition which is designed to automatically assume operation in the event of a failure of the primary channel. The TF display is an E-scope format showing range along the horizontal axis and terrain elevation in the vertical.

2.3.1.2.2 Ground mapping mode. The Ground Mapping (MAP) mode provides a PPI presentation of the terrain ahead of the airplane. Designed primarily for navigational assistance, the MAP antenna scan is ± 30 degrees from the airplane ground track. The antenna, which is stabilized in pitch, roll, and drift in this mode, may be manually adjusted to optimize the display.

2.3.1.2.3 Situation mode. The Situation (SIT) mode is designed to be used in conjunction with the TF mode for obstacle avoidance. The SIT display, antenna scan, and stabilization are the same as for the GM mode of the NRS, but antenna tilt can not be adjusted. Only obstacles and terrain at or above airplane altitude are displayed. The SIT mode offers no clearance information or capability, but is designed for use in flying around, rather than over, obstacles.

2.3.1.3 Operating Parameters

The TFR may be operated at selected clearance levels of 200, 300, 400, 500, 750 and 1000 feet. Either Hard, Medium or Soft ride control levels may be selected depending upon mission requirements and aircrew preference. The negative commanded g-loading is designed to be limited to zero for Hard, 0.5 for Medium, and 0.75 for Soft. Table II shows the designed terrain clearance envelopes for the Hard ride setting. Slightly higher clearances are likely for Soft and Medium rides.

Table II
TFR HARD RIDE CLEARANCE ENVELOPE

Selected Clearance (feet)	Minimum (ft)	Maximum (ft)
200	170	300
300	260	425
400	350	550
500	440	650
750	675	950
1000	900	1200

The TFR also contains an extensive failure warning and caution system designed to provide the aircrew with timely notification of a system or component failure. This feature includes fly-up failure logic designed to give the appropriate manual or automatic fly-up commands when terrain following operations are not able to be continued safely.

2.3.2 Ground Tests

The TFR preflight procedures were evaluated during ground operations for thoroughness, clarity, logical sequencing and time to complete. Three minutes were required to run a series of tests which confirmed the status of the TFR and interfaces with other systems. The procedure was easily completed within the course of pre-taxi checks. A

thorough test of the system may be completed without delaying taxi or launch. The TFR preflight procedures are satisfactory.

2.3.3 Flight Tests

2.3.3.1 Predescent Checks

The TFR predescent checks were evaluated in flight at 14,500 ft MSL for thoroughness, clarity, logical sequencing and time to complete. The predescent checks duplicated the preflight procedures exactly. In addition to the display indications observed on preflight the reaction of the flight control system to test inputs could also be checked. Completion of the checks required the Electronic Warfare Officer to reach across the cockpit to hold the radar altimeter test button while the pilot manipulated the TFR controls and maintained level flight. The checks required the attention of both crew members for approximately three minutes. The crew will be distracted from scanning for traffic and performing other mission duties thereby increasing the possibility of mid-air collision. The requirement for both crew members to devote attention to the TFR predescent checks is a deficiency which must be corrected as soon as practicable.

2.3.3.2 TFR Displays

The TFR display was evaluated in low-level flight at 510 KIAS at all clearance settings. The display was capable of presenting any one of the three modes as selected by the operator. With one TFR channel operated in the TF mode and the other in the MAP or SIT mode, information from only one channel was available to the crew. Viewing the ground map or situation display required the deselection of the E-scope terrain clearance display. The test flight pilot indicated that the inability to monitor all of the information available from the system frequently reduces the effectiveness of the TFR in terrain masking because the operator does not have immediate access to the information required for optimum operating efficiency.⁷ The provision of only one display to monitor both TFR channels is a deficiency which should be corrected as soon as practicable.

2.3.3.3 Blind Let-Down

The blind let-down function of the TFR was qualitatively evaluated from 11,500 ft AGL to 1000 ft AGL over rolling to mountainous terrain. Tip-over and dive angles were comfortable throughout the let-down. The pull-out was smooth and the selected clearance maintained within 50 ft following level-off. The pilot was able to monitor

7. Deluca, interview.

system performance, but did not need to make any control input. The automatic let-down capability will allow safe transition to low-level flight in instrument flight conditions. Within the scope of this test, the blind let-down function of the TFR is satisfactory for the stand-off, close-in, and penetration/escort jamming missions. Further testing is recommended to determine blind let-down performance in all weather conditions.

2.3.3.4 Terrain Following Accuracy

2.3.3.4.1 Clearance settings. The accuracy of the TFR clearance settings was evaluated at 510 KIAS over level to rolling terrain with medium ride quality selected. Data are presented in table III. Despite the fact that both channels maintained the selected clearance level within acceptable limits without operator input, squadron pilots always maintain a close watch on the system and remain prepared to resume manual control upon any indication of a malfunction.⁸ The system will maintain the desired terrain clearance with minimal pilot input allowing the crew to tend to other mission responsibilities. The accuracy of the TFR clearance settings is satisfactory.

8. DeLuca, interview.

Table III
TFR CLEARANCE SETTING ACCURACY

Selected Clearance (feet)	Observed Deviation (feet)
1000	950 to 1100
750	700 to 800
500	475 to 550
400	350 to 425
300	275 to 325
200	175 to 225

2.3.3.4.2 Ride quality. Each of the three TFR ride quality settings was evaluated qualitatively over mountainous terrain with 300 ft clearance selected. Data are presented in appendix A, table IV. Although the hard ride setting produced particularly aggressive terrain following, the ride was not uncomfortable for the crew. Desired terrain masking will be available during low-level ingress by selecting the appropriate ride quality. Within the scope of this test, the TFR ride quality settings are satisfactory.

2.3.3.5 Turn Effects

The effects of turning the airplane on TFR system performance were evaluated during low-level flight at 510 KIAS with 300 ft clearance and medium ride quality selected. Maneuvers up to 45 degrees angle of bank (AOB) produced no detrimental effects. Upon reaching 45 degrees AOB the system initiated an abrupt fly up maneuver and discontinued terrain following operation. The pilot had to fly the airplane manually through the remainder of the turn and re-engage the TFR upon rollout. To avoid exposure to anti-aircraft weapons systems, the pilot will be forced to disengage the TFR during aggressive low-level course changes requiring large bank angles. The limitation of 45 degrees AOB on TFR operation is a deficiency which must be corrected as soon as practicable.

2.3.3.6 Mission Utility

The utility of the TFR was evaluated during a simulated strike escort low-level mission including let-down from altitude and flight over various terrain types with all clearance settings and medium ride quality selected. In the absence of radar returns within a given window ahead of the airplane (as determined by selected ride quality, clearance setting and ground speed) the TFR reverted to a radar altimeter mode to maintain the desired clearance. This phenomenon was evident when approaching large bodies of

water and dry lakebeds. Upon detecting returns within the radar altimeter override window, the system resumed normal operations automatically. The radar altimeter override feature will allow low-level ingress over water and non-reflective terrain without hazard upon approaching rising terrain. Within the scope of this test, the utility of the TFR is satisfactory for the stand-off, close-in and penetration/escort jamming missions. Further testing is recommended to determine TFR system performance approaching high cliffs and volcanic islands rising rapidly from the sea.

2.4 SYSTEM INTEGRATION

2.4.1 General

Integration of the navigation systems is accomplished by the passing of data between units as shown in appendix B, figures 6 and 7. System integration was tested qualitatively throughout the evaluation with specific observations recorded below.

2.4.2 Inertial Navigation System

The steering marker on the pilots HSI provided steering advisories to the position commanded by the INS destination windows. The displayed INS destination also positioned the

NRS cursors in the GA mode. INS updates could be performed using the radar as well as the fly-over method. Integration of the INS with the NRS and HSI will assist in locating, identifying and overflying navigation checkpoints.

2.4.3 Navigation Radar System

In the GA and GV modes the radar cursors are positioned automatically to the location displayed in the INS destination windows. In all air-to-ground modes the position of the azimuth cursor provided an input to the heading indicator on the pilot's HSI. The interface through the NRS allowed waypoint steering advisories to be passed to the pilot upon selection of any INS destination. Immediate availability of steering advisories will enable the pilot to turn to the proper heading enroute to the next turnpoint while flying low-level ingress routes.

2.4.4 Terrain Following Radar

The TFR system received flight condition input from the INS and pitot-static instruments. Momentary failure of any input or the surpassing of any system limitation resulted in the sending of a signal to the automatic flight control system which caused an abrupt upward pitch of the airplane and the termination of automatic terrain following operations. The crew members will be immediately aware of an

unsafe or abnormal condition occurring in the TFR system and be afforded the opportunity to take appropriate action to abort or continue the low-level penetration as necessary.

2.4.5 System Integration Summary

Although each system appeared to be effectively integrated with the others, flight observations and squadron operator comments indicated that the navigation suite as a whole was not well integrated. Momentary abnormalities in INS data, for example, resulted in occasional discontinuation of terrain following operations or in the mispositioning of the NRS cursors. Momentary confusion of the aircrew due to these integration problems will cause unnecessary degradation of the effectiveness of the navigation systems in contributing to the success of the mission. The inadequate overall integration of the navigation systems is a deficiency which should be corrected as soon as practicable.

CHAPTER 3

RECOMMENDED CORRECTIONS TO DEFICIENCIES

3.1 INERTIAL NAVIGATION SYSTEM

3.1.1 General

The deficiencies cited against the INS are primarily human factors issues that require the redesign or replacement of the INS control panel. Since the control panel is an integral part of the Navigation Computer in the AN/AJQ-20 system, it would be desirable to replace the entire computer to correct the problems. Rather than having to design a new interface to the Stabilized Platform it is preferable to replace the inertial system completely. The installation of a ring laser gyroscope system such as the LTN-139 would provide the best upgrade available at the present time. A similar upgrade to F-111F airplanes which includes the installation of the Global Positioning System (GPS) has been determined to cost approximately \$950,000 per airplane.⁹ To address the deficiencies identified in this evaluation the upgraded system would need to include the features identified below.

9. Breck W. Henderson, USAF, Rockwell Begin Work On F-111F/D Avionics Upgrade, Aviation Week & Space Technology, January 29, 1990, p.59.

3.1.1.1 INS Position Set Knobs

The functioning of the INS latitude and longitude set knobs with opposite operative senses should be corrected by replacing the rotary knobs with a data entry keypad of the type described in section 5.15.3 of MIL-STD-1472C, reference D. The desired numerical entries could be easily typed into the system. This simple change will eliminate confusion in the cockpit and save valuable time on low-level missions.

3.1.1.2 INS Position Display Windows

The close proximity of the INS present position and destination display windows should be corrected by replacing the series of mechanical rotary display windows with a single Light Emitting Diode (L.E.D.) display. The present position of the airplane or the desired destination or waypoint coordinates could be selected for display using a key or knob on the keypad. The operator will be able to monitor keypad entries on this display to confirm the accuracy of entered data. This modification to the display of INS data will reduce ambiguities in navigation and so enhance the contribution of the navigation suite to mission effectiveness.

3.1.1.3 Limited Waypoint Capacity

The delay inducing limited capacity for INS waypoint entry and storage should be corrected by designing the new Navigation Computer to store a minimum of 24 waypoint positions. This capacity will allow all of the waypoints for a particular route of flight to be entered before takeoff or while in transit to the initial point of the route. This will eliminate the requirement to continually update waypoint entries throughout the route and will prevent navigation errors due to delays in obtaining the proper steering cues to the next waypoint.

3.1.2 Global Positioning System

In addition to a new inertial system, the upgrade to the navigation suite should include GPS. The accuracies obtained from this latest technology promise to be far above those realized from inertial systems because a satellite based system is not subject to the errors of the Schuler Cycle which prevail in all inertial systems. The GPS control panel could be installed alongside the new INS panel in the space presently housing the current INS control panel and Navigation Computer. The addition of GPS will significantly enhance the accuracy of navigation and so contribute directly to the tactical jamming mission.

3.2 NAVIGATION RADAR SYSTEM

3.2.1 General

Several of the deficiencies identified against the NRS could be corrected by modifying the electrical synchronizer to include a logic circuit that would adjust the automated functions of the system for optimal performance in the selected radar mode. Modern microprocessor technology makes this a rather straight forward and inexpensive upgrade to the system. The specific features required of this addition are described in the following paragraphs.

3.2.1.1 NRS Cursor Slew Control

The oversensitivity of the NRS cursor slew control in the GV mode should be corrected by designing the logic circuit to slow the slew rate of the radar video display when that mode is selected. The normal GV mode requires only 30% of the cursor slew rate used in the PPI modes. The expanded GV display requires only 50% of the normal GV slew rate. This modification will reduce the tendency to drive the desired target video off the display when in the GV mode of operation.

3.2.1.2 Display Consistency

The blossoming and brightening of near returns on the PPI display should be corrected by including an automatic Sensitivity Time Control circuit in the upgraded logic circuitry. This feature would respond to the selected range scale and antenna tilt position by adjusting the gain to optimize the presentation over the entire scale displayed. This modification will save the operator from needing to make continual adjustments to manual radar controls at the expense of the performance of mission duties involving other airplane systems.

3.2.1.3 Mode Changes

The failure of the antenna to revert to a fan beam when switching from air-to-air to air-to-ground modes should be corrected by including an element in the proposed modification that immediately senses a mode change and adjusts the antenna pattern accordingly. This feature will prevent the loss of usable radar video for several sweeps of the antenna following a change in radar mode.

3.2.1.4 Range Scale Changes

The failure of the NRS to maintain a usable display following changes in range scales should be corrected by modifying radar logic circuitry to automatically adjust antenna tilt, IF and video gain to maintain a clear

presentation of the video at the cursor position. This feature will reduce the time required to determine the need for course corrections as a waypoint is approached during low-level ingress to jamming stations.

3.2.2 Roll Stabilization

The severe degradation of radar performance at bank angles in excess of 45 degrees should be corrected by modifying or replacing the antenna mounting hardware and roll control unit as necessary. The mounting should allow sufficient freedom for the antenna to continue to illuminate the ground regardless of aircraft roll attitude. The roll control unit should be designed to use input data from the INS and cockpit attitude instruments to determine the antenna tilt and azimuth angles required to maintain usable radar illumination of the position designated by the radar display cursors. An inexpensive analog system which compares previous antenna position and airplane attitude to the present conditions and makes appropriate adjustments will provide the capability to maintain accurate radar navigation while maneuvering aggressively to maintain course or to optimize jammer orbit positioning.

3.3 TERRAIN FOLLOWING RADAR

3.3.1 Pre-descent Checks

The requirement for both crew members to devote attention to the TFR pre-descent checks should be corrected by changing the radar altimeter test switch. The current spring loaded switch should be replaced by a two position toggle switch. The pilot would simply place the switch to the test position to commence the TFR checks. The Electronic Warfare Operator will then be free to perform navigation duties or maintain visual scan for air traffic while the pilot completes the checklist.

3.3.2 TFR Displays

The provision of only one display to monitor both TFR channels should be corrected by adding an additional display. This monitor could be placed adjacent to the first on the center instrument panel if the Terminal Threat Warning System (TTWS) display were moved. The TTWS display could be relocated to a position made available by the replacement of the INS control panel. Each TFR display could be linked to its respective channel mode selection switch. This modification will enable the crew to monitor both channels of TFR operations, thereby maximizing the potential use of the information provided by the system.

3.3.3 Turn Effects

The limitation of 45 degrees angle of bank on TFR operations should be corrected by modification of the antenna mounting hardware in a manner similar to that recommended for the NRS antenna. The suggested analog circuitry could be expanded to include feedback and command of TFR antenna positioning. This modification will enable TFR operations to continue through hard turns to maintain course during low-level ingress to jamming stations.

3.4 SYSTEM INTEGRATION

The inadequate overall integration of the navigation systems should be corrected by designing all modifications to the present system to include the incorporation of a MIL-STD-1553B data bus. The suggested alterations to the INS computer and NRS synchronizer could easily be specified to be compatible with 1553 architecture. The recommended changes to the NRS and TFR antenna stabilization systems could also be made compatible with the addition of digital-to-analog and analog-to-digital converters. This proposal, although costly, would bring the navigation system to a level of commonality with more recently developed military systems. It would also enhance the opportunity for

and reduce the cost of future updates to components of the navigation and other mission systems because the baseline MIL-STD-1553B architecture would already be in place.¹⁰ The potential long-term savings justify the immediate expense of incorporating this recommendation.

10. Len Buckwalter, "Inside MIL-STD-1553: The Avionics Data Bus," Avionics, June, 1984, p. 33.

CHAPTER 4

CONCLUSIONS

4.1 GENERAL

4.1.1 Overall

Within the scope of this evaluation, the navigation system installed in the EF-111A demonstrated limited potential for the stand-off, close-in, and penetration/escort jamming missions, but will be satisfactory upon correction of the deficiencies cited above.

4.1.2 Inertial Navigation System

The Inertial Navigation System demonstrated limited potential for the assigned missions and should be replaced altogether. The installation of a ring laser gyroscope system such as the LTN-139 would provide the best upgrade available at the present time (paragraph 3.1.1).

4.1.3 Global Positioning System

In addition to a new inertial system, the upgrade to the navigation suite should include the Global Positioning System (paragraph 3.1.2).

4.1.4 Navigation Radar System

The Navigation Radar System demonstrated good potential for the jamming missions and should be improved by modifying the electrical synchronizer to include a logic circuit that would adjust the automated functions of the system for optimal performance in the selected radar mode (paragraph 3.2.1).

4.1.5 Terrain Following Radar

The Terrain Following Radar is satisfactory for the penetration/escort jamming mission.

4.2 SPECIFIC

4.2.1 Inertial Navigation System

4.2.1.1 The functioning of the INS latitude and longitude set knobs with opposing operative senses (paragraph 2.1.2.2.2) should be corrected by replacing the rotary knobs with a keypad for data entry (paragraph 3.1.1.1).

4.2.1.2 The close proximity of the INS Present Position and Destination display windows (paragraph 2.1.2.2.3) should be corrected by replacing the series of mechanical rotary display windows with a single Light Emitting Diode (L.E.D.) display (paragraph 3.1.1.2).

4.2.1.3 The delay inducing limited capacity for INS waypoint entry and storage (paragraph 2.1.3.2) must be corrected prior to incorporation of the system into Naval aircraft by designing the new Navigation Computer to store a minimum of 24 waypoint positions (paragraph 3.1.1.3).

4.2.2 Navigation Radar System

4.2.2.1 The oversensitivity of the cursor slew control in the GV mode (paragraph 2.2.2.2) should be corrected as soon as practicable by designing the logic circuit to slow the slew rate of the radar video display when that mode is selected (paragraph 3.2.1.1).

4.2.2.2 The blossoming and brightening of near returns on the PPI display (paragraph 2.2.3.1.3) should be corrected by including an automatic STC circuit in the upgraded logic circuitry (paragraph 3.2.1.2).

4.2.2.3 The severe degradation of radar performance at bank angles in excess of 45 degrees (paragraph 2.2.3.4.3) must be corrected prior to incorporation of the system in Naval aircraft by modifying or replacing the antenna mounting hardware and roll control unit as necessary (paragraph 3.2.2).

4.2.2.4 The failure of the antenna to revert to a fan beam when switching from air-to-air to air-to-ground modes (paragraph 2.2.3.8.2) should be corrected as soon as practicable by including an element in the proposed modification that immediately senses a mode change and adjusts the antenna pattern accordingly (paragraph 3.2.1.3).

4.2.2.4 The failure of the NRS to maintain a usable display following changes in range scales (paragraph 2.2.3.8.3) should be corrected as soon as practicable by modifying radar logic circuitry to automatically adjust antenna tilt, IF and video gain to maintain a clear presentation of the video at the cursor position (paragraph 3.2.1.4).

4.2.3 Terrain Following Radar

4.2.3.1 The requirement for both crew members to devote attention to the TFR predescent checks (paragraph 2.3.3.1) should be corrected as soon as practicable by changing the radar altimeter test switch to a two position toggle switch (paragraph 3.3.1).

4.2.3.2 The provision of only one display to monitor both TFR channels (paragraph 2.3.3.2) should be corrected as soon as practicable by adding an additional display (paragraph 3.3.2).

4.2.3.3 The limitation of 45 degrees AOB on TFR operation (paragraph 2.3.3.3) should be corrected as soon as practicable by modification of the antenna mounting hardware in a manner similar to that recommended for the NRS antenna (paragraph 3.3.3).

4.2.4 System Integration

The inadequate overall integration of the navigation systems (paragraph 2.4.5) should be corrected by designing all modifications to the present system to include the incorporation of a MIL-STD-1553B data bus (paragraph 3.4).

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REFERENCES

- A. EF-111A Flight Manual, T.O. 1F-111(E)A-1, Change 3. United States Air Force, 1987.
- B. Project Test Plan: Technical Evaluation of the Weapons System Installed in the Advanced Fixed Wing Medium Attack Airplane (VAX). Patuxent River Naval Air Station: United States Navy, 1983.
- C. Preparation of Naval Air Test Center Reports, NATCINST 5213.3F. Patuxent River Naval Air Station: United States Navy, 1987.
- D. Human Engineering Design Criteria for Military Systems, Equipment and Facilities, MIL-STD-1472C. United States Department of Defense, 1981.
- E. Henderson, Breck W. "USAF, Rockwell Begin Work On F-111F/D Avionics Upgrade." Aviation Week and Space Technology, January 29, 1990, p. 59-63.
- F. Buckwalter, Len. "Inside MIL-STD-1553: The Avionics Data Bus." Avionics, June, 1984, p. 10-16, 33.

INTERVIEWS

- 1. Walton, Paul, Captain, USAF. EF-111A Electronic Warfare Officer, 390th Electronic Countermeasures Squadron. Mountain Home Air Force Base, Idaho, May, 1988.
- 2. DeLuca, Dennis, Major, USAF. EF-111A Pilot, 390th Electronic Countermeasures Squadron. Mountain Home Air Force Base, Idaho, May, 1988.

APPENDIXES

APPENDIX A

TABLES

Table I
DETAILED SCOPE OF TESTS
Inertial Navigation System

Event Number	Test Conducted	Flight Number	Event Altitude	Mode
INS 1	Preflight	Ground	On Deck	N/A
INS 2	Controls & Displays	Ground 1 and 2	Full Test Envelope	N/A
INS 3	Dynamic Accuracy	1,2	Full Test Envelope	N/A
INS 4	Mission Utility	1,2	Full Test Envelope	N/A

Table II
DETAILED SCOPE OF TESTS
Navigation Radar System

Event Number	Test Conducted	Flight Number	Event Altitude	Mode
NRS 1	Preflight and BIT	Ground 1 and 2	On Deck	All
NRS 2	Controls & Displays	Ground 1 and 2	Full Test Envelope	All
NRS 3	Scan Limits	1	14,500' MSL	GA
NRS 4	Stabilization	1	14,500' MSL	GA
NRS 5	Max. Detection Range	1	14,500' MSL	GA
NRS 6	Min. Range	1	500' AGL	GA
NRS 7	Qualitative Characteristics	1	14,500' MSL	GA AA
NRS 8	Mission Utility	1 and 2	500' AGL to 14,500' MSL	All

Appendix A

Table III
DETAILED SCOPE OF TESTS
Terrain Following Radar

Event Number	Test Conducted	Flight Number	Event Altitude	Mode
TFR 1	Preflight	Ground	On Deck	All
TFR 2	Controls & Displays	Ground 1 and 2	Full Test Envelope	All
TFR 3	TF Accuracy	1 and 2	500' AGL	Auto
TFR 4	Blind Letdown	2	14,500' MSL to 1000' AGL	Auto
TFR 5	Turning Flight Effects	2	500' AGL	Auto
TFR 6	Mission Utility	1 and 2	500' AGL	Auto

Table IV
RIDE QUALITY RESULTS
Terrain Following Radar

Selected Ride Quality	Qualitative Remarks
Soft	Gentle pull-ups, ballooning over ridge lines, pushovers to 3/4 g
Medium	Pull-ups of up to 2 g at a comfortable distance prior to ridge lines, slight ballooning over ridges, pushovers to 1/2 g
Hard	Aggressive pull-ups, pushovers to zero g, maintains clearance setting ± 20 ft cresting ridge lines

Appendix A

APPENDIX B

FIGURES

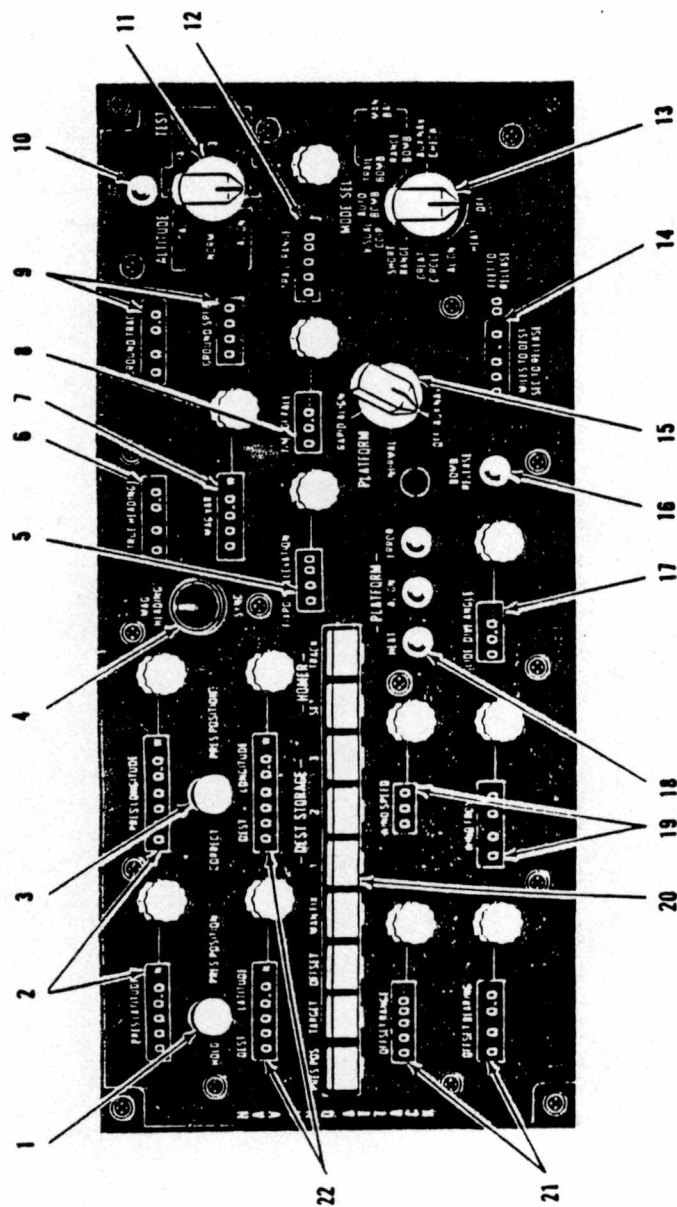


Figure 1

Inertial Navigation System Control Panel

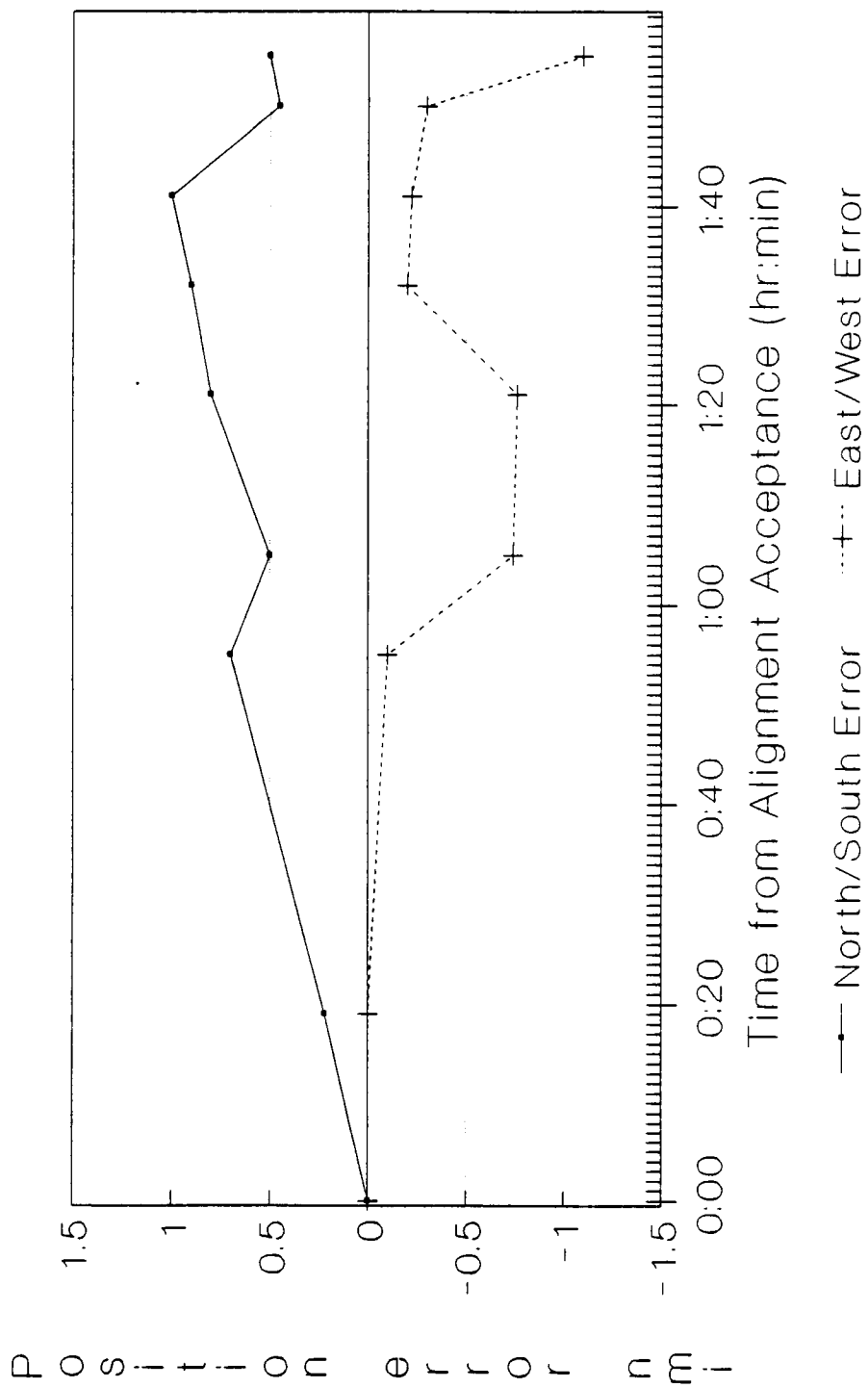


Figure 2
EF-111A Inertial Navigation System
North/South and East/West Position Error

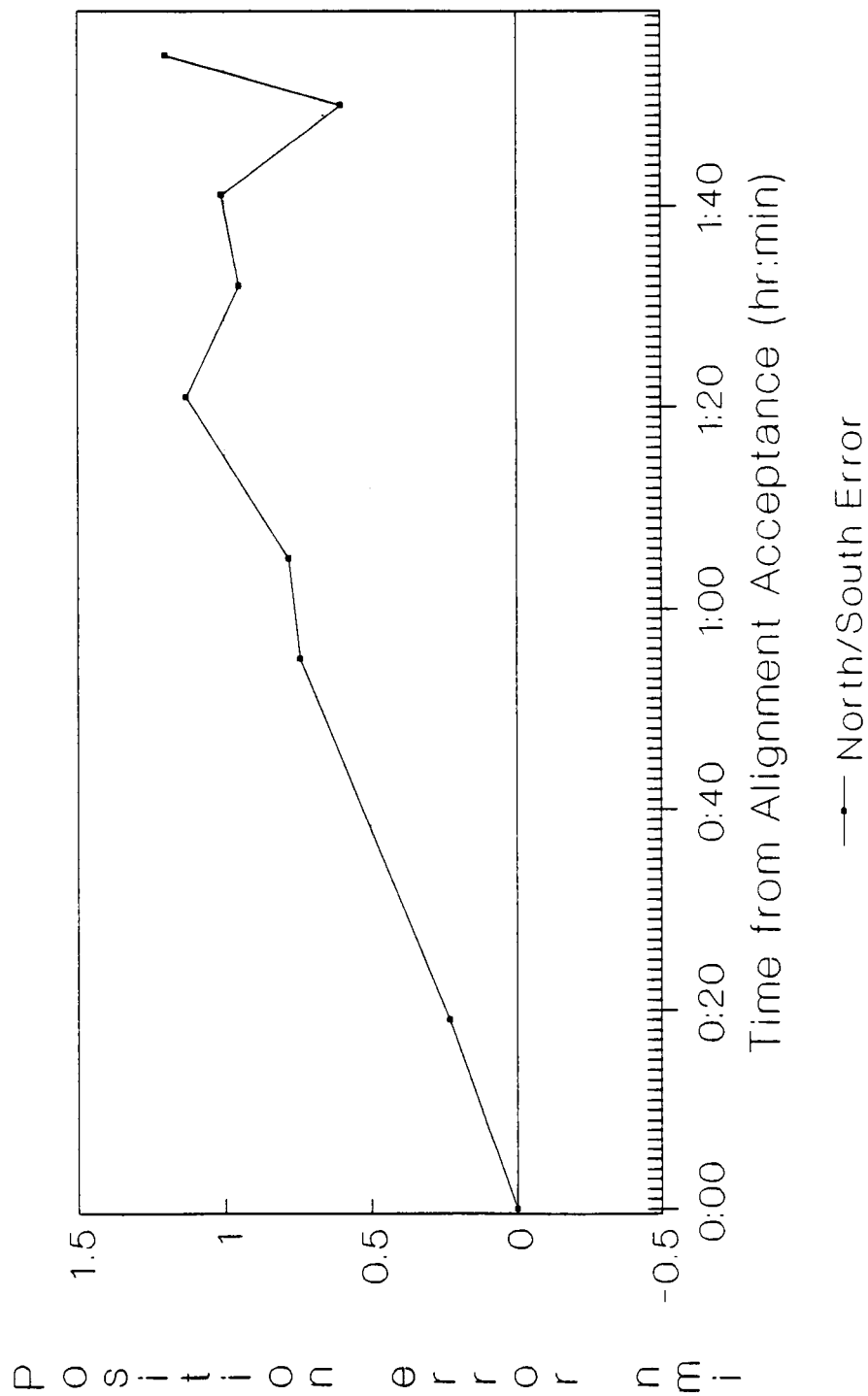


Figure 3
EF-111A Inertial Navigation System
Radial Position Error

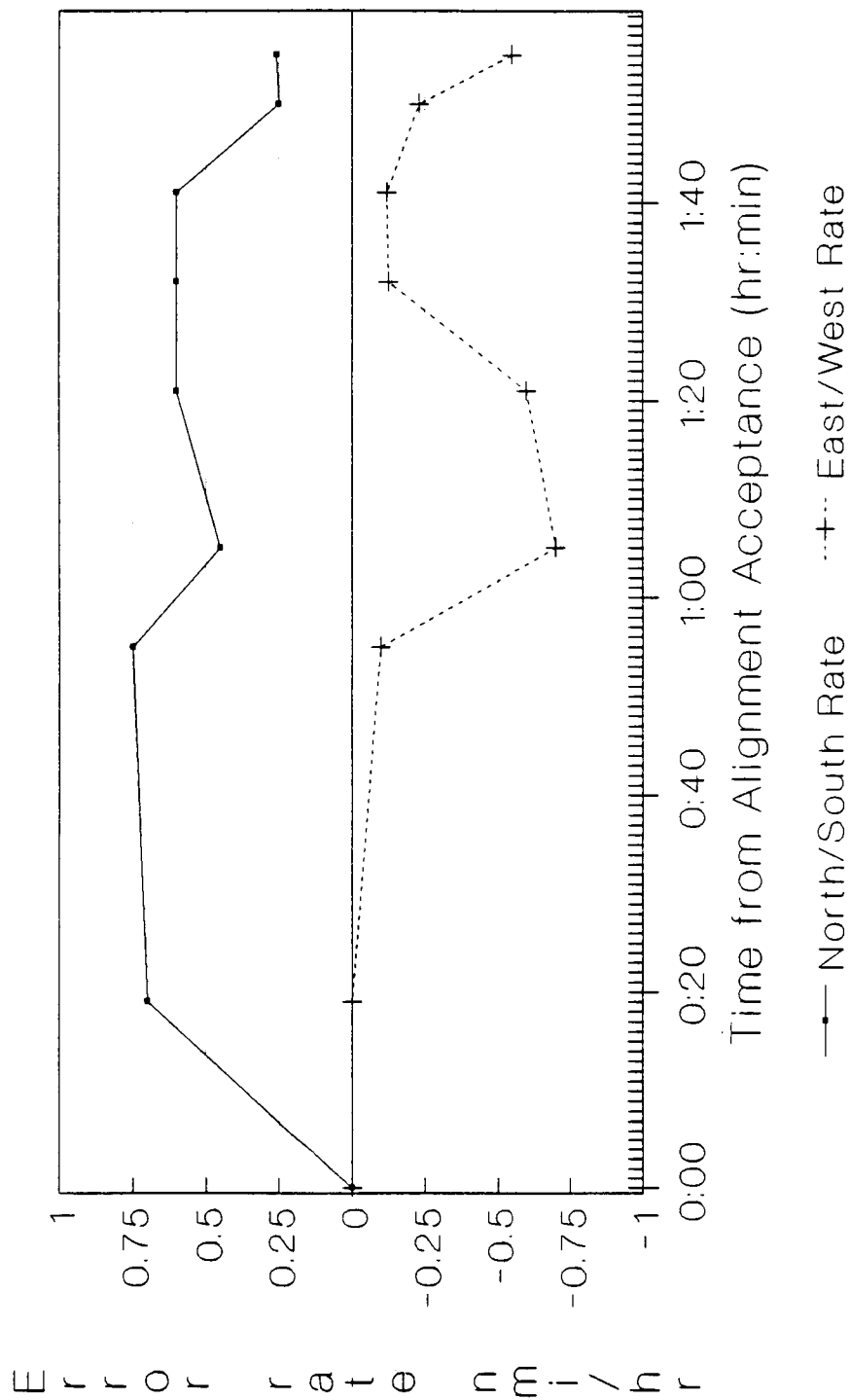


Figure 4
EF-111A Inertial Navigation System
Cumulative Error Rate

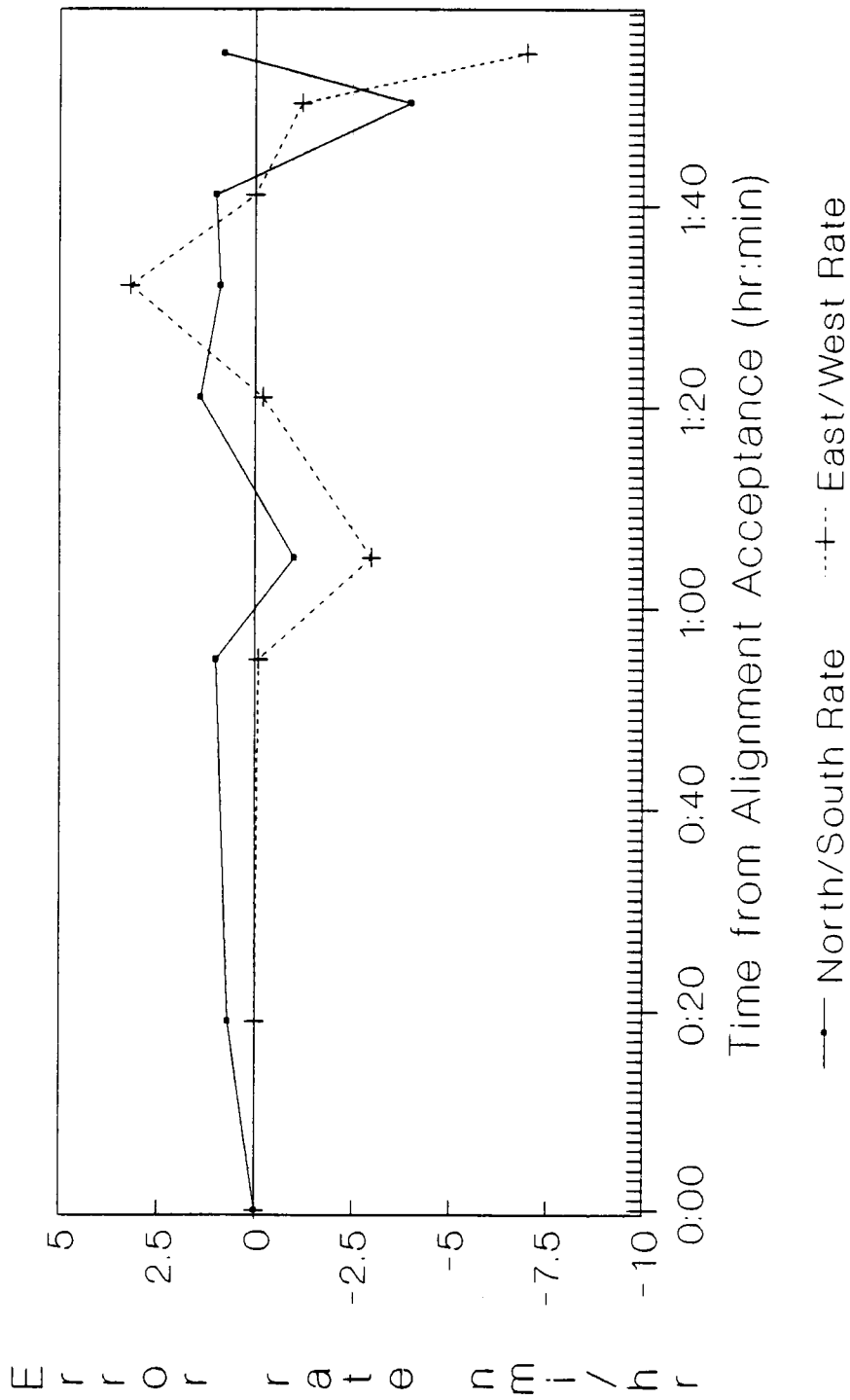


Figure 5
EF-111A Inertial Navigation System
Instantaneous Error Rate

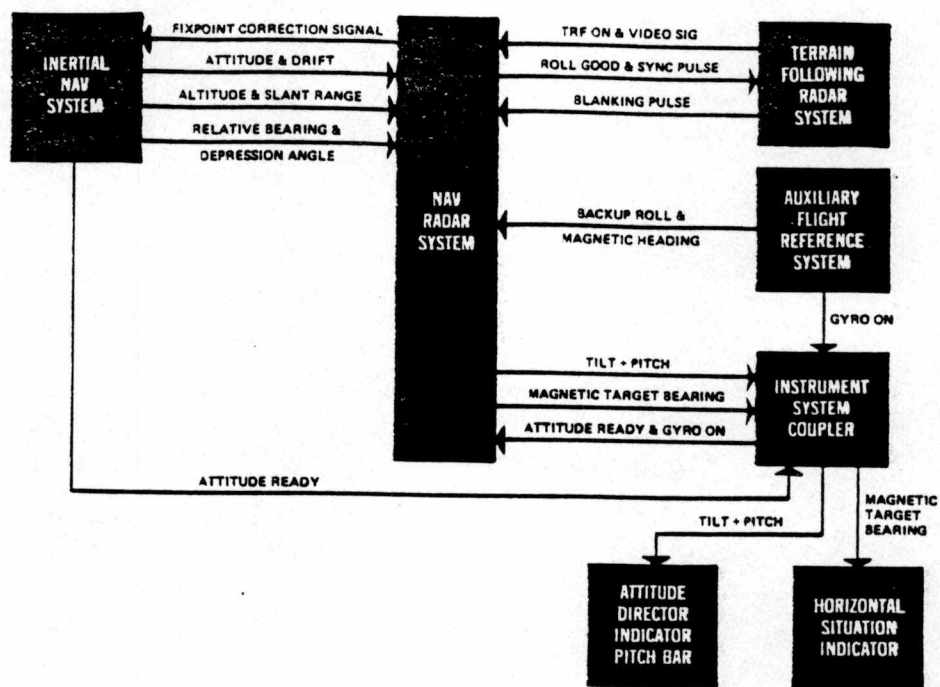


Figure 6

Navigation Radar System Interface

Appendix B

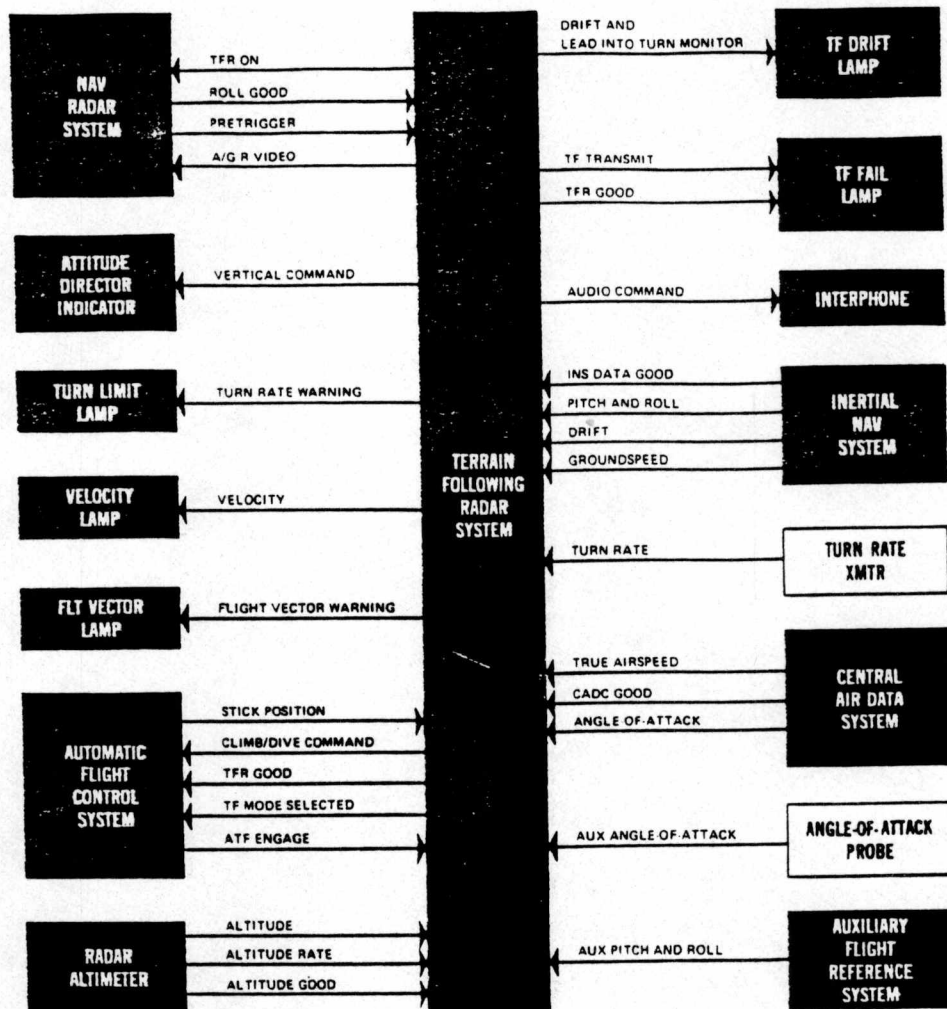


Figure 7

Terrain Following Radar System Interface

Appendix B

VITA

Scott J. Howe was born in Milwaukee, Wisconsin on November 2, 1959. He graduated from Penn High School in Mishawaka, Indiana in May 1977 and was inducted into the United States Naval Academy that July. In May 1981 he received the degree of Bachelor of Science in Aerospace Engineering and was commissioned an Ensign in the United States Navy.

He was designated a Naval Flight Officer upon completion of flight training in 1983 and assigned to duty with Air Antisubmarine Squadron 28 where he was promoted to the rank of Lieutenant. After completing deployments to the Indian Ocean and Mediterranean Sea, he was awarded the Navy Achievement Medal for sustained superior performance.

Lt. Howe attended the United States Naval Test Pilot School at Patuxent River, Maryland from July 1987 to June 1988. He enrolled in the graduate program of the University of Tennessee Space Institute while assigned to the Naval Air Test Center where he conducts technical test and evaluation of the S-3 Viking airplane and airborne antisubmarine warfare systems.