8-2002

Integration of the Control Display Navigation Unit (CDNU) Into the EA-6B Block 89A Aircraft and its Impact on Navigation Operations

Robert Donald Croxson
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Robert Donald Croxson entitled "Integration of the Control Display Navigation Unit (CDNU) Into the EA-6B Block 89A Aircraft and its Impact on Navigation Operations." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Dr. Frank. G. Collins, Major Professor

We have read this thesis and recommend its acceptance:

Dr. Ralph D. Kimberlin, Prof. Fred Stellar

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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INTEGRATION OF THE CONTROL DISPLAY NAVIGATION UNIT (CDNU) INTO THE EA-6B BLOCK 89A AIRCRAFT AND ITS IMPACT ON NAVIGATION OPERATIONS

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

Robert Donald Croxson
August 2002

DEDICATION

This thesis is dedicated to my wife
Deborah
and sons
Robert and John
all have sat and waited for this to be completed for too long.

ACKNOWLEDGMENTS

I would like to thank everyone who helped contribute to this thesis. The list of individuals who helped contribute to the completion of this thesis is long and if you are reading this you are probably one of them.

Thank you.

ABSTRACT

This thesis was to evaluate the attributes of the recent modification and installation of the Control Display Navigation Unit (CDNU) into the EA-6B aircraft. The author conducted multiple ground and flight test events during a three year evaluation of the EA-6B Block 89A aircraft.

The Block 89A modification included an embedded Global Positioning System (GPS)/ Inertial Navigation System (INS) (EGI), enhanced functionality with the recent GPS system modification, and the ability to control the navigation, weapon, and communication on one control panel. This modification was an attempt to replace a failing attitude system and also allow for additional capability. The testing performed included ILS and GPS approaches, holding, air navigation routes, low level military navigation routes, and tactical navigation. The EA-6B is currently not authorized to navigate with the GPS as the sole navigation (NAV) nor authorized to conduct GPS approaches. This evaluation revealed a need for a GPS navigation and approach authorization in the EA-6B. Funding should be started immediately to anticipate meeting the technology requirements once free flight is authorized in the US.

This thesis describes the navigation modes currently used in the EA-6B aircraft. The newest 89A upgrade demonstrates great advances in navigation ability with the addition of the EGI.

The CDNU as installed in the EA-6B Block 89A aircraft satisfies the FAA requirements of a flight management system (FMS). The CDNU also partially satisfies GPS certification requirements for both the FAA and DOD.

The requirement necessary to certify and utilize GPS as a primary navigation source to operate in the NAS not including approaches are RAIM or RAIM equivalent. The CDNU has a function known as EHE that uses an algorithm that was shown to be accurate enough to satisfy this requirement as long as it was used in the blended mode of operation.

GPS accuracy was excellent and pilot displays were easy to read and follow. The capability to execute non-precision approaches were demonstrated in the testing and with the addition of RAIM, an unalterable loadable approach, and an alert within the pilot's primary field of view will allow GPS non-precision approach certification. RAIM capability is available with the GEM IV receivers. An unalterable approach is available with the addition of more memory in the CDNU. An alert is available by physically mounting a new warning light or by activating something on the EFIS displays.

PREFACE

A portion of the information contained within this thesis was obtained from Department of Defense test reports, FAA documents, and product literature and magazine articles on the design features of the avionics systems from Rockwell Collins, Litton, and Northrup Grumman Corporation. The research, discussion, and conclusions presented are the opinion of the author and should not be construed as an official position or an endorsement of these products by the United States Navy or the University of Tennessee, Space Institute, Tullahoma, Tennessee.

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LIST OF ACRONYMS

ACLS	Automatic Carrier Landing System
ADC	Air Data Computer
ADF	Automatic Direction Finder
ADI	Attitude Director Indicator
ADL	Aircraft Datum Line
AECP	Auxiliary EFIS Control Panel
AFCS	Automatic Flight Control System
AIV	All in View
APV	Approach with Precision Vertical guidance
ASR	Approach Surveillance Radar
ATC	Air Traffic Control
ATM	Air Traffic Management
	Automated Teller Machine
ATRK	Along-Track Error
BC	Bus Controller
BDHI	Bearing/Distance/Heading Indicator
BIT	Built-In Test
CAINS	Carrier Aircraft Inertial Navigation System
CAT	Category
CEP	Circular Error Probable
CDNU	Control Display Navigation Unit
CMC	Central Mission Computer
	Commandant of the Marine Corps
CNO	Chief of Naval Operations
COTS	Commercial Off-The-Shelf
CPA	Closest Point of Approach
DA	Drift Angle
	Decision Altitude
DDS	Digital Data Set
DGPS	Differential GPS
DH	Decision Height
DME	Distance Measuring Equipment
DOD	Department Of Defense
DON	Department Of the Navy
DOP	Dilution Of Precision
DR	Dead Reckoning
DSDC	Digital Signal Data Converter
DTM	Data Transfer Module
DT	Developmental Test
DTK	Desired Track
EA	Electronic Attack
EADI	Electronic Attitude Director Indicator

ECM	Electronic Countermeasures
ECMO	Electronic Countermeasures Officer
ECP	EFIS Control Panel
	Engineering Change Proposal
EFIS	Electronic Flight Instrumentation System
EGI	Embedded GPS/INS
EHE	Estimated Horizontal Error
EHSI	Electronic Horizontal Situation Indicator
EIU	Electronic Interface Unit
EPE	Estimated Position Error
EPU	Estimate of Position Uncertainty
ETA	Estimated Time of Arrival
EW	Electronic Warfare
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FMS	Flight Management System
FOM	Figure Of Merit
GPS	Global Positioning System
HARM	High-speed Anti-Radiation Missile
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organization
ICAP	Improved Capability
ICLS	Instrument Carrier Landing System
ICU	Interface Control Unit
IFA	In-Flight Align
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
LAAS	Local Area Augmentation System
LNAV	Long-Range Navigation
LOC	Localizer
MAGR	Miniature Airborne GPS Receiver
MDL	Mission Data Loader
MH	Magnetic Heading
NAS	National Air Space
NATOPS	Naval Air Training and Operating Procedures Standardization
NAV	Navigation
NAVAID	Navigational Aid
NAWCAD	Naval Air Warfare Center Aircraft Division
NCP	Navigation Control Panel
NDB	Non Directional Beacon
NPA	Non-Precision Approach
NVM	Nonvolatile Memory

OBS	Onboard System
OFP	Operational Flight Program
OPEVAL	Operational Evaluation.
OPNAVINST	Office of the Chief of Naval Operations Instruction
OT	Operational Test
PA	Precision Approach
PAR	Precision Approach Radar
PCM	Pulse Code Modulation
PPS	Precise Positioning System
PTA	Planned Time of Arrival
PVT	Precise, Velocity, Time
RAIM	Receiver Autonomous Integrity Monitoring
RNAV	Area Navigation
RNP	Required Navigation Performance
RT	Remote Terminal
RTA	Required Time of Arrival
SA	Selective Availability
	Situational Awareness
SCADC	Standard Central Air Data Computer
SEAD	Suppression of Enemy Air Defenses
SEC	Second
SG	Signal Generator
SID	Standard Instrument Departure
STAR	Standard Arrival
TACAN	Tactical Air Navigation
TAE	Track Angle Error
TAS	True Airspeed
TEAMS	Tactical EA-6B Mission Planning System
TECHEVAL	Technical Evaluation
TH	True Heading
TOF	Time of Flight
TP	Turn Point
TTG	Time To Go
UHF	Ultra High Frequency
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USNTPS	United States Navy Test Pilot School
UTC	Universal Coordinated Time
VAQ	Tactical Electronic Warfare Squadron
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VOR	VHF Omnidirectional Range

VP	Vertical Profile
WAAS	Wide Area Augmentation System

CHAPTER 1: INTRODUCTION

OVERVIEW

Chapter one describes the EA-6B and identifies the author's contribution to the overall testing programs and identifies the problem. Chapter two is divided into sections that discuss navigation historical data, navigation system specifics, FAA and DOD certification process, and EA-6B navigation system description. If the reader is well versed in these areas he may elect to skip chapter two and continue on to chapter three. Chapter three discusses the methods used by the author to test the CDNU integration into the Block 89A EA-6B. Chapter four discusses the results of the CDNU integration and GPS navigation and approaches. Chapter five reveals the author's conclusions based on the information from the results in chapter five and Block 89A developmental testing results shown in appendix B. Chapter six discusses the author's recommendations for GPS integration and other CDNU options.

BACKGROUND

The EA-6B Prowler is a four-seat, twin engine, mid-mounted wing monoplane manufactured by Grumman Aerospace Corporation, Bethpage, Long Island, New York. The aircraft was designed for carrier operation and based on the A-6 Intruder airframe and is shown in Figure 1. The EA in the identifier delineates Electronic Attack, the number 6 delineates the number chosen sequentially by the United States Navy and the B signifies the second production version of the airframe. The EA-6B aircraft is a fully integrated electronic warfare weapon system that combines long range, all weather capabilities with an advanced electronic countermeasures system. The side-by-side cockpit arrangement allows for maximum visibility, efficiency, and comfort.

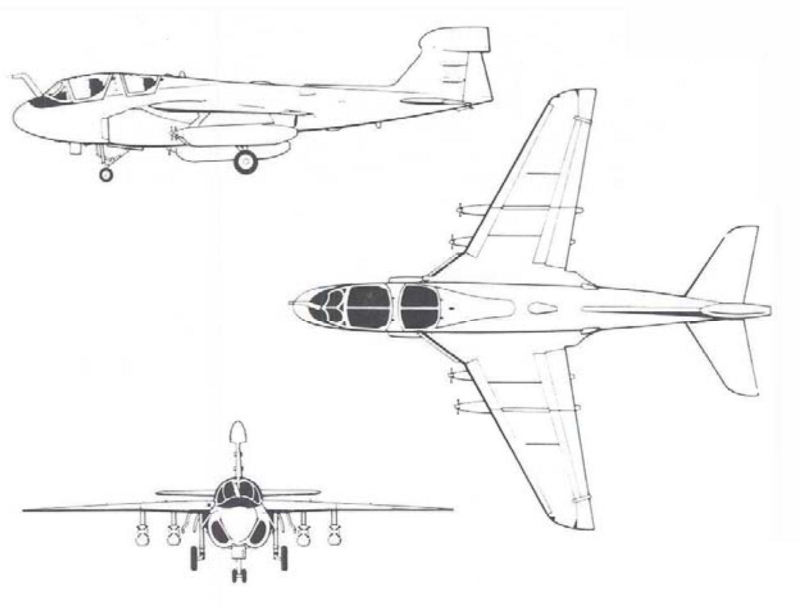


Figure 1: THREE VIEW OF EA-6B AIRCRAFT

Source: *EA-6B NATOPS Flight Manual*, NAVAIR 01-85ADC-1, Interim change No. 72, dated 15 July 1997.

This side-by-side arrangement has resulted in a Chief of Naval Operations (CNO) waiver to conduct dual piloted approaches even though only one pilot and only one set of controls are in the airplane. The dual piloted waiver allows for approaches down to a 100 ft decision height (DH) (*OPNAVINST 3710.7 series, NATOPS General Flight and Operating Instructions*, Department of the Navy (DON) Office of the CNO, January 97).

The EA-6B has evolved over the last 30 years, but due to funding, and wing structural failure, all versions are not the same. Improved capability II (ICAP II) is the current baseline aircraft being operated. Currently the Navy and Marine Corps have three configurations of ICAP II EA-6B aircraft being operated around the world, the Block 82, Block 89, and Block 89A. The Block 82 aircraft is the oldest version and is currently being converted to Block 89A aircraft. The Block 89A upgrade program was a major navigation and avionics improvement incorporating a CDNU and embedded GPS/INS (EGI).

CURRENT PROGRAMS

The purpose of the EA-6B ICAP II and ICAP III modification programs is to upgrade selected avionics employed aboard Navy and Marine Corps EA-6B Aircraft (Navy training system plan for the EA-6B Improved Capability modification II and III, March 2001). The EA-6B Prowler is currently undergoing a variety of enhancements to improve the overall capabilities of the navigation system. There are several phases currently in progress including ICAP II Block 82 improvements, ICAP II Block 89 upgrades, ICAP II Block 89A upgrades, 2nd EGI, and ICAP III. The author is working on all of the current programs and has tested the Block 89A software version 1.0 and 1.1 during operational test and developmental test over the past four years. The author has specifically worked on the navigation system and integration of the CDNU.

EA-6B MISSION

The general mission of the EA-6B Prowler is to operate from aircraft carriers and airfields ashore providing carrier-based and forward-deployed Electronic Attack (EA) operations, day and night, under all weather conditions. Its primary mission is the interception, analysis, identification, and jamming of enemy weapons control and communications systems in support of joint offensive and defensive operations. High priority missions include Suppression of Enemy Air Defenses (SEAD) by denying, delaying, or degrading the enemy's ability to detect and target friendly forces. The EA-6B has a long mission radius or loiter time, large payload, and a crew consisting of one

Pilot and three Electronic Counter Measures Officers (ECMOs). The EA-6B has a five-station capability for electronic counter-measures (ECM) pods, fuel tanks, and chaff pods, and High-speed Anti-Radiation Missiles (HARM).

STATEMENT OF THE PROBLEM

The EA-6B is the sole aircraft used for tactical electronic warfare (EW) support around the world supporting all branches of the US military and its allies. The EA-6B is operated from aircraft carriers and foreign air bases. An accurate navigation source is required while operating in and around hostile countries. Accurate target location and weapon employment are necessary for mission accomplishment. Navigating in the National Air Space (NAS) is equally important due to the high volume of aircraft utilizing the airways. The EA-6B is required to use the tactical air navigation (TACAN) as the primary navigation source while operating in the NAS with the INS and GPS as a supplemental navigation source. The INS and GPS configured aircraft are not currently certified by the federal aviation administration (FAA) or department of defense (DOD) for use as sole means of navigating in the NAS. During military operations the EA-6B uses the INS or INS/GPS (aircraft configuration dependent) as the primary navigation source. The GPS is used for updates to the INS and the TACAN is used for navigating in the vicinity of the aircraft carrier. *The NAS is undergoing a phase out of all the Very-high frequency omnidirectional range (VOR's) and other navigation sources and should rely solely on GPS as early as 2015* (Reingold, L. A., *New Approach*, Air and Space, February 2000). The EA-6B primarily uses military airfields as alternates during bad weather approaches (cloud layer < 3,000ft agl and visibility <3nm) because of servicing and security. The United States Air Force (USAF) has started retiring their precision approach radars (PAR's) and implementing instrument landing system (ILS) approaches. The US Navy uses PAR's as the primary precision approach at Naval Air Stations with no plans to implement ILS. The Navy uses automatic carrier landing system (ACLS) and instrument carrier landing system (ICLS) on the aircraft carriers and at most Naval Air Stations. ACLS and ICLS are single runway/single end precision approach types used for aircraft carrier operations. This leaves the EA-6B with few alternates during inclement weather. The CDNU integration (program upgrade to 89A) allowed the EA-6B to execute category I (CAT I) ILS, and localizer (LOC) approaches, and VOR navigation. With the addition of the CDNU and EGI there has also been a request to conduct GPS navigation in the NAS including approaches with the GPS being the primary navigation source. It is the authors opinion that most of the requirements to conduct GPS operations including navigation and approaches are in place and available to the EA-6B aircrew. The CDNU functions similar to a FMS and the goal of this thesis is to evaluate the CDNU as an FMS and review the requirements of navigating with GPS and recommend a course of action to accomplish the goals of utilizing GPS as a primary navigation source and allowing aircrew to conduct GPS non-precision (NPA) and precision approaches (PA).

CHAPTER 2: REVIEW OF THE LITERATURE

EVOLUTION OF AIRCRAFT NAVIGATION

Aircraft navigation has evolved as rapidly as the aircraft that utilizes them. Early days required simple instruments for day Visual Flight Rules (VFR) operations only. As pilots began flying at night and during instrument conditions navigation and flight instruments improved to allow for a safe departure and recovery.

NAVIGATION PRINCIPLES

Navigation is the process of determining the position, velocity, and orientation of a vehicle with respect to a specified reference position and in a specific coordinate system. The reference position and coordinate system may be fixed in inertial space, fixed with respect to the earth, or fixed with respect to moving reference, such as another vehicle. Airborne navigation is typically presented in terms of latitude, longitude, and altitude (in spherical coordinates). The usual attitude reference directions are north, east, and local vertical (Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996, page 1.1.1).

DEDUCED RECKONING (DR) NAVIGATION

Deduced reckoning (DR) is a navigation mode that requires an initial position and accurate course and speed to determine fixes. Accurate timing is required to determine the fixes. DR always shows where the aircraft has been, but never exactly where it is at an instant in time, primarily due to time required to plot the fix. DR is most accurate during short distances. Timing and speed errors decrease the accuracy of the position over time unless known position updates are utilized.

POSITION FIXING

Position fixing navigation systems determine position as the intersection of two or more lines. Polar coordinate (TACAN), triangulation (NDB/ADF), trilateration (DME), and hyperbolic (LORAN/OMEGA) are examples of position fixing navigation systems.

VISUAL NAVIGATION

Visual navigation is very accurate and depends on the accuracy of the charts used. Visual navigation is difficult at night and impossible during instrument conditions.

CELESTIAL NAVIGATION

Celestial navigation is primarily a ship navigation source and was used for hundreds of years to navigate the globe. Airplane use of celestial navigation has been phased out with addition of newer more accurate navigation sources including OMEGA, LORAN, INS, and GPS.

INSTRUMENT NAVIGATION

Instrument navigation utilizes the instruments on the aircraft to navigate from takeoff to landing. There are many types of navigation equipment that can be used and there are many more ways to display the information to the pilot. Some of the ground based navigation sources, the space based navigation source, inertial navigation source and some hybrid navigation sources used in the Block 89A EA-6B aircraft are discussed in later chapters.

GROUND BASED NAVIGATION

The sources of ground based navigation include NDB/ADF, DME, VOR, TACAN, ILS, LOC, and older systems including A in Range, Omega, and Loran. Some of these are long range airways navigation sources and others are short range approach sources. Some are used for both long range navigation and short range approach sources although not used for precision approaches.

Nondirectional Radio Beacon (NDB)

Nondirectional Radio Beacon (NDB) used in conjunction with the automatic direction finder (ADF) determines the bearing from the aircraft to the transmitting station. Limitations include no ranging information displayed to the operator and only relative bearing.

Distance measuring equipment (DME)

Distance measuring equipment (DME) operates by interrogating ground stations and receiving reply pulses back. The time delay between the sent signal and the received reply is converted into nautical miles. DME operates in the ultra high frequency (UHF) spectrum from 962 to 1213 MHz. DME errors include line of sight error. DME may or may not correct for slant range. This error is smallest at low altitude and long range and greatest when over the ground facility. DME is used in conjunction with other navigation sources including VOR, ILS, NDB, and LOC.

Very-high frequency omnidirectional range (VOR)

Very-high frequency omnidirectional range (VOR) is the primary navigational aid (NAVAID) used by civil aviation in the National Airspace System (NAS)(Federal Aviation Administration, *Instrument Flying Handbook, FAA-H-8083-15*, U.S. Department of Transportation, 2001, page 7-8). The VOR ground station is oriented to magnetic north and transmits azimuth information to the aircraft. The aircraft uses a horizontal situation indicator (HSI) as shown in Figure 2 to display TO/FROM radial information to the operator.

Tactical air navigation (TACAN)

TACAN operates similarly to VOR/DME stations and is better suited to shipboard operations. TACAN was developed primarily for shipboard use. TACAN limitations are the same as VOR and DME.

Instrument Landing System (ILS)

Instrument Landing System (ILS) is a short-range precision navigation approach that allows for 0/0 approaches (ceiling in ft/ visibility in statute miles), if the airport, aircraft, and pilot are certified to conduct such an approach. The majority of the

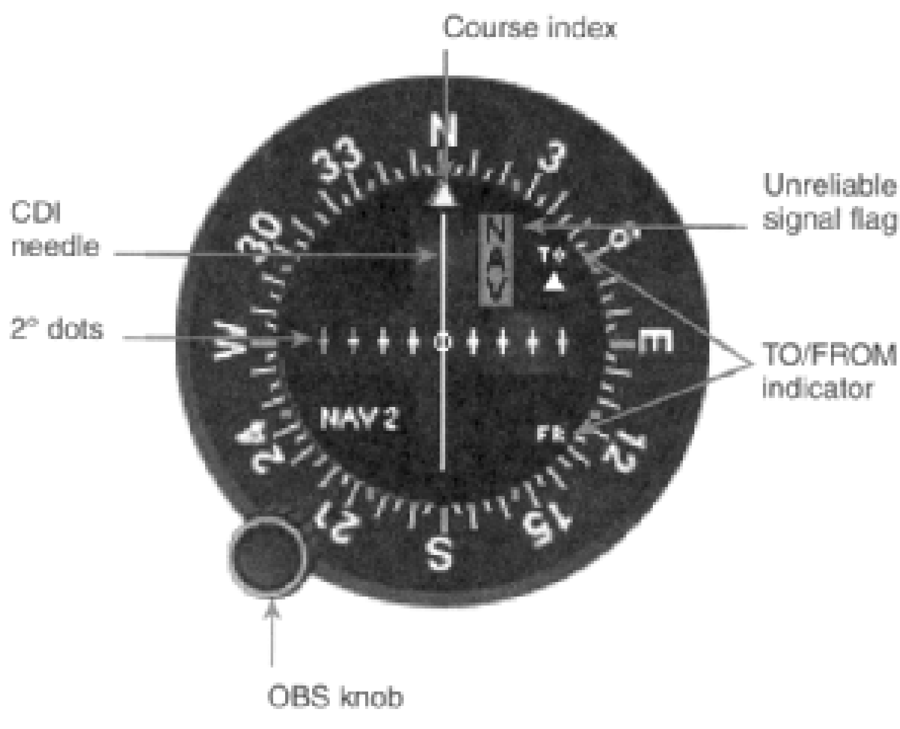


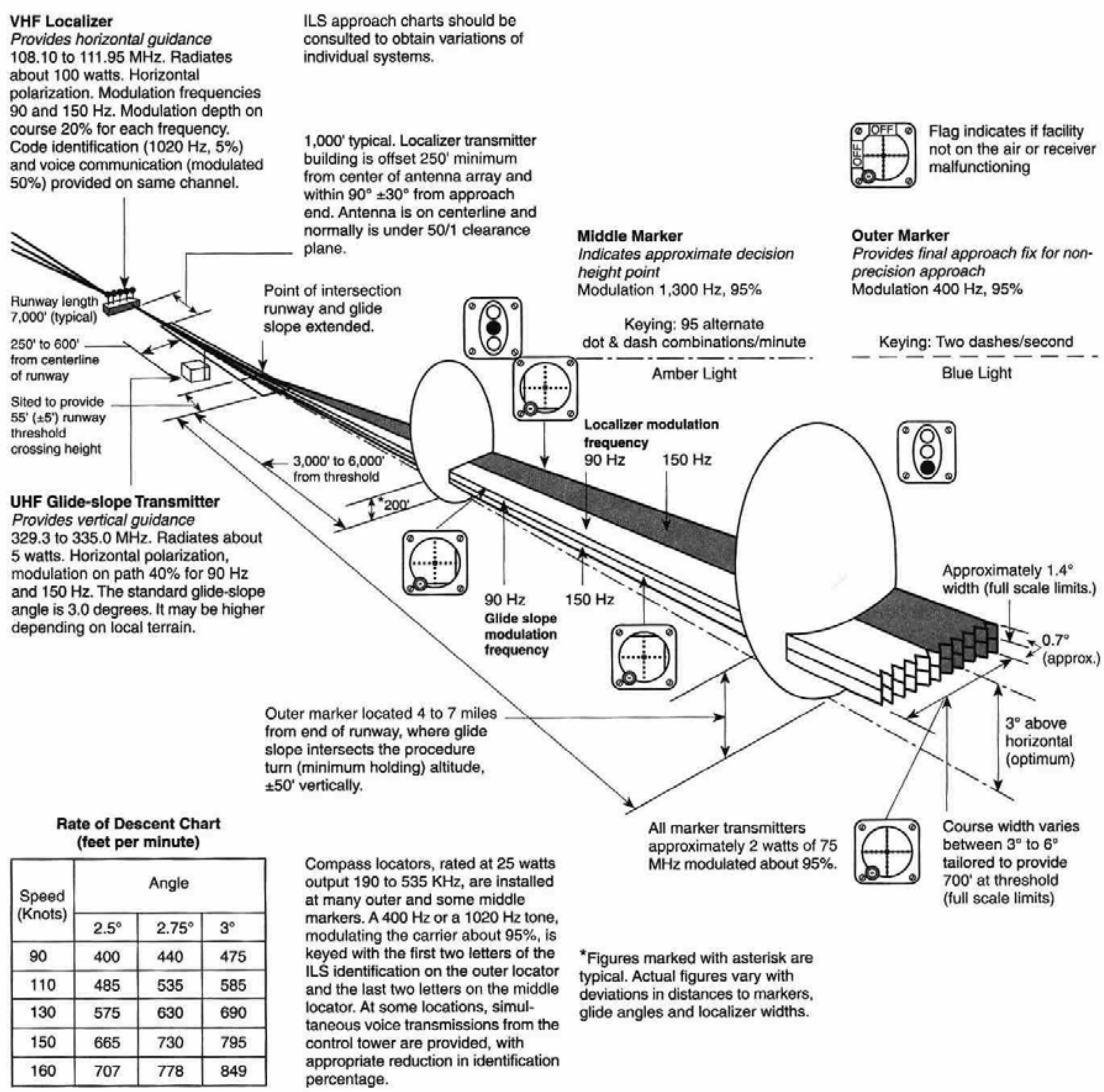
Figure 2: TYPICAL HORIZONTAL SITUATION INDICATOR

Source: Federal Aviation Administration, *Instrument Flying Handbook (FAA-H-8083-15)*, U.S. Department of Transportation, 2001.

approaches in the US are category I certified. *A category I approach has a decision height of 200 feet and 2600 feet visibility, a category II approach has a decision height of 100 feet and 1200 feet visibility, a category IIIA approach has a decision height of 50 feet and 700 feet visibility, category IIIB has a decision height of 35 feet and 150 feet visibility and category IIIC has no decision height* (Reingold, L. A., *Define Precise*, Air and Space, February 2000). ILS utilizes two fixed radio beams to guide an aircraft to a landing. The localizer provides lateral guidance and is displayed to the pilot as a vertical needle on cockpit display such as an attitude direction indicator (ADI). The glideslope transmitter provides vertical guidance to the end of the runway and is displayed as a horizontal needle on an ADI. The outer markers provide the FAF for NPA's. The middle markers indicate decision height (DH). The limitations of ILS approaches include cost at approximately $1 million per installation and that only supplies one end of a single runway. Another limitation is that ILS only accommodates straight in approaches. In some instances curved approaches may save time. A typical ILS approach is shown in Figure 3. A typical ILS aircraft display is shown in Figure 4.

INERTIAL NAVIGATION

Inertial navigation is a deduced reckoning technique that senses vehicle acceleration over time and integrates to determine velocity, and with a second integration can determine position. Problems associated with an INS include: INS cannot measure accelerations due to gravity, centrifugal and coriolis affects are inherent in the solution and must be subtracted out. INS components include a linear accelerometer (transducer that senses linear acceleration), gyroscope (transducer that measures rotational motion of



Speed (Knots)	Angle		
	2.5°	2.75°	3°
90	400	440	475
110	485	535	585
130	575	630	690
150	665	730	795
160	707	778	849

Figure 3: INSTRUMENT LANDING SYSTEM (ILS) DIAGRAM

Source: Federal Aviation Administration, *Instrument Flying Handbook (FAA-H-8083-15)*, U.S. Department of Transportation, 2001.

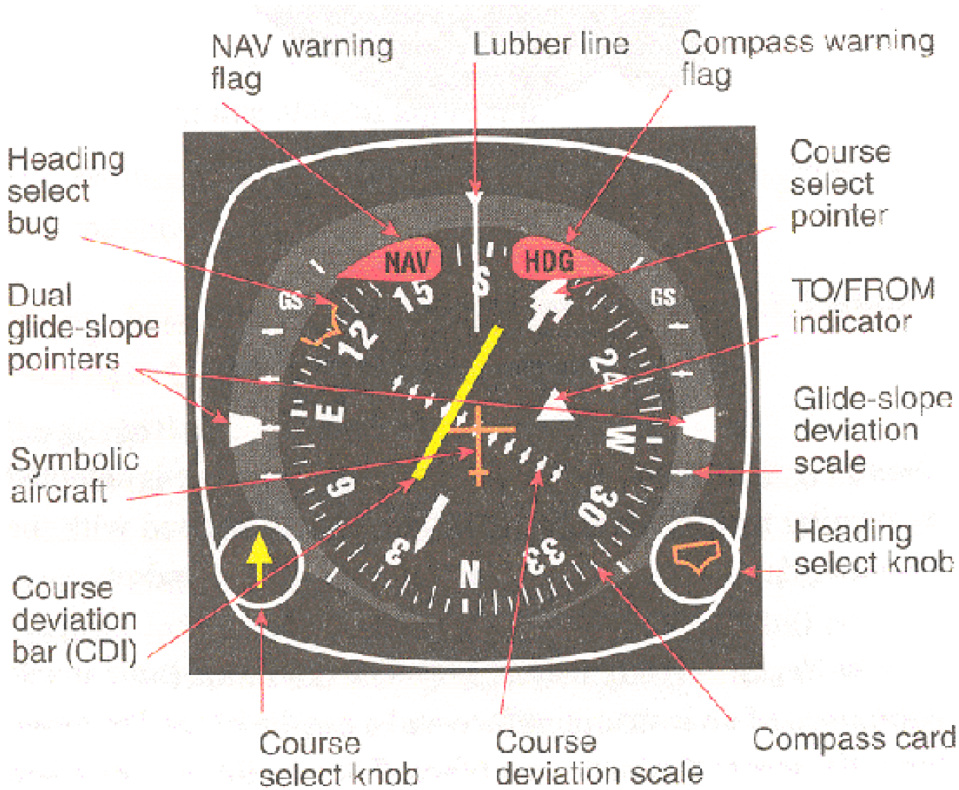
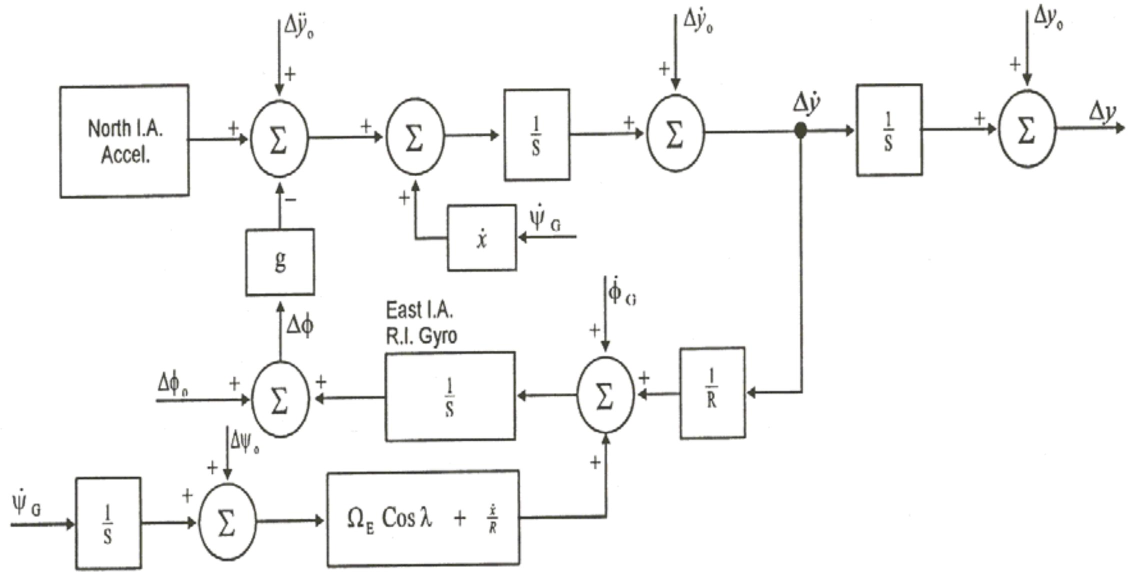


Figure 4: TYPICAL ILS DISPLAY

Source: Federal Aviation Administration, *Instrument Flying Handbook (FAA-H-8083-15)*, U.S. Department of Transportation, 2001.

its case, about the input axis, with respect to inertial space), and the stable platform (physical member with orientation controlled with respect to inertial space). Three types of INS' are employed: analytic, semi-analytic and the strapdown INS. The strapdown INS is used in aviation because it is smaller and lighter. Certain limitations are inherent when sacrificing size. The strapdown INS must be oriented to some type of reference, which must be converted to latitude, longitude, and altitude. Accuracy is also sacrificed due to real time coordinate transformation, and computed gravitational components required in all axes. INS error sources for a single channel are shown in Figure 5. The largest error source is from azimuth gyro drift rate and is shown in Figure 6. Another



g = Gravitational Acceleration

R = Earth Radius

$\dot{x}$ = East Velocity

$\dot{\phi}_G$ = East I.A. Gyro Drift Rate

Δy = Error in Computed North Position

$\Delta\dot{y}$ = Error in Computed North Velocity

Δy_o = Error in Initial North Position

$\Delta\dot{y}_o$ = Error in Initial North Velocity

$\dot{\psi}_G$ = Azimuth Gyro Drift Rate

λ = Latitude

Ω_E = Earth Spin Rate

$\Delta\ddot{y}_o$ = Error in Initial North Acceleration

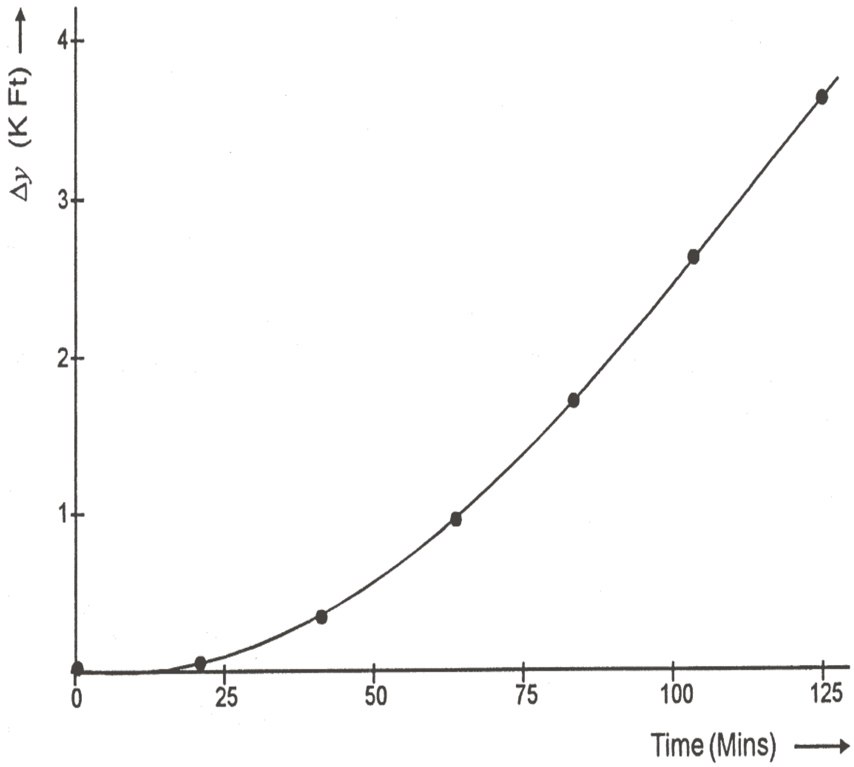
$\Delta\phi$ = Error in Platform Angle about East-West Axis

$\Delta\phi_o$ = Error in Initial ϕ

$\Delta\psi_o$ = Error in Initial Platform Azimuth

Figure 5: ERROR MODEL FOR N/S CHANNEL OF SEMI-ANALYTIC INS

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.



$$\Delta y = R\Omega_E \cos(\lambda)\ \left\{(1/2)t^2 - \left(1/\omega_S^2\, t\right)\ \left[1-\cos(\omega_S t)\right]\right\}\ \dot{\psi}_G$$

$$R = 2.1 \times 10^{7}\ (\text{Ft})$$

$$\Omega_E = 7.3 \times 10^{-5}\ (\text{Rad/Sec})$$

$$\cos(\lambda) = 0.9$$

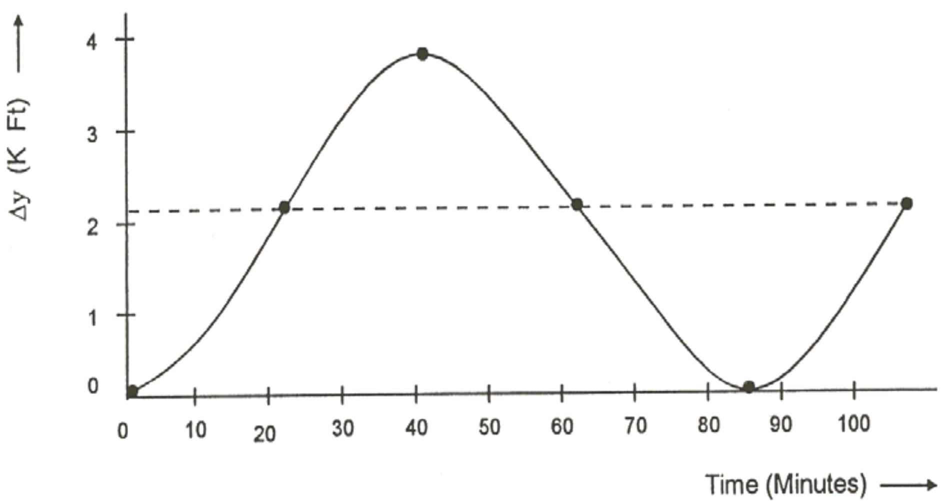
$$\omega_S = 1.25 \times 10^{-3}\ (\text{Rad/Sec})$$

$$\dot{\psi}_G = 9.7 \times 10^{-8}\ (\text{Rad/Sec})$$

Figure 6: AZIMUTH GYRO DRIFT ERROR

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

interesting error source that is inherent in all INS's is the Schuler cycle. The Schuler cycle is an 84.4 minute period caused by local vertical tracker orientation to compensate for platform misalignment and is shown in Figure 7. The second largest error source is accelerometer errors because they get integrated twice as shown in Figure 8. All of the error sources add up and have been as large as 1-2 nm per hour. INS initialization and alignment is required prior to operation and is done by comparing system parameters and known references.



$$\Delta y = R\left[1 - \cos(\omega_s t)\right](\Delta\phi_o) \quad \text{(Feet)}$$

$$R = 2.1 \times 10^{7} \quad \text{(Ft)}$$

$$\omega_s = 1.25 \times 10^{-3} \quad \text{(Rad / Sec)}$$

$$\Delta\phi_o = 1.0 \times 10^{-4} \quad \text{(Rad)}$$

Figure 7: INS SCHULER CYCLE AS A RESULT OF N/S POSITION ERROR DUE TO E/W PLATFORM TILT

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

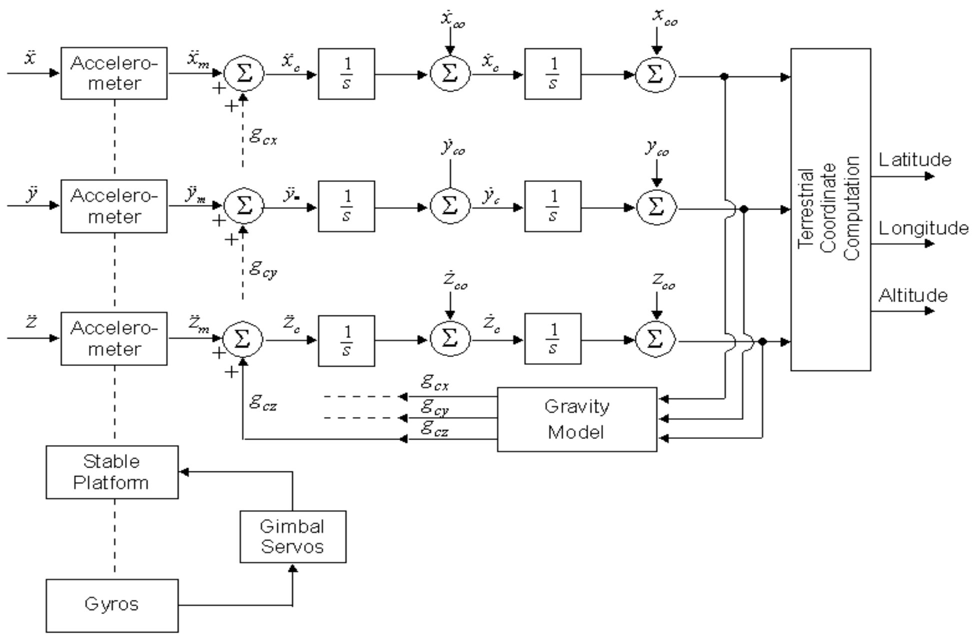


Figure 8: COMPUTATIONAL DIAGRAM FOR UNDAMPED STRAPDOWN INS

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

GPS NAVIGATION

GPS is a space based navigation system that utilizes satellites to provide position and velocity in three dimensions to operators. The GPS satellite system consists of 24 satellites (designed to provide 5 satellites in view to be used to navigate from on any point on earth), a control segment (ground tracking stations), and the user. Each satellite transmits, ephemeris data, time of transmission, signal propagation information, satellite operational status, acquisition information on other satellites, and special messages. The user uses this information to correct for timing errors, pick acceptable

satellites for use, and determine accurate time. The user uses four equations (with information from four satellites) as shown in Figure 9 to determine x,y,z, and t.

$$R_1 = \left[(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2\right]^{1/2} = C\left(t_{R^1} - t_{t^1} + \Delta t\right)$$

$$R_2 = \left[(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2\right]^{1/2} = C\left(t_{R^2} - t_{t^2} + \Delta t\right)$$

$$R_3 = \left[(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2\right]^{1/2} = C\left(t_{R^3} - t_{T^3} + \Delta t\right)$$

$$R_4 = \left[(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2\right]^{1/2} = C\left(t_{R^4} - t_{t^4} + \Delta t\right)$$

Figure 9: PSEUDO RANGE EQUATIONS USED TO DETERMINE GPS LOCATION AND ELEVATION

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

These four unknowns are converted to latitude, longitude, elevation and time is left as time. The satellites transmit on two frequencies 1227.60 Mhz (L2) and 1575.42 Mhz (L1) and each signal has spread spectrum pulse code modulation (PCM) attached. Coarse/ acquisition (C/A) code is at 1.023 MHz on L1 and Precision (P) code is 10.23 MHz on L1 and L2. The signal strength for L1 C/A is –160 dB, L1 P is-163 dB, and L2 P is –166 dB. Currently the civilian market cannot receive the P code because it has been encrypted by the DOD. This second frequency has corrections for refractive error. Continuous receivers have four or more hardware channels, allow for four satellites tracking and use the fifth channel to read navigation messages of the next satellite to be selected. GPS ranging errors include propagation delays, multipath effects, satellite ephemeris and timing, and user equipment errors. The actual error budget is shown in Table 1 and Table 2 and it shows an error of 18 meters horizontally and 23 meters vertically with C/A code. P code errors are considerably less as shown in Table 2.

Table 1: C/A SPHERICAL ERRORS

Error Sources (NO SA, NO Differential) Typical C/A Code Spherical Errors with Geometric Dilution of Precision (GDOP)		
-	Pos (M)	Vel (M/S)
Vertical	18	0.1
Horizontal	23	1.2

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

Table 2: GPS ERROR SOURCE

Error Sources (NO SA, NO Differential)		
Error Source	Typical RMS Errors (M)	
-	C/A Code	P Code
Propagation Delays	7	0.6
Multipath effects	3	1.2
SAT Ephemeris and Time	4	4.0
User Equipment errors	3	0.3
RSS Total	9	4.3

Source: Masters, G. Dr., *Navigation Systems Test and Evaluation*, USNTPS class notes, 31 July 1996.

Problems associated with GPS receivers are accuracy, integrity, and availability. Accuracy is required to conduct precision approaches in the NAS. Integrity is required to monitor the system during navigation and approach operations. Availability is required for all users in the NAS and other operators (agricultural, shipping, etc.).

AUGMENTATION SYSTEMS

Differential GPS uses a local ground segment that transmits corrections to the local user. It assumes that the user is using the same satellites as the ground site. This augmentation system could be used for zero/zero approaches with accuracy on the order of a few meters.

The FAA is developing the WAAS and the Local Area Augmentation System (LAAS). The WAAS will cover the Continental U.S. and provide a navigation signal capable of supporting navigation from enroute through Category I precision approach. LAAS will cover approximately a 30-mile radius and will provide up to a Category III precision approach. WAAS and LAAS will work together to provide users a navigation capability for all phases of flight (Federal Aviation Administration Website, *Wide area augmentation system (WAAS),* Independent Review Board (IRB) tasked by the Federal Aviation Administration, 2001). WAAS uses a system of ground stations to provide necessary augmentations to the GPS secure precision signal (SPS) navigation signal. A network of precisely surveyed ground reference stations are strategically positioned across the country including Alaska, Hawaii, and Puerto Rico to collect GPS satellite data. Using this information, a message is developed to correct any signal errors. These correction messages are then broadcast through communication satellites to receivers onboard aircraft using the same frequency as GPS. The WAAS is designed to provide the additional accuracy, availability, and integrity necessary to enable users to rely on GPS for all phases of flight, from en route through GPS approach for all qualified airports within the WAAS coverage area as shown in Figure 10. This will provide a capability for the development of more standardized precision approaches, missed approaches, and departure guidance for approximately 4,100 ends of runways and hundreds of heliport/helipads in the NAS. WAAS will also provide the capability for increased accuracy in position reporting, allowing for more uniform and high-quality worldwide Air Traffic Management (ATM).

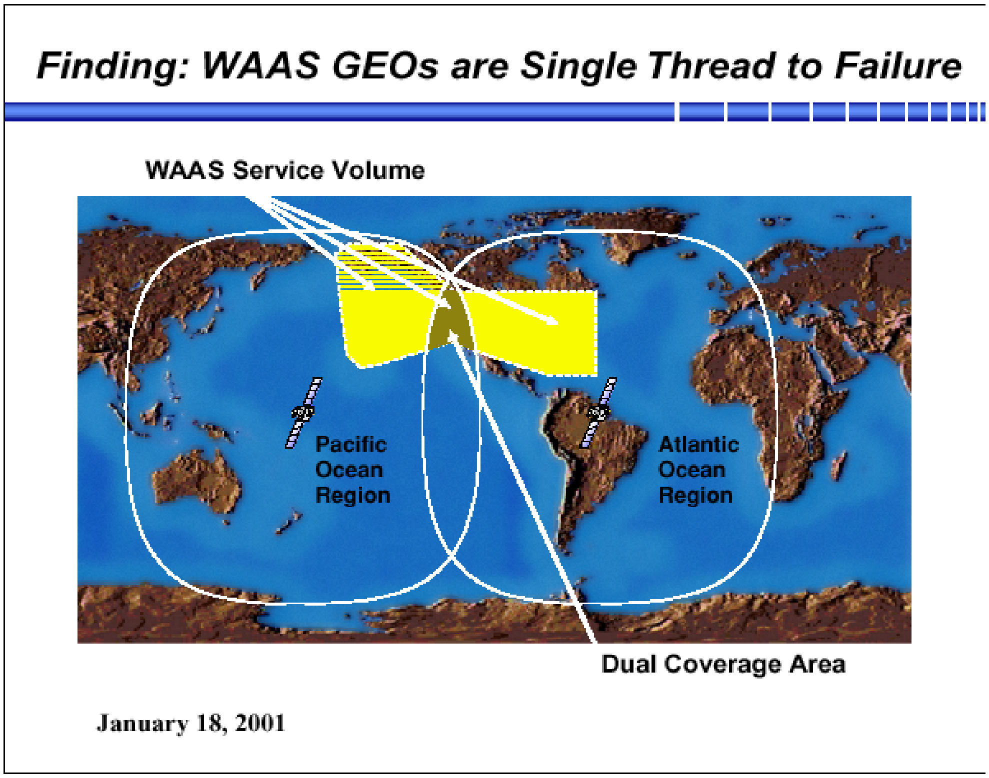


Figure 10: WIDE AREA AUGMENTATION SYSTEM SERVICE COVERAGE

Source: Federal Aviation Administration Website, *Wide Area Augmentation System (WAAS),* Independent Review Board (IRB) tasked by the Federal Aviation Administration, 2001.

The benefits of WAAS to the user include replacement of VOR, DME, NDB, and most Category 1 ILS receivers with a single WAAS receiver, and improved safety when operating in reduced weather conditions due to precision vertical guidance. Other WAAS benefits include providing an inexpensive, Instrument Flight Rules (IFR) area navigation system, with global coverage, leading to greater runway availability, reduced separation, more direct en route paths, new precision approach services, and reduced disruptions (delays, or diversions). WAAS current coverage is shown in Figure 10 and two more satellites are being launched in 2002 to maintain system availability. WAAS approach accuracy estimates are shown in Table 3. Full operational capability will be

Table 3: TESTED AND VERIFIED WAAS CAPABILITY

WAAS Capability 95% of the time over 50% of CONUS	VPL (Vertical protection limit)	HAT (Height above Touchdown)	Visibility (Statute Mile)
LNAV/VNAV	50	400	1
APV	30	300	1
GLS (GPS Landing System)	12	200?	?

Source: Federal Aviation Administration Website, *Wide area augmentation system (WAAS),* Independent Review Board (IRB) tasked by the Federal Aviation Administration, 2001.

available in March of 2003 (Federal Aviation Administration Website, *Wide area augmentation system (WAAS),* Independent Review Board (IRB) tasked by the Federal Aviation Administration, 2001) although this date may get pushed out to 2010.

<u>HYBRID SYSTEMS</u>

Two types of hybrid systems have been utilized in the NAS that combine both GPS and INS. A coupled system can be either manual or automatic. A manually coupled system is known as a loosely coupled system. A loosely coupled system uses manual GPS inputs to correct an INS. It gives the INS position, velocity, and time (PVT) to correct the system. A manual system is less accurate because it requires an operator to input corrections directly into the INS. An automatically coupled system is known as a tightly coupled system. Automatic systems allow the operator to concentrate attention elsewhere. A tightly coupled system uses a Kalman filter to develop a separate solution. This type of system thus has three solutions, an INS, a GPS, and a blended solution. The Kalman filter produces an accurate solution, but relies on good raw rate inputs to be precise.

Kalman Filter

The Kalman filter is a digital filter with time varying gains. It provides a simple algorithm to predict linear systems. It is a real time adaptive predictor/corrector. Integrating the GPS, INS and Kalman filter as shown in Figure 11 allows for a more precise solution. The INS supplies noiseless outputs that drift over time to the Kalman filter while GPS provides very noisy outputs. The Kalman filter takes advantage of the two different error sources and determines a "best" output.

FAA GPS OPERATIONAL REQUIREMENTS

To operate IFR with GPS you must have approved GPS equipment per TSO-C129, and installed per AC 20-138 or AC 20-130A, and you must be equipped with an approved and operational alternate means of navigation. Active monitoring of the

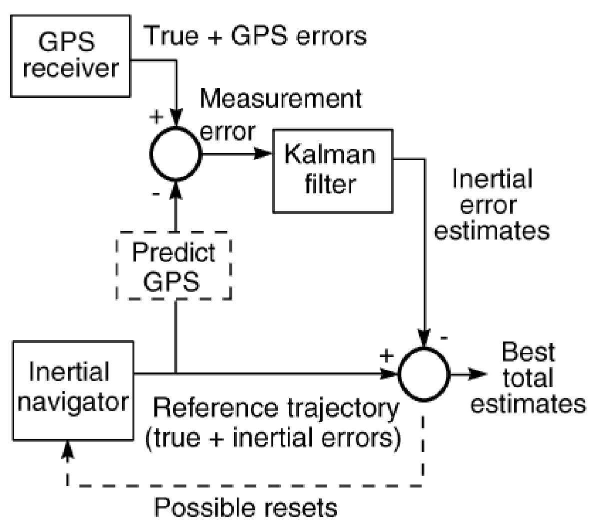


Figure 11: INS/GPS KALMAN FILTER DIAGRAM

Source: Levy, Larry, *The Kalman Filter: Navigation's Integration Workhouse*, John Hopkins University Applied Physics Laboratory.

alternate equipment is not required if the GPS receiver uses receiver autonomous integrity monitoring (RAIM). Active monitoring of the alternate means of navigation is required when the RAIM capability of the GPS equipment is lost (AC 90-94A, Guidelines for operators using Global Positioning System equipment for IFR enroute and terminal operations and for non-precision instrument approaches in the U. S. National Airspace system, page 4).

FAA GPS EQUIPMENT REQUIREMENTS

Equipment requirements are divided into three classes: A, B, and C. A addresses GPS stand alone equipment, B addresses GPS equipment that provides data to a FMS, and C addresses equipment that provides data to a FMS which provides enhanced guidance to a flight director or autopilot. Class B equipment best describes what is currently installed in the EA-6B Block 89A aircraft.

RECEIVER AUTONOMOUS INTEGRITY MONITORING (RAIM)

Integrity monitoring by the receiver is accomplished by comparing a single receiver sample of pseudorange measurements from the acquired satellites in view to determine whether a GPS satellite is out of tolerance. If the algorithm exceeds a predetermined threshold then it issues an integrity alarm. Traditional algorithms use Monte Carlo sampling or chi-square probability solutions to determine false alarm and missed detection rates (Pullen, S.P., Pervan, B.S., Parkinson, B.W., *A New Approach to GPS Integrity Monitoring Using Prior Probability Models and Optimal Threshold Search*, Dept of Aeronautics and Astronautics at Stanford University).

TSO C-129 RAIM REQUIREMENTS

RAIM is required for certification of GPS equipment. RAIM is any algorithm resident in the receiver that verifies the integrity of the position output using GPS measurements and barometric aiding. An algorithm which uses additional information (e.g.,multi-sensor system) to verify the integrity of the position output may be acceptable as a RAIM-equivalent. The RAIM function (and equivalent function) shall provide a worldwide availability of at least 95% given the optimal 21 GPS constellation (evaluated at a maximum resolution of 3 degrees in latitude, 180 nm in longitude, every 5 min). Barometric altitude aiding may be necessary to achieve this availability. The integrated navigation system with which the GPS sensor is interfaced must provide the RAIM function with terminal integrity performance as specified in Table 2-1 of RTCA/DO-208 within 30 nm of the departure and destination points. In addition, approach mode (class B1 equipment) integrity performance shall be provided from 2 nm prior to the final approach fix to the missed approach point. En route integrity performance shall be provided during other conditions. The equipment shall automatically select the RAIM integrity performance requirements applicable to the phase of flight. Equipment certified to class B1 shall provide a RAIM prediction function:

a. This function must automatically predict the availability of RAIM at the final approach fix and missed approach point of an active approach when 2 nm inbound to the final approach fix.

b. This function shall provide the pilot, upon request, a means to determine if RAIM will be available at the planned destination at the estimated time of arrival (ETA) (within at least +15 minutes computed and displayed in intervals of 5 minutes or less).

Once complete almanac data has been received, this capability shall be available at any time after the destination point and estimated time of arrival at that point are established. The availability of corrected barometric altitude (either by automatic or manual altimeter setting input) may be assumed for this purpose. (For the purposes of this calculation, an acceptable value of s baro is 50 meters). A means to manually identify a satellite that is expected to be unavailable (for scheduled maintenance as identified in an FAA Notice to Airmen) shall be provided. Identification of such a satellite for RAIM prediction purposes should not affect the satellite selection process or deselect that satellite from use in the navigation solution.

c. This function shall display, upon request, RAIM availability at the ETA and over an interval of at least +15 minutes computed in intervals of 5 minutes or less about the ETA.

The GPS equipment shall detect a pseudorange step error greater than 1000 meters, including steps which cause loss of lock for less than 10 seconds. A pseudorange step is defined to be a sudden change in the measured distance to a satellite. If a pseudorange step is detected for a satellite, that satellite shall be excluded from use in the navigation algorithm until its integrity can be verified through fault detection (RAIM). The manufacturer is free to choose any method to calculate the predicted pseudorange or to detect a step. However, any method used should properly take into account satellite movement and aircraft dynamics up to a groundspeed of 750 knots and accelerations up to 14.7 meters/second/second.

FAULT DETECTION AND EXCLUSION (FDE)

Some GPS receivers have the capability to isolate a corrupt satellite signal and remove it from the navigation solution. Fault detection and exclusion (FDE) requires six satellites in view or five if baro-aiding is used to isolate and continue to provide a valid navigation signal.

REQUIRED NAVIGATION PERFORMANCE (RNP) CONCEPT

Required Navigation Performance (RNP) for area navigation (RNAV) is an International Civil Aviation Organization (ICAO) concept to improve flexibility, and accuracy around the globe. Specific requirements are defined in Table 4. This RNP requirement is based on a containment value that requires the aircraft to remain inside a square 95% of the time of which twice the RNP value is ½ the length of the side. For example a RNP-4 RNAV requires the aircraft to remain inside a +/- 8 nm square.

Table 4: RNP BASED OPERATIONS

OPERATION	RNP TYPE	EXAMPLE APPLICATION
Oceanic/Remote	RNP – 20	Spacing between tracks/ATS Routes
Oceanic/Remote	RNP – 12.6	N. Atlantic FL285-420
Oceanic/Remote	RNP – 10	50 nm Separation
Oceanic/Remote	RNP – 4	30/30 nm Separation
Enroute Europe	RNP – 5	20 nm Separation
Enroute Domestic	RNP – 2 RNAV	8 nm Route Spacing
Terminal Area	RNP – 1 RNAV	4 nm Spacing
Approach	RNP – 0.3 RNAV	LNAV(NPA)
Approach	RNP – 0.3 RNAV	LNAV/VNAV (Approach Procedure with Vertical Guidance, APV)
Departure	RNP – 0.3 RNAV	LNAV

Source: *Functional Requirements Document for Required Navigation Performance Area Navigation*, Chief of Naval Operations (CNO), May 2002.

Requirements defined by RNP

Area navigation general requirements include the following: Accuracy, Integrity, Estimate of Position, Estimate of Position Error, Containment radius, and Flight path.

Specific requirements include: alerts to RNP accuracy must be in the Pilot's primary field of view. Navigation database requirements include: all airport reference points, VOR's, DME's, VORTAC'S, NDB's, all named fixes shown on charts and approach plates, all RNP RNAV procedures (routes, SID's, STAR's, approaches, holding patterns, etc.), and all airports accessible using ICAO nomenclature. Approach specific requirements include: auto sequencing of successive waypoints from approach initiation through the missed approach holding point (MAHP). The system will transition to a manual mode upon reaching the MAHP. The system will allow for a direct to the final approach fix (FAF) and begin auto-sequencing beyond that point. The aircraft shall supply an approach enable alert within 30 nm and no approach selected. This alert may be a text display on a CDNU type device. Approaching the final approach fix the RNP RNAV value shall maintain 1 until FAF becomes the active waypoint and automatically sequence to RNP 0.3 RNAV. RNP specific display requirements are shown in Table 5 and Table 6. GPS PPS Navigation system integrity requirements are shown in Table 7.

MILITARY REQUIREMENTS TO OPERATE GPS

OPNAVINST 3710.7 is the guidance document that the US Navy uses regarding aviation. It contains rules and guidance for aircraft operations. The OPNAVINST 3710.7 review conference of 15-19 Nov 1999 recognized and added GPS approaches to the list of nonprecision approaches. The restrictions imposed on the GPS use include:

Table 5: RNP DISPLAY REQUIREMENTS

Parameter	Resolution Display	Resolution entry
Numeric Cross- Track	0.1 nm to 9.9 nm, 1.0 nm to 20 nm	NA
Distance	0.1 nm≤ 9.9 nm, 1.0 nm ≥ 10.0 nm	0.1 nm≤ 9.9 nm, 1.0 nm ≥ 10.0 nm
Desired Track (DTK)	1 degree	1 degree
Track Angle Error (TAE)	1 degree	NA
Groundspeed	1 knot	NA
Fix Latitude/ Longitude	0.01 min	0.1 min
Bearing	1 degree	1 degree
Track Angle	1 degree	NA
RNP RNAV type	x.xx <10, xx.x ≥ 10	x.xx <10, xx.x ≥ 10
Present Position Display	0.1 min	0.1 min
Altitude	Flight level or 1 foot	Flight level or 1 foot
ETA	1 min	NA
RTA	0.1 min	0.1 min
Vertical speed	1 ft/min	1 ft/min
Airspeed	1 knot, 0.01 M	1 knot, 0.01 M
Vertical Path Deviation	10 feet	NA
Flight Path Angle	0.01 degree	0.01 degree
Temperature	1 degree	1 degree
EPU Display Resolution	0.01 nm	NA

Source: *Functional Requirements Document for Required Navigation Performance Area Navigation*, Chief of Naval Operations (CNO), May 2002.

Table 6: CONTROL DISPLAY RESPONSE TIMES FOR RNP PERFORMANCE

Function	Time Allowed
Access primary navigation information	2 sec
Direct –to any named waypoint in a published departure, Arrival, or approach procedure already in the active flight Plan	10 sec
Direct –to any named waypoint in a published departure, Arrival, or approach procedure not already in the active flight Plan	20 sec
Select a course to or from an active waypoint	10 sec
Select and activate an approach at the departure airport, which may be Pre-programmed as an alternate flight plan	10 sec
Select and activate an approach at an airport, given that the Airport is the active waypoint	13 sec
Runway change after an approach has been selected and activated	10 sec

Source: *Functional Requirements Document for Required Navigation Performance Area Navigation*, Chief of Naval Operations (CNO), May 2002.

Table 7: GPS PPS NAVIGATION SYSTEM INTEGRITY REQUIREMENTS

Integrity Parameter	PPS operation	
Enroute Navigation	Domestic Enroute	Oceanic Enroute
Time to alert	30 sec	1 min
Horizontal alert Limit	2 nm	4 nm
Detection availability	99.9%	99.9%
Exclusion Availability	97.0%	97.0%
Terminal Navigation		
Time to alert	10 sec	
Horizontal alert Limit	1 nm	
Detection availability	99.9%	
Exclusion Availability	97.0%	
Non-Precision Approach Navigation		
Time to alert	10 sec	
Horizontal alert Limit	0.3 nm	
Detection availability	99.9%	
Exclusion Availability	97.0%	
All Phases of Navigation		
Fault Detection Probability	99.9%	
Probability of Unalarmed Hazardously Misleading Information (UHMI) with Fault detection	1×10^{-7}	
Fault Exclusion Probability	99.9%	
False Alert	10^{-5} /flt hr	
Pseudorange Step Detector	Steps > 700 m	

Source: *Functional Requirements Document for Required Navigation Performance Area Navigation*, Chief of Naval Operations (CNO), May 2002.

Military receiver integrations : all approved military GPS receivers, when keyed and integrated with aircraft navigation systems, may be used for:

A. Primary means of navigation in military-controlled airspace and for military operations (e.g. weapons delivery and timing).

B. As an aid to visual navigation in civil controlled airspace.

C. Practice of GPS approaches in visual meteorological conditions (VMC), if the approach procedure is electronically loaded.

Integrity capable GPS integrations may be used as a primary or supplemental means navigation system for enroute, terminal, and GPS NPA operations only after approval by a CNO N78 fleet introduction letter. Integrity is the ability of a position, navigation, and timing (PNT) system to provide timely warnings to enable a user to determine when the system should not be used for PNT to support the mission or phase of operation. Non-US government GPS approaches not published in DAFIF must be approved in advance by the NAVAL flight information group (NAVFIG) using existing guidance and procedures. Approach procedures shall be loaded electronically. DoD flight information publications (FLIP) is still required in the cockpit and is considered the primary source of approach procedures.

Coupled systems: Navigation systems that can directly couple the GPS with the INS (i.e. EGI, etc.) are subject to the same restrictions as above when operated in the "blended" or "aided" mode.

CNO N78 approved receiver integrations : TSO-C129A/C145/C146 GPS receiver integrations may be used as a primary or supplemental means navigation system for enroute, terminal, and GPS NPA operations as specified by CNO N78 fleet introduction *approval letters. When approved for NPA, the integration may be used for any GPS-based NPA procedure listed in the DAFIF or Jeppesen navigation publications* (*GPS Policy for Naval Aviation message draft version*, CNO, 25 May 2002).

ILS RESULTS DURING INITIAL EFIS INTEGRATION

Due to the limited capability of the ILS ground test equipment, EFIS ILS ground evaluation was insufficient to establish satisfactory performance to the FAA's CAT I ILS approach minimum (200 ft AGL decision height and 1,800 ft runway visual range (RVR)). Therefore ILS dynamic performance was evaluated while flying simulated instrument approaches using the FAA's CAT II ILS approach minima (100 ft DH and 1,200 ft RVR). Criteria for success included achievement of indicated airspeed and heading satisfactory for normal flare and landing, and at the 100 ft DH, the cockpit was tracking to remain within the lateral confines of the runway extended. All 21 approaches were successful. EFIS ILS flight indications were satisfactory while flying FAA CAT II ILS manual approaches. Recommend EFIS ILS equipped EA-6B airplanes be cleared for FAA CAT I (200 ft DH and 1,800 ft RVR) ILS manual approaches at ILS equipped military and civilian fields (*Technical Evaluation of the Electronic Flight Instrument System, Global Positioning System, and Instrument Landing System as installed in the EA-6B Block 89 Airplane*, NAWCAD Patuxent River). EA-6B NATOPS manual currently restricts the aircraft to CAT I approaches (EA-6B NATOPS Manual).

EA-6B NAVIGATION SYSTEM DESCRIPTION

BLOCK 82

Primary navigation in the EA-6B has evolved from dead reckoning to doppler navigation to inertial navigation and finally to global position aided inertial navigation. The current fleet baseline aircraft (Block 82 and 89) use the carrier aircraft inertial navigation system (CAINS) to compute wind corrected steering inputs to the next waypoint as shown in Figure 12. The 30 waypoints are manually entered or loaded via the tactical computer load panel into the control display indicator (CDI) and are selected to give steering to the pilots electronic horizontal situation display (EHSI) and electronic attitude direction indicator (EADI). The points are limited to one decimal place (ie. N 34 30.1) and require waypoint selection upon waypoint passage. Advantages of this system include simplicity and ease of use, and the ability to select and receive steering to future and past waypoints. Disadvantages include accuracy of +/- 2 nm depending on the alignment time, and only 30 selectable waypoints. System degradation will increase the operator workload to a point of constant monitoring, dead reckoning backup, and multiple updates to the system. The navigation system is used for navigation and control of the weapon system and must be operational and accurate at all times. CAINS has a tendency to drift and over a 2 hour flight has been noted as being in error by 2-3 nm. The gyro drift dominates the system error and position only updates airborne are not recommended due to inputting more errors without fixing the drift problem (*EA-6B NATOPS Flight Manual,* NAVAIR 01-85ADC-1, January 2000). The error problem ultimately lies with INS gyroscopic drift over time.

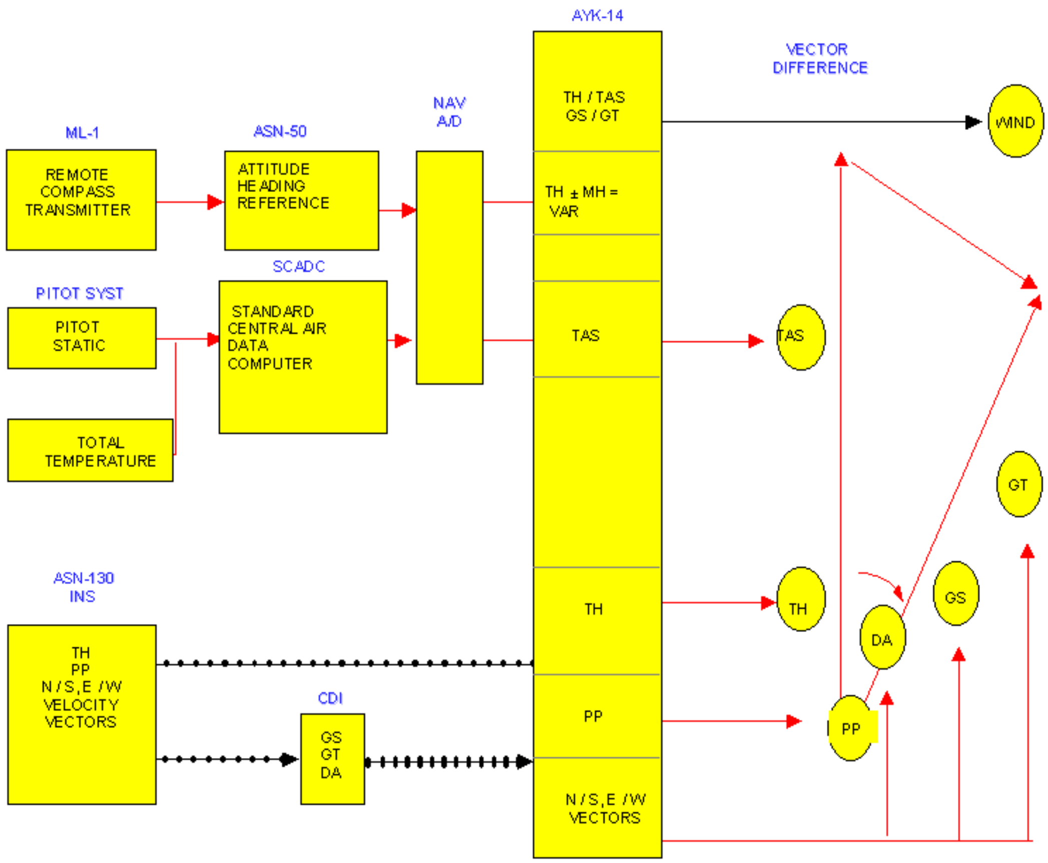


Figure 12: EA-6B BLOCK 82/89 NAVIGATION SYSTEM SCHEMATIC

Control Display Indicator (CDI)

The control display indicator (CDI), Figure 13, on the ECMO 1 instrument panel is an interactive command/display indicator with a five-line data display. Operator controls for the CDI consist of a PWRRESET switch, a brightness/test (BRTR) control, a rotary DISPLAY MODE selector, display pushbutton switches and a pushbutton keyboard. Communication with the navigation system is via a MIL STD 1553 data bus. The five-line display consists of eight alphanumeric characters per line. Each alphanumeric character consists of 16 red light segments, and the present character set includes 47 characters with provision for expansion to a maximum of 66 characters. If the data to be displayed in the selected display mode exceeds the available five lines, additional pages are formatted and can be called up by use of the PAGE pushbutton.

Figure 13: CONTROL DISPLAY INDICATOR

Standard Central Air Data Computer (SCADC)

The standard central air data computer (SCADC) accepts inputs from the pitot static system and the total temperature probe to compute true airspeed (TAS).

ASN-50 Automatic Heading Reference System (AHRS)

The ASN-50 automatic heading reference system (AHRS) receives inputs from the ML-1 compass and provides magnetic heading information to the symbol generator and the digital signal data converter (DSDC).

Compass Controller

Heading reference from the ASN-50 to the various navigation and heading displays is controlled by the compass controller on the center console (placarded COMP). The controller provides for selecting magnetic heading (COMP), roll-stabilized magnetic heading (SLAVE), and free-gyro/unslaved heading (FREE). Controls are also provided for synchronization, heading set, and correction for apparent precession. Heading reference power is from the essential bus. Heading information from the ASN-50 is displayed on the EADI and EHSI only when MAG/TRUE switch on the auxiliary EFIS control panel is in the MAG position.

ML-1 Gyrocompass

The ML-1 gyrocompass is the source for magnetic heading and is the input for the ASN-50. The ML-1 works similar to a wet compass and when operated in the free mode displays wet compass characteristics (lead, lag, reversal).

AN/AYK-14 Tactical Computer (TC)

The AN/AYK tactical computer is a 1980's era computer used primarily for navigation computations. The computer uses TAS inputs from the SCADC, MH from the ASN-50, TH, present position, N/S, E/W and vertical velocity vectors to compute winds and steering commands displayed on the horizontal situation indicator.

Carrier Aircraft Inertial Navigation System (CAINS)

The carrier aircraft navigation system is an inertial based stand-alone system that uses accelerometers mounted on three axes of a gyro-stabilized platform. The CAINS is the primary aircraft attitude reference and provides present position (in latitude and longitude format), true heading (TH), north, south, east, west and vertical velocity vectors. The accelerometers sense any change in aircraft acceleration and generate acceleration change signals. Synchros generate heading and attitude signals, as sensed by the accelerometers. All these signals are sent to the Tactical Computer and Control Display Indicator (CDI) where other navigational information is calculated. Attitude is also sent from the ASN-130 to the Digital Signal Data Converter (DSDC) for use by aircraft systems.

In order for the CAINS to provide navigation and attitude information, the platform must first be aligned. The alignment process may be conducted either on the ground or on a carrier deck and is controlled by means of the CDI. The CAINS requires 115 V Ac for normal operation. The system operates normally on the right AC bus with a 26 V dc backup supplied by the left DC bus. This backup allows the alignment and normal operation to be retained for up to 7 seconds in flight and 2 seconds on the ground in the event of a power transient or transfer. The system has a lithium battery that allows memory to be retained for more than 10 years.

CAINS Alignment

The orientation of the gyro-stabilized platform is maintained with respect to three mutually perpendicular axes, referred to as the X, Y, and Z axes, and it is along these axes that the accelerometers measure aircraft acceleration. The Z-axis is coincident with the local vertical and the direction toward the center of the earth is defined as positive. Alignment is the process whereby the platform is precisely leveled and the orientation of the X and Y axes with respect to the true north is determined. When ground- or carrier-based alignment is started, initially the gyros are brought up to speed, the platform is leveled, and it is optically slaved to the aircraft ADL. Following this, the orientation of the aircraft ADL with respect to true North is determined by comparing X and Y axis acceleration signals with known earth rotation rate effects. The angle thus determined, known as wander angle, is retained for all future calculations. Aircraft present position must be provided so that the proper earth rate is used. When a carrier-based alignment is conducted, carrier speed and heading must also be provided. The following alignment options are available: ground, stored heading, cv-cable, and cv-manual.

Analog to Digital Converter (A/D)

The analog to digital converter (A/D) is used to convert standard central air data computer (SCADC) and ASN-50 analog inputs to digital inputs for the computer. Inputs include true airspeed (TAS), total temperature, and magnetic heading (MH).

Electronic Flight Information System (EFIS)

The EFIS system consists of an electronic horizontal situation indicator (EHSI), electronic attitude direction indicator (EADI), digital signal data converter (DSDC), electronic interface unit (EIU), and EFIS 50 symbol generator. All of the systems are shown in Figure 14.

Electronic Horizontal Situation Indicator (EHSI)

The EHSI as shown in Figure 15 and Figure 16 is used to display navigation information in either a map mode or HSI mode. The options available in HSI mode include TACAN needle, VOR needle, ADF needle, FMS needle and ILS needle. The map mode offers an overview of the flight plan with some other waypoints displayable including TACAN stations.

Electronic Attitude Direction Indicator (EADI)

The Electronic Attitude Direction Indicator (EADI), shown in Figure 17, is used to display aircraft attitude in reference to the horizon. The EADI also has an electronic turn needle and ball as shown in Figure 17. The EADI is capable of displaying 3 sets of needles to the pilot routed through the EIU. The HARM, ACLS, and ICLS needles were chosen because of mission requirements and operations in the vicinity of the aircraft carrier. The ACLS, ICLS, and HARM needles are routed through a remote cockpit relay box, the EIU, the EFIS symbol generator and finally displayed on the EADI. The needles message also goes through a scaling amp in the EIU as shown in Figure 14. Needle deflection scaling for EHSI and EADI depiction is shown in Table 8. The ILS symbology is routed directly from the KNR-634A ILS receiver to the symbol generator via the ARINC 429 navigation bus as shown in Figure 14.

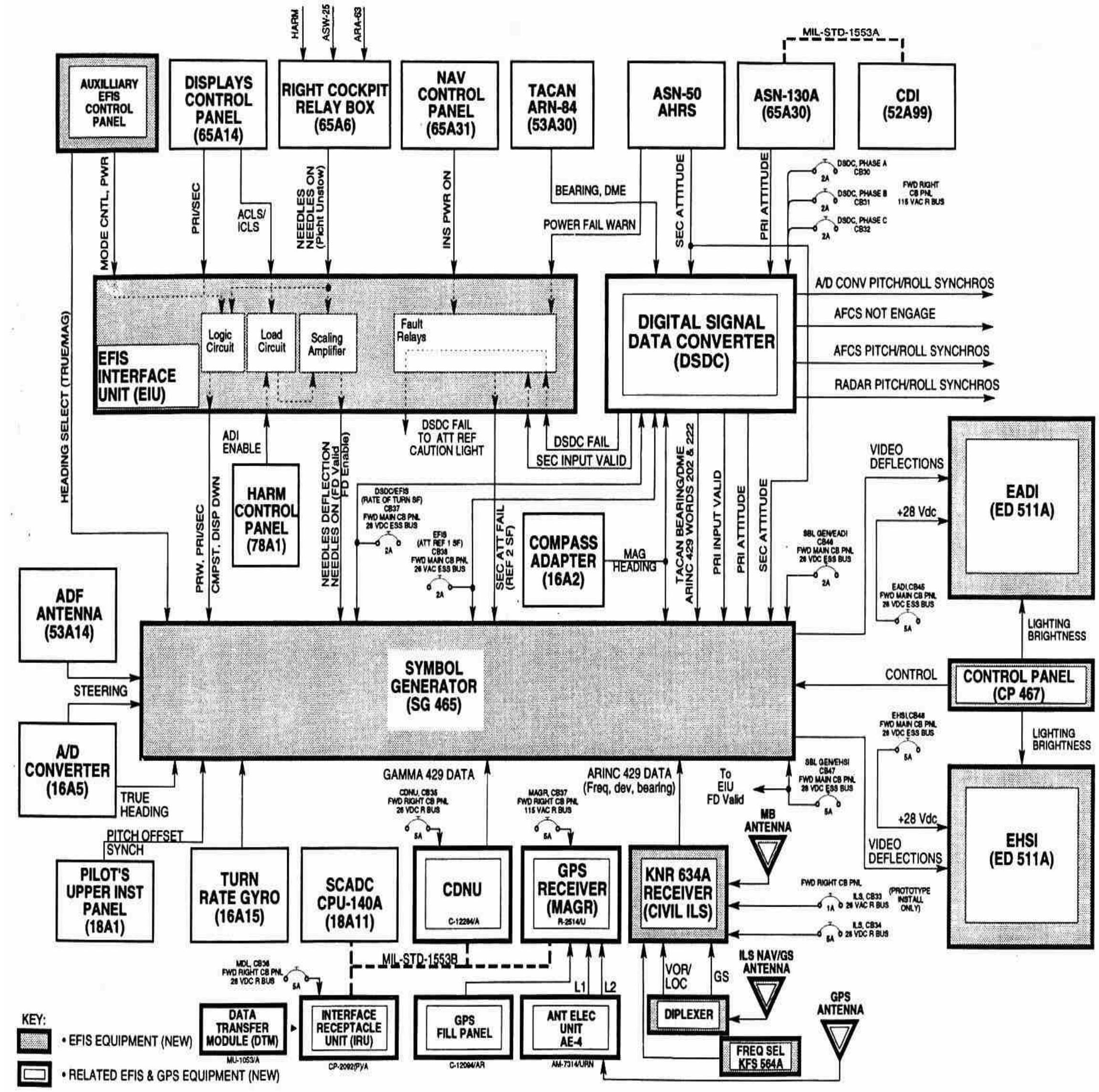


Figure 14: BLOCK 89A NAVIGATION DIAGRAM DEPICTING ILS NEEDLE SOURCES

Figure 15: HSI MODE OF EHSI IN BLOCK 89 AND 89A EA-6B

Figure 16: MAP MODE OF EHSI IN BLOCK 89 AND 89A AIRCRAFT

Figure 17: EADI BLOCK 89 AND 89A EA-6B

Table 8: NEEDLE DEFLECTION ON THE EHSI IN DIFFERENT NAVIGATION MODES

Needle	1 dot	2 dot
FMS1 (E)	2.0 nm	4.0 nm
FMS1 (T)	0.5 nm	1.0 nm
FMS1 (A)	0.15 nm	0.3 nm
ILS/LOC	2.5°	5.0°
TAC/VOR	5.0°	10.0°
ADF	7.5°	15.0°

EFIS Control Panel (ECP)

The EFIS control panel as shown in Figure 18, is used to select what is displayed on the EHSI and EADI. The course knob rotates the deviation pointer for flying approaches. The heading knob is used to rotate the heading select bug. The HSI button cycles the HSI mode and MAP mode. The ARC pushbutton displays a larger view on the EHSI of 85 degrees. The NAV pushbutton cycles through the four different modes:

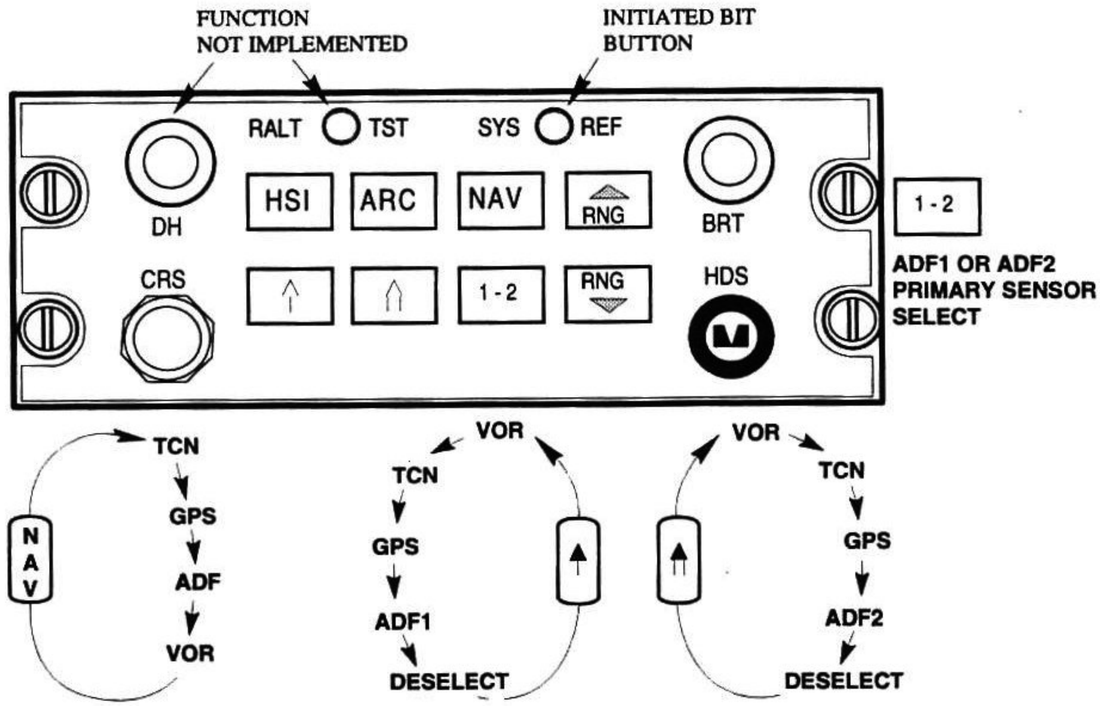


Figure 18: EFIS CONTROL PANEL

TCN, GPS, ADF, and VOR. The single needle pushbutton cycles through and displays VOR, TCN, GPS, ADF1, or deselect. The double pushbutton cycles through and displays VOR, TCN, GPS, ADF2, or deselect.

BLOCK 89 INTEGRATION ACCELERATED PHASE ADVANCED UPGRADE

The BLOCK 89 Advanced upgrade program added a CDNU and non-integrated GPS navigation to the EA-6B. The EA-6B ICAP II Block 89A Accelerated Phase program was known as the Accelerated Electronic Flight Instrument System (EFIS) program since the program upgraded the attitude and position referencing systems to proven digital technology on all Block 82 and Block 89 EA-6B Aircraft. All Block 82 and Block 89 aircraft have EFIS installed. Incorporation of these changes established the baseline for upgrading to Block 89A.

Control Display Navigation Unit (CDNU)

The CDNU was placed on the far right of the panel and had stand-alone capability only. Precise Latitude and Longitude information could be accessed via the CDNU, but the information was not integrated into the navigation system. The CDNU could hold a large database of navigation points including airport information, TACANs, VOR's, and user assigned points. Navigation flight plans could be loaded via the mission data loader (MDL) to get time to go (TTG), distance, course information, and altitude information. The CDNU software is programmable and is different from other military CDNU users. Pages of the CDNU are shown in appendix C. The CDNU has function keys on the control head below the display. The function keys are used to access lower subsystems. The CDNU contains a CRT display, keyboard and associated electronics, input/output electronics, built in test (BIT) electronics, and microcomputer system. The system processor is an Intel 80386/80387 running at 16 MHz. The A3 memory card contains 128K bytes of UVPROM, 1024K bytes of EEPROM, 256K bytes of RAM and 64K bytes of non-volatile memory (NVM). The current Block 89A CDNU memory is 80% full. A5 is an empty memory expansion slot.

RNAV Page

The first page shown after selecting the RNAV pushbutton is RNAV1. RNAV1 page displays the EHE (estimated horizontal error), FOM (figure of merit), and the number of satellites tracked.

Estimated Horizontal Error (EHE)

Estimated Horizontal Error (EHE) is computed by the GPS receiver-processor unit (RPU). *The RPU takes into account satellite vehicles (SV's),* *ionospheric/trophospheric corrections, accelerations (Nz's) and a few other parameters to compute a dilution of precision (DOP) sphere. The RPU also determines the errors possible from the Kalman filter covariance model and weights the equation to produce a worst case scenario* (Franiak, Joe, Litton EGI technical director via email, 2002). EHE is used to gage the precision of the GPS present position estimate. If EHE is 5m, there is a 95% probability that the aircraft is somewhere within a 5 m sphere centered at the GPS estimate. If the EHE computed by the sensors utilized in the current navigation solution (Blended or GPS) exceeds the defined threshold for the current flight mode, the CDNU shall display an annunciation on the CDNU. The annunciations and failure criteria for the three flight modes are as follows:

INVLD ENR if enroute mode and 3 sigma > 1000 meters

INVLD TRM if terminal mode and 3 sigma > 500 meters

INVLD APP if approach mode and 3 sigma > 100 meters

where the 3 sigma value is equal to three times the EHE.

The CDNU shall drive a display on the EHSI to show a navigation warning whenever the annunciation is displayed on the CDNU.

Figure of Merit (FOM)

Figure of Merit (FOM) is an arbitrary number used to gage the GPS accuracy as shown in Table 9.

Data Entry Procedures

Data required for navigation operations included flight plans, waypoint data, airspace boundaries, NAVAID's, enroute fixes, and airports. Secondary information

Table 9: FIGURE OF MERIT TO ESTIMATED POSITION ERROR TRANSLATION

Figure of Merit (FOM)	Estimated Position Error (EPE)	
	Meters (m)	Feet (ft)
1	Less than 25	Less than 82
2	Less than 50	Less than 164
3	Less than 75	Less than 246
4	Less than 100	Less than 328
5	Less than 200	Less than 656
6	Less than 500	Less than 1640
7	Less than 1000	Less than 3280
8	Less than 5000	Less than 16400
9	Unknown	Unknown

included airport information, magnetic variation, GPS almanac data, and other miscellaneous data. All of this data can be input by hand via the CDNU control panel or via the mission data loader. All of the information is contained on a data transfer module (DTM) that is used to transfer data from the TEAMS to the aircraft.

MISSION DATA LOADER (MDL)

The mission data loader (MDL) as shown in Figure A-2, contains the following different areas of memory: the primary identifier database, the reversionary database, the flight plan data base, and the magnetic variation data base. The MDL can hold up a large number of 50 point flight plans that can be loaded and activated or loaded and altered. The system allows the operator to have two flight plans open with one being the active. The active flight plan cannot be altered and then saved to the MDL. The other flight plan selected can be saved after changes have been made to it. The MDL can also hold a primary identifier database of 20,004 identifiers. The identifiers include: geographic points that are divided into checkpoints, airports, and radio navigation aids. The checkpoints contain latitude and longitude. Airport identifiers also include elevation, and radio navaids also include type of navigation aid, frequency of navigation aid and station declination. The reversionary database contains 200 points that are maintained in the CDNU through power off periods and power interrupts.

DATA TRANSFER MODULE (DTM)

The data transfer module is a memory storage device used to transfer CDNU information from the TEAMS machine to the aircraft.

Instrument Landing System (ILS)

A major addition to the navigation capabilities of the EA-6B include the addition of ILS approaches. The capability to perform ILS approaches is becoming more and more important with the proposed phase out of PAR and ASR approaches at Air Force airfields. As the PAR/ASR's are phased-out the need for a suitable IFR divert is becoming more and more important. The EA-6B is the first tactical aircraft to get the capability to execute ILS approaches. One of the limitations imposed on the EA-6B is CAT I approaches only and the requirement to be forward of the wing line and no Back Course approaches. The EA-6B approach speed is 120-140 KIAS and is considered CAT C for approach procedures as shown in Table 10.

Table 10: APPROACH CATEGORY CHART

Category	Maneuvering Table (knots)
A	0-90 knots
B	91-120 knots
C	121-140 knots
D	141-165 knots
E	166 knots or more

Global Positioning System (GPS)

Global positioning was added with the Miniature Airborne GPS Receiver (MAGR). The primary mission of the GPS is to provide worldwide, all weather, real time and continuous precise PVT data to the host platform. *The Chief of Naval Operations (CNO) and Commandant of the Marine Corps (CMC) issued a joint positioning/navigation (POS/NAV) policy in Aug, 1991 (CNO/CMC Ser 09/ 1U500942 of 1 Aug 91) designating GPS as the primary external reference system for naval operations and directed integration with on-board special purpose systems to the maximum extent feasible. The CNO GPS Integration Guidance (CNO document of 6 May 94) was promulgated as the USN/USMC standard for incorporation of GPS into Naval aircraft.* (TEMP 0190-04 Rev B Ch.3, page I-1). *Additionally, GPS is intended to replace the current land-based Tactical Air Navigation (TACAN) and VOR systems as the primary navigation system for flight in U.S. National Air Space (NAS) and ultimately worldwide controlled airspace. Current CNO policy allows for the unrestricted tactical use of GPS in Naval aircraft. Current military GPS avionics have neither an integrity monitoring capability nor a comprehensive navigation waypoint database. Therefore, current military GPS is not authorized for supplemental, primary or sole means of air navigation for instrument flight in controlled airspace. System integrity and navigation data base issues must be resolved prior to certification of the GPS for use as the primary means of navigation in controlled airspace (Note: Use of TACAN for shipboard operations (e.g., non-precision approaches) remains unchanged at this time). The target date to begin phasedown of land-based TACAN services is 2008 per CJCSI 6130.01B (TACAN services will continue at Navy/Marine Corps Air Stations and facilities). The Office of the*

Secretary of Defense-sponsored NAVSTAR GPS joint service navigation satellite program attained full operational capability (FOC) for DoD operations in July, 1995. The CDNU controlled the operation of the system and was the power source for the system. The almanac data was stored in the CDNU for quick alignment reference. The INS could not be automatically updated as in a coupled system. A loose interpretation of a decoupled system was possible when the operator updated the INS with GPS coordinates.

VOR Navigation

VOR navigation was another added feature incorporated into the EA-6B via the ILS panel. VOR navigation is authorized as long as the VOR is forward of the wing line (*EA-6B NATOPS Flight Manual,* NAVAIR 01-85ADC-1, January 2000). VOR approaches are not authorized due to lack of testing.

BLOCK 89A INTEGRATION

Overall changes to the system involved the addition of a ring laser gyro and moving the primary navigation source (CAINS) to a secondary role. The CDNU replaced the CDI on the panel as shown in Figure A-2. GPS navigation was routed to the EHSI and the EADI for a more accurate navigation source. The following are block 89A improvements: The Embedded GPS Inertial Navigation System (EGI) replaced the current AN/ASN-50 Compass System and AHRS. The AN/ARC-210 UHF/VHF Radio Set replaces the AN/ARC-182 UHF/VHF Radio Set. The CDNU replaced the CDI.

Control Display Navigation Unit (CDNU)

New functionality has been implemented into the CDNU as a result of the integration into the 89A. The CDNU is the primary controller of the EGI and the CAINS navigation system, the HARM weapon system, and the ARC-210 radio communication system. The new functionality is available through the function keys. F1 is used for communications page in 89A. F2 is used for radar cursor control mode. F3 is used for HARM targeting. F4 is used for timing functions and incorporates 3 count-up and count-down timers. F5 and F6 are currently not used. F7 is used for copying information.

Ring Laser Gyro

The ring laser gyro was a maintenance replacement and is designed to give drift accuracies on the order of 0.6 to 0.8 nm/hr. The functionality of the INS was retained, but the ring laser gyro has less moving parts and a lower initial failure rate. The ring laser gyro is a dithering laser gyro. Dithering applies a known time delay that can be deleted later to allow for a lower detection range and a more accurate gyro. Accuracies of the ring laser gyro are shown in appendix B.

Embedded GPS/INS (EGI)

The LN-100G (EGI) was a lightweight ring laser gyro inertial navigation system with a fully integrated embedded GPS (INS/GPS). This unit included a sensor assembly with three Zero-lock Laser Gyros, an A-4 accelerometer triad, and five electronic assemblies including a system processor card with digital and discrete input/output (I/O), a sensor electronics card, an embedded Global Positioning System (GPS) receiver, a low-voltage power supply, and a high-voltage power supply. This EGI made use of a Kalman filter that blends inertial, GPS, and other sensor data to provide the maximum accuracy output data. The LN-100G provided three simultaneous navigation solutions: hybrid GPS/INS, free inertial, and GPS only. The processing was a 32-bit Power PC Motorola microprocessor, and the software was Ada. The LN-100G combined GPS and INS data to provide enhanced position, velocity, attitude, and pointing performance. EGI system integration is shown in Figure 19.

ARINC-429 DATA BUS

The Block 89A airplane uses seven ARINC-429 serial interfaces, primarily for transfer of NAV data and status to the EFIS. EFIS bus interfacing is with the CDNU, DSDC, EGI, Instrument Landing System (ILS) receiver. ARINC-429 is a commercial standard, unidirectional, 32-bit serial word comprised of a label field indicating the purpose and content of the message. Both high-speed (100 kbps) and low-speed (13 kbps) buses are used.

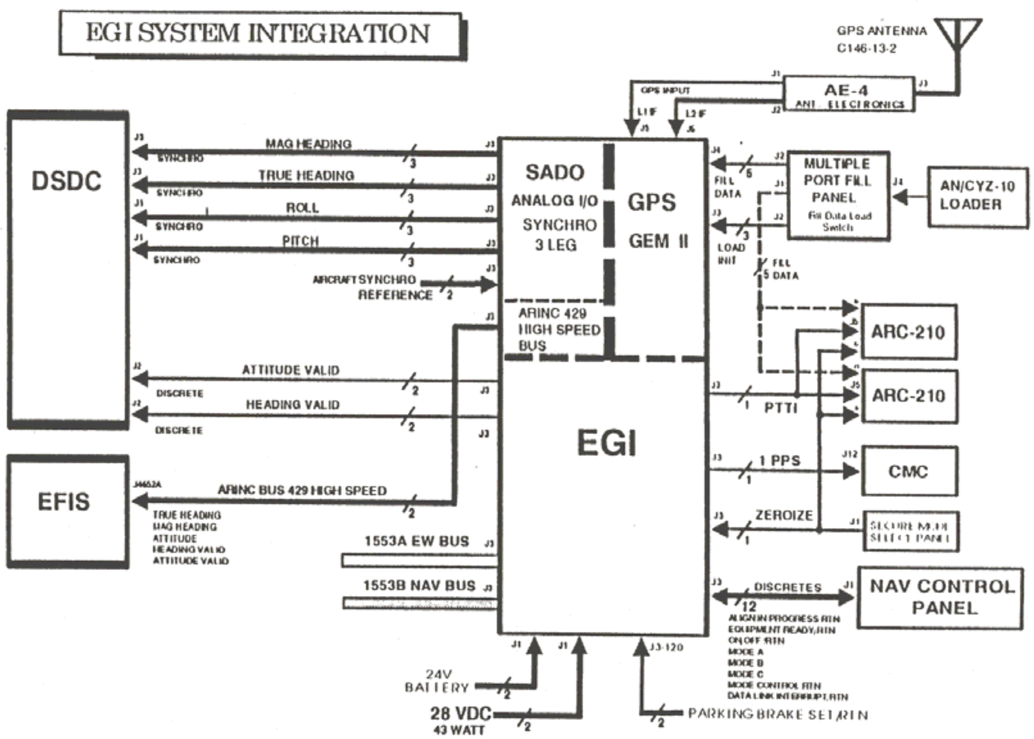


Figure 19: EGI SYSTEM INTEGRATION

Alignment Process and Time

The EGI alignment process is simple with few steps. It takes the EGI about 30 seconds to acquire satellites and complete alignment is complete in 2-3 minutes. Attitude information occurs almost immediately with positive indications on the EADI. It takes 3-5 seconds for the CDNU to complete a self built in test (BIT) upon initial startup. Index, Start, EGI start is all that is required to start the alignment via the CDNU. The EGI control knob must also be turned to align for the gyros to spin up.

In Flight Alignment (IFA)

In Flight Alignment was not possible with the CAINS system due to implementation problems. Updates were possible, but they were not as accurate as a new alignment. The CDNU/EGI allows for precise In Flight Alignments.

Navigation Procedures

New navigation systems were incorporated into the 89A. GPS navigation was incorporated with the addition of the EGI. CAINS were systems left over from the previous versions of the EA-6B.

INSTRUMENT LANDING SYSTEM (ILS)

ILS approach capability was a great improvement to the navigation suite inherent to the EA-6B. ILS as shown in Figure 23 on page 66, allows the EA-6B to execute CAT I approaches to civilian and some Air Force airfields. This allows the use of these fields as weather diverts as required by Navy Operating Instruction 3710 series (*OPNAVINST 3710.7 series, NATOPS General Flight and Operating Instructions*, Department of the Navy Office of the CNO, January 97). Limitations imposed on the EA-6B due to testing constraints (limited amount of testing completed due to funding) and antenna placement on the aircraft, require vectors to the final course before clearance to execute the approach. Glideslope is shown with a deviation carrot and horizontal depiction is shown with a runway. Accurate approaches have been flown to airfields within the US NAS.

CARRIER AIRCRAFT INERTIAL NAVIGATION SYSTEM (CAINS)

CAINS accuracy is the same as previous versions, but a direct update to the system allows damping of the schuler cycle with the addition of a blended solution. The update rate is 2 Hz. This results in an extremely accurate solution. The CAINS also provides secondary attitude and heading information to the navigation system.

CHAPTER 3: METHODOLOGY

GENERAL

This chapter will discuss the author's methodology used to evaluate the CDNU and its affect on GPS navigation operations. Testing of the 89A software version 1.0 for the purposes of this thesis began in January 1999 and ended in June 2002. Navy operational testing was conducted on the west coast and ended in December 2000. Developmental testing began on 89A software version 1.1 in January of 2002 and concluded in June 2002. Software versions had no impact on the results of this evaluation. Over 11 flights were flown and more than 25 approaches were flown to validate the data and conclusions of this evaluation. It was not the intent of the author to conduct sole GPS or INS navigation testing during the 89A operational and developmental testing period. Data were collected during familiarization flights, currency flights, and two test flights. The data collected during the flights were mostly qualitative in nature, with most of the precise data taken from dedicated testing that had been completed earlier. 89A testing of developing software (2.0) continues to this day as problems are identified and funding and time become available to fix them. Testing was completed in two aircraft with similar CDNU software. Both aircraft were Block 89A aircraft, but the second aircraft had other test equipment installed. The first three flights were flown at Naval Air Weapons Station China Lake CA. The testing was part of 89A initial operational testing. The outcome was fleet introduction and follow on testing and evaluation. The flights flown in California involved airways navigation and approaches. Airways navigation testing was conducted using the GPS and TACAN as backup. The second aircraft was flown at Naval Air Station Patuxent River MD. Differences between the first and second aircraft include the replacement of the CAINS with a second EGI. The secondary EGI navigation system was not used and the secondary EGI did not affect the testing of the original EGI.

CONFIGURATIONS

Aircraft configuration for airways navigation consisted of 3 pods and two drop tanks. The gross weight varied from 38,000 lbs to 58,600 lbs. The approach phase involved lowering the flaps, slats, landing gear, and speed brakes and were flown from 135-155 KIAS. Software configurations for the CDNU were 89A 1.0 and 1.1.

DATA RECORDING

Data was recorded on kneeboard cards and reduced with Excel spreadsheets. Most of the data recorded were qualitative in nature.

TRUTH DATA

Truth data for the flights were GPS data displayed on the CDNU and compared to barometric altimeter data that was set to local altimeter setting. The baro-alt was set to standby and has a possible error of +/- 75 feet. All other data used were as accurate as the equipment that supplied it and errors are shown in Table 11. Approach data were also compared to TACAN and VOR data to determine distances and bearing information.

Table 11: ERROR SOURCE AND AMOUNT

Indicator	Amount of error read from gauge
Airspeed	+/- 5 kias
Altitude	+/- 50 ft
Heading	+/- 5 degrees
Latitude/ Longitude	+/- 0.1 secs
TACAN/ VOR	+/- 1 deg/ +/- 0.5 nm

DESCRIPTION OF TEST EVENTS

First, a cockpit evaluation was performed on the Block 89A aircraft with emphasis on controls and displays. Second, a navigation ground and flight evaluation were conducted. Third, GPS and ILS approaches were flown and evaluated for accuracy. A review of the Block 89A developmental test results and advanced EFIS integration were used to support the author's conclusions on accuracy of the GPS, INS, and ILS systems. The navigation testing was conducted as outlined in Systems Flight Test Manual (USNTPS Flight Test Manual 109, 2000).

COCKPIT EVALUATION

The cockpit evaluation was conducted in China Lake per USNTPS Systems Flight Test Manual, chapter 2. Controls and displays were evaluated for readability, clarity, operation, labeling, functionality, size, brightness, and placement. The evaluation was conducted during day-time conditions and evaluated from the copilots seat. The dedicated evaluation lasted for 2 hours, but notes were recorded during every ground and flight event.

GROUND NAVIGATION TEST

The ground navigation portion tested the alignment times of the ring laser gyro and INS drift over time. A dedicated ground INS test was not conducted per reference 11. Preflight and postflight positions were analyzed for errors.

AIRBORNE NAVIGATION TEST

Navigation System Accuracy

Maneuvering and non-maneuvering INS navigation testing was conducted during the evaluation. The testing was conducted by flying over surveyed locations and recording the INS and GPS locations indicated by the CDNU and then compared to the actual surveyed latitude/ longitude coordinates. Both of the EA-6B's used for this evaluation had instrumented navigation buses. The data was examined in excel, but is not presented in this thesis. GPS testing was evaluated the same way with the knowledge that the GPS solution is more accurate than the test because of inaccuracies with data taking. 89A DT report in appendix B shows accurate laser tracker data compared to INS, GPS, and hybrid solution performance. Low altitude navigation was conducted during both OT and DT. A navigation route was entered into the CDNU and over flight at 500 – 3500 ft was compared for accuracy.

Qualitative CDNU Software Evaluation

The CDNU was evaluated as an FMS. Flight plan entry and use were evaluated for accuracy and ease of use. Radio control via the CDNU was evaluated for ease of use, and time required for entry.

Enroute

Enroute testing consisted of airways navigation, low-level operations, and airways holding. Airways navigation was qualitatively assessed during TACAN direct to and from. Data was compared to the TACAN information displayed on the EHSI and EGI information displayed on the CDNU.

Terminal testing was conducted before the approach phase. It consisted of slowing the aircraft to intercept a holding fix. Most of the TACAN approaches began with a one or two turn in holding to assess the software and visual cues. A dedicated holding flight was conducted in the R2508 China Lake range to assess holding off of a TACAN station. Data required were ease of use, accuracy, and correct display presentation.

Inflight Alignment

Inflight alignments were conducted on a flight in the Patuxent River local operating area. The system was shut down and IFA was selected on the NAV control panel (NCP). Time to align was recorded using system time. Over flight of surveyed points were conducted after good alignment indications were displayed on the CDNU.

Approach

ILS APPROACHES

ILS approaches were conducted at many airports around the country per the EA-6B NATOPS manual (*EA-6B NATOPS Flight Manual,* NAVAIR 01-85ADC-1, January 2000). The types and numbers are shown in Table 12 on page 63. The ILS was set up during the descent and approach to landing and prior to the inbound course. Radar altimeter was set to the DH and the appropriate altimeter setting was set prior to the approach. Course was dialed in to the deviation bar on the EHSI, LOC mode was selected for the EADI. As the deviation bar began to move, the aircrew intercepted the final course and centered both bearing and elevation needles. The gear was lowered at 250 knots inside 10 nm and the aircraft was slowed to approach speed of 135 knots. ILS needles were flown to middle marker indication on the EHSI. Altitude was maintained above 200 feet agl until runway was acquired visually. Data recorded were display indications, transition from inside instrument scan to external visual cues, mental workload ratings, and whether the approach could continue to 100 ft.

GPS APPROACHES

GPS approaches were conducted to various airfields around the country as shown in Table 12 on page 63. All approaches were conducted under day visual meteorological conditions (VMC) and during another EA-6B approved approach. Visual straight-ins, ILS, TACAN, VOR, and PAR/ASR approaches were conducted and GPS data were gathered. The approach fixes were typed into the CDNU and displayed on the map. All of the fixes typed in were already in the database with the exception of the runway DA waypoint. The author had to use the runway diagram on preflight to determine the exact coordinates. The flight mode was changed to “A” (approach) on the CDNU to allow for smaller deviations on the display as shown in Table 8. The GPS map display and ILS display were cycled to compare the two during the approach. The range scale was scaled down to maintain two fixes on the display to allow for a more accurate approach. Data recorded was display indications, transition from inside instrument scan to outside visual scan information, mental workload ratings, and whether the approach could continue to DA.

CHAPTER 4: RESULTS

TRAINING ISSUES

Aircrew training issues were not perceived to be a problem with most aircrew getting approximately 15-20 hours per month of flight time, most of which was in the EA-6B. Both squadrons fly other aircraft and it was common to fly in other than EA-6B's to stay current. Currency and proficiency are two different things. Most of the aircrew stayed proficient by reading the NATOPS manual, studying the test cards a day or two before the flight and by using simulators. The aircrew also gained some proficiency by performing the ground evaluation prior to the flight tests. This allowed for a proficient use of flight time.

FLIGHT PLANNING

Flight planning was conducted on the Tactical EA-6B mission system (TEAMS). All of the waypoints, low level routes, air space boundaries, navaids, and airports were loaded onto the MDL. The MDL held 20,000 waypoints and 12 navigation routes. The MDL will not hold the entire US database, but only about 90% of it.

CDNU SOFTWARE ISSUES

The CDNU software was evaluated for ease of use. It was a large improvement over the CDI/CAINS system. The software allowed more information to be available to the operator with simple button pushes. The CDNU is an excellent asset and satisfies all the requirements to be a flight management system.

RADIO GUARD FREQ

With CDNU control of the radios and selection of 243.0 or 121.5 on the keypad, manually entered, caused the CDNU to lock out other frequencies. No other radio station was selectable until a 15-20 minute OFP reload was completed. This seriously impacted operator use if selected inadvertently.

MAGNETIC VARIATION

Magnetic variation of the waypoint selected was used to determine the magnetic variation of the course. If the waypoint was a navaid, and at a great distance from the aircraft this computation error could be as large as 15 degrees. Flying from Key West with a magnetic variation of 4 degrees west to China Lake with a magnetic variation of 14 degrees east it was observed that the navigation system was using the magnetic variation of China Lake, the final destination, in a two point flight plan. The magnetic variation was off by 10 degrees. A 10 degree error over a 1800 nm trip caused a flight route that was directed 300 nm south of China Lake. The route if flown would have been an arc.

GROUND NAVIGATION TEST RESULTS

Ground Alignment

All ground alignments were timed and the longest was 5 minutes. The average was 4 minutes. The INS alignment was complete 2-3 minutes before the pilot finished his before taxi checks. The CAINS system required waiting 2-3 minutes after the pilot was ready to go or have the alignment going prior to engine start.

AIRBORNE NAVIGATION TEST

In Flight Alignment

Inflight alignments were easy to conduct and required very little operator assistance during the alignment and resulted in an operator assessment of workload being a 1 on the Bedford Workload Rating scale (Roscoe, A.H., Inflight Assessment of Workload Using Pilot Ratings and Heartrate, in A.H. Roscoe (Ed.) *The practical assessment of pilot workload,* AGARDograph No. 282, 1987). It was recommended to try to stay wings level while aligning. The overall alignment times were 20 min each to reach a q of 1.0 (quality factor with 0.5 being the best). The alignment also reset the attitude information shown on the EADI. After switching to IFA the EADI went blank and the display returned in 20-30 seconds with a stable platform as compared to the standby gyro and the horizon.

Aircraft Holding

Holding was easy to conduct with a minimal amount of button pushing. The holding point was identified and activated. The leg lengths were entered and this allowed the CDNU to alert the aircrew 10 seconds prior to turn on the outbound legs. The second waypoint selected was a waypoint identified by a range and bearing from a KNID (NAS China Lake TACAN). The 030/30 nm was entered with 4 nm leg lengths. The CDNU began to blink just prior to the turn inbound. The third holding test was conducted during a flight at Patuxent River. ATC instructed the test aircraft to hold at CHOPS. The low altitude fix was loaded in the reversionary database and was added to the flight plan by typing it in. The course, leg length, and direction of turn were entered after selecting the hold function key. To reactivate the flight plan, the operator had to select the next waypoint. The entire task was accomplished with enough spare capacity to accomplish other copilot duties including communications with ATC and navigation responsibilities. The workload rating was assessed as a 3 on the Bedford Workload Rating scale (Roscoe, A.H., Inflight Assessment of Workload Using Pilot Ratings and Heartrate, in A.H. Roscoe (Ed.) *The practical assessment of pilot workload,* AGARDograph No. 282, 1987).

History Waypoints

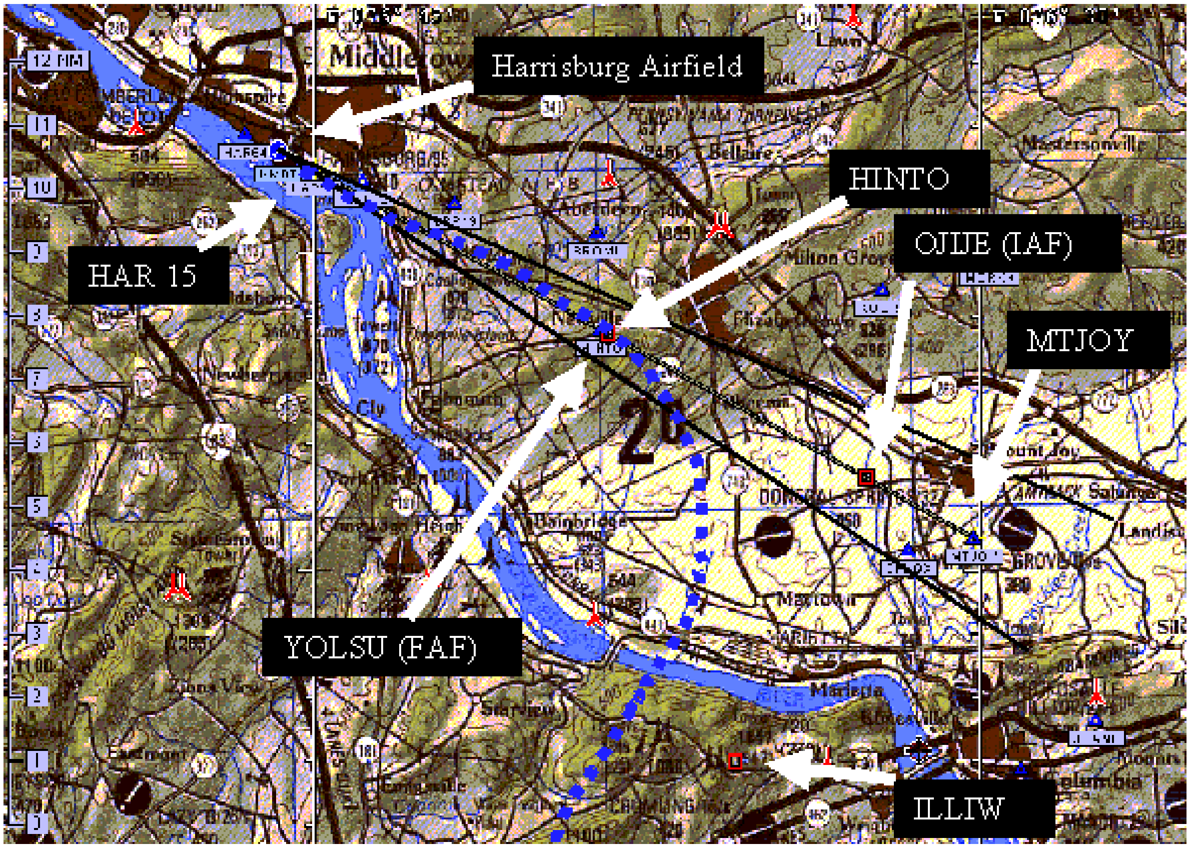
One of the biggest issues with the CDNU navigation software was found during testing. Navigating from one point to the next was accomplished via the CDNU. All of the navigation points were entered into the CDNU either manually or by the MDL. Waypoint selection could be done automatically or manually. If set to automatic sequencing the CDNU would automatically shift to the next waypoint after closest point of approach (CPA) had been reached. Upon reaching the CPA the system overwrites the waypoint with the CPA position. Reselection of the waypoint was not possible. Manual cycling allowed the operator to keep the waypoint position correct.

GPS APPROACHES

GPS approaches flown are shown in Table 12. Qualitative comments are also shown. All of the approach plates discussed in this evaluation are shown in appendix A. Harrisburg INTL was used as a representative of the other approaches flown. Actual displays are replicated and shown in Figure 21and Figure 22. A depiction of the approach from above overlain on a chart is shown in Figure 20. The overhead view

Table 12: ILS/ GPS APPROACHES FLOWN

Approach	Discussion/Observations
Edwards AFB ILS RWY 22	Radar Vectors to ILS Final Good Indications to DH
Vandenberg AFB ILS/DME RWY 30	Radar Vectors to ILS Final Good Indications to DH
South Lake Tahoe LDA/DME –1 RWY 18	VOR to SWR 060 degrees outbound to intercept KINGS intersection/Compared with KINGS and L/L of RWY 18 approach end to determine accuracy of GPS approach. Good LDA indications to MAP
South Lake Tahoe LDA/DME –1 RWY 18	Radar Vectors to LDA final. Good indications to Low approach
Nellis AFB TACAN or ILS/DME 1 RWY 21L	Vectors to final, Good indications to touchdown.
Monterey Peninsula LOC/DME RWY 28L	Radar Vectors to Final, Good indications
Manzanar (Retired airport) GPS approach only	T design approach was made and used Approach mode to give altitude deviation indicator. Good indications laterally, but altitude indications were difficult to fly and positioned aircraft below 200 ft as compared to the radar altimeter.
JFK INTL RNAV (GPS) Z RWY 31L and ILS RWY 31L and RNAV (GPS) Y	ILS was flown from radar vectors and compared to the GPS approaches. Good indications to touchdown
Harrisburg INTL RNAV (GPS) RWY 31	Radar vectors to ILS final with backup of GPS on MAP mode of EHSI. Good indications to DH.
State College ILS RWY 24	Only approach with a negative result. Vectored to intercept ILS final and indications of the approach never started and overshot final bearing around 15 nm. ATC had to correct back on to the final approach course and then received good indications. Two more approaches were conducted to evaluate the ILS and all indications were normal.



Blue Filled In Squares= Aircraft Path
Red Empty Squares= GPS T approach points

Figure 20: HARRISBURG ILS/GPS APPROACH RESULTS

shows the ILS corridor and the GPS approach points. The aircraft approached from the south. The approach shows a slight overshoot until inside HINTO (FAF). The GPS and ILS displays are shown in Figure 21, Figure 22, Figure 23, and Figure 24. The 5.3 nm display showed excellent accuracy and matched up exactly with the ILS.

<u>GPS ACCURACY</u>

GPS accuracy results were compared to INS and mark on top visual surveyed points. GPS points were tested in blended coupled mode as selected on the CDNU. Data are presented in Table 13 and confirms the data that were found in the 89A report. Therefore, accuracy of the GPS and INS is best seen in the 89A report in appendix A.

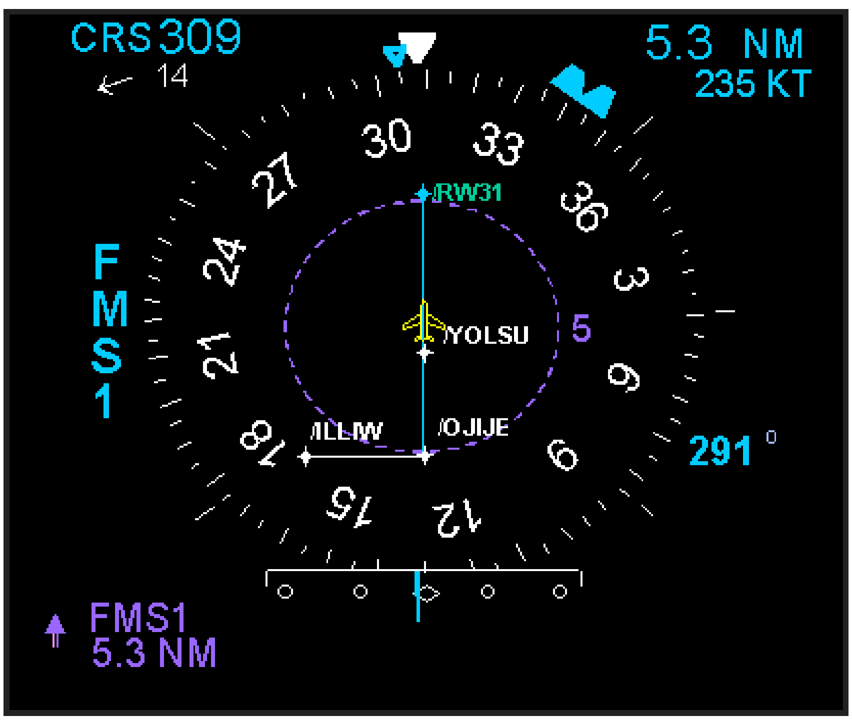


Figure 21: EHSI DISPLAY OF HARRISBURG APPROACH IN MAP MODE IN 5 NM SCALE

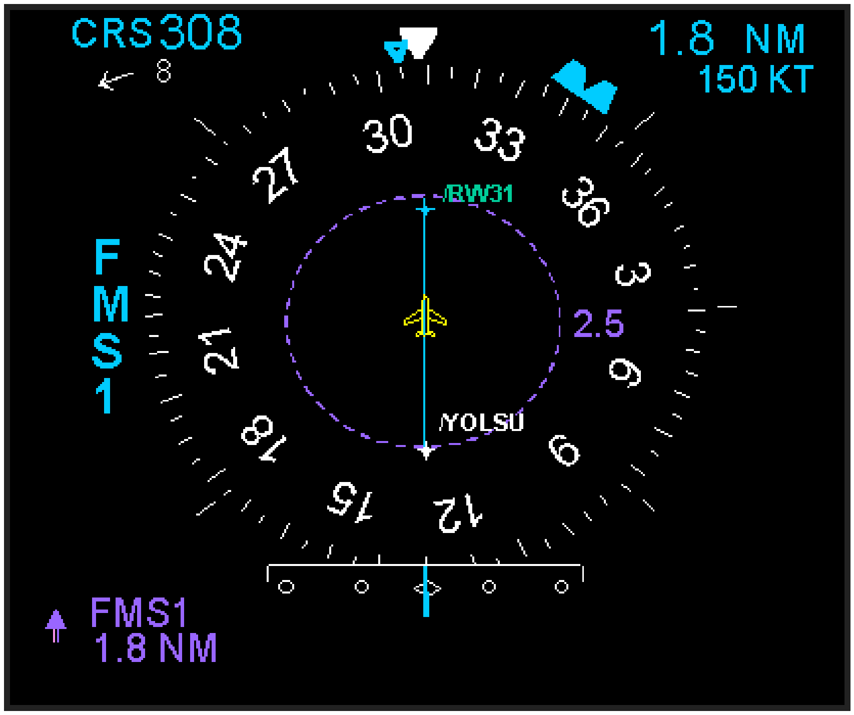


Figure 22: EHSI DISPLAY OF HARRISBURG GPS APPROACH IN 2.5 NM SCALE

Figure 23: EADI ILS MODE

Figure 24: EADI ILS MODE WITH NEEDLES

Table 13: BLOCK 89A NAVIGATION SYSTEM ACCURACY IN DIFFERENT NAVIGATION MODES

Overfly Point	Navigation mode	Latitude	Longitude	Error
Hannibal	Blended Coupled	-	-	171/ 0.11 nmi
Pt Lookout	Blended Coupled	-	-	142/ 0.05
Smith Point	Blended Coupled	-	-	084/ 0.08
Hannibal	Blended Coupled	N3802.3	W7609.3	354/ 0.04
Pt Lookout	Blended Decoupled	N3802.3	W7619.3	100/ 0.09
Smith Point	Blended Decoupled	N3753.460	W7614.272	123/ 0.10
Hannibal	Blended Decoupled	N3802.255	W7609.130	330/ 0.22
Smith Point	Blended Decoupled	N3753.575	W7614.339	147/ 0.22
Smith Point	INS	N3752.947	W7614.969	065/ 0.80
Hannibal	INS	N3801.669	W7609.928	044/ 0.90
Smith Point	INS	N3752.855	W7614.956	059/ 0.85
Hannibal	INS	N3801.599	W7609.927	041/ 0.96
Smith Point	Blended Decoupled	N3753.439	W7614.263	113/ 0.09
Hannibal	Blended Decoupled	N3802.275	W7609.145	329/ 0.2

The accuracy was determined by a laser tracker and shows excellent accuracy of the 89A in all modes.

ILS APPROACHES

The ILS approaches were shown to be within limits and all were flown to touchdown, and were easily conducted with vectors to ILS final. Cockpit setup was easy and displays were intuitive. The visual cues to the pilot were a runway left and right of course and an elevation carrot. The EADI was not capable of displaying needles to the pilot. Rising runway was difficult to see from the copilots seat.

CHAPTER 5: CONCLUSIONS

GENERAL

The author asked himself " what does GPS approach capability offer the aircrew compared to normal precision and non-precision approaches?" GPS has a lower non-precision approach minimum a shown in the Harrisburg approach plate in Figure A-16. What advantages does GPS sole navigation capability offer to the user as compared to the TACAN or VOR based system? GPS navigation will allow the EA-6B to file RNAV navigation flight plans and request GPS direct during long flights. This will allow easier flight planning and more safe and efficient flights. GPS direct will also help ATM controllers in congested areas. The answers to the questions above were concluded based on the results in the previous chapter and the results referenced from the 89A DT report.

CDNU

With the exception of the guard, history waypoint, and magnetic variation problem, the CDNU integration was excellent. The alignment controls were easy to use and placed within reach for both the pilot and ECMO 1. The system had more navigation information than the CDI, but was easy to find with seven top level function keys. The software pages were more than three deep as shown in appendix C, but were easy to access. Arrows at the bottom left of the CDNU showed the operator what pages were available. A FMS is an interface between flight crews and flight deck systems (Federal Aviation Administration, *Instrument Flying Handbook (FAA-H-8083-15)*, U.S. Department of Transportation, 2001), a computer with a large database of airport, NAVAID locations, and associated data, aircraft performance data, airways, intersections, DP's and STAR's. The FMS also has the capability to store routes, can quickly define a desired route, and perform flight plan computations. With the exception of aircraft performance data, the CDNU is by definition a flight management system. The F1 function key allowed the operator to get to the radio control page. After receiving a radio change it was easier to select F1 and type in the frequency, than to write it down. If the frequency was wrong or the controller was not available, a simple button push was all that was required to return to the previous frequency. The radio page stored 30 preset frequencies for local area operations and they were selected by button number or typing in the name of the agency (ie "tower").

GPS APPROACHES

GPS accuracy was excellent and was satisfactory for airways navigation and non-precision approaches. Integrity monitoring using EHE was sufficient for airways navigation, but not acceptable for non-precision approaches. RAIM is necessary for NPA's and PA's.

ILS APPROACHES

ILS approaches to CAT I minimums was satisfactory, but could be more precise with the addition of needles instead of the rising runway display.

SUMMARY

Conversion of the EA-6B to Block 89A has resulted in a better navigation system as shown by increased accuracy and less cross check time. The addition of 2 new approach types allow the EA-6B to operate more safely and efficiently around the world. Certification procedures are confusing to understand and difficult to implement, but as the EA-6B has evolved it has added more required items that satisfy the FAA and DOD certification guidelines for GPS precision and non-precision approaches. Adding a few software changes should allow the EA-6B to operate in the NAS utilizing the full GPS capability. With a few more changes to the software and some minor hardware changes it is possible to execute GPS precision approaches to 200’ and ½ nm.

CHAPTER 6: RECOMMENDATIONS

GENERAL

Recommendations for improvement to the ICAP II Block 89A aircraft were numerous and could be completed through simple software fixes. In the authors own opinion GPS enroute navigation in the NAS should be approved by the FAA and DOD. The ability to conduct GPS approaches in the NAS should also be allowed with a few changes to incorporate requirements imposed by the FAA and DOD.

GPS USAGE

ENROUTE NAVIGATION

Enroute navigation in the NAS should be accomplished by one of two ways. The first way is to certify the INS and the GPS blended coupled mode of operation. Accuracy of the EGI is sufficient for airways navigation. Changes required include software that limits the amount of error the total solution has compared to the INS only solution. This would allow for a slow INS drift of 1-2 nmi per hour and once the rate or acceleration of one or more of the satellites exceeds some predetermined rate then the INS only solution would take over until new satellites were acquired. The cockpit would require the addition of a caution light that illuminates when the RNP value falls below the required number depending on the phase of flight. This light could be added to the EHSI or EADI or physically mounted to the front panel. Regardless of the light location another recommendation would be to remove the course information when the RNP value falls below the required number. This would be the quickest and satisfies FAA requirements. The first option however does not satisfy the requirements set forth by the DOD for either enroute or NPA procedures. A waiver for DOD requirements to operate in the NAS would have to be requested.

The second option that would satisfy FAA and DOD requirements is by integrating RAIM capability into the EGI, updating the memory in the CDNU, rewriting multiple OFP's, and installing a warning light. RAIM capability already exists in EGI's that contain GEM IV receivers. The author recommends activating the remaining unused channels (7) to comply with the all in view (AIV) satellite requirements (12) and writing new EGI software code to utilize the inherent RAIM capability of the GEM IV receiver. The CDNU memory should be increased to allow for an additional OFP by the addition of a memory card in A4. A physical change to the front panel should incorporate an integrity light which would illuminate when navigation parameters were outside limits. A summary of the recommendations are shown in Table 14.

Table 14: AUTHORS RECOMMENDATION FOR GPS REQUIREMENTS

Requirements	NAS Navigation	NPA	PA	WAAS (NPA)
RAIM GEM III	-	X	-	-
AIV GEM IV	-	-	X	-
EGI OFP	-	X	X	-
CDNU OFP	-	X	X	X
EHSI OFP	-	X	X	X
EHE indication	X	X	-	-
EHE alert	X	X	-	-

TERMINAL NAVIGATION

Terminal navigation requirements are satisfied with either of the above changes.

NONPRECISION APPROACH

Approach procedure requirements could be satisfied by incorporating the changes as described above with the additions of a few more DOD and FAA required options. The first requirement to execute a NPA is an unalterable approach procedure. This could be accomplished by increasing the memory of the CDNU, altering the OFP to activate one of the function keys that would place the navigation into an approach mode. This mode would allow entry of a single approach to a specified airport with a minimum of six button pushes and a maximum of seven button pushes to activate an approach. The approach would be unalterable by the aircrew and displayed on the EHSI map mode. The mode entry on the CDNU should take the operator to the map mode and display the requested approach at a range option that shows the entire approach through the missed approach point (MAP). A simple GPS "T" FAA designed approach can be shown on a 20 nm scale and as waypoints are passed the scale would readjust automatically to keep the track up and the MAWP on the display as shown in Figure 21 and Figure 22. The CDNU software is currently set up to cycle waypoints after CPA.

PRECISION APPROACH

The author recommends installing software to allow for the use of WAAS information to conduct precision GPS approaches. Install the capability to recognize errors in the number of satellites received (RAIM) or currently being tested AIME to allow for CAT I precision approaches down to 200 feet and ½ mile visibility. Other requirements that need to be evaluated include VNAV/VSI pointer operation.

ILS APPROACHES

The author recommends incorporating another EIU with scaling amp adjustments to allow the symbol generator to display ILS needles as shown in Figure 24, instead of the current runway and carrot display as shown in Figure 23.

GROWTH CAPABILITY

Two CDNU function keys are not currently used for any function. The possibility exists to run engine or other flight control parameters to these pages. Another option would be to add checklists to the EHSI or CDNU. The LN50 EHSI has the capability, but was not purchased with the original release. This would allow aircrew to pull up a checklist page prior to takeoff, descent, and landing. Available memory in the CDNU currently does not exist as the computer system is currently running on 80% capacity. Recommend adding a new memory card to the system in slot A4 to allow for future growth.

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APPENDIX

APPENDIX A
FIGURES

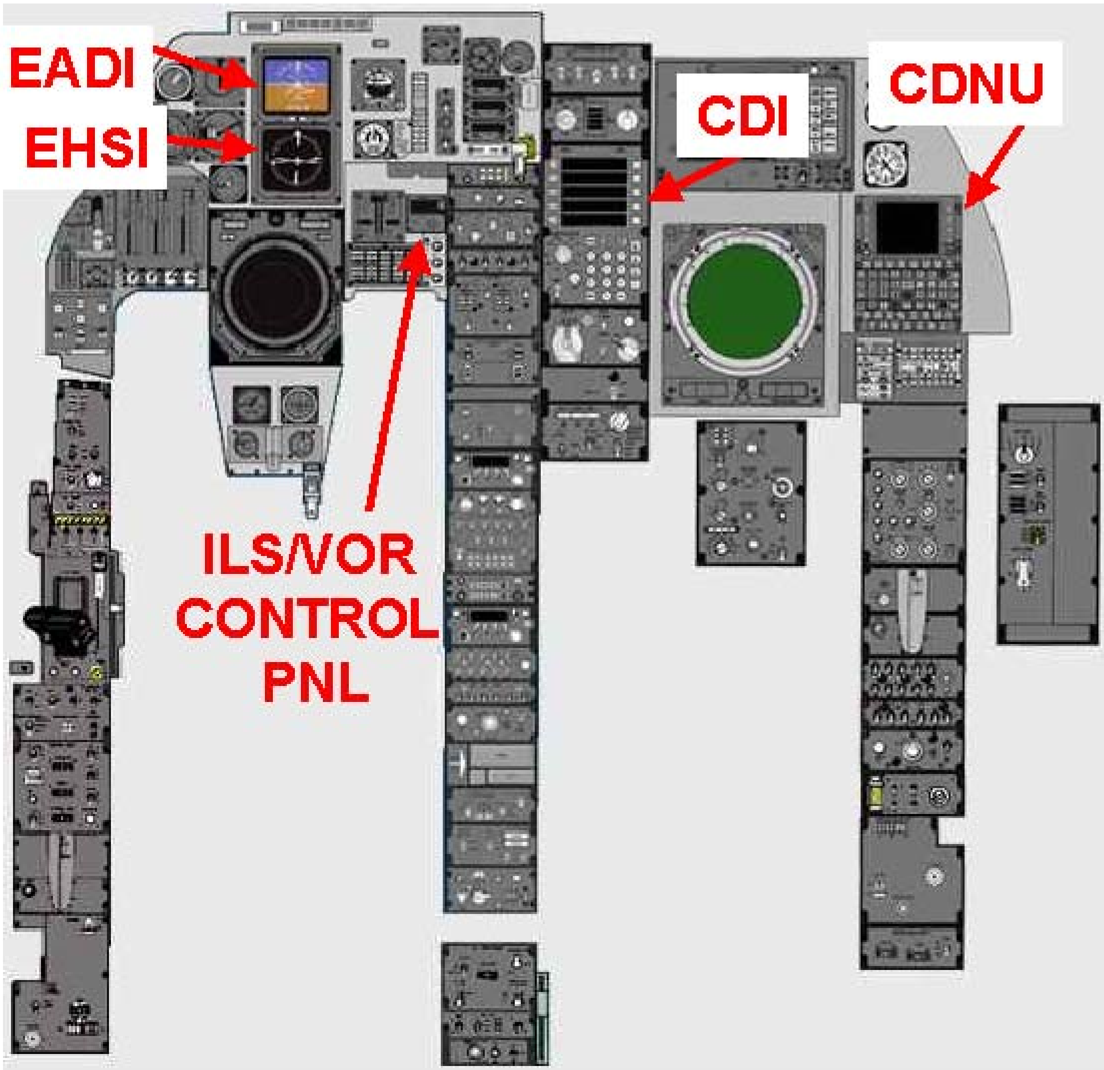


Figure A-1: COCKPIT VIEW OF ECMO 1 POSITION AS SHOWN IN BLOCK 82 AIRCRAFT

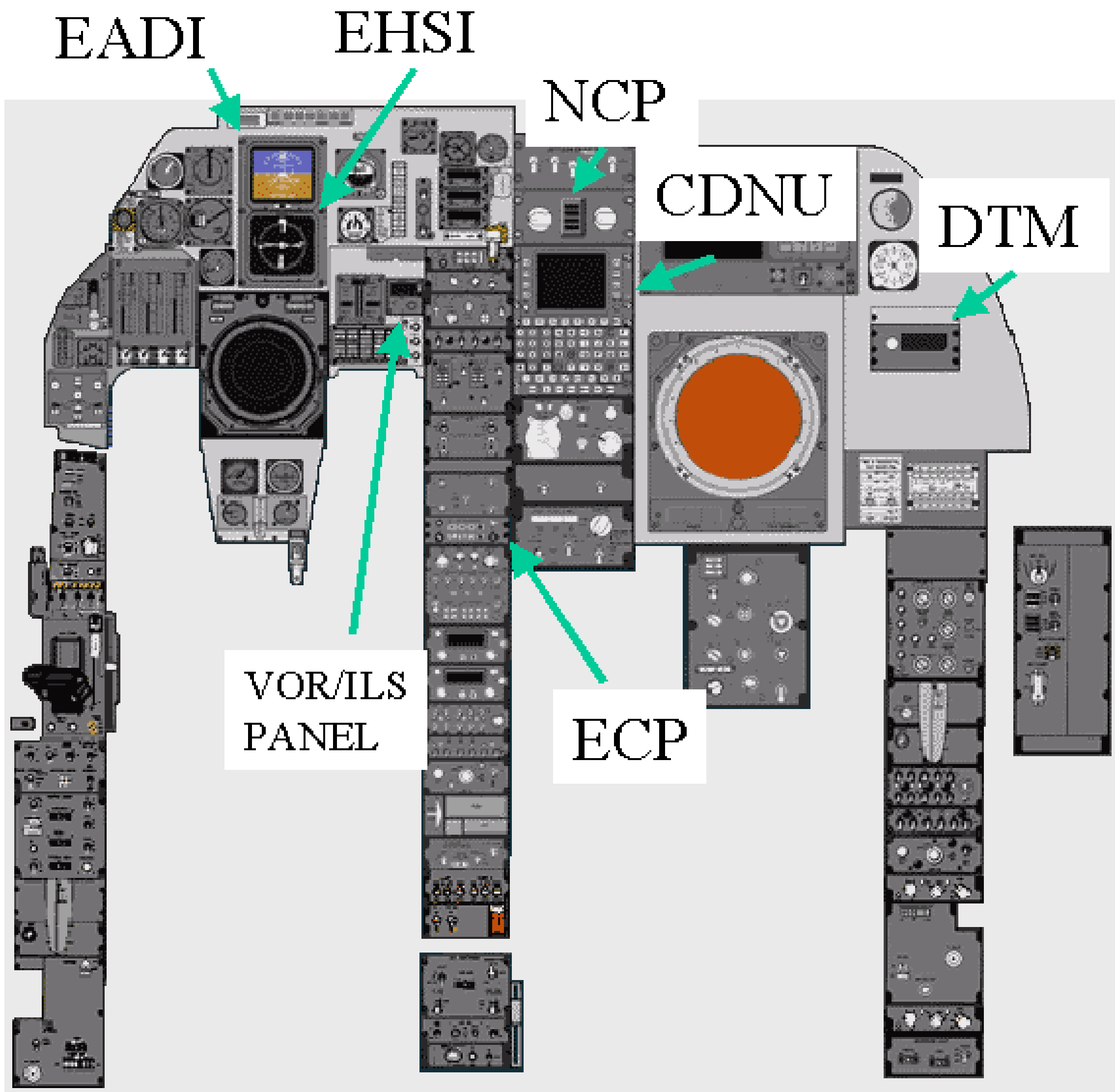


Figure A-2: COCKPIT VIEW OF BLOCK 89A

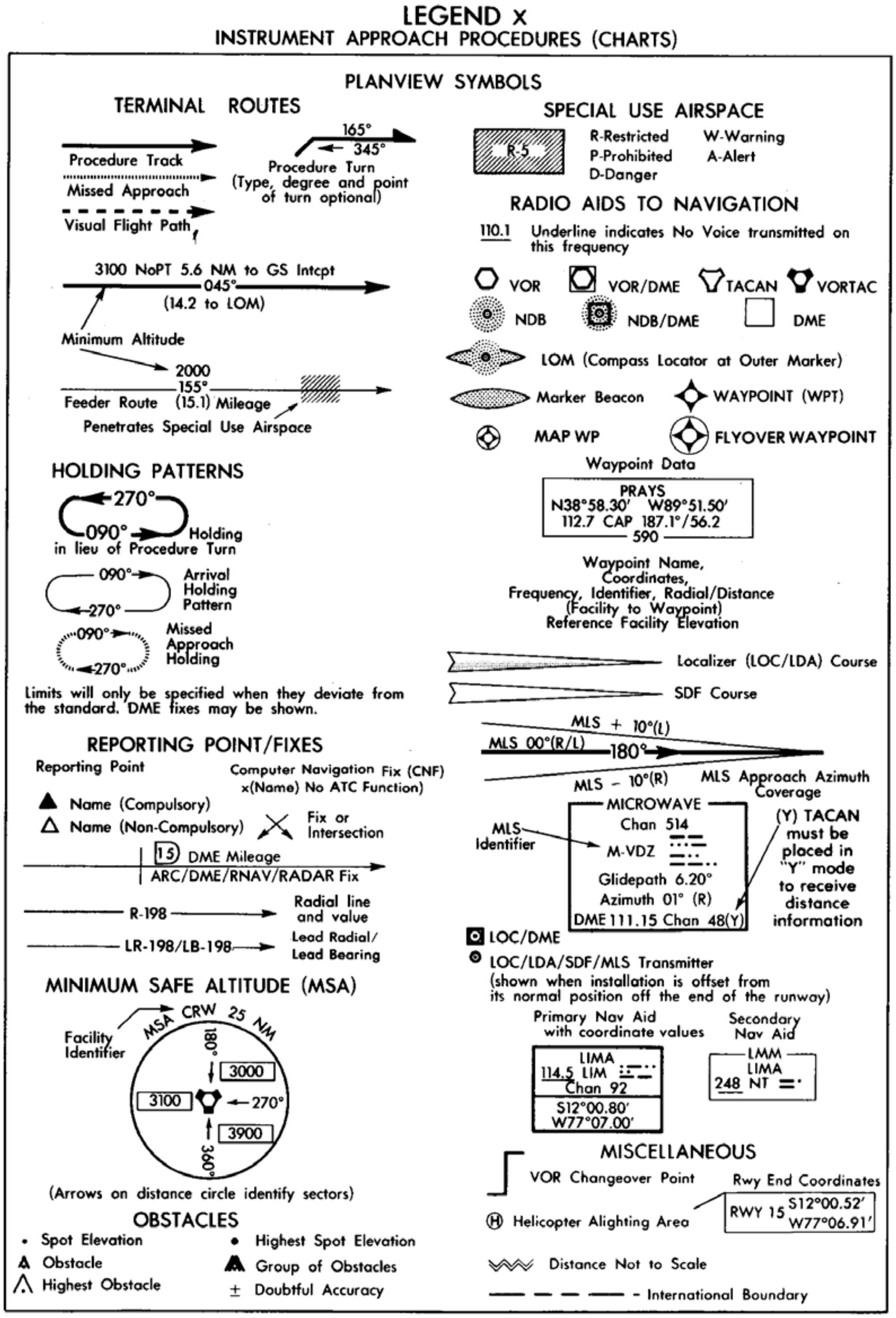


Figure A-3: LEGEND INSTRUMENT APPROACH PROCEDURES (1 OF 5)

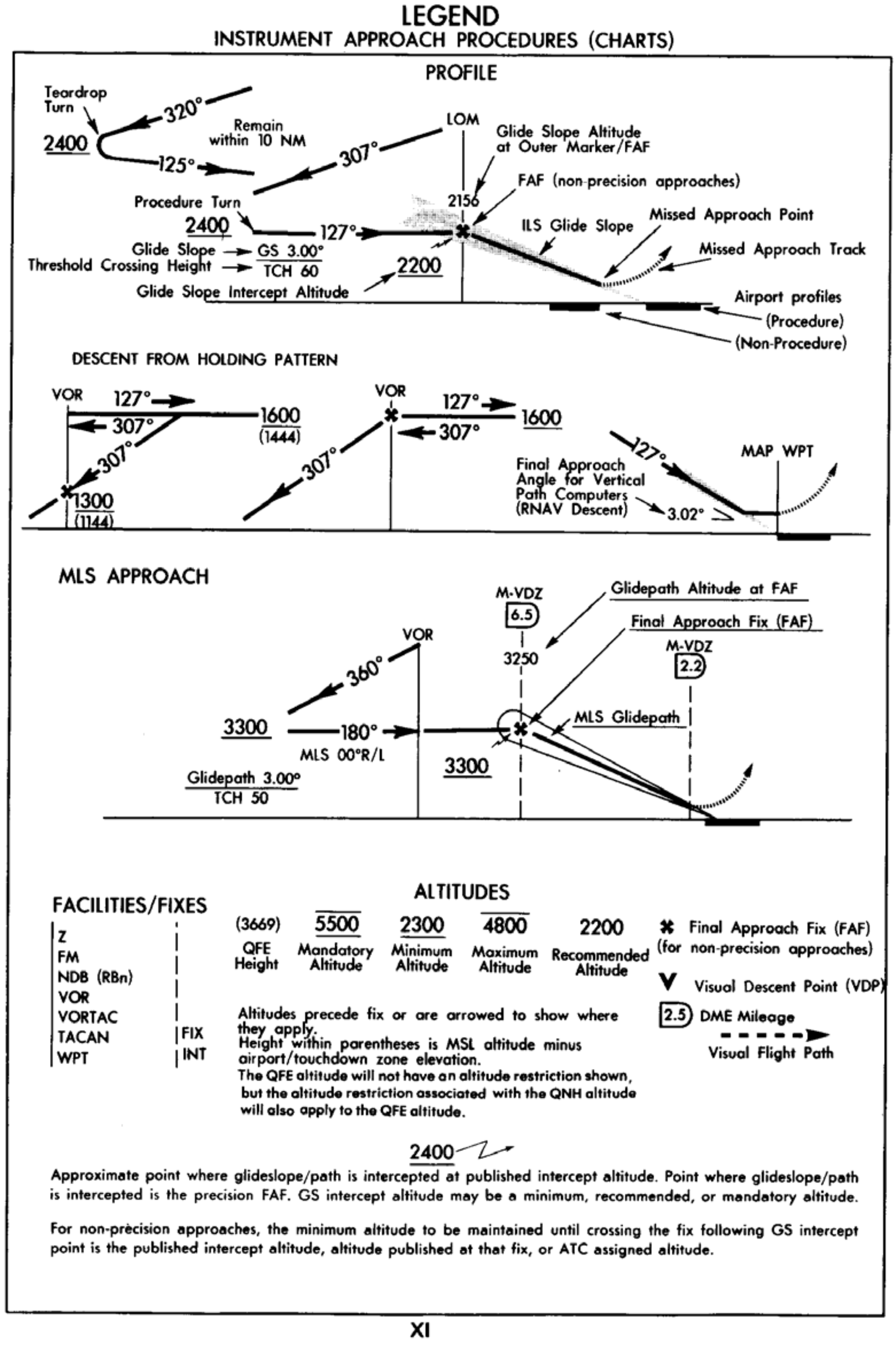


Figure A-4: LEGEND INSTRUMENT APPROACH PROCEDURES (2 OF 5)

IFR LANDING MINIMA

Landing minima are established for six aircraft approach categories (ABCDE and COPTER). In the absence of COPTER MINIMA, Helicopters may use the CAT A minimums of other procedures. The standard format for portrayal of landing minima is as follows:

RNAV MINIMA

CATEGORY	A	B	C	D
LNAV/DA VNAV	1500/24 318 (400-½)			1500/40 318 (400-¾)
LNAV MDA	1700/24 518 (600-½)		1700/50 518 (600-1)	1700/60 518 (600-1¼)
CIRCLING	1760-1 578 (600-1)		1760-1½ 578 (600-1½)	1760-2 578 (600-2)

RNAV minimums are dependent on navigation equipment capability, as stated in the applicable AFM or AFMS and as outlined below.

LNAV/VNAV (Lateral Navigation/Vertical Navigation) Must have WAAS equipment approved for precision approach, or RNP-0.3 system based on GPS or DME/DME, with an IFR approach approved Baro-VNAV system. Other RNAV approach systems require special approval. Use of Baro-VNAV systems is limited by temperature, i.e., "Baro-VNAV NA below -20°C(-4°F)". (Not applicable if chart is annotated "Baro-VNAV NA").

LNAV (Lateral Navigation) Must have IFR approach approved WAAS, GPS, GPS based FMS systems, or RNP-0.3 systems based on GPS or DME/DME. Other RNAV approach systems require special approval.

NOTE: DME/DME based RNP-0.3 systems may be used only when a chart note indicates DME/DME availability, for example."DME/DME RNP-0.3 Authorized." Specific DME facilities may be required, for example:"DME/DME RNP-0.3 Authorized. ABC, XYZ required."

INSTRUMENT APPROACH MINIMA
LOW ALTITUDE

CATEGORY	A	B	C	D
S-ILS 27	362/24 200 (200-½)			
S-LOC 27	440/24 278 (300-½)		440/40 278 (300-¾)	
CIRCLING	520-1 350 (400-1)	620-1 450 (500-1)	620-1½ 450 (500-1½)	720-2 550 (600-2)
S-PAR 27	262/16 100 (100-¼) GS 2.5°			

Precision Straight in to Runway 27 → S-ILS 27

Non-Precision (Localizer) Straight in to Runway 27 → S-LOC 27

Precision Approach Radar Straight in to Runway 27 → S-PAR 27

Aircraft Category → CATEGORY A

Decision Height (DH) MSL → 362

*Prevailing Visibility/RVR (RVR in 100s of feet) → 24

Height of DH above touchdown zone (HAT) → 200

Ceiling in feet & Prevailing Visibility in SM → (200-½)

Minimum Descent Altitude (MDA) → 520

Height of MDA above airport (HAA) → 450

Glide Slope Angle → GS 2.5°

Height of MDA above touchdown zone(HAT) → 278

COPTER MINIMA ONLY

CATEGORY	COPTER
H-176°	680-½ 363 (400-½)

Copter Approach Direction → H-176°

Height of MDA/DH Above Landing Area (HAL) → 363

No circling minimums are provided

*Slash(/) denotes RVR Values and a dash(-) denotes Prevailing Visibility

MINIMA DATA

▲ Alternate Minimums not standard USA/USAF/USN pilots refer to appropriate regulations.

▲NA Alternate Minimums are Not Authorized due to unmonitored facility or absence of weather reporting service.

▼ Take-off Minimums not standard and/or Departure Procedures are published. Refer to Tabulation.

Figure A-5: LEGEND INSTRUMENT APPROACH PROCEDURES (3 OF 5)

IFR LANDING MINIMA
(Continued)

RADAR MINIMA

* Prevailing Visibility/ RVR (RVR in 100s of feet)

Ceiling in feet & Prevailing Visibility in SM

	RWY	GS/TCH/RPI	CAT	DH/ MDA-VIS	HAT/ HAA	CEIL-VIS
PAR	35	2.5°/35/800	ABCDE	130/ 16	100	(100-¼)
ASR	35		AB	380/24	350	(400-½)
	26		CDE	380/40	350	(400-¾)
			AB	520/40	490	(500-¾)
			C	520/50	490	(500-1)
			D	520/60	490	(500-1¼)
			E	520-1½	490	(500-1½)
CIR	17-35		A	460-1	430	(500-1)
			B	480-1	450	(500-1)
			C	480-1½	450	(500-1½)
			DE	580-2	550	(600-2)
	26		AB	580-1	550	(600-1)
			C	580-1½	550	(600-1½)
			D	680-2	650	(700-2)
			E	680-2¼	650	(700-2¼)

*Slash (/) denotes RVR Values and a dash (-) denotes Prevailing Visibility

NOTE:

1. Minima shown are the lowest permitted by established criteria. Pilots should consult applicable directives of their respective services for aircraft model/command restrictions.
2. The minima for straight-in and circling approaches appear under the aircraft category. When there is no division line between categories, the minima apply to two or more categories. In the above illustration, precision straight-in minima are the same for all listed aircraft categories. For circling, however, note that landing minima differs by aircraft category.
3. The circling MDA and weather minima to be used are those for the runway to which the final approach is flown – not the landing runway. In the above RADAR MINIMA example, a category C aircraft flying a radar approach to runway 26, circling to land on runway 35, must use an MDA of 580 feet with weather minima of 600-1½.
4. IFF/SIF SERVICE: This service is considered to be an integral part of the radar system. Where this capability does not exist at an individual installation, the remarks "IFF/SIF svc not aval" are included in FOOTNOTE REMARKS.
5. Within countries that observe daylight saving time, a suffix symbol (++) will be added to the UTC(z) time to indicate that during daylight saving time the effective hours will be one hour earlier than shown.
6. Weather Planning Minimums: Ceiling is computed by subtracting the field elevation from the DH or MDA and, if not in even hundreds (of feet), this value will be rounded off upwards to the next hundred foot. Planning visibility is the published visibility for the approach.

XIII

Figure A-6: LEGEND INSTRUMENT APPROACH PROCEDURES (4 OF 5)

METAR CONVERSION CHART

CEILING

PUBLISHED MINIMA FEET	REQUIRED EQUIVALENT METERS
100	30
200	60
300	90
400	120
500	150
600	180
700	210
800	240
900	270
1000	300
1100	330
1200	360
1300	390
1400	420
1500	450

RUNWAY VISIBILITY

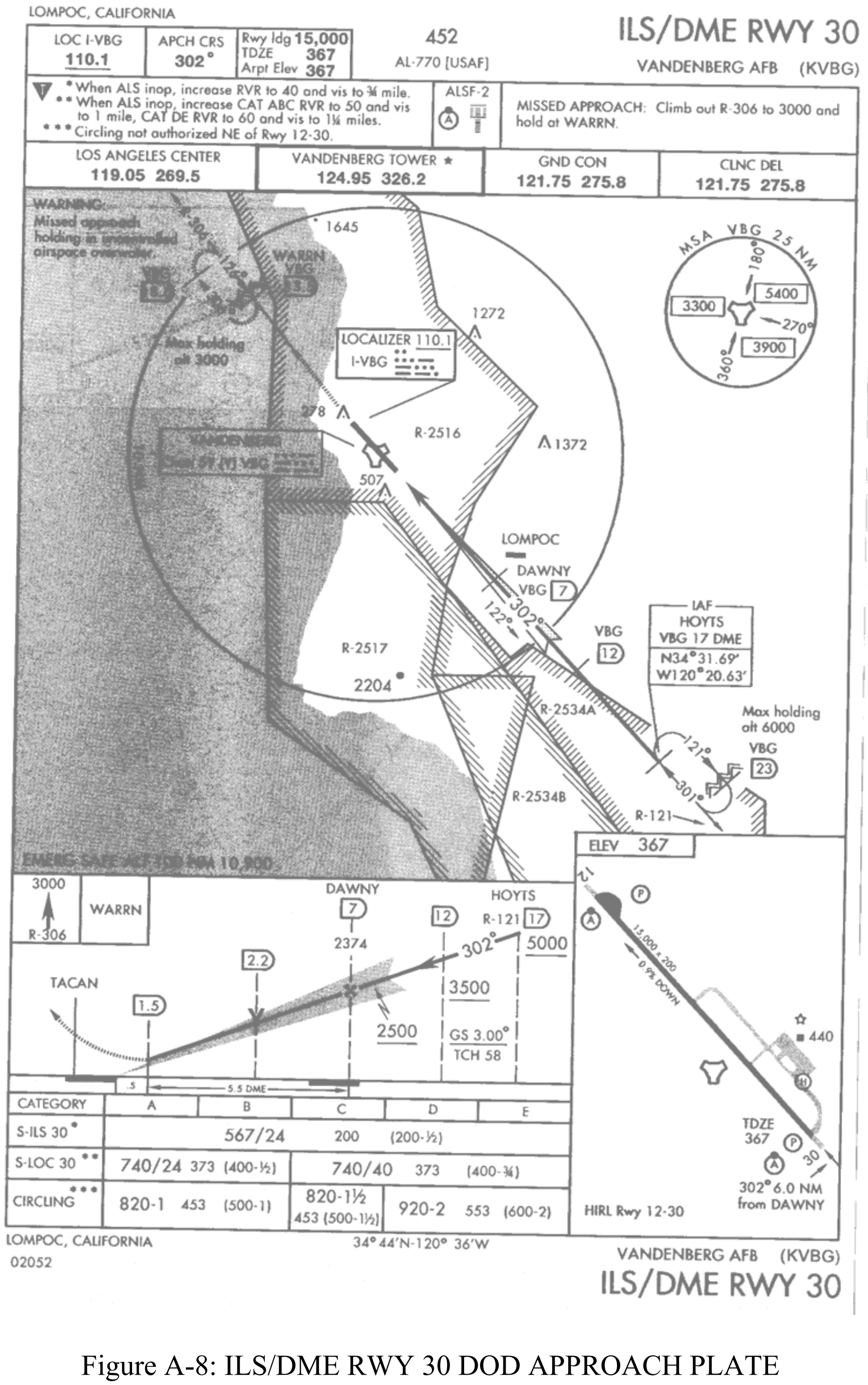
RVR VALUES PUBLISHED IN HUNDREDS OF FEET	STATUTE MILE EQUIVALENT	NAUTICAL MILE EQUIVALENT	METERS EQUIVALENT	KILOMETERS EQUIVALENT
12	1/4 (Helicopter Only)	2/10	370	.4
16	1/4	2/10	490	.5
20	3/8	3/10	610	.6
24	1/2	4/10	730	.7
32	5/8	6/10	970	1.0
40	3/4	7/10	1220	1.2
45	7/8	8/10	1370	1.4
50	1	9/10	1520	1.5
60	1-1/4	1-1/10	1830	1.8

PREVAILING VISIBILITY

STATUTE MILES	NAUTICAL MILES	METERS	KILOMETERS
1/8	1/10	200	.2
1/4	2/10	400	.4
3/8	3/10	600	.6
	4/10	700	.7
1/2		800	.8
	5/10	900	.9
5/8		1000	1.0
	6/10	1100	1.1
3/4		1200	1.2
	7/10	1300	1.3
7/8		1400	1.4
	8/10	1500	1.5
1		1600	1.6
	9/10	1700	1.7
1-1/8	1	1800	1.8
1-1/4	1-1/10	2000	2.0
1-3/8	1-2/10	2200	2.2
1-1/2	1-3/10	2400	2.4
1-5/8	1-4/10	2600	2.6

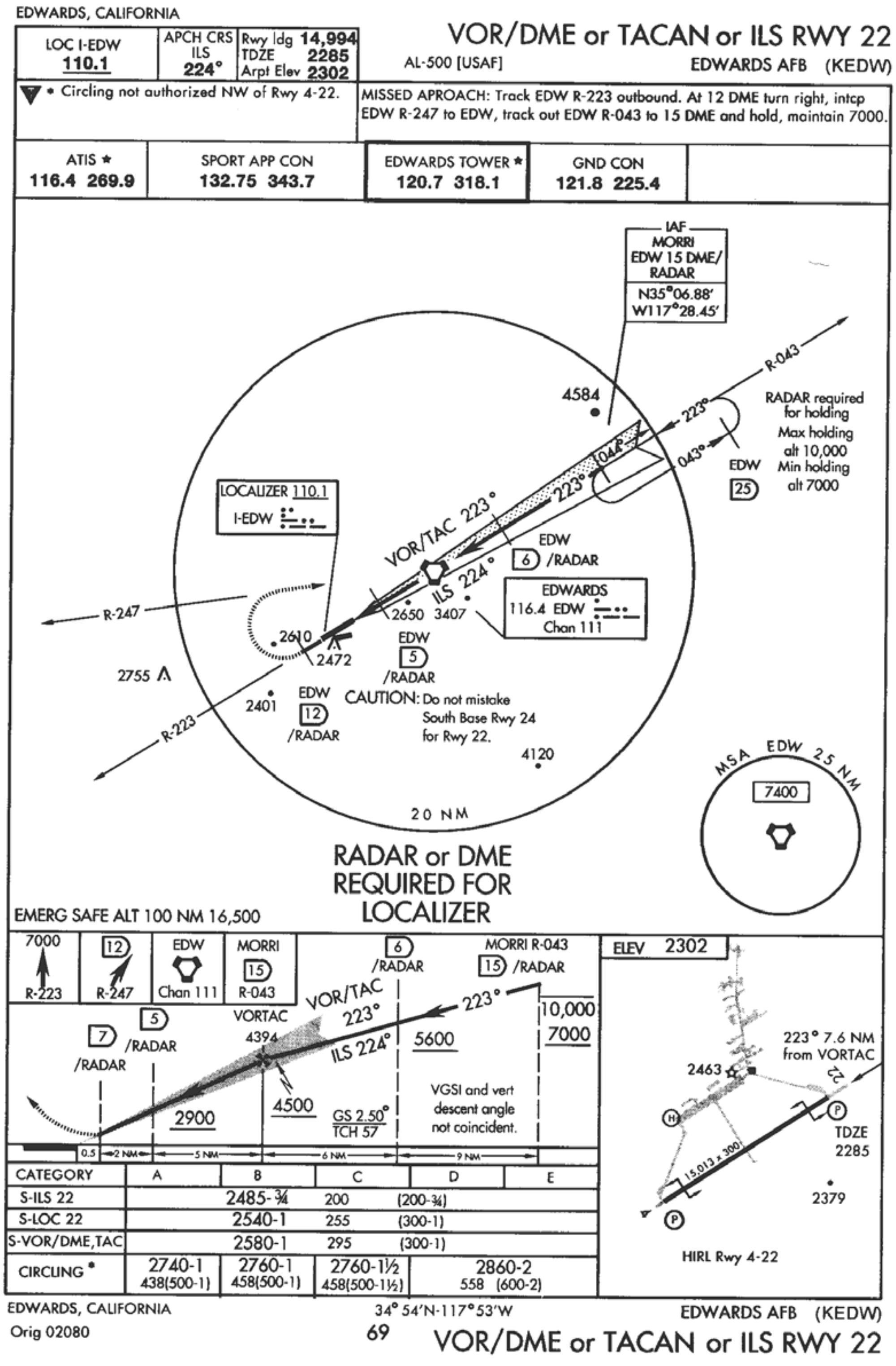
STATUTE MILES	NAUTICAL MILES	METERS	KILOMETERS
1-3/4	1-5/10	2800	2.8
1-7/8	1-6/10	3000	3.0
2	1-7/10	3200	3.2
	1-8/10	3400	3.4
2-1/4	1-9/10	3600	3.6
	2	3700	3.7
	2-1/10	3900	3.9
2-1/2	2-2/10	4000	4.0
2-5/8		4200	4.2
	2-3/10	4300	4.3
2-3/4		4400	4.4
	2-4/10	4500	4.5
2-7/8		4600	4.6
	2-5/10	4700	4.7
3	2-6/10	4800	4.8
	2-7/10	5000	5.0
	2-8/10	5200	5.2
	2-9/10	5400	5.4
	3	6000	6.0

Figure A-7: LEGEND INSTRUMENT APPROACH PROCEDURES (5 OF 5)



CATEGORY	A	B	C	D	E
S-ILS 30 *	567/24		200 (200-½)		
S-LOC 30 **	740/24 373 (400-½)		740/40 373 (400-¾)		
CIRCLING ***	820-1 453 (500-1)		820-1½ 453 (500-1½)	920-2 553 (600-2)	

Figure A-8: ILS/DME RWY 30 DOD APPROACH PLATE



CATEGORY	A	B	C	D	E
S-ILS 22	2485-¾ 200 (200-¾)				
S-LOC 22	2540-1 255 (300-1)				
S-VOR/DME,TAC	2580-1 295 (300-1)				
CIRCLING •	2740-1 438(500-1)	2760-1 458(500-1)	2760-1½ 458(500-1½)	2860-2 558 (600-2)	

Figure A-9: VOR/DME OR TACAN OR ILS RWY 22 DOD APPROACH PLATE

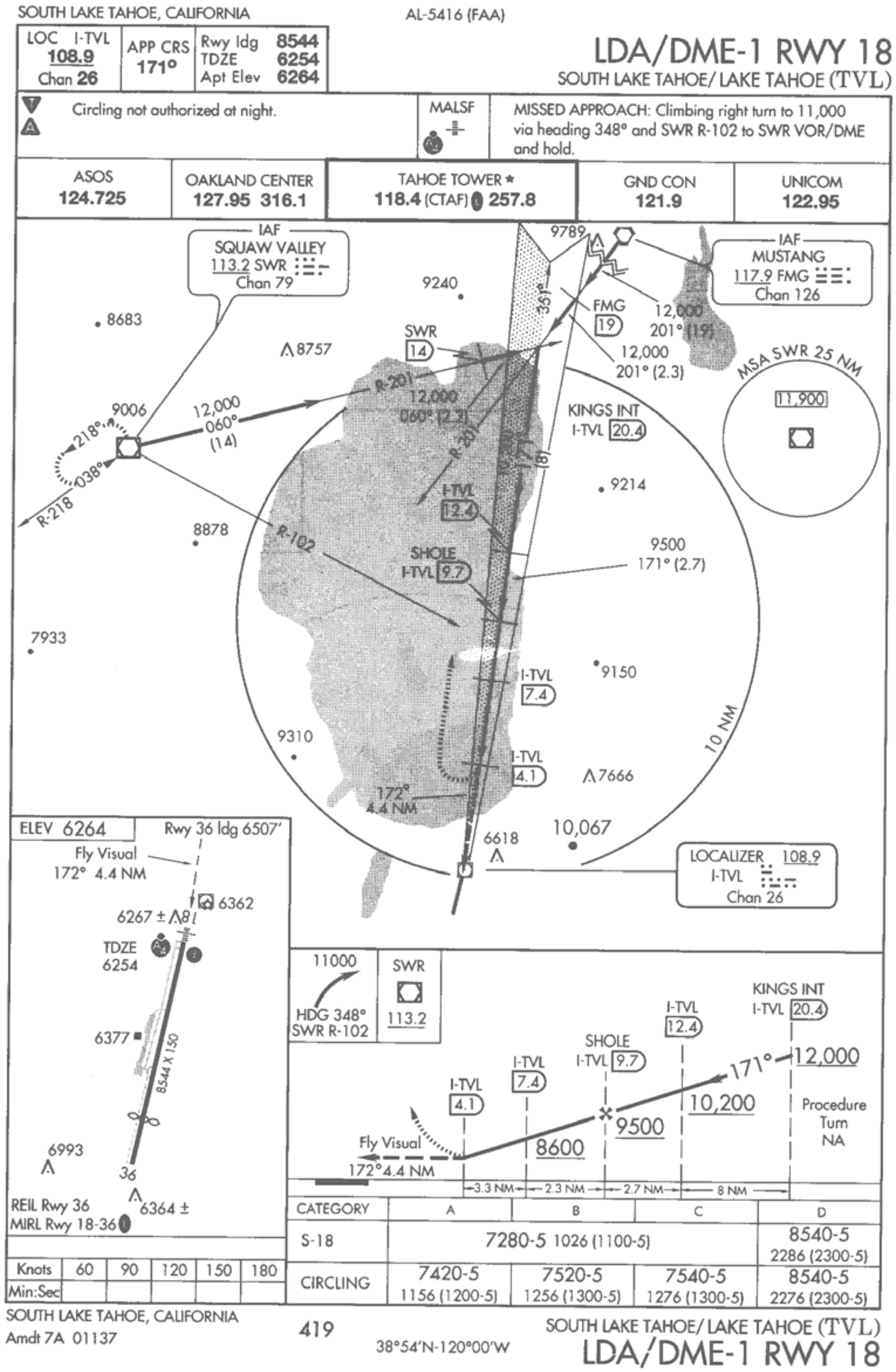


Figure A-10: LDA/DME-1 RWY 18 DOD APPROACH PLATE

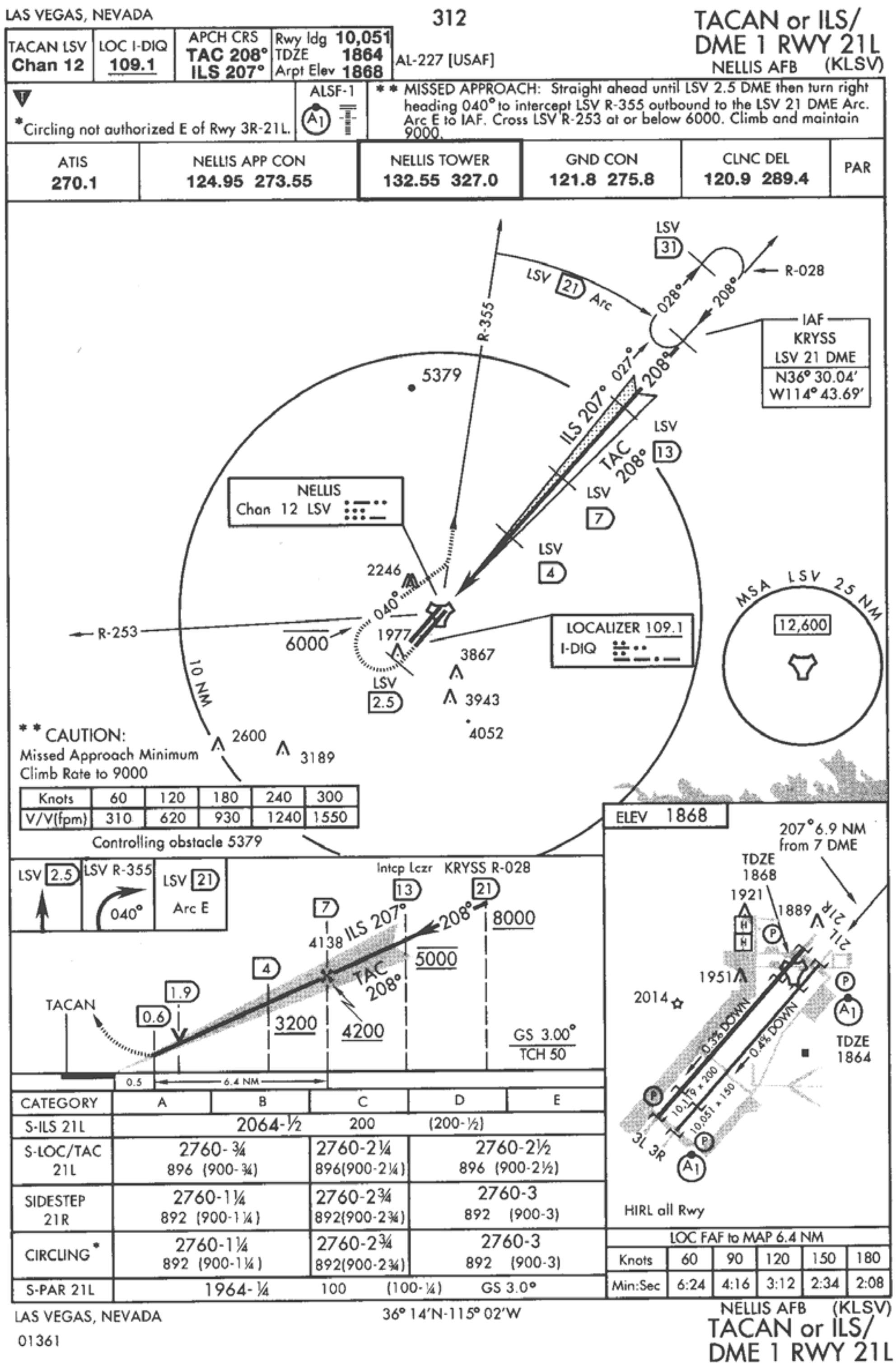
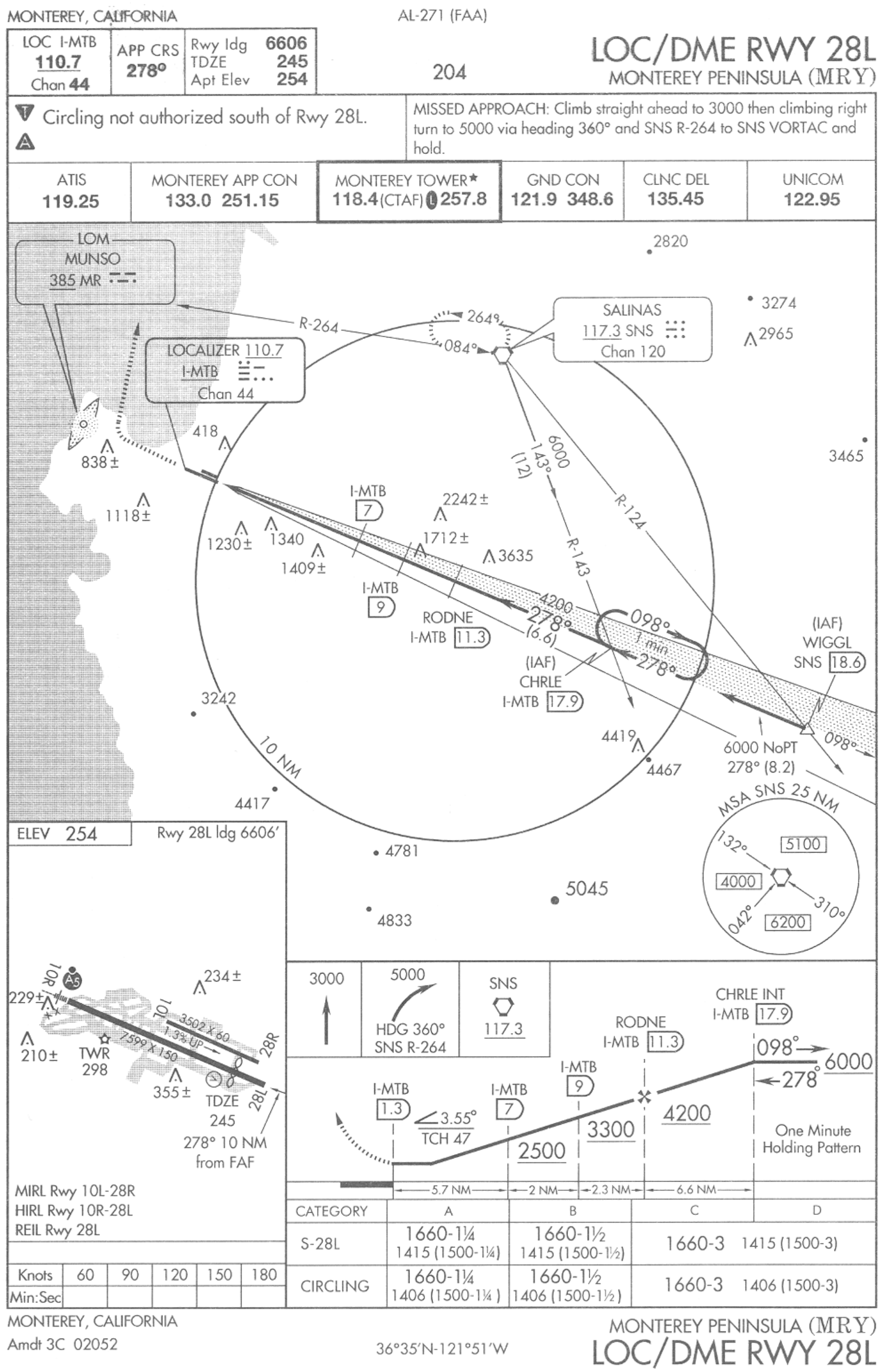


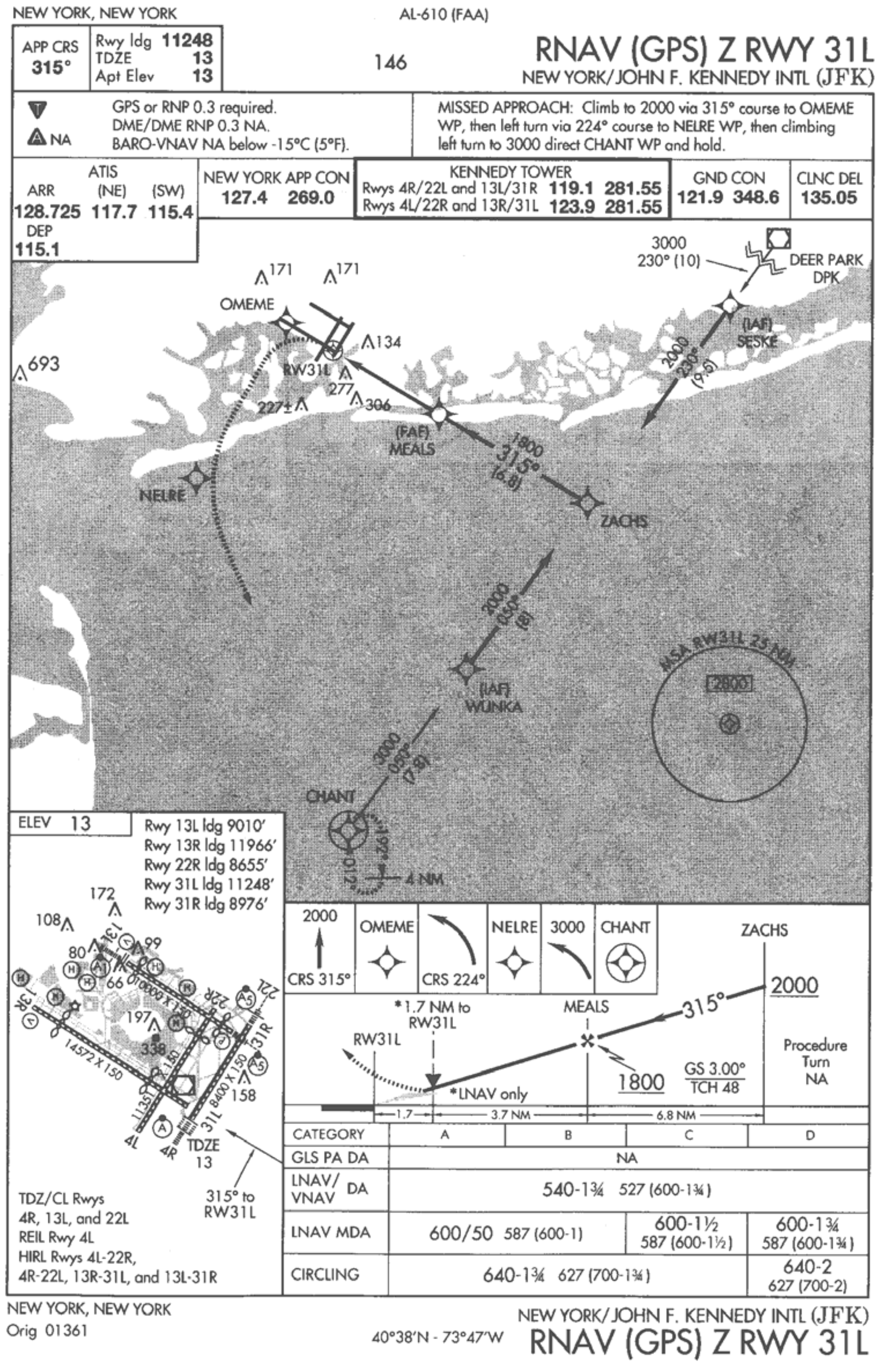
Figure A-11: TACAN OR ILS/DME 1 RWY 21L DOD APPROACH PLATE



CATEGORY	A	B	C	D
S-28L	1660-1¼ 1415 (1500-1¼)	1660-1½ 1415 (1500-1½)	1660-3 1415 (1500-3)	
CIRCLING	1660-1¼ 1406 (1500-1¼)	1660-1½ 1406 (1500-1½)	1660-3 1406 (1500-3)	

Knots	60	90	120	150	180
Min:Sec					

Figure A-12: LOCALIZER/DME RWY 28L MONTEREY PENINSULA DOD APPROACH PLATE



CATEGORY	A	B	C	D
GLS PA DA	NA			
LNAV/VNAV DA	540-1¾ 527 (600-1¾)			
LNAV MDA	600/50 587 (600-1)		600-1½ 587 (600-1½)	600-1¾ 587 (600-1¾)
CIRCLING	640-1¾ 627 (700-1¾)			640-2 627 (700-2)

Figure A-13: RNAV (GPS) Z RWY 31L DOD APPROACH PLATE

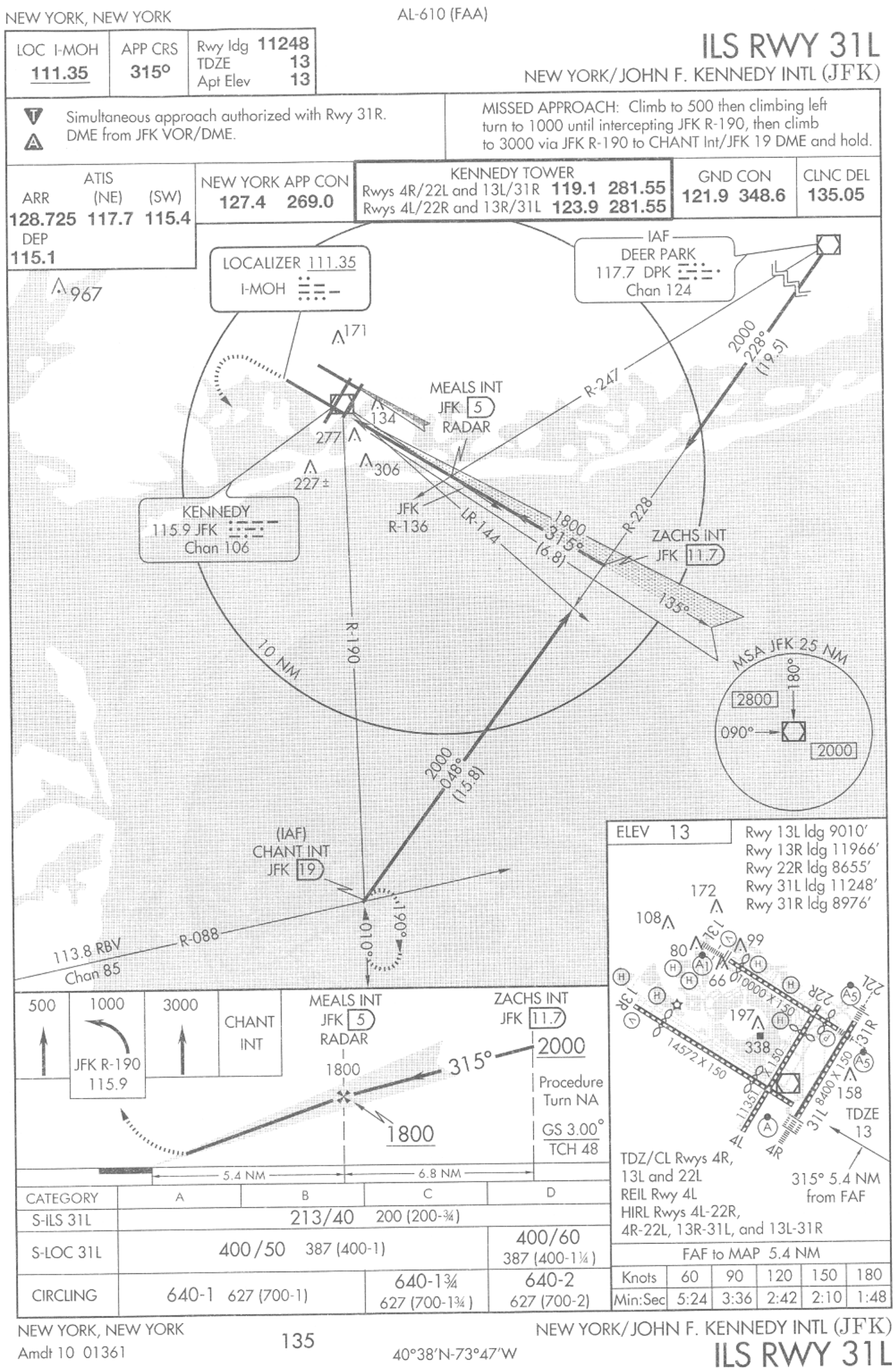
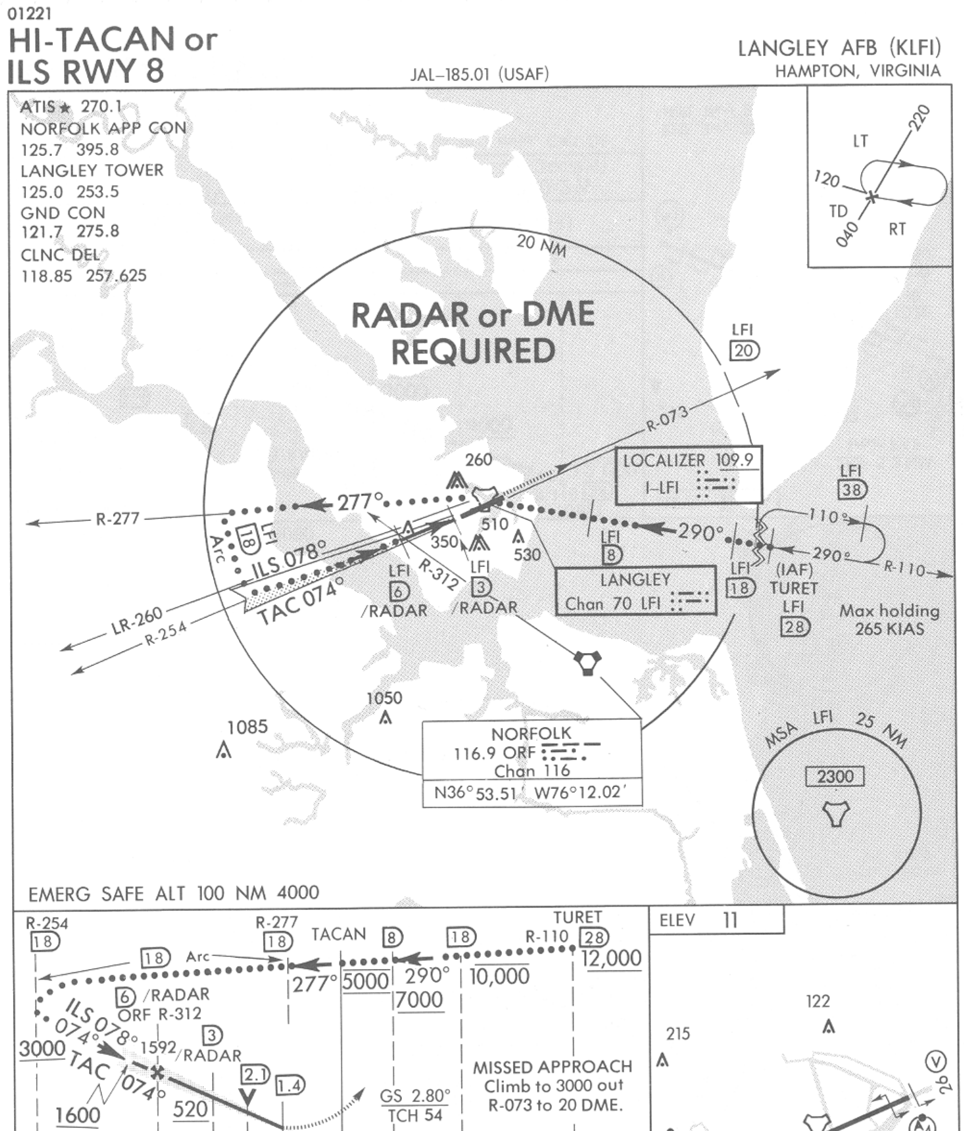


Figure A-14: ILS RWY 31L JFK DOD APPROACH PLATE



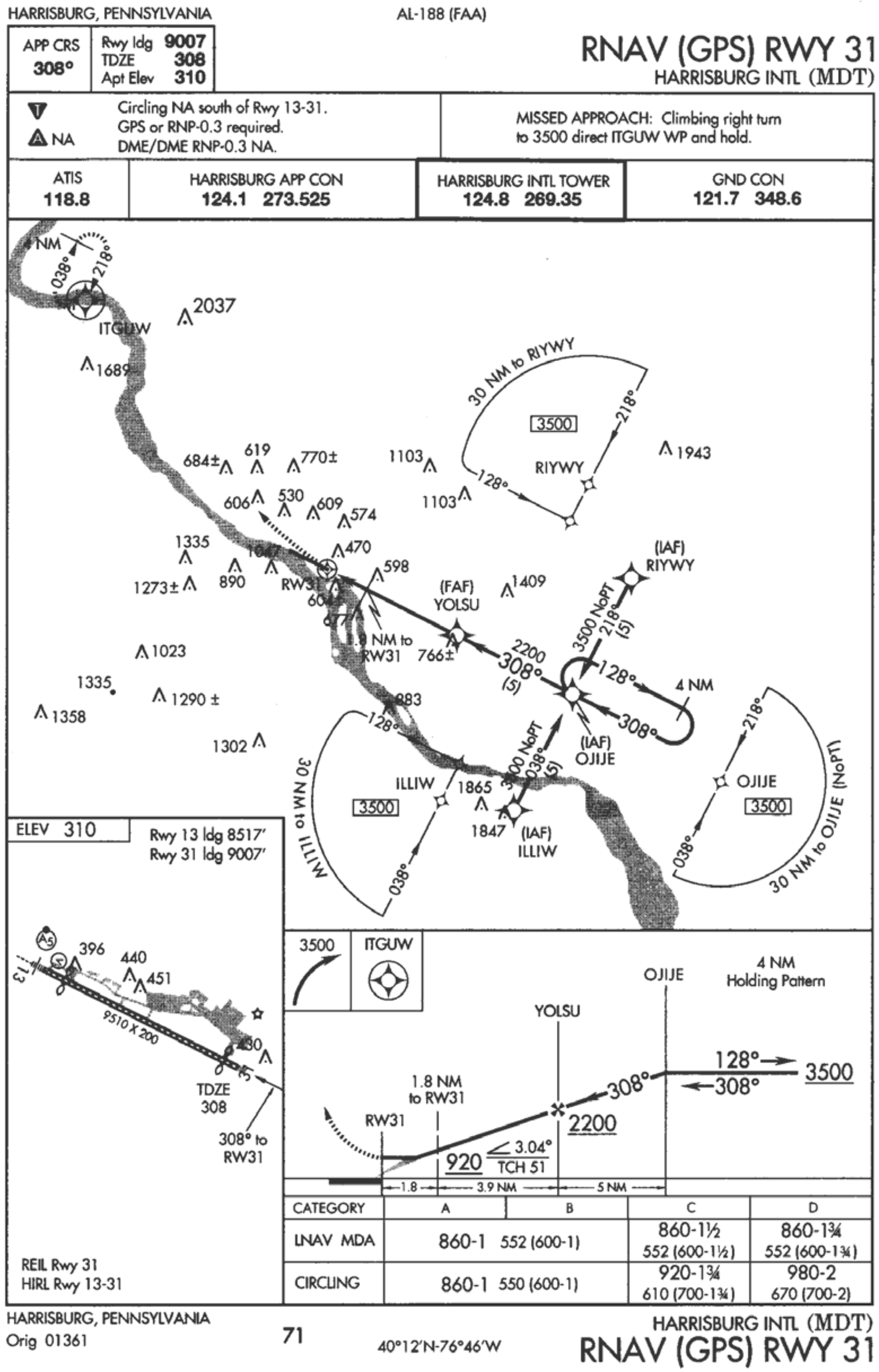
CATEGORY	C	D	E
S-ILS 8*	209/24	200	(200–½)
S-LOC,TAC** 8	400/40 391 (400-¾)		400/50 391 (400-1)
CIRCLING***	560-1½ 549 (600–1½)	580-2 569 (600–2)	740-2½ 729 (800-2½)

*When ALS inop, increase vis ¼ mile.
**When ALS inop, increase CAT C vis ¼, DE vis ½ mile.
***Circling S of Rwy 8-26 not authorized for CAT E acft.

FAF to MAP 4.6 NM					
Knots	120	140	160	180	200
Min:Sec	2:18	1:58	1:44	1:32	1:23

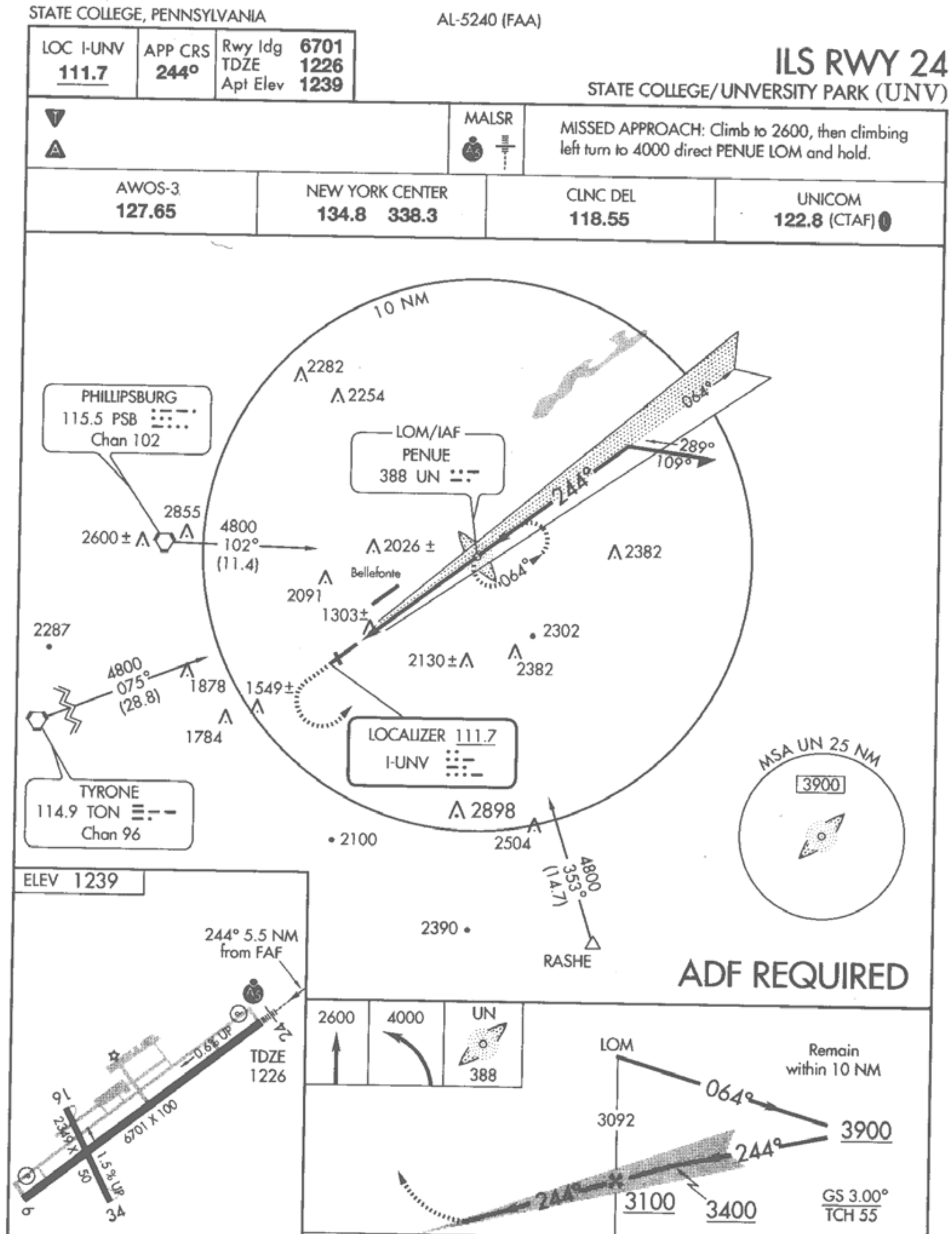
HI-TACAN or ILS RWY 8 — 37°05′N–76°21′W — 87 — HAMPTON, VIRGINIA, LANGLEY AFB (KLFI)

Figure A-15: HI-TACAN RWY 8 LANGLEY AFB DOD APPROACH PLATE



CATEGORY	A	B	C	D
LNAV MDA	860-1 552 (600-1)		860-1½ 552 (600-1½)	860-1¾ 552 (600-1¾)
CIRCLING	860-1 550 (600-1)		920-1¾ 610 (700-1¾)	980-2 670 (700-2)

Figure A-16: RNAV (GPS) RWY 31 DOD APPROACH PLATE



CATEGORY	A	B	C	D
S-ILS 24	1426-½ 200 (200-½)			
S-LOC 24	1620-½ 394 (400-½)			1620-¾ 394 (400-¾)
CIRCLING	1620-1 381 (400-1)	1700-1 461 (500-1)	1700-1½ 461 (500-1½)	2100-2¾ 861 (900-2¾)

FAF to MAP 5.5 NM

Knots	60	90	120	150	180
Min:Sec	5:30	3:40	2:45	2:12	1:50

STATE COLLEGE, PENNSYLVANIA
Amdt 8B 02052
291
40°51'N-77°51'W
STATE COLLEGE/UNIVERSITY PARK (UNV)
ILS RWY 24

Figure A-17: ILS RWY 24 STATE COLLEGE DOD APPROACH PLATE

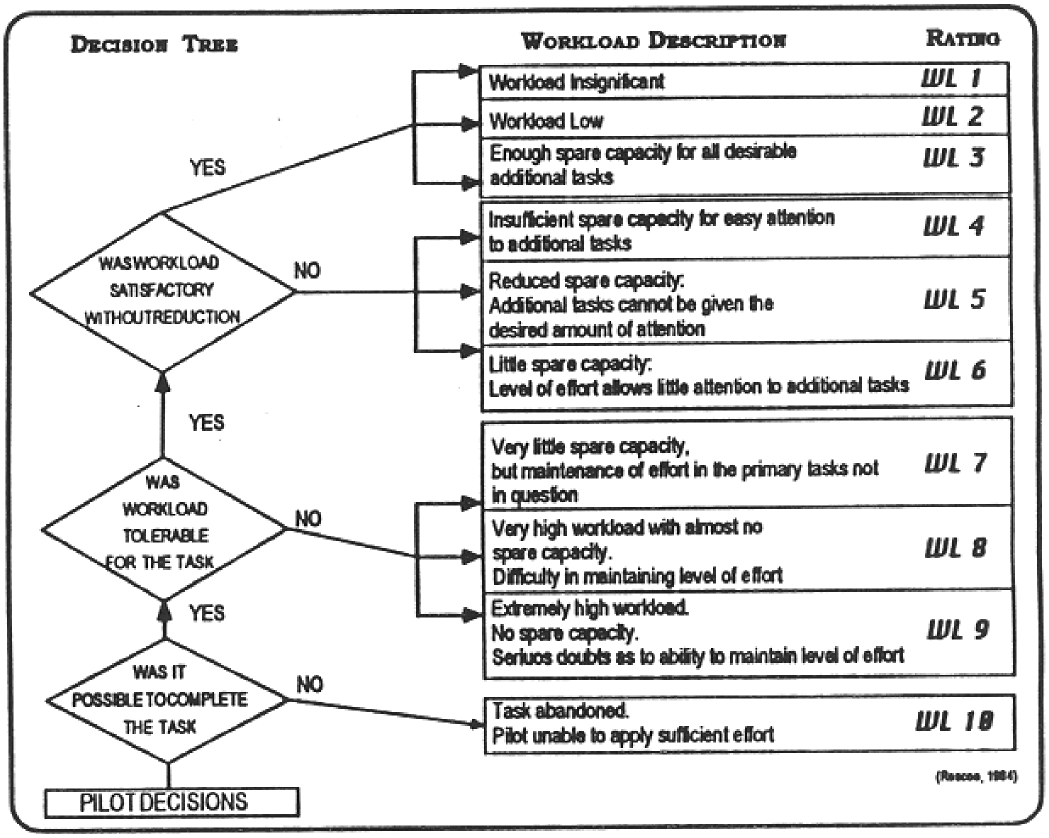


Figure A-18: BEDFORD WORKLOAD RATING

APPENDIX B
BLOCK 89A DEVELOPMENTAL TEST RESULTS

The Laser data gathered by ATR during one flight was used as truth data to evaluate the accuracy of the EGI GEM III position solution. The Tracking range of the ATR laser system was 8.5 miles, and the Root Mean Square (RMS) accuracy was three feet in range, with an angular accuracy of 0.1 mils. This accuracy was sufficient to compare with the GPS-only data. Three groups of tables are presented in this section. Inputs to the tables, and the number of data samples differ, but the overall layout of the tables is the same. Data values are expressed in meters. Table B-2 and Table B-5 are comprised of 2,931 data points, and include statistical information on the comparison of ATR laser position data and the GPS-only position data. Table B-3 and Table B-6 are comprised of 3,080 data points, and include statistical information on the comparison of ATR laser position data and the EGI hybrid position data. Table B-4 and Table B-7 are comprised of 89,017 data points and include statistical information on the comparison of EGI hybrid position data and the GPS-only position data. Table B-2, Table B-3, and Table B-4 represent the same type of statistics, with only the input data differing, so the explanation of columns and rows for these three tables is the same. An explanation of the rows follows: Number of samples represents how many data points were used in the calculations. The Mean is the sum of all the data points divided by the number of data points (average). The Median is a value in an ordered set of values below and above which there is an equal number of values, or which is the arithmetic mean of the two middle values if there is no one middle number. The standard deviation is the square root of the variance. The minimum is the lowest value of the position delta. The maximum is the highest value of the position delta. The midrange is numerically equidistant between the maxima and minima. 2DRMS is the 2 dimensional root mean square (3 dimensional root mean square for spherical). The columns represent statistical information based on one (cross track, along track, and altitude), two (horizontal), and three (spherical) dimensional calculations.

Table B-1: GPS ONLY VS. LASER OVERALL STATISTICS EXCEPT FOR THE NUMBER OF SAMPLES, VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
Number Of Samples	2961	2961	2961	2961	2961
Mean	2.1	-0.04	-7.31	4.01	9.08
Geometric Mean	-	-	-	3.42	7.76
Median	2.37	-0.28	-7.56	3.63	8.57
Standard Deviation	4.58	5.59	5.19	6.37	7.38
Minimum	-84.39	-106.47	-20.57	0.17	1.88
Maximum	142.97	189.57	2.95	237.21	237.54
Midrange	29.29	41.55	-8.81	118.69	119.71
2dRMS	-	-	-	15.05	23.4

Table B-2: HYBRID VS. LASER OVERALL STATISTICS
EXCEPT FOR THE NUMBER OF SAMPLES, VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
Number Of Samples	3080	3080	3080	3080	3080
Mean	3.09	-1.16	-7.87	5.19	10.33
Geometric Mean	-	-	-	4.33	9.27
Median	3.43	-1.12	-8.3	4.87	9.51
Standard Deviation	4.9	5.6	5.17	6.28	6.94
Minimum	-84.69	-97.84	-19.52	0.05	0.89
Maximum	140.61	188.58	2.45	232.58	232.84
Midrange	27.96	45.37	-8.54	116.32	116.87
2dRMS	-	-	-	16.28	24.89

Table B-3: HYBRID VS. GPS ONLY OVERALL STATISTICS
EXCEPT FOR THE NUMBER OF SAMPLES, VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
Number Of Samples	89017	89017	89017	89017	89017
Mean	-0.12	-0.07	-0.12	3.35	4.05
Geometric Mean	-	-	-	2.43	3.17
Median	-0.21	-0.02	0	2.57	3.29
Standard Deviation	11.27	3.92	2.91	11.45	11.6
Minimum	-301.66	-312.08	-158.95	0.01	0.03
Maximum	1558.46	354.85	29.87	1589.39	1589.4
Midrange	628.4	21.38	-64.54	794.7	794.71
2dRMS	-	-	-	23.86	24.56

Table B-5, Table B-6, and Table B-7 represent the same type of statistics, with only the input data differing, so the explanation of columns and rows for these three tables is the same. An explanation of the rows follows: 50th – the distance centered on the true value within which is contained 50% of the observations. 95th – the distance centered on the true value within which is contained 95% of the observations. 99th – the distance centered on the true value within which is contained 99% of the observations. The columns represent statistical information based on one (cross track, along track, and altitude), two (horizontal), and three (spherical) dimensional calculations. Table 5, GPS-only vs. laser, 50th percentile row, Spherical column, shows the SEP is well within the 16 meter SEP requirement for GPS position accuracy. Table 6, hybrid vs. laser, 50th percentile row, Spherical column, also shows the SEP is well within the 16 meter SEP requirement for

GPS position accuracy. Table 7, hybrid vs. GPS-only, shows a 50th percentile, SEP value of 3.29 meters. This was expected, since the Kalman filter within the EGI highly weights the GPS data in the estimating process. As a result, there was high confidence that the GPS-only solution had typical GEM III PPS accuracy, and was subsequently used as truth data to generate the various radial position error plots for both the CAINS and the EGI INS.

Figure B-1 and Figure B-2 represent the CAINS position solution referenced to the EGI GPS-only position solution. Only 12 of the total number of DT flights were included in the CAINS plots. GPS-only data with Figure of Merit (FOM) less than 4, and state 5 tracking (a receiver channel is precisely tracking the carrier signal and demodulating system data from the carrier) was used as reference data.

Figure B-1 input is based on particular points in time spanning all 12 flights. As the number of flights with long durations decreases, there is a rather sharp increase in the 95th Median ranked curve. Generally, with fewer than approximately 15 flights, the 95th Median ranked radial position error is not statistically representative and simply approaches the highest radial position error data value. Figure B-1 can be interpreted by matching the time of a normal flight profile with the position on the curve of the 50th Median ranked Radial Error position to estimate the most likely radial error value based on actual CAINS data.

Table B-4: FROM RANK AND PERCENTILE (ABSOLUTE DISTANCE)
GPS ONLY VS. LASER STATISTICS VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
50th (LEP/CEP/SEP)	2.43	2.04	7.56	3.63	8.57
95th	4.33	5.52	15.9	6.31	17.14
99th	6.4	6.15	17.53	8.63	19.34

Table B-5: FROM RANK AND PERCENTILE (ABSOLUTE DISTANCE)
HYBRID VS. LASER STATISTICS VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
50th (LEP/CEP/SEP)	3.52	2.27	8.3	4.87	9.51
95th	7.17	6.94	15.64	8.43	17.27
99th	8.27	8.16	17.3	9.75	19.24

Table B-6: FROM RANK AND PERCENTILE (ABSOLUTE DISTANCE)
HYBRID VS. GPS ONLY STATISTICS VALUES ARE IN METERS

	North	East	Altitude	Radial	Spherical
50th (LEP/CEP/SEP)	1.57	1.42	1.22	2.57	3.29
95th	6.73	5.22	4.72	7.89	8.65
99th	9.41	7.88	7.92	10.66	12.28

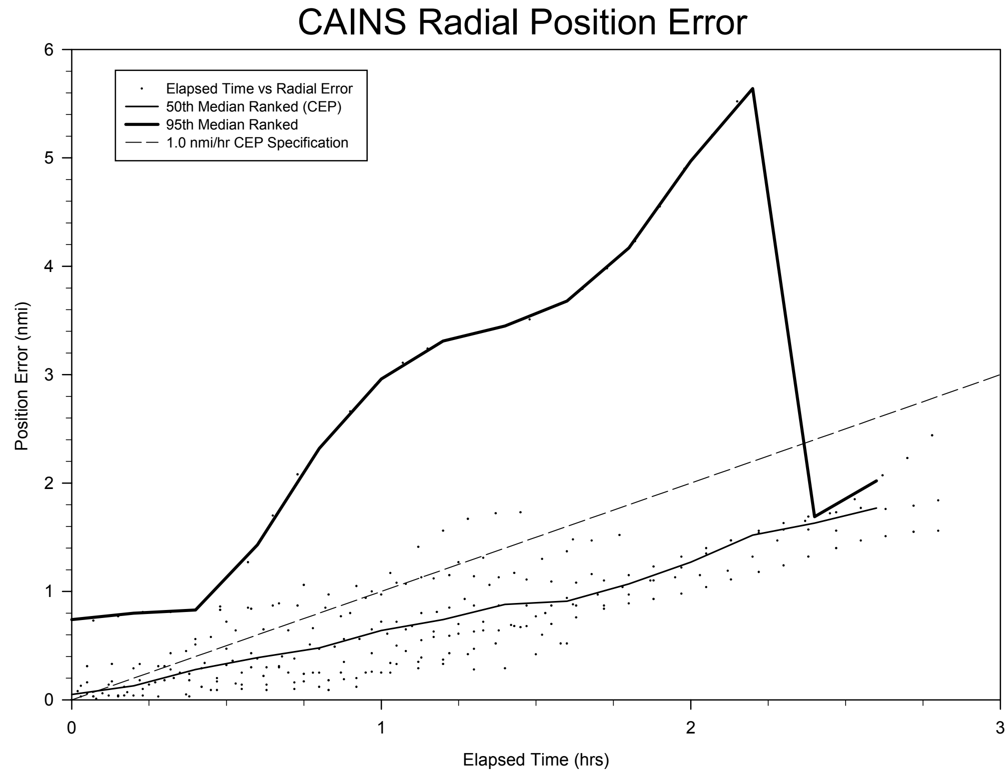


Figure B-1: CAINS Radial Position Error

Figure B-2 input is also based on particular points in time spanning all 12 flights. The curves on this figure represent different ways of expressing navigation accuracy distributions. When the curves from the different distribution types are similar in shape and close in value, as seen on this plot, there is a high confidence that the data is statistically representative. The divergence of the AIRSTD R50, Weibull R50, Bivariate R50 and Median R50 on this figure is caused by a decrease in sample size - there were few flights of long duration.

Drift of the CAINS with respect to EGI GPS-only position is: 0.64 nautical miles (at 1 hour) CEP from Median Ranked Data 0.74 nautical miles (at 1 hour) CEP from AIRSTD (A Navy approved method of determining CEP) 2.14 nautical miles (at 1 hour) 2dRMS.

Figure B-3 and Figure B-4 represent the EGI INS position solution referenced to EGI GPS-only position solution. Fifteen flights were used to calculate the data.. GPS-only data with Figure of Merit (FOM) less than 4, and state 5 tracking (a receiver channel is precisely tracking the carrier signal and demodulating system data from the carrier) was used as reference data.

Figure B-3 input is based on particular points in time spanning all 15 flights. As the number of flights with long durations decreases, there is a rather sharp increase in the 95^{th}

Median ranked curve. Generally, with fewer than approximately 15 flights, the 95th Median ranked radial position error is not statistically representative and simply approaches the highest radial position error data value. Figure B-3 can be interpreted by matching the time of a normal flight profile with the position on the curve of the 50th Median ranked Radial Error position to estimate the most likely radial error value based on actual EGI INS data.

Figure B-4 input is also based on particular points in time spanning all 15 flights. The curves on this figure represent different ways of expressing navigation accuracy distributions. When the curves from the different distribution types are similar in shape and close in value, as seen on this plot, there is a high confidence that the data is statistically representative. As also seen in Figure B-2, the divergence of the AIRSTD R50, Weibull R50, Bivariate R50 and Median R50 on this figure is caused by a decrease in sample size - there were few flights of long duration. Drift of the EGI INS with respect to EGI GPS position is: 0.62 nautical miles (at 1 hour) CEP from Median Ranked Data 0.65 nautical miles (at 1 hour) CEP from AIRSTD 1.72 nautical miles (at 1 hour) 2dRMS

During DT, observations of altitudes on various cockpit displays showed different values. Therefore, altitude data from the laser flight was compared to altitude sensors on the aircraft.

Figure B-5 represents the overall magnitude of the difference in meters between the GPS-only altitude and the laser altitude for the times when the laser was tracking the aircraft. The magnitude of the error is fairly small, since both the GPS-only altitude and the laser altitude are both based on Mean Sea Level (MSL). Note the magnitude of the altitude delta remains fairly constant through all altitudes. The laser accuracy is dependent on slant range, and that is why the altitude error decreases with decreased range. There are a large number of data points at a laser altitude of 800 meters, probably caused by the laser initially getting a lock on the aircraft while the aircraft was still flying at level altitude.

Figure B-6 represents the overall magnitude of the difference in meters between the EGI Hybrid altitude and the laser altitude for the times when the laser was tracking the aircraft. The magnitude of the error is fairly small, since the EGI hybrid altitude is influenced by the GPS-only altitude, and as noted in Figure B-5, the GPS-only and laser altitude difference is small. Individual runs can be seen on this figure. The altitude errors decrease as the aircraft range to the laser decreases, since the laser data accuracy is based on slant range. The data points on the top right are most likely caused by a poor laser track. There are a large number of data points at a laser altitude of 800 meters, probably caused by the laser initially getting a lock on the aircraft while the aircraft was still flying at level altitude.

Figure B-7 represents the overall magnitude of the difference in meters between the EGI INS altitude and the laser altitude for the times when the laser was tracking the aircraft. The magnitude of the error is more significant than Figure B-5 and Figure B-6, since the EGI INS altitude is Baro Inertial altitude. Individual runs can be seen on this figure. The altitude errors decrease as the aircraft range to the laser decreases, since the laser data accuracy is based on slant range. The data points on the top right are most likely caused by a poor laser track. There are a large number

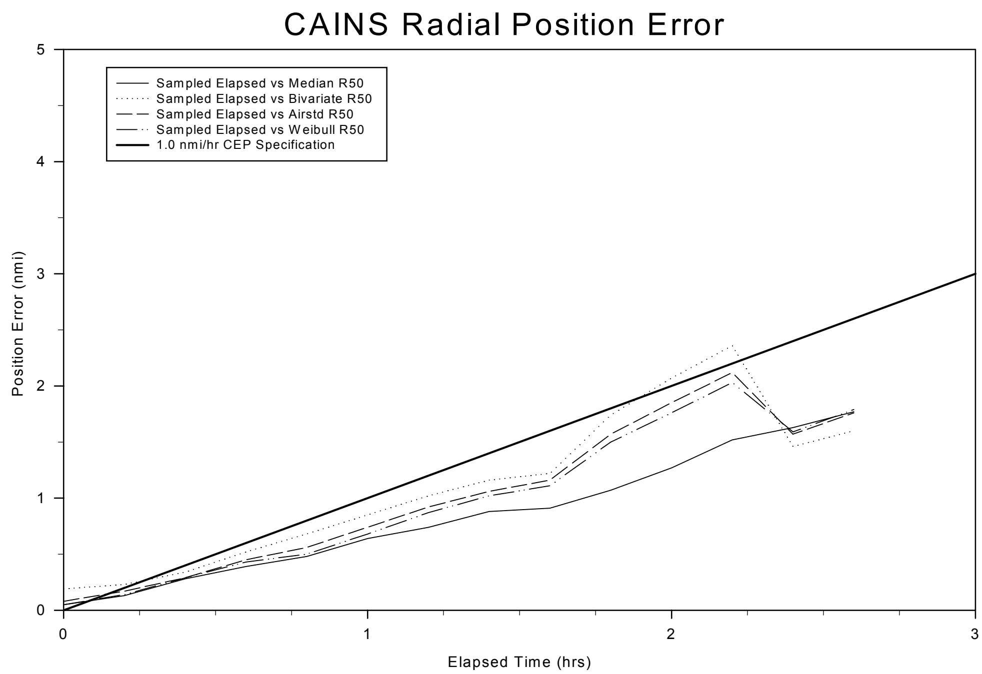


Figure B-2: CAINS RADIAL POSITION ERROR

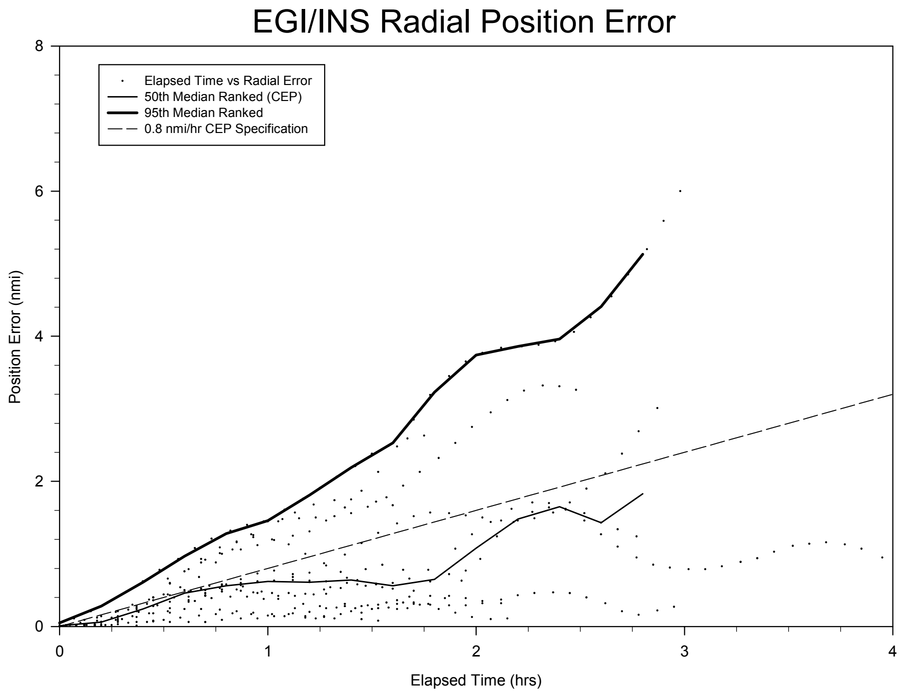


Figure B-3: EGI/INS RADIAL POSITION ERROR 50TH AND 95TH MEDIAN RANKED

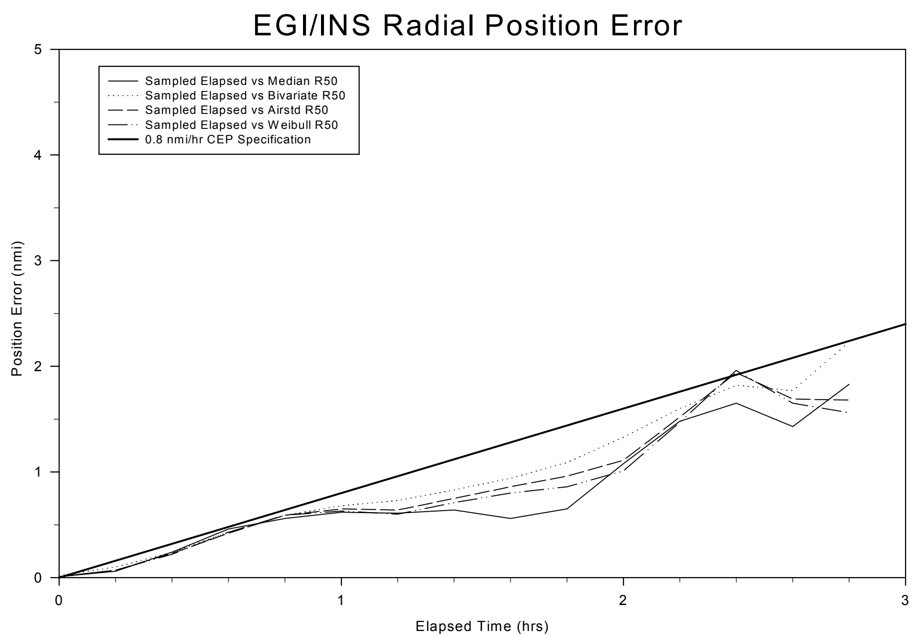


Figure B-4: EGI/INS Radial Position Error

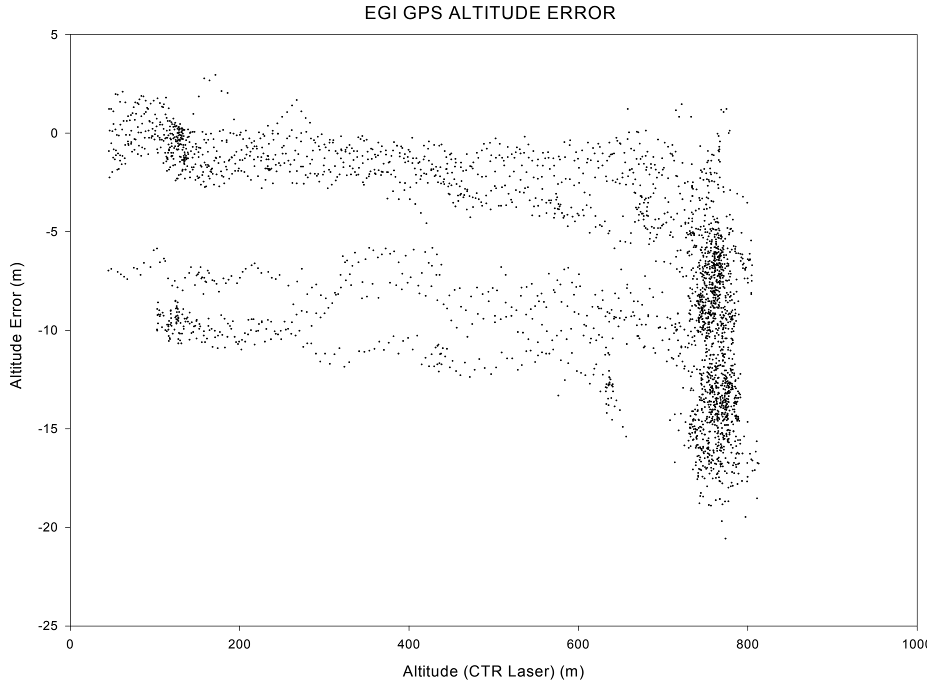


Figure B-5: EGI GPS ALTITUDE ERROR WITH RESPECT TO CTR LASER ALTITUDE

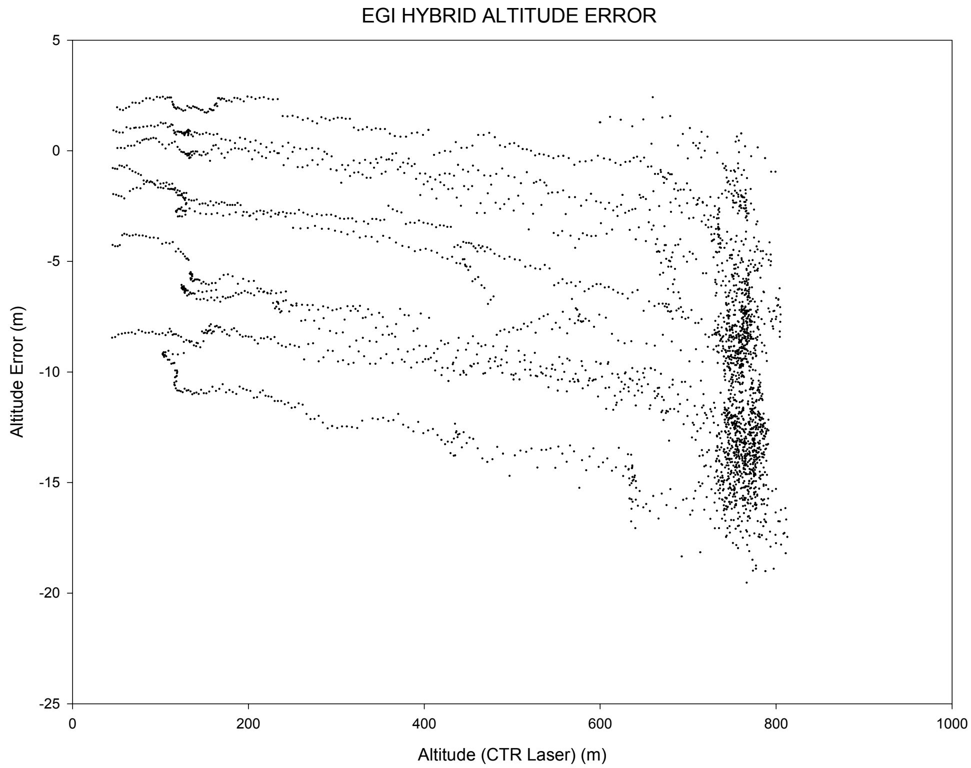


Figure B-6: EGI HYBRID ALTITUDE ERROR WITH RESPECT TO CTR LASER ALTITUDE

of data points at a laser altitude of 800 meters, probably caused by the laser initially getting a lock on the aircraft while the aircraft was still flying at level altitude. Figure B-8 represents the overall magnitude of the difference in meters between the CAINS altitude and the laser altitude for the times when the laser was tracking the aircraft. The magnitude of the error is more significant than Figure B-5 and Figure B-6, and similar to Figure B-7, since the CAINS altitude is also Baro Inertial altitude. Individual runs can be seen on this figure. The altitude errors decrease as the aircraft range to the laser decreases, since the laser data accuracy is based on slant range. The data points on the top right are most likely caused by a poor laser track. There are a large number of data points at a laser altitude of 800 meters, probably caused by the laser initially getting a lock on the aircraft while the aircraft was still flying at level altitude.

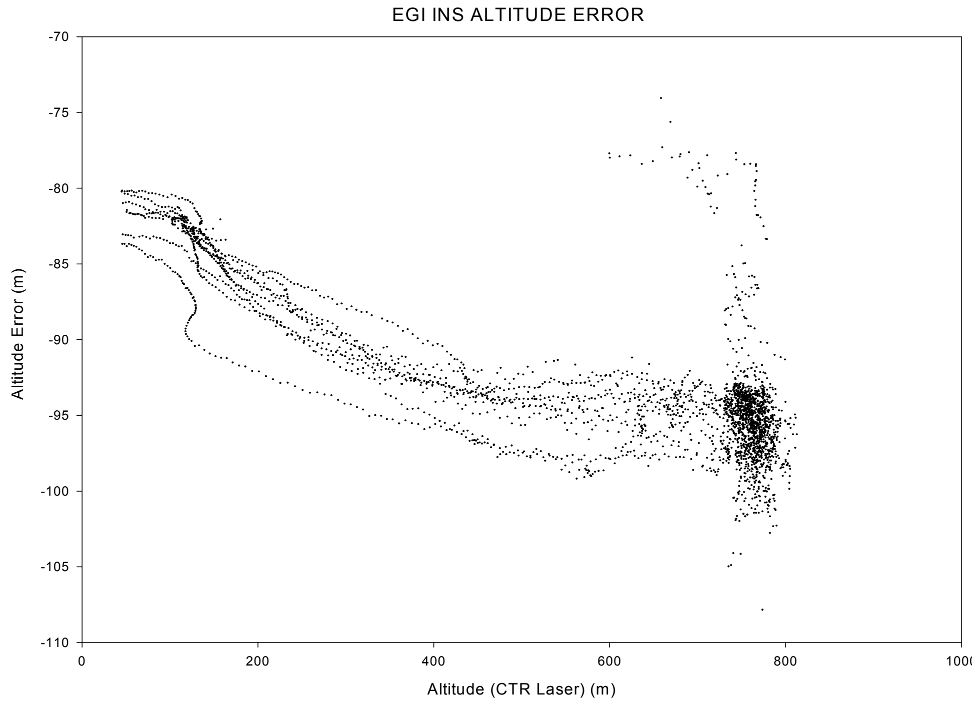


Figure B-7: EGI INS ALTITUDE ERROR WITH RESPECT TO CTR LASER ALTITUDE

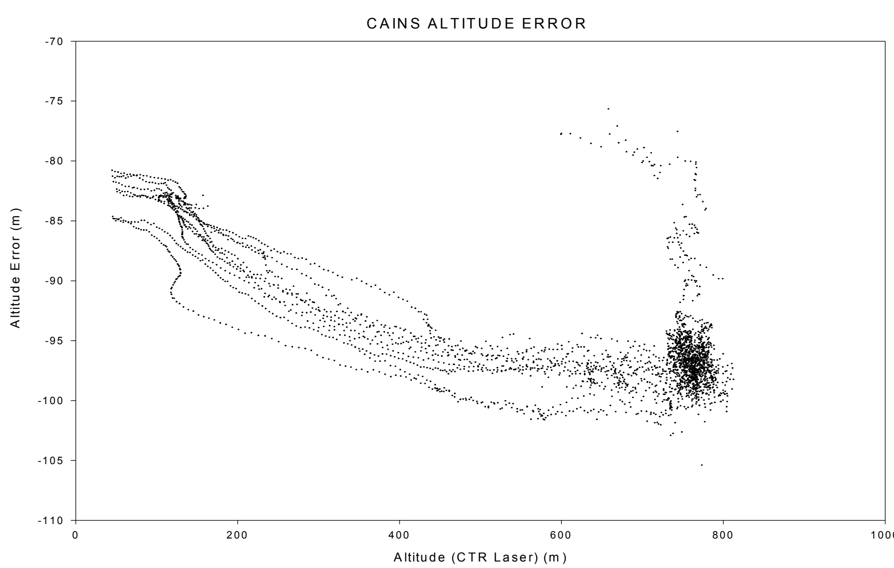


Figure B-8: CAINS ALTITUDE ERROR WITH RESPECT TO CTR LASER ALTITUDE

Table B-7: NAVIGATION SYSTEM TEMP CRITICAL TECHNICAL PARAMETERS AND RESULTS

Critical **TECHNICAL** Parameters	Horizontal Position M-CEP Threshold	DT Results M-CEP (2 drms)	Velocity KN/HR-LEP Threshold	DT Results KN-LEP	Altitude M-LEP Threshold	DT Results M-LEP
En Route Nav Airway Low Level Terminal	≤1,000 (2 drms) ≤50 (2 drms) ≤500 (2 drms)	16.3 (Pass) 16.3 (Pass) 16.3 (Pass)	≤0.1	0.04 (Pass) Note 2	FL180-600 ≤±22.5	8.3 (Pass)
Approach/Landing Nonprecision Land Sea Precision Land Sea	≤±100 (2 drms) ≤±12 (2 drms) ≤±5.2 (2 drms) ≤±0.6 (2 drms)	Note 1 Note 1 Note 1 Note 1	≤0.9	Note 1	250-3,000 ft ≤±3 ≤±1.7 VP ≤±0.6 VP	Note 1 Note 1 Note 1
EW Mission	≤22.5	16.3 (Pass)	≤0.3	0.04 (Pass) Note 2	≤22.5	8.3 (Pass)

M-CEP - meters-circular error probable.
2 drms – two-dimension root mean square.
KN/HR-LEP - knots per hour - linear error probable.
KN-LEP - knots - linear error probable.
M-LEP - meters-linear error probable.

NOTES: (1) Precision/nonprecision GPS approaches and landings not required. Precisions/ nonprecision approach and landing systems same as in previous block aircraft, no performance changes.

(2) Value calculated is mean of 18 postflight updates.

Table B-8: EMBEDDED GPS/INS TEMP CRITICAL TECHNICAL PARAMETERS AND RESULTS

Critical Technical Parameters	Threshold	Test Results
Inertial Only Performance		
Position (CEP)	≤1 nmi/hr (1 hr)	0.62 nmi/hr (Pass)[(1)]
Velocity (X, Y)	≤3.0 fps	2.6 fps (Pass)[(1)]
Velocity (Z)	≤2.0 fps	0.3 fps (Pass)[(1)]
Pitch, Roll (rms)	≤0.05 deg	0.02 deg (Pass)[(1)]
Platform Azimuth (rms)	≤0.05 deg	0.02 deg (Pass)[(1)]
True Heading (rms)	≤0.1 deg	0.02 deg (Pass)[(1)]
Alignment (Ground)	≤4 min	4 min (Pass)[(1)]
GPS Only Solution		
Position (SEP)	≤16 m	6.2 m (Pass)[(1)]
Velocity (rms)	≤0.1 m/sec	0.1 msec (Pass)[(1)]
Time (rms)	< 100 nsec	87.9 nsec (Pass)[(1)]
GPS/INS Blended Solution		
Position (SEP)	≤16 m	6.9 m (Pass)[(1)]
Velocity (rms)	≤0.1 m/sec	0.1 msec (Pass)[(1)]
Pitch, Roll (rms)	≤0.05 deg	0.02 deg (Pass)[(1)]
Platform Azimuth	≤0.05 deg	0.02 deg (Pass)[(1)]

NOTES: (1) These uninstalled EGI values were provided by the EGI Technical Director (Code: ASC/SMYB), EGI Tri-Service Program Office, Wright-Patterson AFB, on 7 December 1998 based upon several reports which are available upon request.

Table B-9: BLOCK 89A SYSTEM ALTITUDES

Date: 14 September 1998

Aircraft BuNo: 160434
CDNU OFP: 06.01.25
CMC OFP: 02.00.16

Altimeter Setting	PA Aiding (ft)	Altimeter (Standby – ft)	Altimeter (Reset - ft)	ALQ-99 System (ft)	CDNU (ft)	True Airspeed (KTAS)
29.92	19,940	20,040	19,940	20,988	21,015	420
29.72	17,100	17,000	16,950	17,916	18,000	400
29.73	12,150	12,000	N/A	12,760	12,760	330
29.73	1,950	1,900	N/A	N/A	N/A	231
29.73	N/A	3,950	3,900	4,116	4,116	290
29.73	15,080	15,000	14,950	15,704	15,680	465
29.92	19,970	19,950	20,000	20,820	20,820	460
29.77	11,550	11,500	11,450	12,024	11,980	440
29.77	N/A	3,000	3,050	3,052	N/A	412

APPENDIX C
BLOCK 89A SOFTWARE VERSION 1.0 CDNU PAGES

INDEX START

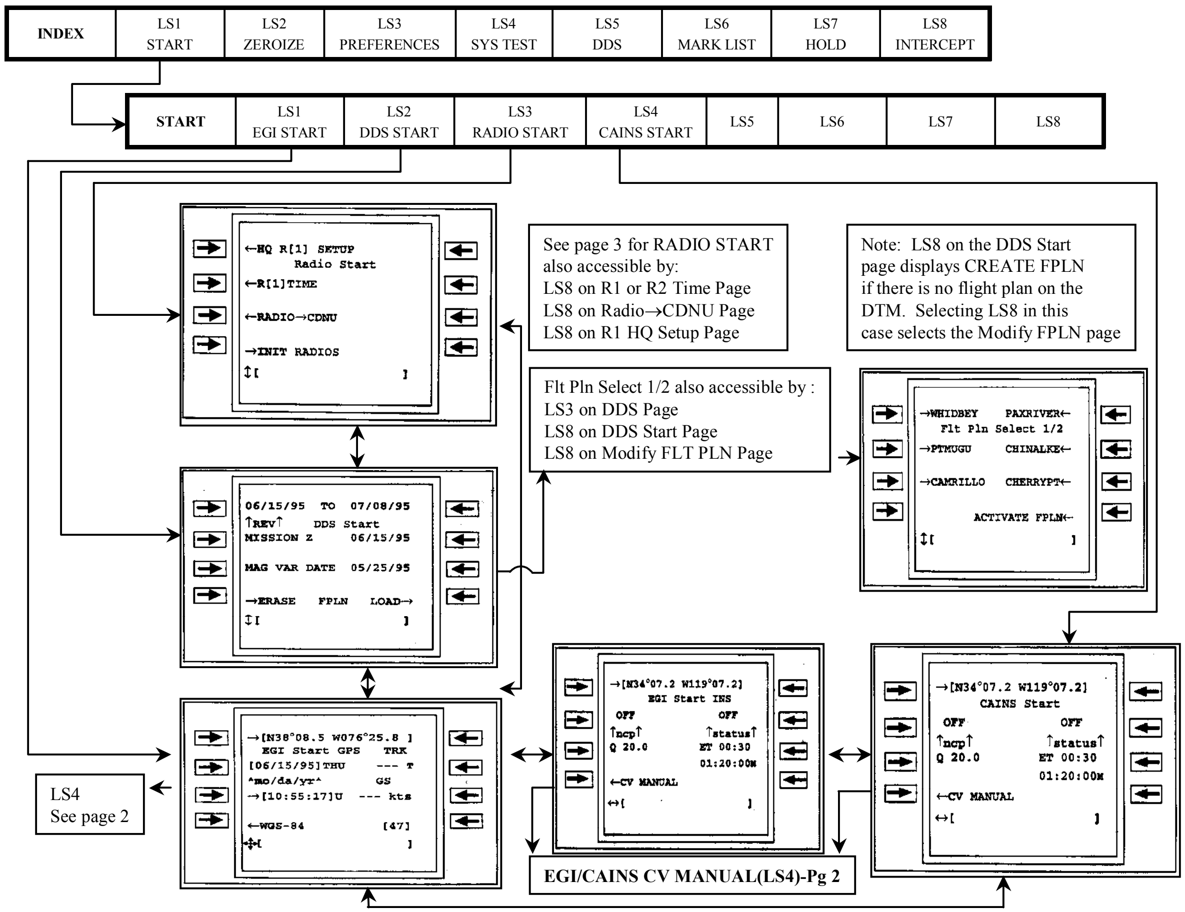
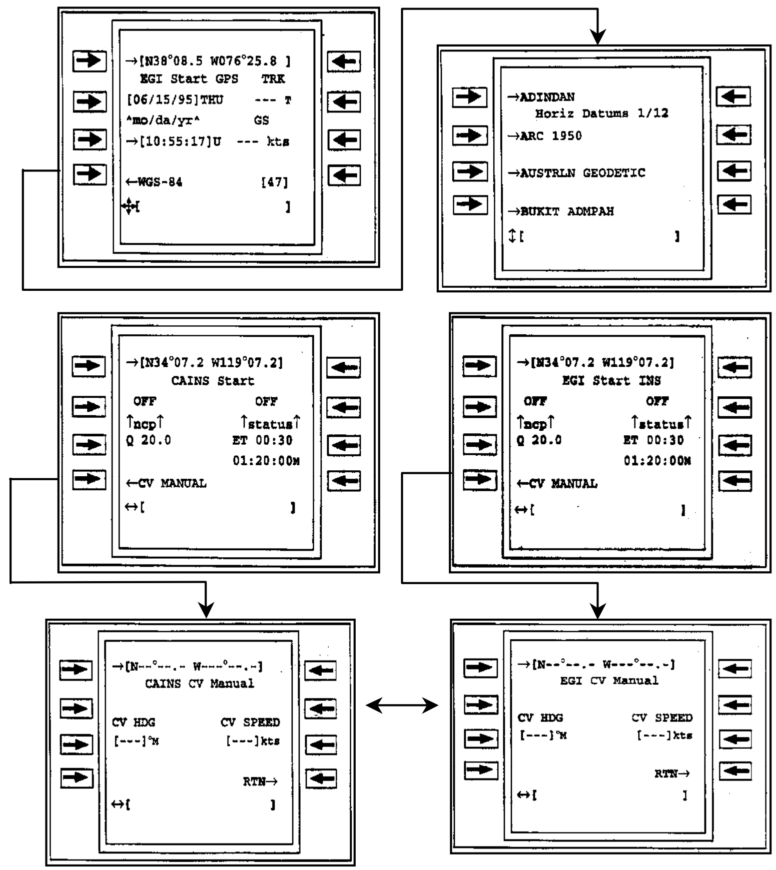


Figure C-1: INDEX START

HORIZ DATUMS
AND
EGI/CAINS CV MANUAL

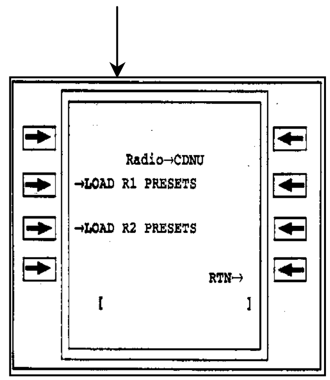


Notes:
1. Selecting LS1-LS4 from the Horiz Datums page selects the datum and then returns to the EGI Start GPS page.
2. RTN returns to the next higher software level.

Figure C-2: HORIZONTAL DATUMS AND EGI/CAINS CV MANUAL

RADIO START

RADIO START	LS1	LS2	LS3 RADIO -CDNU	LS4 INIT RADIOS	LS5	LS6	LS7	LS8

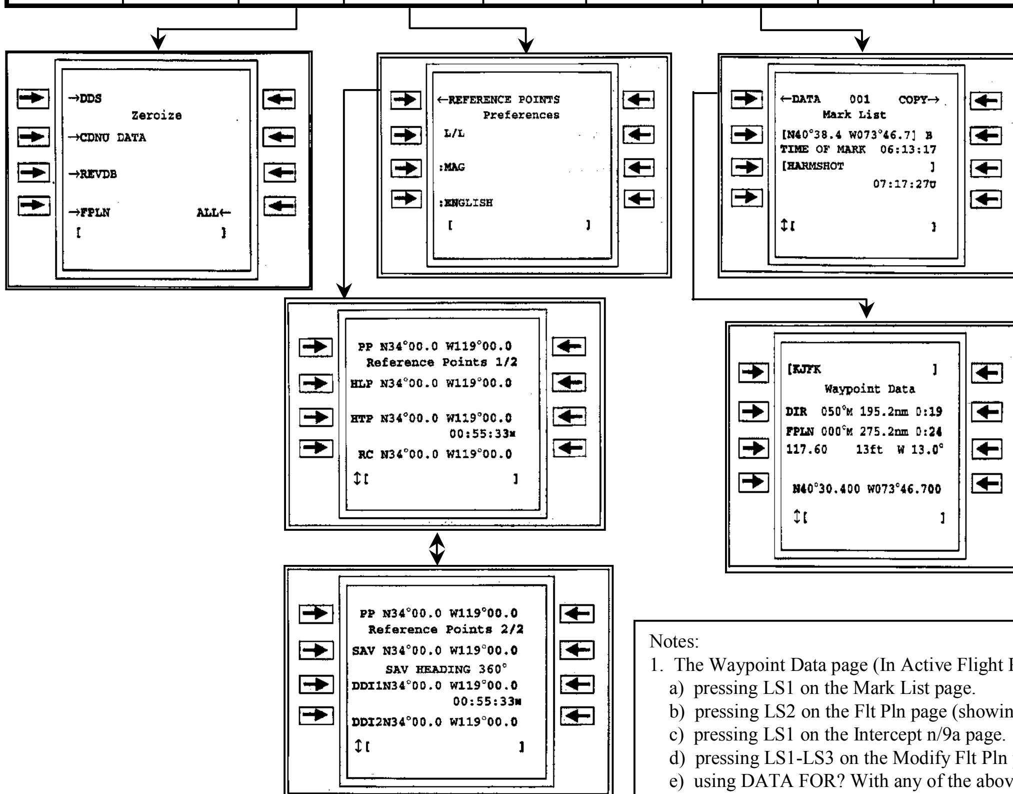


Notes:
1. R1 and R2 pages are identical in controls and displays, therefore only the R1 pages are presented.
2. RTN returns to next highest level in the software.

Figure C-3:RADIO START

INDEX ZEROIZE, PREFERENCES, MARK LIST

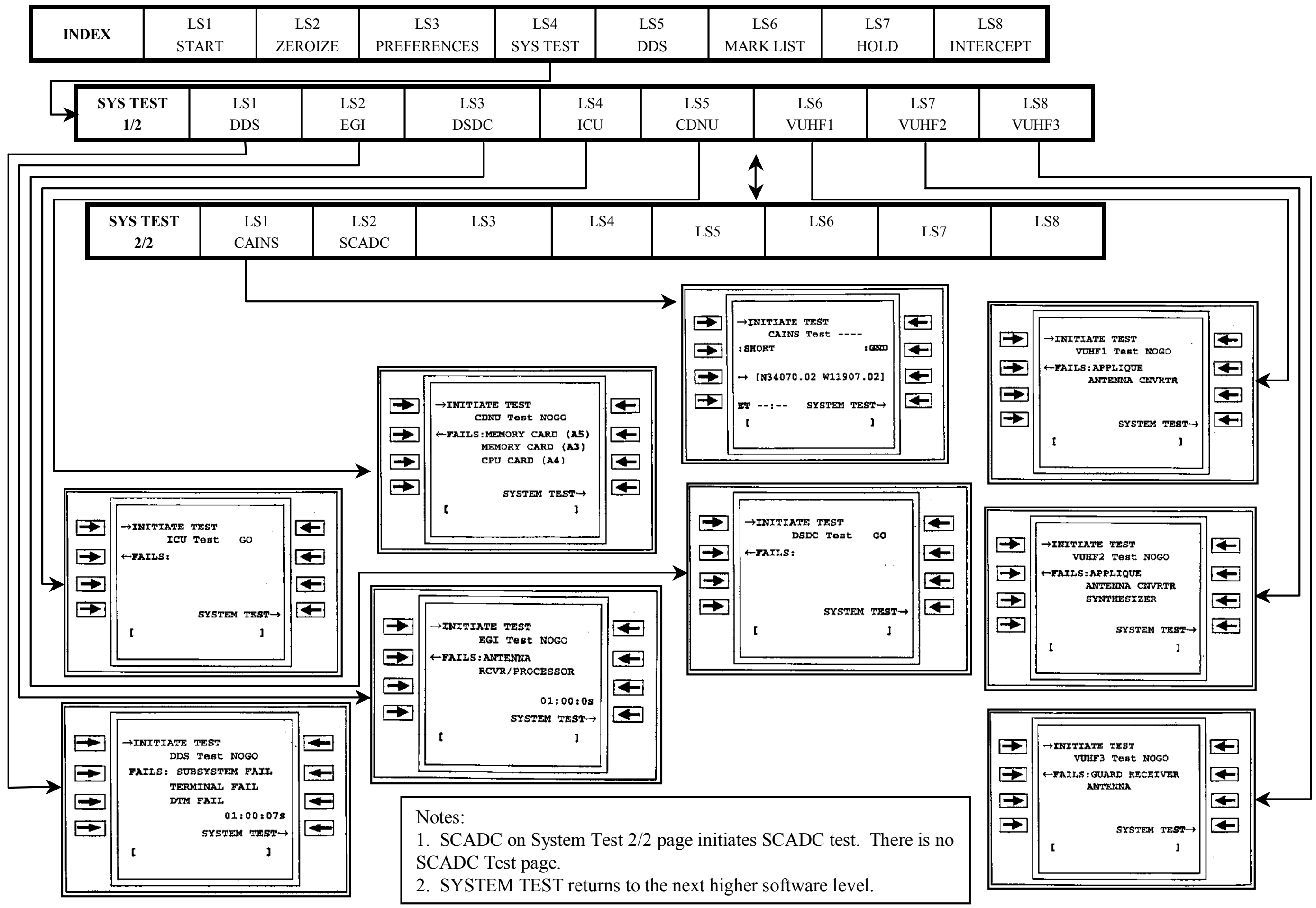
INDEX	LS1 START	LS2 ZEROIZE	LS3 PREFERENCES	LS4 SYS TEST	LS5 DDS	LS6 MARK LIST	LS7 HOLD	LS8 INTERCEPT



Notes:
1. The Waypoint Data page (In Active Flight Plan) is accessible by:
   a) pressing LS1 on the Mark List page.
   b) pressing LS2 on the Flt Pln page (showing Active Waypoint).
   c) pressing LS1 on the Intercept n/9a page.
   d) pressing LS1-LS3 on the Modify Flt Pln page.
   e) using DATA FOR? With any of the above.
   f) pressing LS1-LS4 on the Flt Pln page (not showing Active Waypoint Compact Format).
   g) pressing LS1 or LS3 on the Flt Pln page (not showing Active Waypoint Expanded Format).
   h) pressing LS7 on the Radar Cursor page.

Figure C-4: INDEX ZEROIZE, PREFERENCES, AND MARK LIST

INDEX SYS TEST

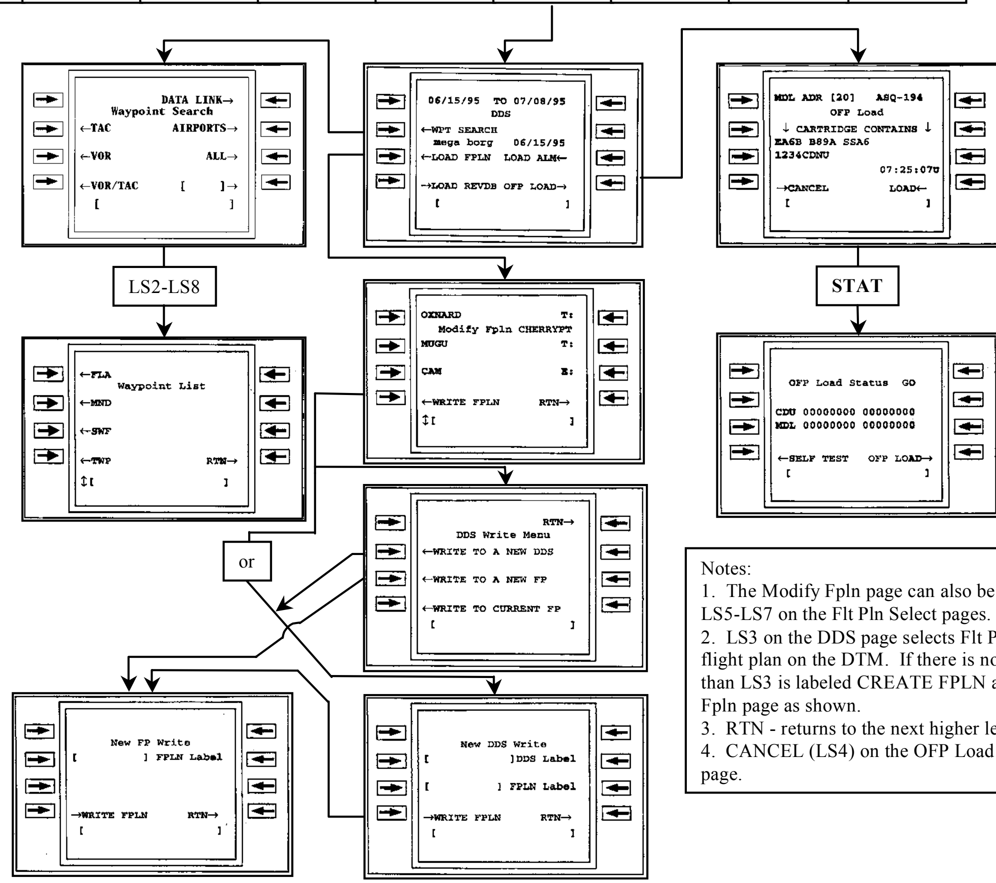


Notes:
1. SCADC on System Test 2/2 page initiates SCADC test. There is no SCADC Test page.
2. SYSTEM TEST returns to the next higher software level.

Figure C-5: INDEX SYSTEM TEST

INDEX DDS

INDEX	LS1 START	LS2 ZEROIZE	LS3 PREFERENCES	LS4 SYS TEST	LS5 DDS	LS6 MARK LIST	LS7 HOLD	LS8 INTERCEPT



Notes:
1. The Modify Fpln page can also be accessed by LS1-LS3 or LS5-LS7 on the Flt Pln Select pages.
2. LS3 on the DDS page selects Flt Pln Select 1/2 if there is a flight plan on the DTM. If there is no flight plan on the DTM than LS3 is labeled CREATE FPLN and accesses the Modify Fpln page as shown.
3. RTN - returns to the next higher level in the software
4. CANCEL (LS4) on the OFP Load page returns to the DDS page.

Figure C-6: INDEX DDS

INDEX HOLD and INTERCEPT

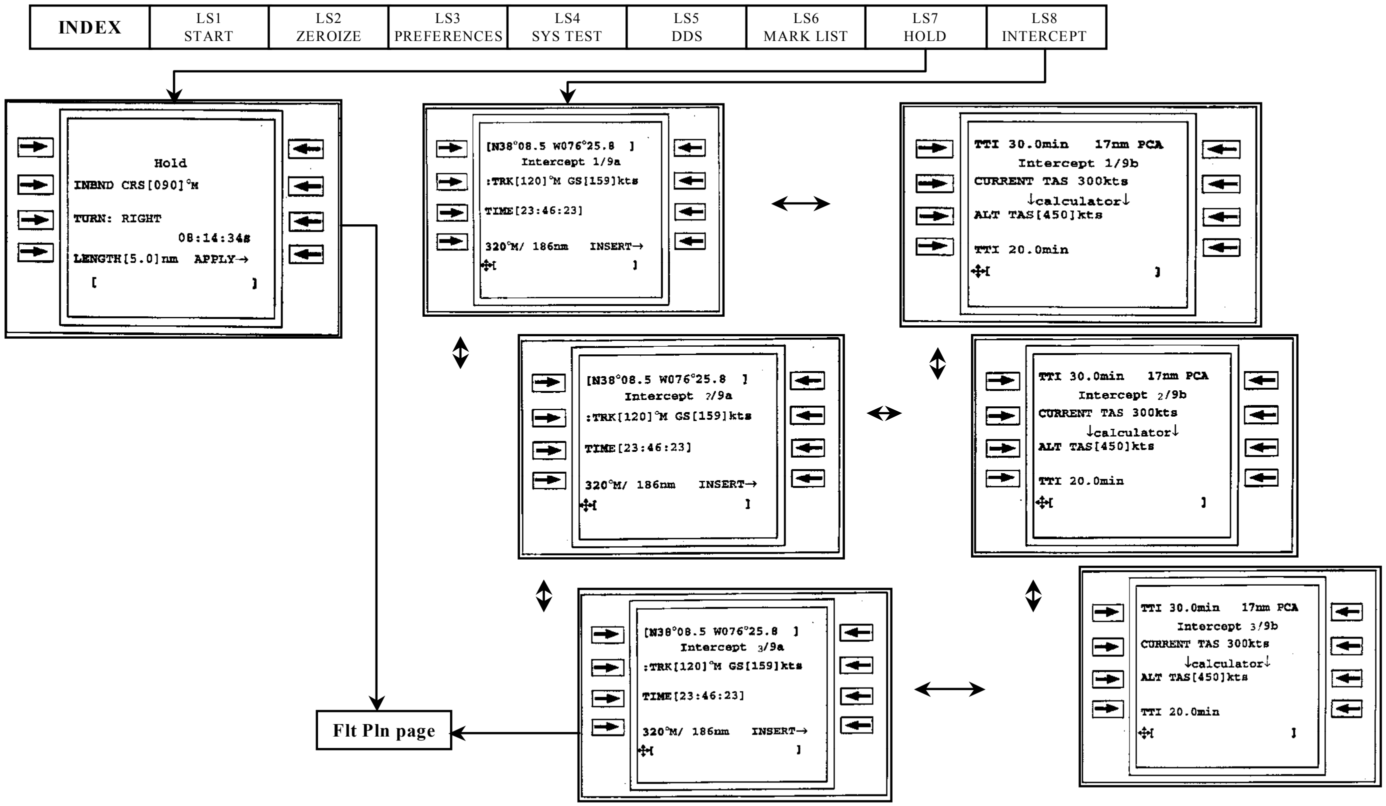
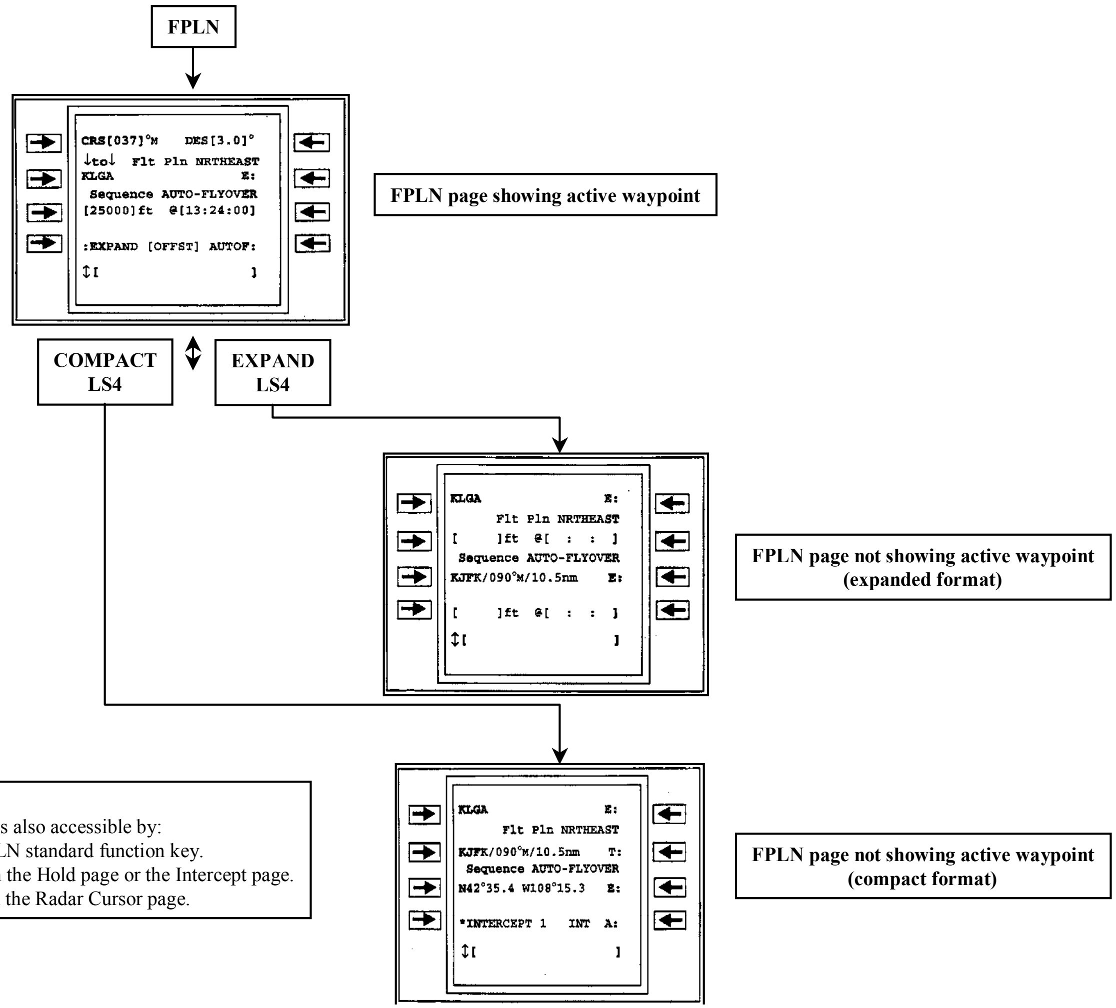


Figure C-7: INDEX HOLD AND INTERCEPT

FPLN



Notes:
1. The FPLN page is also accessible by:
  a. pressing the FPLN standard function key.
  b. pressing LS8 on the Hold page or the Intercept page.
  c. pressing LS7 on the Radar Cursor page.

Figure C-8: FLIGHT PLAN

PROG

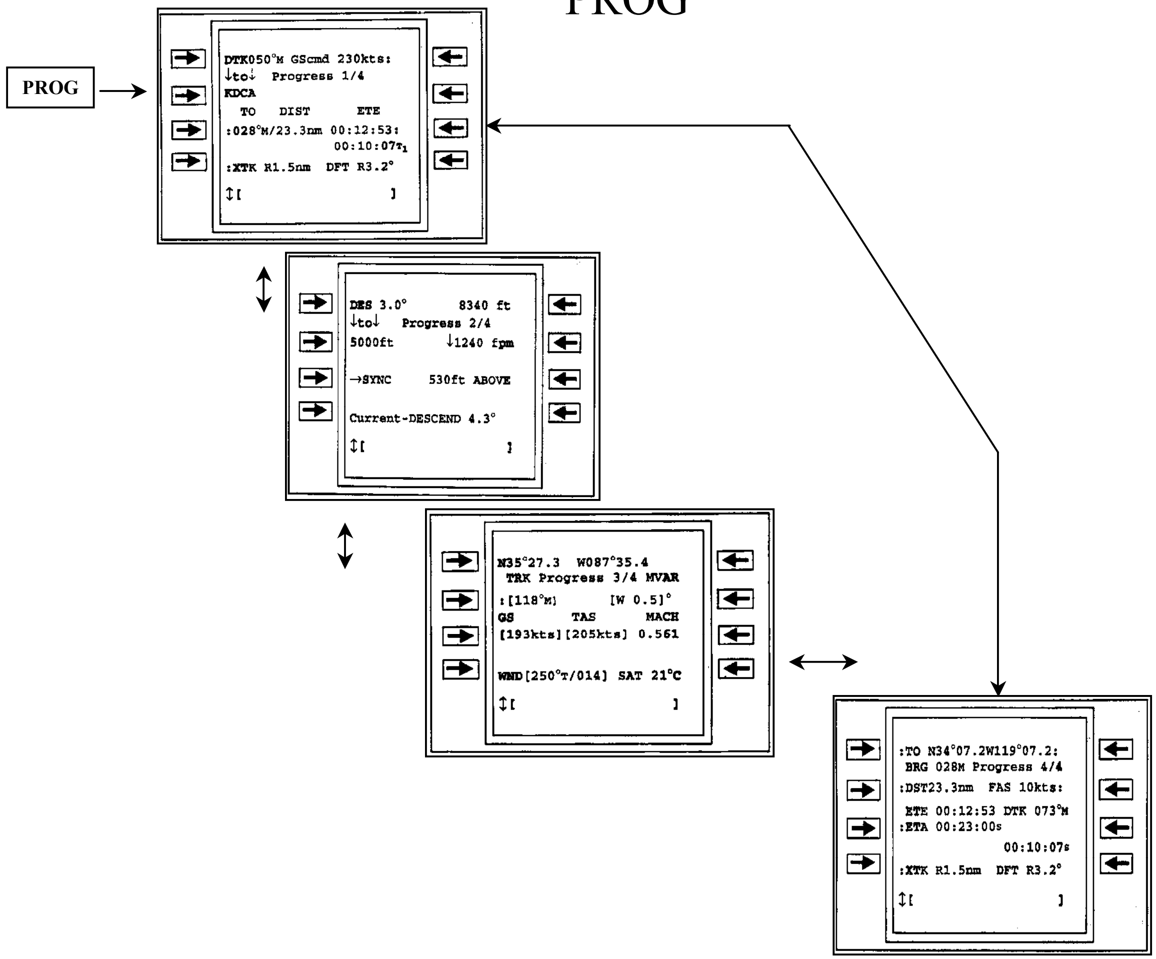
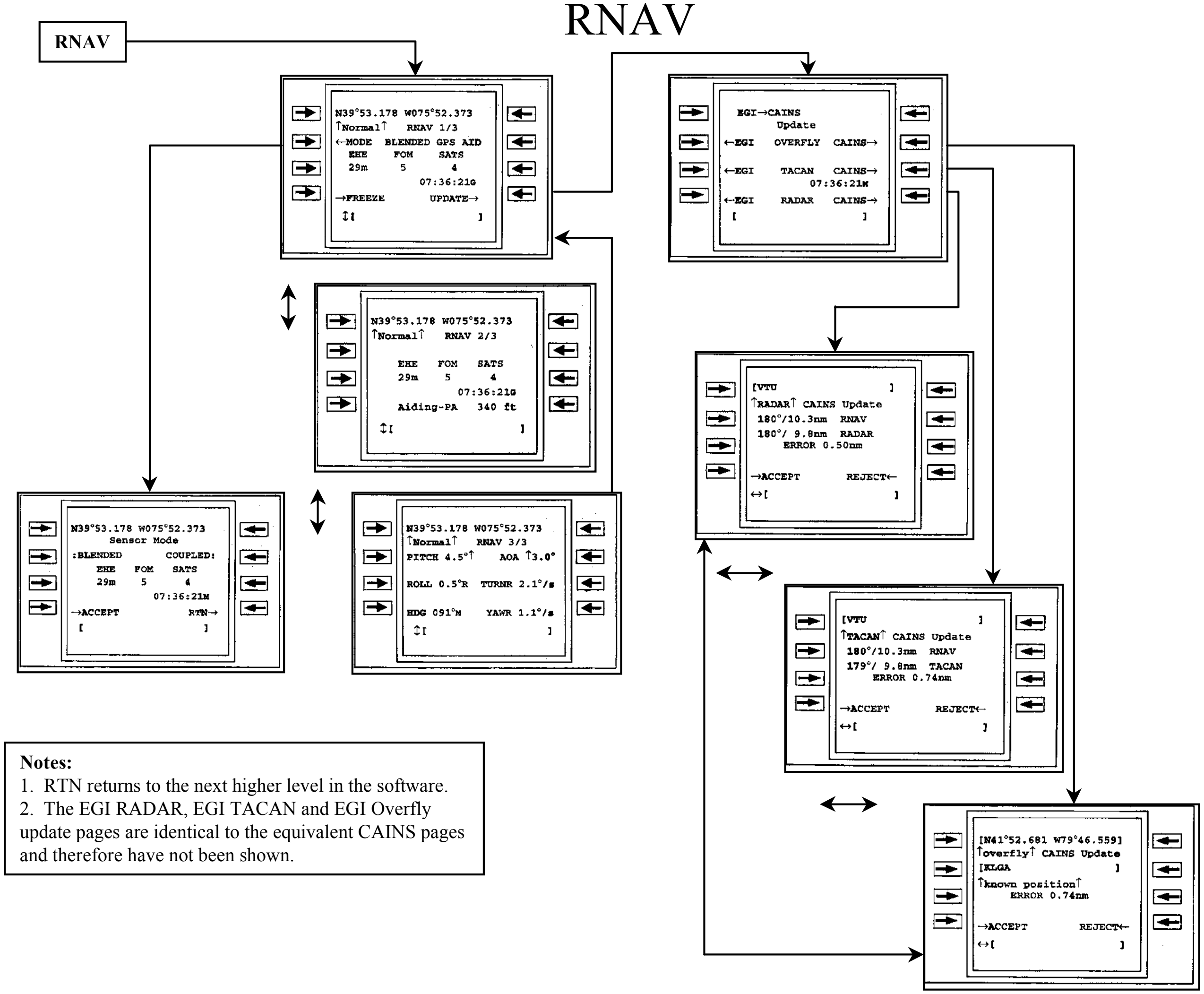


Figure C-9: PROGRESS

RNAV



Notes:
1. RTN returns to the next higher level in the software.
2. The EGI RADAR, EGI TACAN and EGI Overfly update pages are identical to the equivalent CAINS pages and therefore have not been shown.

Figure C-10: RNAV

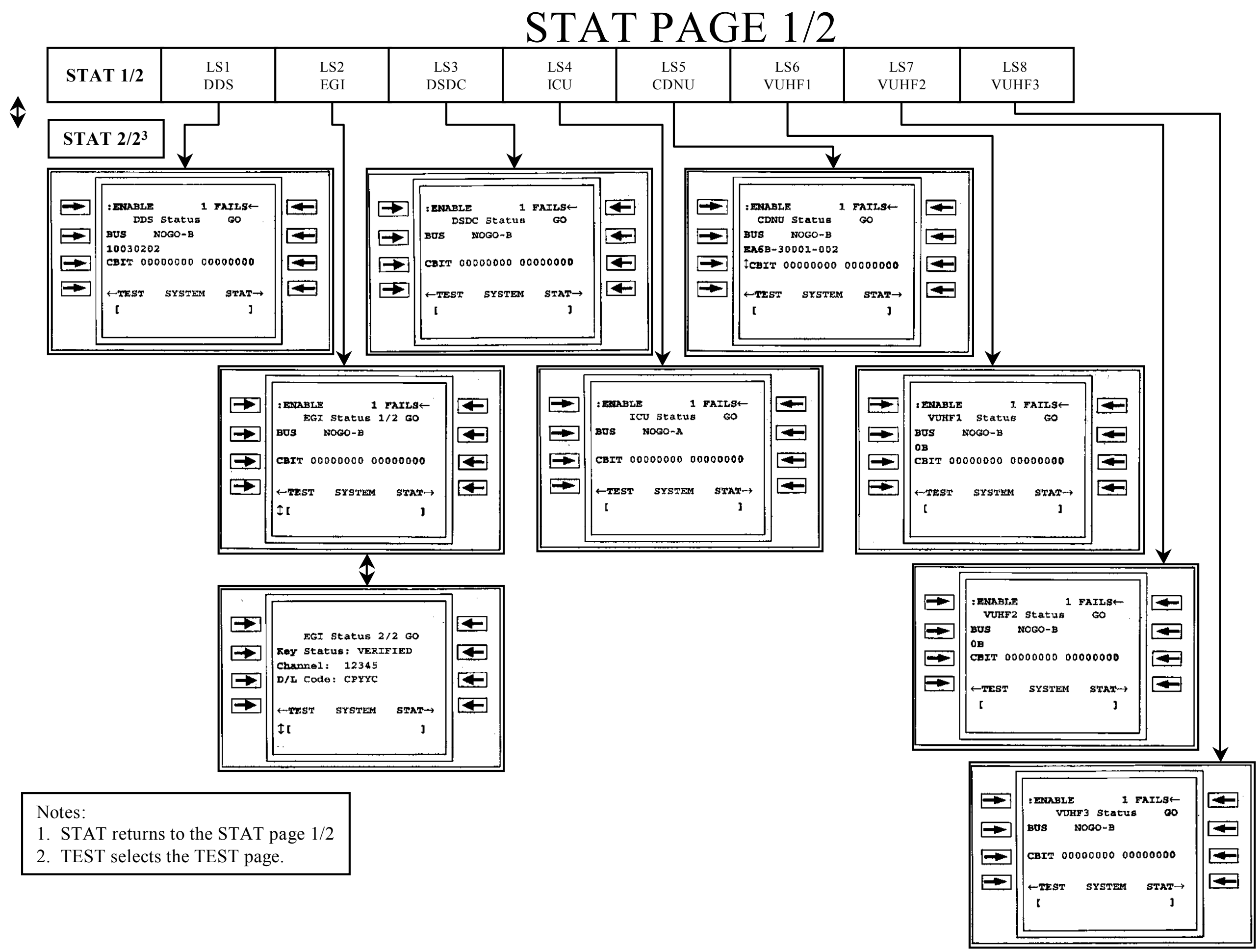
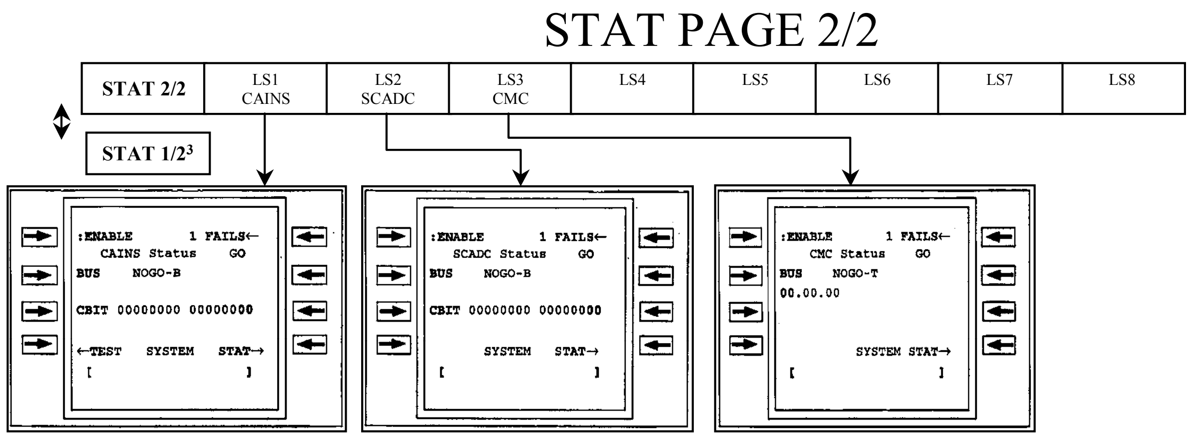


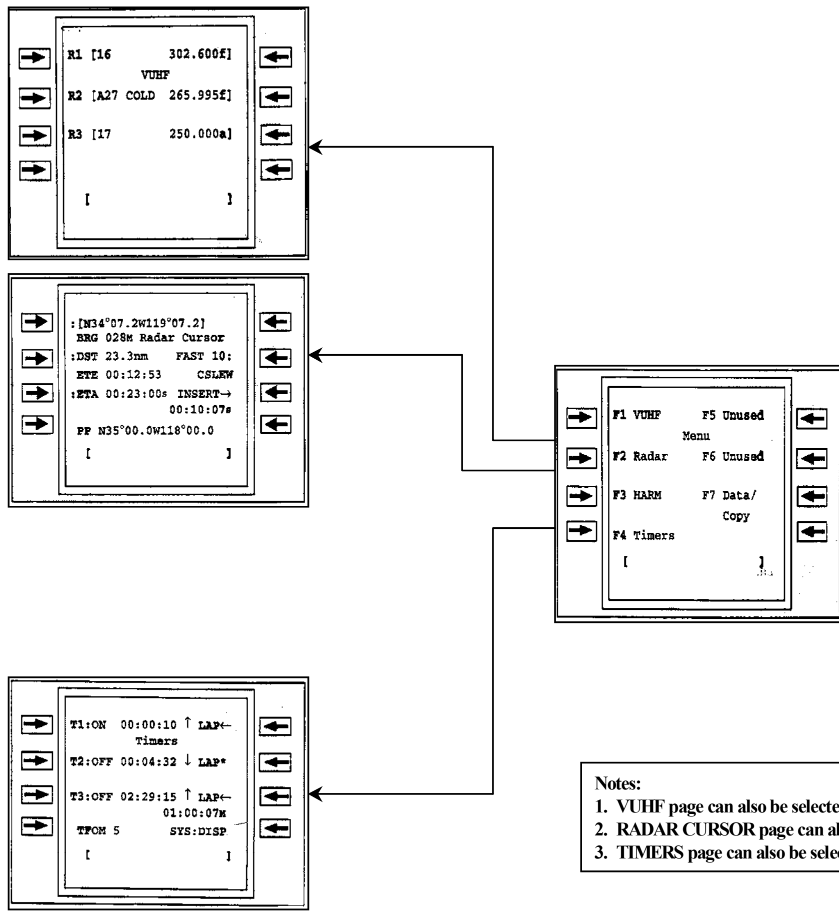
Figure C-11: STATUS PAGE 1/2



Notes:
1. STAT returns to the STAT page 1/2
2. TEST selects the TEST page.

Figure C-12: STATUS PAGE 2/2

MENU



Notes:
1. **VUHF page can also be selected via the F1 key.**
2. **RADAR CURSOR page can also be selected via the F2 key.**
3. **TIMERS page can also be selected via the F4 key**

Figure C-13: MENU

VITA

Robert Donald Croxson was born on October 06, 1970 in Flint MI. He graduated from Flushing High School in 1988. He earned a Bachelors of Science in Chemistry from Eastern Michigan University in 1992 and was commissioned in the United States Navy in the summer of 1992. He was designated a Naval Flight Officer in 1994 and completed Electronic Countermeasures Officer training in 1995. He served on three aircraft carriers while attached to VAQ-135. His testing career began in 1999 when he reported to Air Test and Evaluation Squadron Nine (VX-9) in China Lake,Ca and worked as an Operational Tester on EA-6B, and FA-18 aircraft. He was selected for the United States Naval Test Pilot School in 2000 and was designated a Naval Flight Test Engineer in December 2001.

He is currently attached to Air Test and Evaluation Squadron Two Three (VX-23) as the lead Developmental Tester on the EA-6B ICAP III program.