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INTEGRATION OF GLOBAL POSITIONING SYSTEM

IN THE E-2C HAWKEYE AND THE AFFECT

ON WEAPONS SYSTEM ACCURACY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Edward Joseph Najmy

May 1993

DEDICATION

THIS THESIS IS DEDICATED TO MY

LOVING WIFE TAMARA AND MY DAUGHTER LAUREN

FOR THEIR PATIENCE DURING THE MANY HOURS OF WORK

AND

MY PARENTS EDWARD AND HELEN

WHO HAVE ENCOURAGED ME IN MY SEARCH FOR KNOWLEDGE

ACKNOWLEDGEMENTS

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I thank God for a loving family whose support, encouragement, patience, and love has been unfailing since my assignment for duty at the Naval Air Warfare Center Aircraft Division.

ABSTRACT

The Grumman E-2C Hawkeye is an all weather carrier and shore based airborne early warning (AEW) and control aircraft that patrols tasks force defense perimeters. It provides early warning of approaching enemy aircraft and vectors interceptors into attack position. In addition to this primary AEW function, the Hawkeye can also provide strike and air traffic control, area surveillance, search and rescue guidance, navigational assistance, and communication relay.

The integrated functions of the E-2C's navigation system provide aircraft navigation and guidance capabilities, plus reference information to the associated avionics systems for stabilization and orientation.

The primary navigation system has known drift rates overtime where the navigational errors become large. The positional errors become five times larger in the final stage of a five hour flight. As new systems are integrated in the airplane, the E-2C weapons system must provide realtime positional data information to the operators and over command and control data networks. Therefore, there is a need for the navigation system to be continuously updated. The solution is to integrate the Global Position System as the primary navigation system. This thesis covers the history, policy, operation, installation, and benefits of incorporating GPS in the E-2C Hawkeye.

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LIST OF ABBREVIATIONS

ACO	Air Control Officer
ADC	Air Data Computer
ADF	Airborne Direction Finder
ADI	Attitude Director Indicators
ADU	Auxiliary Display Unit
AEW	Airborne Early Warning
AEW & C	Airborne Early Warning and Control
AFCS	Automatic Flight Control System
ANCU	Air Navigation Computer Unit
BDHI	Bearing Distance Heading Indicator
BIT	Build in Test
C/A Code	Course/Acquisition Code
CAINS	Carrier Aircraft Inertial Navigation System
CAC	Compass Adapter Compensator
CAU	Converter-Amplifier Unit
CDU	Control Display Unit
CIC	Combat Information Center
CICO	Combat Information Center Officer
CIG	Control Indicator Group
CIU	Control Indicator Unit
CP	Computer Programmer
CRT	Cathode Ray Tube
CTR	Chesapeake Test Range
DAF	Digital Acquisition Formatter
DLRP	Data Link Reference Point
DME	Distance Measuring Equipment

DPU	Digital Processor Unit
DX	Data Extraction
EMI	Electromagnetic Interference
EOT	End of Tape
GASD	Grumman Aircraft Systems Division
GPDC	General Purpose Digital Computer
GPS	Global Positioning System
GSCS	Ground Stabilized Coordinate System
HARS	Heading Attitude Reference Point
HDDR	High Density Digital Recorder
HSR	High Speed Recorder
ICS	Inter-Communication System
IF	Intermediate Frequency
IFF	Identification Friend or Foe
IFPM	Inflight Performance Monitor
IMU	Inertial Measuring Unit
INS	Inertial Navigation System
IRIG	International Regulatory Instrumentation Group
IPS	Inches per Second
I/O	Input/Output
JTIDS	Joint Tactical Information Data System
LASER	Light Amplification by Stimulated Emission of Radiation
LOP	Line of Position
LORAN	Long Range Navigation
LPTS	Low Power Time Source
L1	GPS L-Band Frequency (1575.42 MHZ)

L2	GPS L-Band Frequency (1227.6 MHZ)
MDU	Main Display Unit
MEJB	Main Electronic Junction Box
MFCDU	Multi-function Control Display Unit
MHz	Mega-Hertz
MH	Magnetic Heading
MV	Magnetic Variation
NACWAD	Naval Air Warfare Center Aircraft Division
NAV	Navigation
NiCad	Nickel Cadmium
NMPH	Nautical Miles per Hour
P Code	Precise Position Code
PCM	Pulse Coded Modulation
PDS	Passive Detection System
PSU	Power Supply Unit
PTTI	Precise Time and Time Interval Radar
REL NAV	Relative Navigation
RF	Radio Frequency
RO	Radar Officer
SCADC	Standard Central Air Data Computer
SDC	Signal Data Converter
SINS	Ships Inertial Navigation System
STRP	System Tracking Reference Point
TACAN	Tactical Air Navigation
TAS	True Air Speed
TH	True Heading
VCR	Video Cassette Recorder

VCU	Video Control Unit
VOR	VHF Omnidirectional Range

1. INTRODUCTION

Navigation began with the first man. One of his first conscious acts probably was to home in on some object that caught his eye, and thus land navigation was undoubtedly the earliest form. His first venture upon the waters may have come shortly after he observed that a larger object, perhaps a log, would support him. Marine navigation was born as he attempted to guide his craft. Air navigation by men came much later.

Thus, navigation is involved whenever a purposeful change of location takes place. Originally, navigation was almost entirely an art. Man used his senses to determine direction, distance, speed, and position. This was not difficult where landmarks were plentiful; however, when man became bold enough to venture out of sight of land, skill was involved in reading the instruments of nature--the wind, waves, and sky. Although skill is still involved in successful navigation, precise and ingenious instruments have been and are being invented to make the measurements needed to navigate. The successful navigator uses these instruments intelligently and depends on his knowledge to interpret the results and to make decisions regarding his future courses of action. Therefore, modern technology is playing a significant and essential role in navigation, supplementing and enhancing the ability of the human navigator.[1]

From the foregoing, it can be seen that "navigation is the process of directing the movements of a craft (or a person) from one point to another."[2] It involves coordinates of position; direction, time, and speed. The craft, whether it be land, sea, or airborne, may be any vehicle capable of purposeful motion. This thesis is concerned with the Navy's E-2C Hawkeye aircraft which is an all weather carrier and shore based Airborne Early Warning (AEW) and tactical command and control aircraft manufactured by Grumman Aircraft Systems Division (GASD). In addition to its AEW mission, the E-2C is designed to provided strike control, carrier air traffic control, over-the-horizon targeting, search and rescue coordination, and communications relay. The E-2C, while navigating the skies above the United States Navy Battle Group, aids other aircraft to navigate as they perform their missions and transmit their position to the rest of the Battle Group.

Historically, navigation of slow moving aircraft has been involved primarily in answering the question: "Where am I?" From the answer the captain then decided whether to continue the present heading and speed or to make some alteration.

As speeds increased and the number of aircraft multiplied, the time lag between measurement and decision regarding the significance of positional information became ever more intolerable. The aircrafts' navigator began to ask: "Which way and how far?" to the destination or next way point.

As the number of aircraft continues to increase, limiting the amount of airspace available to individual aircraft, an additional question becomes increasingly important: "Where am I with respect to where I should be at this moment?" Accordingly, continuous, real-time outputs of steering information and coupling of the autopilot directly to a guidance computer or weapons system are becoming more important.

In general, two basically different methods of navigation exist: dead reckoning and position fixing. Dead reckoning consists of extrapolation of a known position to some future time. It involves measurement of direction of motion and distance traveled.[3]

Dead reckoning has been characterized as the basis of all navigation, with position fixing constituting a method of updating it. Actually, dead reckoning and position fixing complement each other, each providing an independent means of checking the accuracy of the other. Where position fixing is intermittent, with relatively long intervals (such as hours) between fixes, dead reckoning is appropriately considered the primary method. If fixes are available continuously or at very short intervals (such as once each minute), the primary method might then be either dead reckoning or position fixing or an integrated output from both.

In contrast to dead reckoning, position fixing is the determination of the position of the aircraft (a fix) without reference to any former position. There are a number of ways in which this is accomplished. The most common is by individual measurements, each of which establishes a line of position--a line on which the aircraft is presumed to be located.[4] The line might be a small circle, great circle, hyperbola, or other curve constituting the intersection of the surface of the earth (or a concentric surface at the altitude of the aircraft) with a plane, cone, hyperboloid, etc. The common intersection of two or more nonparallel lines of position constitutes the fix.

With the first flight of the Wright Flyer I in 1903 a new craft was developed for man to travel between two points. As the technology developed U.S. Senator Sam Sheppard of Texas convinced Congress to fund a regularly scheduled aerial mail system. The necessary funding was included in the steamboat mail appropriation for fiscal 1918. The first route ran between New York--Philadelphia--Washington, D.C. On May 15, 1918, LT George Boyle left the Nation's Capital with 140 pounds of mail bound for Philadelphia. Soon after takeoff LT Boyle became hopelessly lost, landing in a plowed field 24 miles from Washington, D.C.[5] As the aircraft industry grew, many more pilots would become hopelessly lost while navigating the skies. Today, with the development of modern aircraft and the missions they perform, navigation systems have been developed to meet their needs. Principle airborne navigation systems are: Inertial Navigation, Doppler Radar Navigation, Airborne Direction Finder (ADF), Distance Measuring Equipment (DME), VHF Omnidirectional Range (VOR), Tactical Air Navigation (TACAN), Long Range Navigation (LORAN), Omega Navigation Aid, Transit Satellite Navigation, Global Positioning System (GPS).

2. GPS OVERVIEW

2.1 HISTORY

Since the early 1960's, both the U.S. Air Force and Navy have actively pursued the idea that navigation and positioning could be performed using RF signals transmitted from space vehicles. The impetus for development of a space-based system was created by the desire for a global, highly accurate positioning and navigation system that could meet the needs of a broad spectrum of users. It was felt that considerable cost benefits would be derived by reducing the proliferation of specialized navigation systems.

The U.S. Navy has sponsored two navigation satellite programs, TRANSIT and TIMATION. TRANSIT became operational in 1964 and was made available to nonmilitary users in 1967. The Navy sponsored TIMATION, a high-technology program to advance the state of the art of two-dimensional navigation. The U.S. Air Force concurrently conducted preliminary concept formulations and system design studies for a highly accurate three-dimensional navigation system called System 621B.[6]

A key step in the integration of these activities took the form of a memorandum issued by the U.S. Deputy Secretary of Defense on 17 April 1973. The memorandum designated the Air Force as the executive service to coalesce these navigation system concepts into a generally acceptable, comprehensive, and cohesive all-weather navigation system program. A system concept designated "Navstar Global Positioning System" emerged as a synergistic combination of the best features of the previous satellite concepts.[6]

2.2 GENERAL SYSTEM DESCRIPTION

The Global Positioning System (GPS) consists of three major parts: Satellites, Ground Control System, and Navigation Sets. Figure 1 illustrates the relationship of the three parts.

2.2.1 Satellites

The GPS satellites provide navigation data to the navigation sets. There will be 21 satellites, including 3 operational spares, evenly spaced around the globe, all orbiting at an altitude of 10,900 nautical miles (figure 2). At this altitude each satellite will orbit the earth twice per day, thus providing visibility of 6 to 11 satellites at 5 degrees or more above the horizon to users located anywhere in the world at any time.[8] Each satellite broadcasts two spread-spectrum radio frequency (RF) signals. Each signal is modulated with a unique code sequence and a navigation data message. The code sequence allows the navigation set to identify each satellite. The navigation data message provides the navigation set information about the operation of the satellite.[11]

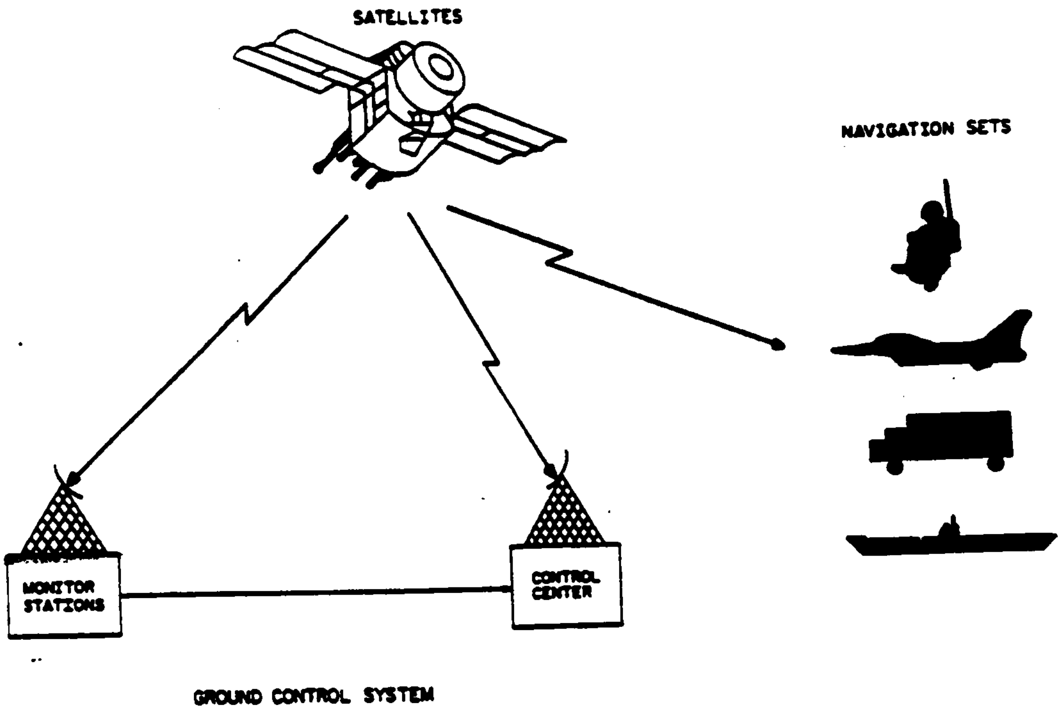


Figure 1

NAVSTAR GPS SYSTEM

Source: Adapted from NAVAIR 16-30ARN151-1 Technical Manual Collins Government Avionics Division, Rockwell International Corp. Publication. Cedar Rapids, IA, p. 4.2)

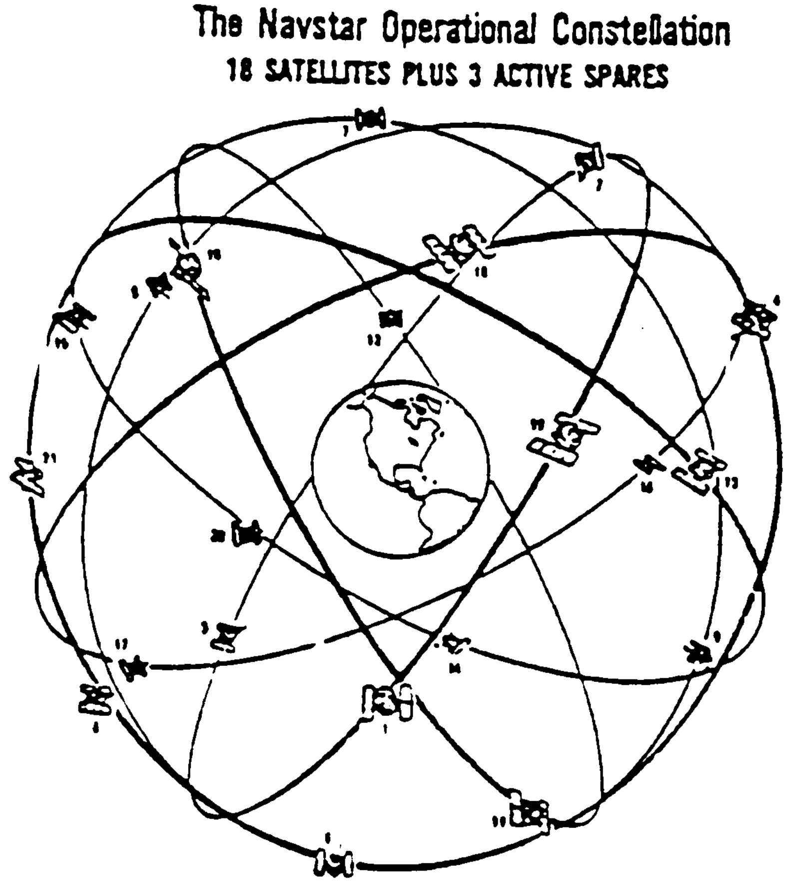


Figure 2 Operational Satellite Constellation

Source: Adapted from GPS - Principles and Practice, Dixon, R. C., The George Washington University, 1982, p. 58.

2.2.2 Ground Control System

The ground control system tracks the satellites, monitors and controls satellite orbits, and updates the satellite navigation data message. The ground control system consists of monitor stations located at Hawaii, Kwagalein, Diego Garcia, and Ascension; and a control center located in Colorado Springs, Colorado as shown in figure 3. Monitor stations are unmanned stations using special GPS receivers to track each satellite. The tracking information is sent to the control center. The control center uses the tracking information to calculate precise satellite position and satellite clock error for each satellite. This is called ephemeris data. The control center also calculates satellite position for all satellites, called almanac data. Once each 24 hours, the control center transmits the ephemeris and almanac data to each satellite to update the navigation data message.[11]

2.2.3 Navigation Sets

Navigation sets receive and decode RF signals from satellites and include aircraft, ships, land vehicles, and small hand held receivers. The information is used to calculate three-dimensional position, three dimensional speed, and precise time data. The navigation sets measure the time the signals take to travel from the satellite to the navigation set. By calculating time divided by speed, the

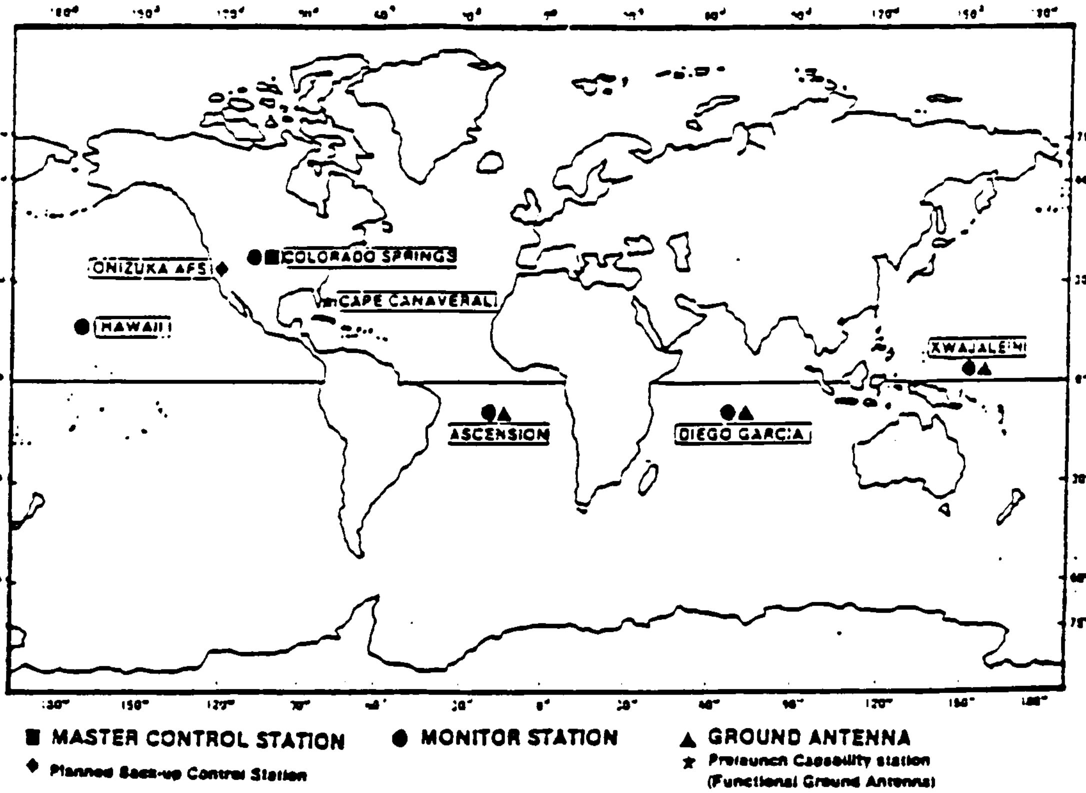


Figure 3 Ground Control System Locations

Source: Adapted from GPS overview, SCI Technology, Inc., 8600 S. Memorial Pkwy, Huntsville, AL, 35807, Nov. 1990 p. 1-3.

navigation set determines the precise distance to each satellite. By calculating the distance to four satellites, precise three-dimensional position can be calculated. Speed is calculated by the navigation sets by measuring the rate of change of the RF signals.[11]

2.2.4 Navigation Set Performance

The performance characteristics of a Navigation Set are dependent upon a number of interrelated factors. Some of these factors are predictable, others may be bounded with certain confidence levels, and still others can only be estimated based upon mission and role scenarios to which the host vehicle will be subjected. Key factors that affect performance and system accuracy include:[6]

- Host vehicle dynamics including velocity and angular acceleration.
- Ionospheric and tropospheric effects
- Multipath effects
- Uncompensated clock errors
- Ephemeris prediction uncertainties
- Receiver noise and resolution
- Extreme environmental conditions such as temperature, altitude, vibration, and shock
- Hostile environmental conditions such as jamming, spoofing, EMP, and nuclear events

- Satellite constellation geometry relative to the Navigation Set position.

2.3 THEORY OF OPERATION

GPS measures directly the amount of time it takes a signal to travel from satellite to receiver, and that time is then converted into distance from the satellite by multiplying it by the speed of light. Distance from the satellite results in a Line of Position (LOP). GPS uses three distance measurements to define an intersection in a three-dimensional framework--latitude, longitude, and altitude.

GPS is a passive system, working all time and does not require any interrogation by the user. Active systems can use simple and inexpensive quartz oscillators to time the interval between the start of an interrogation and the receipt of a return pulse, but passive systems normally cannot make accurate, direct measurements of elapsed time unless both units have been exactly synchronized, which requires an extremely stable clock at each end. Only atomic clocks are capable of the kind of stability required and are incredibly expensive.[8]

One way around this problem is to work with time differences rather than with time directly. Also, GPS accepts the fact that a quartz oscillator at the receiving end will be somewhat inaccurate, and uses an LOP from the fourth satellite to correct for that error.[8]

2.3.1 Satellite Signal Structure and Navigation Data Message

Each satellite continuously broadcasts the navigation data message on two spread spectrum RF signals. The L1 signal is centered at 1575.42 megahertz (Mhz) and is modulated by a precision code (P code) modulated over 20.46 MHz and a coarse/acquisition code (C/A code) modulated over 2.046 MHz. The L2 signal is centered at 1277.60 MHz and is modulated only by the P code. The P mode is for military use only and will not be available to the public. The C/A mode is the civilian mode. The C/A code has a chipping rate of 1.023 MHz and repeats every millisecond. The relatively slow chipping rate and short repeat sequence allows the navigation set to acquire the satellite signals quickly. The P code has a chipping rate of 10.23 MHz and repeats every seven days. While more difficult to acquire, the P code allows for greater accuracy of the position calculations. The C/A code is normally acquired first and a transfer is made to the P code by the use of the handover word contained in the navigation data stream. The handover word allows transfer to be made at the termination of any six second subframe.[11]

The navigation message contains the data that the user's receiver requires to perform the operations and computations for successful navigation with the GPS. The data includes information on the status of the space vehicle; the time synchronization information for the transfer from the C/A to the P code; and the parameters for computing the clock correction, the ephemeris of the space vehicle and the corrections for delays in the propagation of the signal through the atmosphere. In addition, it contains almanac information that defines the approximate ephemerides and status of all the other space vehicles, which is required for use in signal acquisitions. The data format also includes provisions for special messages.[7]

2.3.2 Satellite Signal Acquisition

During operation, the navigation set collects and stores the satellite almanac data in a non-volatile critical memory. The almanac data is normally available when the navigation set is first turned on and provides information about location of the satellites. The navigation set operator may input information about the navigation set position, time, and velocity to enhance the information in the critical memory. With this information, the navigation set determines which satellites are available and searches for the code sequence that identifies the available satellites. When the C/A code of the satellite is identified, the navigation set switches to the more accurate P code, collects the navigation data message and updates the critical memory. With the updated almanac data, the navigation set can then quickly acquire and track the three other satellites needed to compute the position, speed, and time data.[11]

2.3.3 Time Measurements

Once the GPS receiver computer has acquired the code and synchronized itself as closely as possible with the satellite code, it can then measure the elapsed time since transmission by comparing the phase shift, or remaining difference, between the two codes: the more the two disagree, the greater the length of time since transmission, and length of time since transmission multiplied by the speed of light equals distance. An example is provided: if the receiver computer determines that the closest the two codes can be synchronized is 0.07 seconds, then multiplying 0.07 by 162,000 nautical miles per second results in a distance of 11,340 nautical miles between satellite and receiver. Thus, by measuring phase shifts in the code, distance between satellite and receiver can be computed. Since the P code is 10 times more precise than the C/A code, it can measure the phase shift 10 times more precisely, which is why the P mode is so much more accurate than the C/A mode.[8]

2.3.4 Position Fixing

If we know our distance from a specific point in space, then it follows that we must be located somewhere on the surface of a sphere with a radius of that distance, centered on that point. Figure 4 illustrates the aircraft position on the surface of a sphere. The first distance measurement then gives us our first Line of Position.

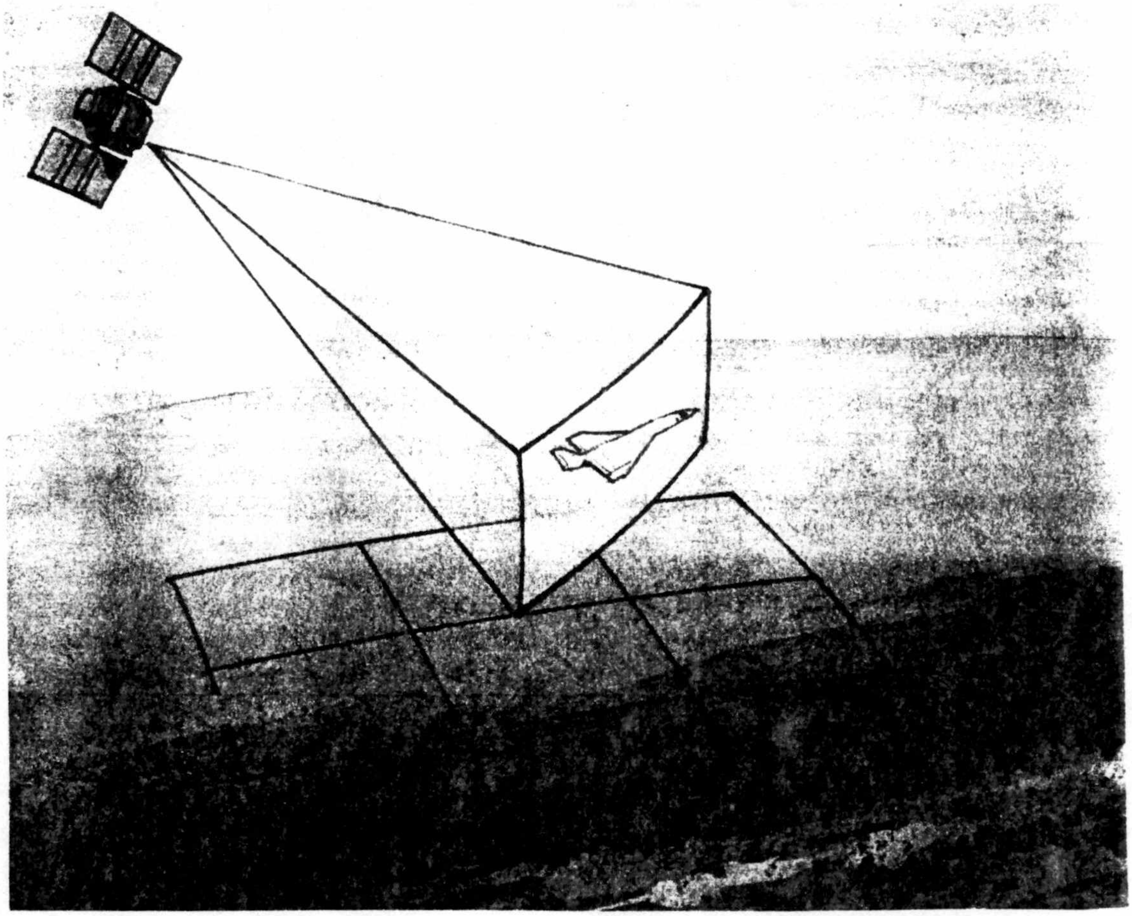


Figure 4 Aircraft Position on Surface of Sphere

Source: Clausing, Donald J., "The Aviator's Guide to Modern Navigation", Tab Books Inc, Blue Ridge Summit, PA, 17214, pg. 173.

With two satellites and two distances, position can be further refined to the intersection of two spherical surfaces, which is a curved line. A third satellite provides a third surface, and the intersection of that surface with the previously established curve is a point in space based on the distance in nautical miles between the aircraft and each of the satellites as shown in figures 5 and 6.

Knowing that one is 13,000 nautical miles from satellite #1, 14,000 nautical miles from satellite #2, and 15,000 nautical miles from satellite #3 is not in itself useful information, especially since each of the satellites is traveling at 7,500 NMPH and is no longer where it was a second ago. This problem is solved by having each satellite transmit its position--its ephemeris-- to the receiving computer, so that it can translate those distances into useful information: longitude, latitude, and altitude.[8] This explanation however, does not account for any errors.

2.4 ERROR SOURCES

Errors contained in the pseudo-range measurements can be divided into the categories listed in table 1. Various corrective techniques are employed in the system to reduce the magnitude of these errors in range that impact the estimates of user position.

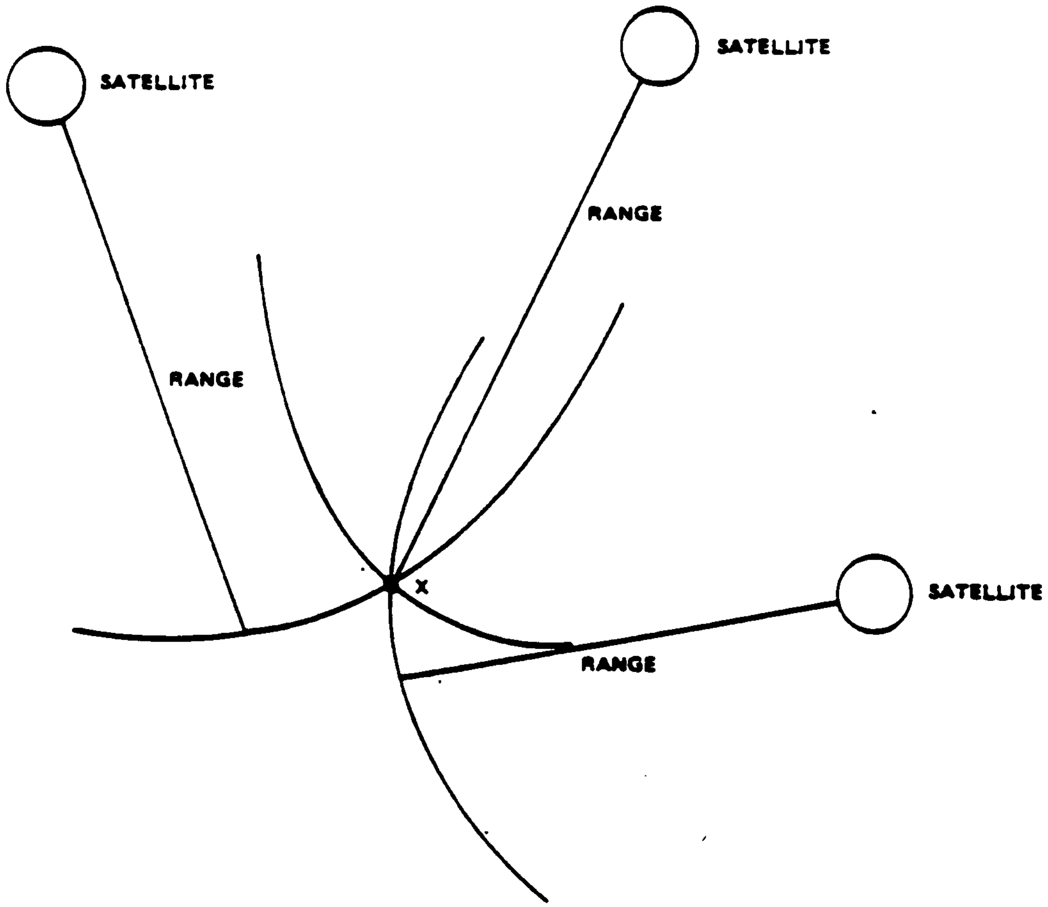


Figure 5 Satellite Ranging

Source: Adapted from NAVAIR 16-30ARN151-1, Technical Manual Collins Government Avionics Division, Rockwell International Corp. Publication. Cedar Rapids, IA, p. 4-9)

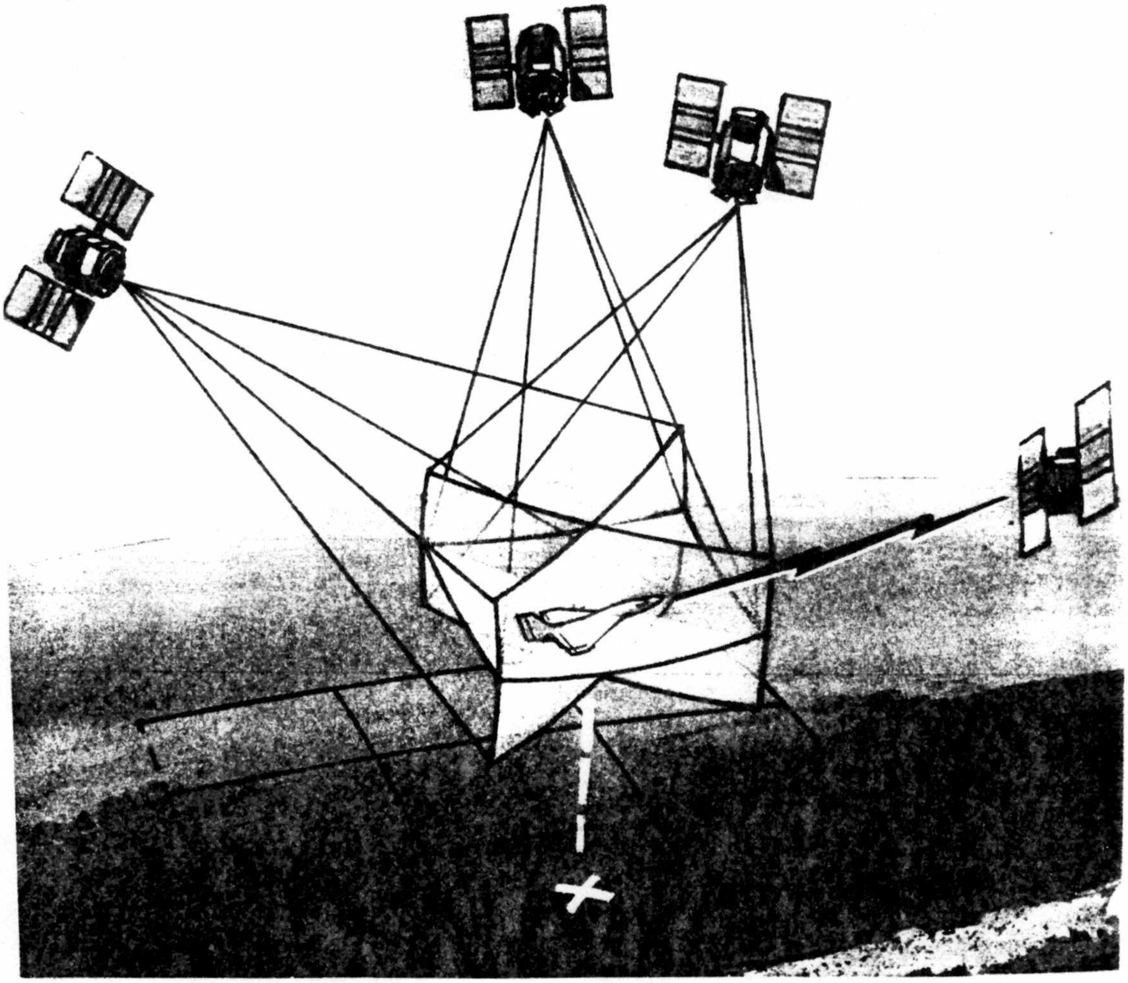


Figure 6

Satellite Position Fixing

The intersection of three surfaces of three spheres results in a fix in three dimensions. A fourth satellite is used to correct for clock errors.

Source: Clausing, Donald J., "The Aviator's Guide to Modern Navigation", Tab Books Inc, Blue Ridge Summit, PA, 17214, pg. 174.

Table I

RANGE ERROR

SOURCE	METERS	FEET
Clock errors/Ephemeris Errors	1.5	5.0
Atmospheric Delays	2.4 - 5.2	8.0 - 17.0
Group Delay	1.0	3.3
Multipath	1.2 - 2.7	4.0 - 9.0
Receiver Noise and Resolution	1.5	5.0
RSS	3.6 - 6.3	11.8 - 20.7

Source: Millilen, R. J. and Zoller, C. J., Principle of Operation of Navstar and System Characteristics, The Institute of Navigation, Washington D.C., 1980, pg 9.

2.4.1 Satellite Clock and Position Errors

Individual satellite clocks, although highly stable, may deviate as much as 976 microseconds from GPS system time. The uncorrected errors due to clock deviation alone are very small (on the order of one foot of equivalent range) and are indistinguishable from certain components of ephemeris errors so they are combined with the ephemeris errors in table 1.[7]

The monitor stations closely track the satellites to detect any errors in the clocks or orbits. Calculated error in the satellite clock and orbit are transmitted to the satellite every 24 hours as ephemeris and almanac data. The ephemeris data contains specific position and clock correction data for each satellite. The almanac data contains satellite position data for all satellites. The navigation set receives the ephemeris and almanac data from the satellites and compensates for the clock and position errors when calculating the navigation data.[11]

2.4.2 Ephemeris Errors

Satellite ephemerides are determined by the Master Control Station based on monitoring of individual satellite navigation signals by four monitoring stations. This operation results in a sort of inverted range process which enables the Master Control Station to calculate the position of a satellite as if it were the user and the four monitoring stations were the satellites. The ephemeris determination is aided by precision clocks at the monitoring stations and by daily tracking over long periods of time with optimal filter processing. The determination process derives progressively refined information defining the gravitational field influencing the spacecraft motion; solar pressure parameters; and the locations, clock drifts, and signal delay characteristics of the monitoring stations. Based on this process, the Master Control Station generates the ephemeris parameters that are uploaded in the satellite periodically and included in the navigation data message where they are employed in the ephemeris model to calculate spacecraft position at the time of transmission of the received signals.[7]

The satellite position errors resulting from this process are still on the order of several meters. However, it is the ranging errors that are of primary significance, and the effect of these is relatively small. The combined effects of residual uncertainties in satellite clock offsets and ephemeris determinations are estimated to result in range errors of about 1.5 meters (5 feet).

2.4.3 Atmospheric Delays

The time delay of RF signals passing through the ionosphere is due to a reduction in speed and the bending of the ray, both effects being due to refraction. The overall delay in the signal is nearly inversely proportional to the square of the frequency. The transmission of the navigation signal at the two frequencies (L1 and L2) is provided so that the magnitude of the delay can be calculated by a comparison of the two frequencies and removed with a satisfactory degree of accuracy.[7] Ionosphere delay will phase shift the lower frequency more than the higher frequency. The navigation set measures the ionospheric delay by measuring phase shift between the L1 and L2.[11]

Tropospheric errors are independent of frequency. They are relatively small but can be modeled fairly simple by receivers, using the elevation angle of the spacecraft. The combined effect of ionospheric and tropospheric errors are estimated to result in a range error of 2.44 to 5.18 meters (8 to 17 feet).[7]

2.4.4 Multipath

Multipath errors result from the combination of data from more than one propagation path that distorts the signal characteristics from which the range measurements are made. These errors are dependent on the nature and location of reflective surfaces peculiar to each user location. Aircraft simulation have indicated the these errors to be relatively small and have resulted in an error estimate of from 1.2 to 1.7 meters (4.0 to 9.0 feet).[7]

2.4.5 Receiver Noise and Resolution

Noise and resolution errors resulting from the processing of signals by the receiver hardware and software will contribute to errors in the determination of range. With high-performance four channel receivers, it is expected that these errors will be about 1.52 meters (5 feet).[7]

3. E-2C AIRCRAFT OVERVIEW

3.1 INTRODUCTION

The E-2C Hawkeye has been in service with the U.S. Navy since the mid-1970's and recently with several foreign governments. It is the latest airborne early warning command and control aircraft built by Grumman. The advanced version, the result of progressive airframe, propulsion, and systems development over the past 20 years, represents the state-of-the-art in airborne early warning command and control.

3.2 E-2C AIRFRAME

The E-2C is a high-wing, all-weather, carrier and shore based airborne early warning and control (AEW & C) aircraft that patrols task force defense perimeters. It provides early warning of approaching enemy aircraft and vectors interceptors into attack position. In addition to this primary AEW function, the Hawkeye can also provide strike and traffic control, area surveillance, search and rescue guidance, navigational assistance, and communications relay. The airplane may be easily identified by its 24 foot diameter rotodome and the four vertical tails (figure 7).[14]

Portions of the rotodome, the inboard vertical tails, pylon doors, and the upper portions of the outboard vertical tails are of fiberglass construction. The flight controls are

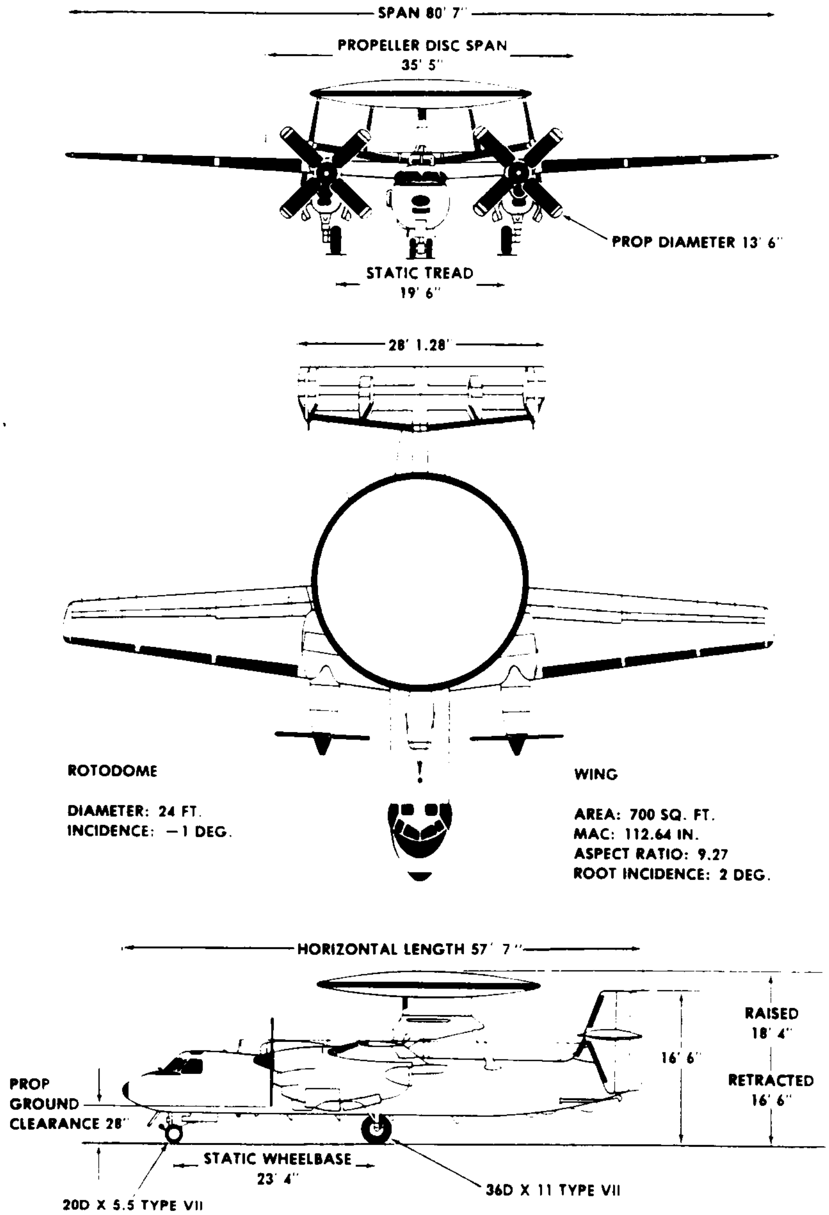


Figure 7 E-2C Hawkeye

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. I-1-2.

powered by two independent hydraulic systems. The aircraft is powered by two Allison T56-A-427 turboprop engines with Hamilton-Standard constant speed propellers. The engines each develop a maximum of 5,100 indicated horsepower at takeoff.[14] Aircraft weights and dimensions are shown in table 2 and 3, respectively.

The E-2C flight crew will normally consist of a Pilot, Copilot, and three weapons systems operators: the Combat Information Center Officer (CICO), the Aircraft Control Officer (ACO), and the Radar Officer (RO). The interior arrangements of the fully pressurized cabin facilitates the interchange of crew positions in an environment, that is normally oxygen mask-free.[14] Figure 8 shows interior arrangements.

The automatic flight control system provides crew relief by means of a maneuvering autopilot with both attitude and altitude hold modes. Precise holding of attitude and turn rate in wings-level turns is provided by the flat-turn mode.

The E-2C is operable from all angle-deck CVA-19 and larger class aircraft carriers and is catapulted with a nose-tow catapult system. Cockpit controlled wing-fold permits hangar deck servicing. The rotodome is fixed in the extended (up) position. For purposes of servicing/maintainability, the rotodome may be lowered using ground support equipment and an external hydraulic power source.[14]

Table II E-2C Aircraft Weights

Basic weight	40,200 pounds
Operating weight (zero fuel)	41,200 pounds
Maximum ramp weight (100% fuel)	53,600 pounds
Maximum takeoff weight	53,000 pounds

Table III E-2C Aircraft Dimensions

Wing Span	
wings spread	80 feet 7 inches
wings folded	29 feet 4 inches
prop tip to prop tip	35 feet 5 inches
Length	57 feet 7 inches
Height	
rotodome extended	18 feet 4 inches
rotodome retracted	16 feet 6 inches
rotodome diameter	24 feet
rotodome thickness	2 feet 6 inches

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. I-1-3.

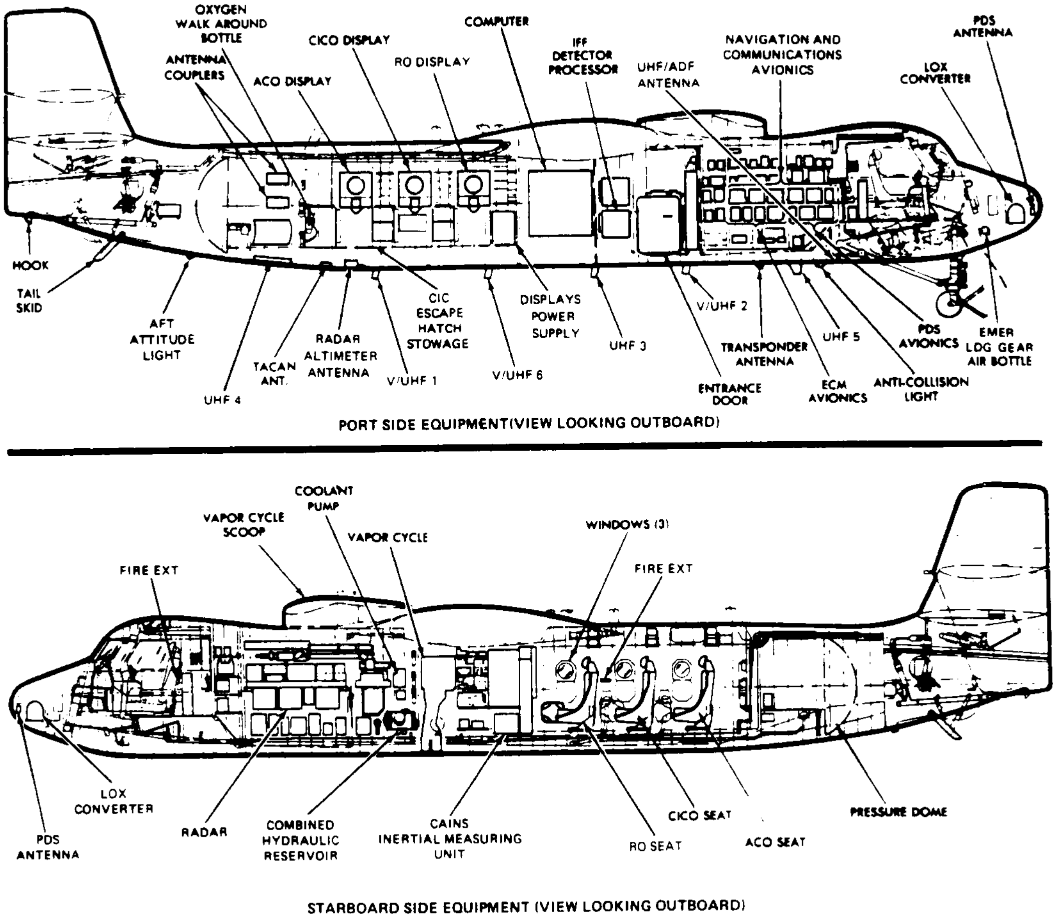


Figure 8 E-2C Interior Profile

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. I-1-3.

3.3 E-2C WEAPONS SYSTEM

The E-2C + features a new generation of avionics and a new equipment cooling system. A suite of avionics that offer both expanded capabilities and improved reliability and maintainability has been developed for packaging in the E-2 Hawkeye airframe using the latest techniques in microelectronics.[15]

The E-2C's advanced radar system, working through a high-speed digital computer automatically locates and tracks airborne and surface targets over land and water. Fighter-size targets are detected at ranges well beyond 200 miles; larger targets, such as bombers, are detected to the radar horizon limits; air- or surface-launched cruise missiles are detected at better than 125 miles. And the E-2C can carry on effective detection and tracking operations even under heavy enemy jamming.[10]

While surveying more than three million cubic miles of surrounding air space at sea, the E-2C is also monitoring nearly 150,000 square miles of ocean surface. It can detect virtually any maritime target, moving or stationary, patrol boats beyond 100 miles and larger ships to the radar horizon, even in relatively high sea states.[10]

Apart from its radar, the E-2C carries a passive detection system (PDS) unique in the AEW world. Operating in total radio-frequency silence, thus the enemy never suspects he is under surveillance, the PDS simply listens, intercepting signals from other electronic emitters on aircraft, surface vessels or land sites, alerting the E-2C operators to potential threats long before they come into radar range.[10]

Though the E-2C can operate independently, it normally functions as an extension of existing air defense systems. All data obtained aboard the plane can be relayed over UHF or HF data link to a surface command post or to the carrier's combat information center for display and decision making. Simultaneously, target information from other air defense elements or from the command post itself can be transmitted to the E-2C for correlation with on board data.[10]

High target density poses no problems for the E-2C. Its central processing system will automatically keep track of more than 600 separate targets. Target course, speed, altitude, and identification (friend or foe) are continuously available for in-flight display and/or real-time transmission to the surface. The E-2C thus provides a complete, up-to-the-minute picture of the tactical situation.[10]

The E-2C's computer compares a target's threat priority and establishes position and velocity relative to a friendly fighter's position, fuel state, armament, and performance. The E-2C system then assigns the best available interceptor to a particular target and the best flight path for intercept. It also provides navigation and steering data to strike aircraft for the best paths into and out of a target area to avoid enemy defenses and topographic hazards.[10]

3.4 NAVIGATION SYSTEMS

The integrated functions of the navigation system illustrated in figure 9 provide aircraft navigation and guidance capabilities, plus reference information to associated avionics systems for stabilization and orientation.

Primary functions of the navigation system are:[14]

1. To provide heading, attitude, groundspeed, and latitude-longitude to the cockpit displays for the pilot.

2. To provide for computer-programmer (CP) ground stabilization for target data and computer indicator group (CIG) displays, and supply the CIG display a north reference.

3. To calculate ownship latitude-longitude position for display and for use by the CP to compute link 11, ownship, and data link reference point (DLRP) position data.

The following on board sensors provide inputs to the navigation system:

1. Heading and Attitude Reference System (HARS) AN/ASN-50.

2. Standard Central Air Data Computer (SCADC) CPU-140/A.

3. Carrier Aircraft Inertial Navigation Systems (CAINS) AN/ASN-92(V).

The CP and the CAINS navigation computer each use the data from these sensors and perform independent solutions of navigation information. Cockpit control permits manual entries of data and visual or radar present position updates

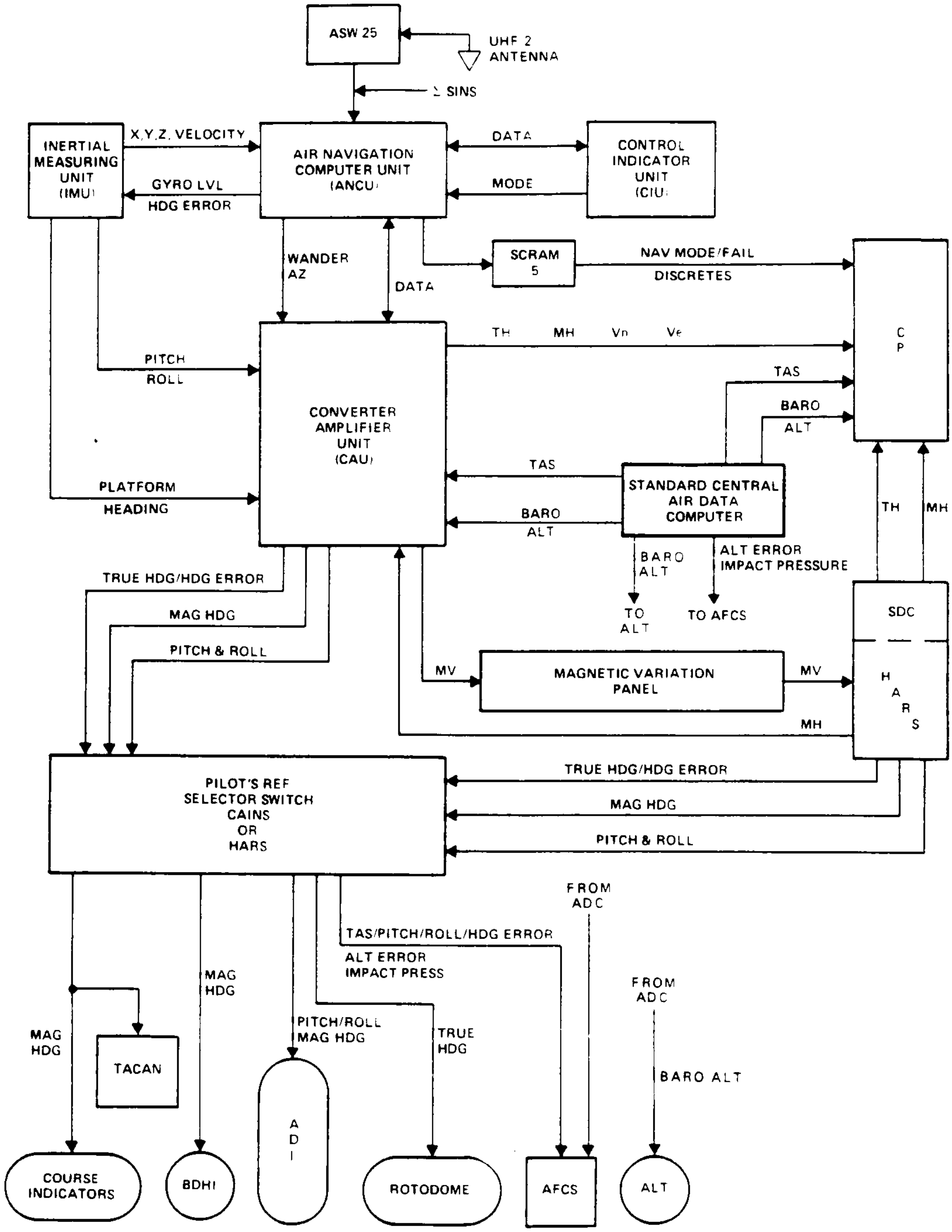


Figure 9 E-2C Navigation System

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. VII-22-2.

for either of both solutions. The pilot may select the source of heading and attitude reference for his instruments and the stabilization source for the weapons system; the copilot may select heading and attitude reference for his instruments and the CICO's bearing, distance, heading indicator (BDHI).[14]

The outputs from the navigation system to associated systems are as follows:

1. North and east component velocities to CP.

2. True heading to CP and rotodome antenna.

3. Magnetic heading to CP, TACAN, and flight instruments.

4. Heading error to automatic flight control system (AFCS).

5. Pitch and roll to the AFCS.

6. Pitch, roll, and heading to the Attitude Director Indicators (ADI's).

7. True air speed and altitude to the CP.

8. Altitude to the AIMS altimeter, the transponder, and the CP.

9. Altitude error to AFCS.

10. Impact pressure to AFCS.

3.4.1 Carrier Aircraft Inertial Navigation System

The CAINS, AN/ASN-92(V), figure 10, provides the aircraft with its primary guidance and navigation capabilities. CAINS

Figure 10 E-2C CAINS Control Panel

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. VII-22-5.

is capable of self-contained navigation without the use of external reference.

The outputs to the remainder of the weapons system include: pitch, roll, true and magnetic heading, north and east velocities, and various discrete for mode and malfunction indication. By using data from the SCADC, CPU-140/A, CAINS will operate in an augmented mode where the time dependent (Schuler) drift characteristic of the inertial system will be damped.[14]

The CAINS consists of the following units:

1. Inertial Measuring Unit (IMU), CN-1263/ASN-92(V).
2. Air Navigation Computer Unit (ANCU), CP-964/ASN-92(V).
3. Converter-Amplifier Unit (CAU), CV-2566/ASN-92(V).
4. Power Supply Unit (PSU), PP-6188/ASN-92(V).
5. Control-Indicator Unit (CIU), C-7883/ASN-92(V).

The IMU, consisting of a four-gimbal, three-gyro inertial platform, senses aircraft accelerations in three planes, and used for the following:[14]

1. Pitch and roll outputs to attitude indicators and AFCS via CAU.
2. North and east velocity calculation by the ANCU.
3. Platform heading output to the CAU for true heading computation.

The CAINS ANCU is a general purpose digital computer (GPDC), which makes use of inputs from the IMU and SCADC to calculate an independent solution to the navigation problem. In normal operations, the ANCU automatically selects the best CAINS NAV mode based on its evaluation of SCADC inputs, and its continuous self test of all CAINS units. The pilot may select a more degraded mode of operation, and the ANCU will use the selected mode. With weight-on-wheels, the ANCU controls the AN/ASW-25B ACLS receiver for RF and SINS alignments. North and east velocities and CAINS system status are sent to the CP.[14]

The CAU is the basic interface unit between CAINS and the other navigation subsystems. The CAU provides the following functions:[14]

1. Computes CAINS true heading (TH) using platform heading from the IMU and wander angle from the ANCU.

2. Computes magnetic variation (MV) by comparing CAINS TH with HARS magnetic heading (MH).

3. Outputs pitch and roll.

4. Computes CAINS MH using CAINS TH and manually entered MV if HARS MH is not available.

5. Computes a non-inertial TH by comparing HARS MH with manually entered MV in the MAG SLAV degraded mode.

The PSU provides power to the CAU, IMU, and ANCU from the right generator bus. A NiCad battery is provided to maintain CAINS alignment in the event of a power interrupt. This battery receives charging voltages whenever the right generator bus is energized.[14]

3.4.2 Heading and Attitude Reference System

The HARS AN/ASN-50 provides an alternate source of attitude and heading information in the form of continuous signal outputs about the pitch, roll, and azimuth axes. MH is supplied to CAINS for calculation of magnetic variation (MV). HARS may also provide both TH and MH to the CP as a backup to CAINS (figure 9).[14]

The HARS consists of the following units:

1. Remote Compass Transmitter (flux valve) ML-1.
2. Switch Rate Gyro.
3. Displacement Gyro.
4. Compass Adapter Compensator (CAC).
5. Compass Controller.
6. Signal Data Converter (SDC).

The ML-1 flux valve, in the left outboard vertical stabilizer sends magnetic heading information to the CAC.[14]

The switch rate gyro senses aircraft turns in excess of 15 degrees per minute, and sends this signal to the CAC.[14]

The displacement gyro is composed of 2 separate gyros; the directional gyro and the vertical gyro. The directional gyro supplies aircraft relative heading to the CAC. The vertical gyro senses aircraft pitch and roll, and outputs them to the Main Electronics Junction Box (MEJB) for distribution.[14]

The CAC produces smooth MH in one of three forms, depending on the mode selected on the compass controller (figure 11). They are as follows:[14]

SLAVE - This is the normal operating mode of HARS. In straight and level flight, ML-1 inputs are stabilized by relative heading inputs from the displacement gyro. When turns in excess of 15 degrees per minute are sensed by the switch rate gyro, ML-1 inputs are disabled, and relatives heading is used to track smoothly through the turn. Upon completion of the turn the system is returned to initial conditions. To compensate for errors, a correction signal from the CAC completes the smoothing process.

COMP - In this mode, the relative heading signal from the displacement gyro is disabled. ML-1 inputs are corrected by the CAC to produce MH. This mode may be required in response to a displacement gyro malfunction.

FREE - In this mode ML-1 inputs are disabled, and relative heading is used. An initial reference heading must be slewed in on the compass controller using the PUSH TO TURN knob. The knob must be pushed in and then turned right to increase heading, and left to decrease heading. This mode is used in latitudes above 70 degrees and in areas where the earth's magnetic field is appreciably distorted. It may also be used if the ML-1 is inoperative.

3.4.3 STANDARD CENTRAL AIR DATA COMPUTER

The SCADC computes true airspeed (TAS), impact pressure and altitude from static and total pressure supplied by the

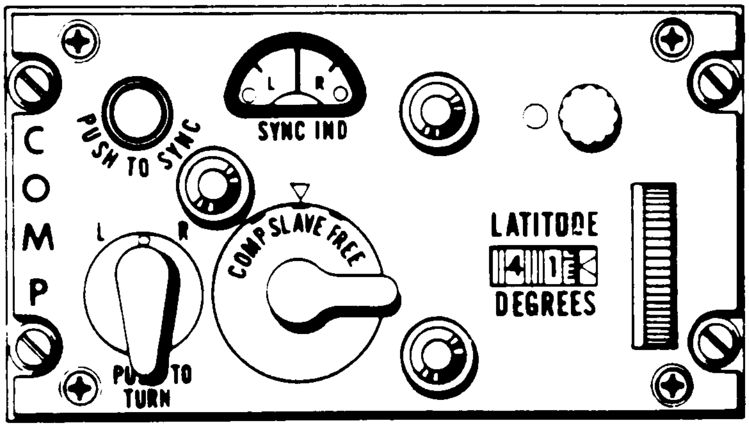


Figure 11 E-2C HARS Compass Controller

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. VII-22-14.

pitot static system and ambient air temperature supplied by the total temperature probe. These computed quantities are supplied upon request to CAINS and CP with the CP receiving priority. Altitude converted to an analog signal goes to the APX-100 transmitter for use in the AIMS altitude reporting system. Analog signals of true airspeed, altitude error and impact pressure are sent to the AFCS.[14]

The SCADC operation is fully automatic. During each pass through its program it checks internally for faults, which are reported to the In-Flight Performance Monitor (IFPM), and updates all information sent out on both analog and digital channels.[14]

4. GLOBAL POSITIONING SYSTEM INTEGRATION

4.1 SYSTEM CONFIGURATION AND DESCRIPTION

The GPS integrated into the E-2C aircraft avionics system consists of the Receiver Processor, the Fixed Reception Pattern Antenna, and Antenna Electronics. Operator interface is through the MFCDU, one in the cockpit and one in the CIC. Figure 12 shows the GPS equipment installation.

4.1.1 Global Positioning System Receiver Processor

The GPS Receiver Processor (AN/ARN-151), RCVR-3A, contains the receiver/signal processor, data processor, and interface modules to receive, track, and process the GPS signals from the antenna subassembly; and provide highly accurate three dimensional position, velocity, and time information to the E-2C interfaces. It features five parallel channels, 12-state Kalman filter, BIT, and low-power time source (LPTS). This receiver operates with the standard GPS L-Band frequencies of 1575.42 Mhz (L1) and 1227.6 Mhz (L2). The acquisition and processing of both Course Acquisition (C/A) code and Precision (P) code assure location accuracy to 16 meters, velocity accuracy to 0.10 meters per second and time accuracy to 100 nanoseconds. The Receiver is interfaced to the L-304 computer processor by the navigation 1553B data bus. The receiver also provides information the Precise Time

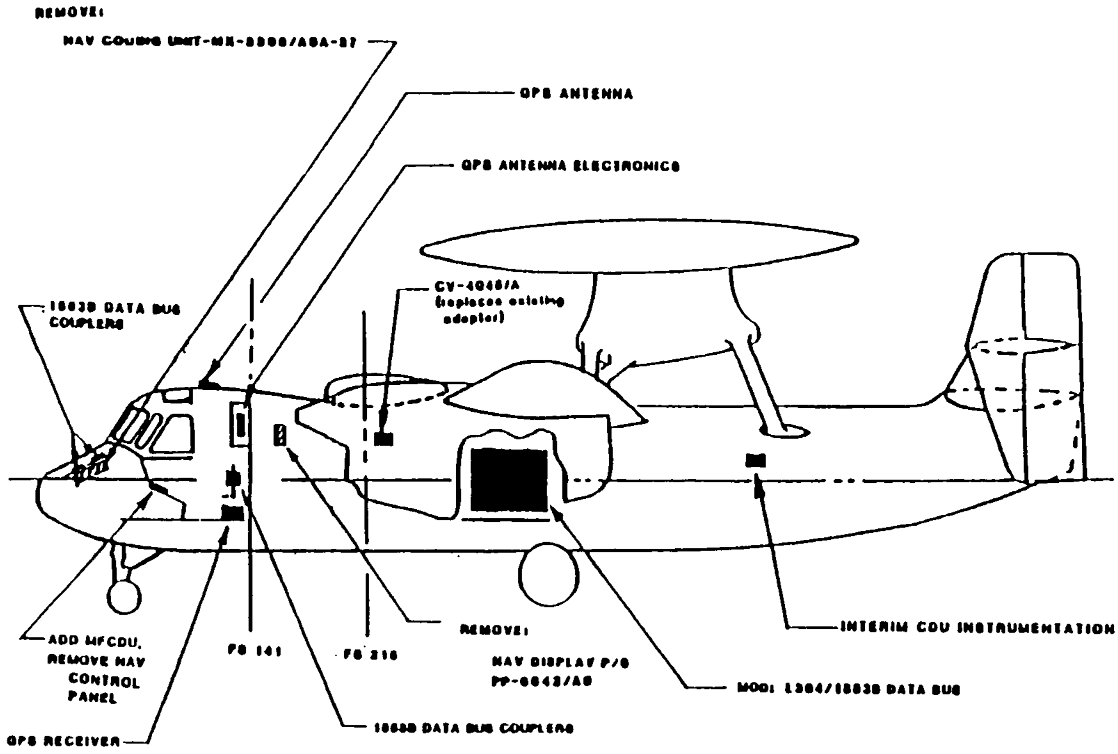


Figure 12 GPS Equipment Location

Source: E-2C JTIDS/GPS Status Review Conference, Grumman Aircraft Systems Division, Bethpage, New York, July 24-26, 1990, pg 75.

and Time Interval (PTTI), Selective Availability and Antispoofing (SA/AS) and MFCDU interfaces. The receiver's dimensions are: 7.62 inches wide, 7.53 inches high, 17.05 inches long, and it weighs approximately 37 pounds. The E-2C supplies single phase 115 VAC, 400 HZ power to the GPS receiver. The total power consumed by the GPS receiver is 140 watts peak, 68 watts average.[12]

4.1.2 Fixed Reception Pattern Antenna

The surface mounted Fixed Reception Pattern Antenna, FRPA-3, provides the reception of the right hand, circularly polarized, radiated signal from the GPS satellites. The navigation signals are contained within two 20.46 MHZ bands centered about the carrier frequencies L1 and L2. The antenna elements are contained in a casing with dimensions of .94 inches high, 4.62 inches wide, 4.62 inches long and weighs 0.5 pounds.[12]

4.1.3 Antenna Electronics Unit

The Antenna Electronics Unit, AE-4, provides the interface between the FRPA-3 and the RCVR-3A. It amplifies the composite RF (L1 and L2) input signal, splits this signal into separate L1 and L2 signals, down converts them and then outputs each signal at a common intermediate frequency (IF) on separate L1-IF and L2-IF coaxial cables. The electronic components are contained within a single unit weighing 2.15

pounds, and is 4.25 inches wide, 1.86 inches high, and 9.0 inches long.[12]

4.1.4 GPS Interface Modules

A block diagram showing the basic E-2C GPS interface is provided in figure 13.

1. MIL-STD-1553 Data Bus
2. Barometric Altimeter
3. Precise Time and Time Interval (PTTI)
4. SA/AS Interface

4.2 MULTI-FUNCTION CONTROL AND DISPLAY UNIT

The Multi-Function Control and Display Unit (MFCDU) is a computer, keyboard, and display screen installed in the cockpit and the CIC compartment. It is used to provide control over the GPS and JTIDS terminal. It also displays information to the pilot from the CIC operators.[14]

The pilot makes selections from options displayed on the computer screen, these inputs determine MFCDU programming. The MFCDU augments E-2C mission capability. The MFCDU improves flight management, increases situational awareness, and decreasing pilot cockpit work load by storing, displaying, and performing calculations on a large navigational databases typically required by the operators. The pilot has immediate reference to the location of mission parameters (waypoints, threat areas, and no-fly zones). The MFCDU by continuing to

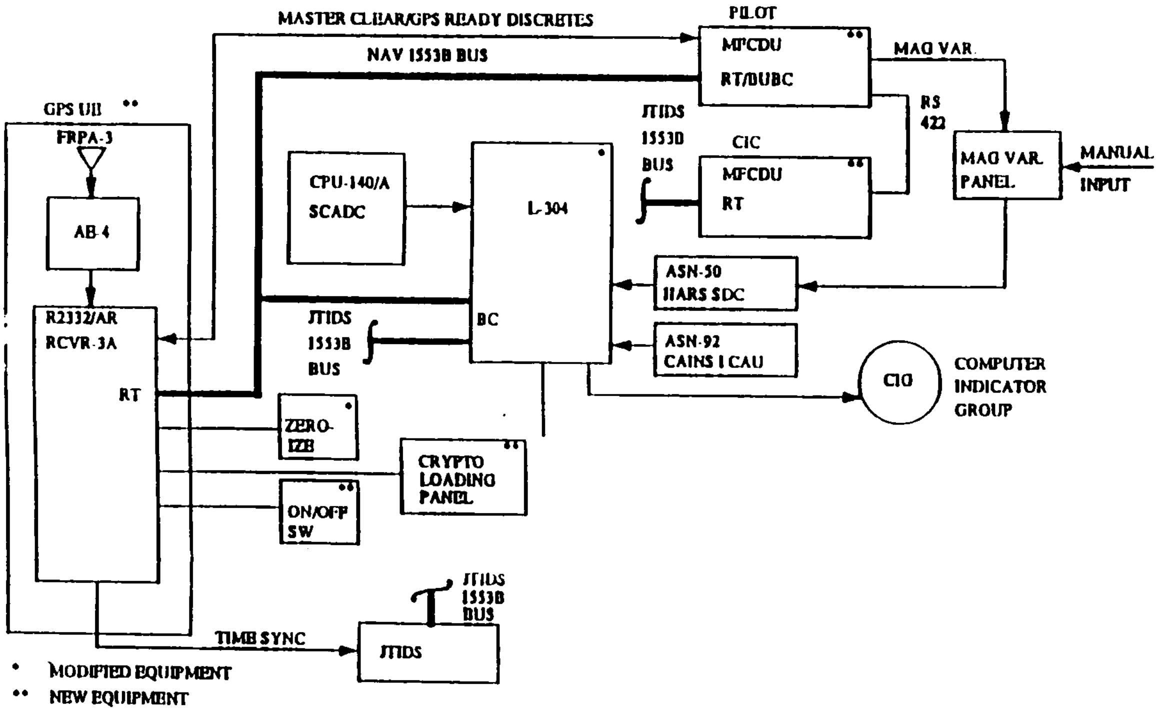


Figure 13 E-2C GPS Interface

Source: E-2C JTIDS/GPS Status Review Conference, Grumman Aircraft Systems Division, Bethpage, New York, July 24-26, 1990, pg 79.

process and display GPS navigation information is an accurate and reliable backup to the L-304 mission computer. The pilot can quickly and efficiently enter, change, and recall mission essential positions, conduct or revise flight plans or do fuel calculations to alternates. The MFCDU automatically updates E-2C present position for a continuous and accurate flow of information to the pilot.[17]

Navigation data is derived from several (GPS, INS) sources and when combined with the Air Data Computer (ADC) and the Heading and Altitude Reference System (HARS) positional error is reduced. Table 4 lists the main menu displays available for selection and states the purpose of the programming.[17]

4.2.1 System Description

The MFCDU is a programmable navigation device controlled by a menu interface. One hardware MFCDU box is in the cockpit and one in the CIC flight station, connected by communication (data transfer) buses. The MFCDU is programmed to send and receive data rapidly between several devices. In addition, it will continue to provide position information when the L-304 mission computer is inoperative.[17]

The vital system components are the data bus controllers and data buses. These include the MIL-STD-1553 data bus, the L-3304 digital data bus controller, MFCDU backup bus controller, and the RS-422 data bus. The MIL-STD-1553 data

Table IV

MFCDU Main Menu

OPERATING FEATURES

Table 2-1

MENU	PURPOSE
CATEGORY	Soft key selection for all main menus below.
DATA	Define waypoint, waypoint offset, threat area and no-fly-zone positions, and association of message data to waypoint data.
FLIGHT PLAN	Flight plan activation and access to flight plan creation by linking waypoint data, or selecting present position direct to a waypoint.
CALCULATOR	Calculation of transit times, fuel requirements, ground speed, bearing and ranges to waypoints, etc.
HORIZONTAL SITUATION (MAP)	Overhead view of current position, threat, no-fly-zone, waypoint, and flight plan information; referred to as horizontal situation.
E-2C INST	Program MFCDU with date, time, position, etc.. Initial conditions information.
JTIDS	CLASSIFIED INFORMATION, NOT COVERED IN THIS DOCUMENT
CPNAV	Displays wind direction and speed and provides for selection and de-selection of navigation inputs to the MFCDU.
FIX	Position update by a mark on top maneuver or to designate and store positions flown over.
REVIEW	Review contents of the MFCDU data base.
TEST	Check operation of GPS, keyboard, computer, display, primary and backup data bus controllers.

Source: Jackson, R. et.al., MFCDU Operator's Manual, VEDA Inc., 300 Exploration Drive, Lexington Park, MD, 20670, Jan 1992, pg 2-1.

bus ensures data gets to its proper destination. The L-3304 digital data bus controller times the data transfer. The MFCDU backup bus controller assumes timing control when the L-3304 cannot. The RS-442 data buss connects the two MFCDU (front and back seats) independently.[17]

This system architecture is termed "automatic priority dual redundant bus control." This is easily described in two parts. The first part, "automatic priority" refers to the bus control. If the L-304 mission computer or L-3304 digital data bus controller develop a problem the MFCDU backup bus controller automatically takes over bus control. When the problem is corrected the L-3304 automatically resumes control. The bus control transition is a seamless operation with no pilot action required. However, there will be degradations when the MFCDU backup bus controller is operating. With the L-304 off-line, some navigation sources (ADC, HARS, INS) are not available. Position will be derived from GPS and JTIDS REL-NAV sources. The second part, "Dual redundancy" refers to the MIL-STD-1553 data bus. There are two paths for data transfer called Primary A and Secondary B, each with the same capabilities.[17]

The flight station MFCDU communicates with the L-304 mission computer and GPS on the MIL-STD-1553 data bus. It is referred to as the Navigation MFCDU because it combines GPS position information with the navigation solution received from the L-304 computer (ADC, HARS, INS). The CIC MFCDU is referred to as the JTIDS MFCDU because it communicates with the JTIDS terminal and the L-304 computer on the MIL-STD-1553. The two MFCDUs are connected together independently by the RS-422 data bus. GPS and JTIDS REL-NAV data is always transferred between the MFCDUs on this bus. The RS-422 data bus, because it is separate, allows the CIC MFCDU to maintain a partial navigation solution it the event of L-304 mission computer failure. It also reduces the down-time when the L-304 comes back on-line.[17]

The MFCDU's ability to control the L-304's navigation function allowed for removal of hardware from the E-2C. The navigation control indicator and doppler control panel are no longer installed in E-2C's with MFCDU's. Full control of GPS and the L-304 mission computer navigation functions are now managed via MFCDU software.

4.2.2 Controls and Indicators

The MFCDU menu architecture is very efficient and user friendly. If the operator is knowledgeable of the indications it becomes easy to control and indicators are clear.

Keyboard entry control the MFCDU, the Cathode Ray Tube (CRT) screen display, status, alert, and fault indications. The MFCDU hardware display screen and control panel is illustrated in figure 14.[17]

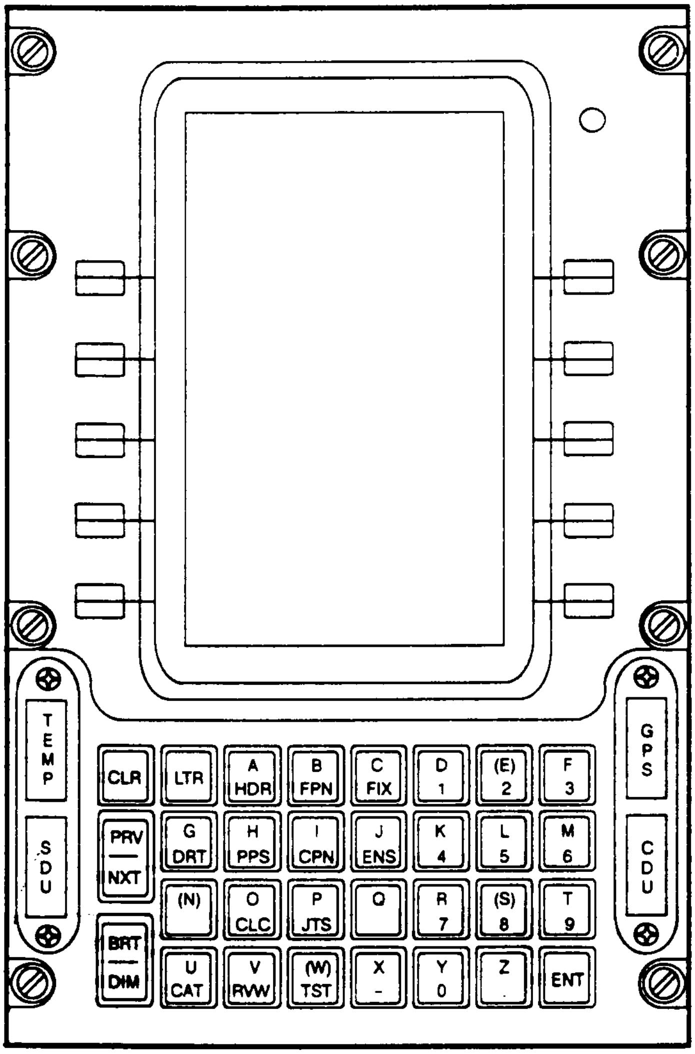


Figure 14 Mult-Function Control Display Unit

Source: NATOPS Flight Manual Navy Model E-2C Plus Aircraft, NAVAIR 01-E2AAB-1, Naval Air Technical Services Facility, 700 Robbins Ave., Philadelphia, PA, 19111-5097, 1991, pg. VII-22-27.

4.3 COMPUTER PROGRAMMER NAVIGATION

The function of the navigation subprogram of the CP is to provide ground stabilization to the weapons system. While navigation is a capability that exists independent of any particular mission, the ability to perform a particular mission, such as strike control, is affected to a great extent by navigation accuracy.[9]

With the integration of GPS in the E-2C, operation of the navigation subsystem, after initialization, is automatic. The mode of operation is selected by the navigation program within the computer program on the basis of operator selection or deselection of sensors at the Multi-Function Control Display Unit (MFCDU), and operational capability of the navigation subsystem.

The program incorporates navigation subsystem In-Flight Performance Monitor (IFPM) features to enable fault detection and isolation of navigation subsystem malfunctions, within both the computer program and the interfacing units. Periodically, tests are performed on the navigation Input/Output (I/O) converter unit, and in the event of a failure, a test fail flag is set. Periodic tests are also performed by the 1553B Protocol Program on the 1553B data buses that will present failure indications to the operator.[9]

4.3.1 Navigation Functions

The navigation function provides accurate ownship position data, and other navigation data, for:[9]

1. Ownship Navigation
2. Strike control
3. Target tracking computations and display.
4. Data link reporting of target and ownship positions.

The major functions performed or computed by the navigation program are:

1. Maintain an updated record of the present latitude, longitude, and altitude of ownship.
2. Maintain an updated record of X (east/west), Y (north/south) and Z (up/down) distance covered on the surface of the earth.
3. Ground speed and track of ownship.
4. Update matrices to transform STRP coordinates to local level, and local level coordinates to STRP.
5. Speed and direction of wind.
6. Navigation oriented IFPM tests.
7. I/O loop tests.

4.3.2 Navigation Mode

The program receives inputs from five navigation sensors: Global Positioning System (GPS), JTIDS Relative Navigation (REL NAV), Inertial Navigation System (INS), Heading and

Attitude Reference System (HARS - used only for heading) and Air Data Computer (ADC). Using the inputs from these sensors, the navigation program can operate in any one of twelve modes. Depending upon individual sensor status and pitot selection, /the program will automatically select the best operating mode available according to the following priority:[9]

A. Normal (GPS/INS/ADC)

B. GPS/INS

C. GPS/ADC

D. GPS-ONLY

E. REL NAV/INS/ADC

F. REL NAV/INS

G. REL NAV/ADC

H. REL NAV-ONLY

I. INS/ADC

J. INS

K. ADC

M. MANUAL

4.3.3 Mode Selection

Initialization - The navigation program will not select a navigation mode until one of the following occurs:

1. A non-zero latitude and longitude entry for ownship position (via the ADU or the MFCDU).
2. Activation of the CP NAV INIT softkey (via the MFCDU on the E-2C INIT screen).

Upon initiation by one of the above methods, the navigation program attempts to select a nav mode based on the availability of GPS, REL NAV, INS and ADC. Sensor availability is determined by the validity bits and NO-GO information provided by each of the sensors, and by operator selection.[9]

4.3.4 Operator Selection of Sensors

The MFCDU provides to the pilots and weapons system operators the capability to manually select or deselect the navigation sensors to be used. This allows for manual override of validity testing performed for each sensor.

On the CP NAV screen (figure 15 and table V) of the MFCDU, the operator can manually select or deselect GPS, REL NAV, INS and ADC by activating the appropriate softkey. Initially, all four sensors are set to AUTO, indicating that sensor availability will be determined solely by a test of data validity.[9]

1. The first activation changes the sensor to DESELECTED - the sensor will not be used by the navigation program regardless of data validity.

2. The second activation changes the sensor to SELECTED - data from this sensor may be used even if validity checks indicate the data is invalid.

3. The third activation returns the sensor to AUTO.

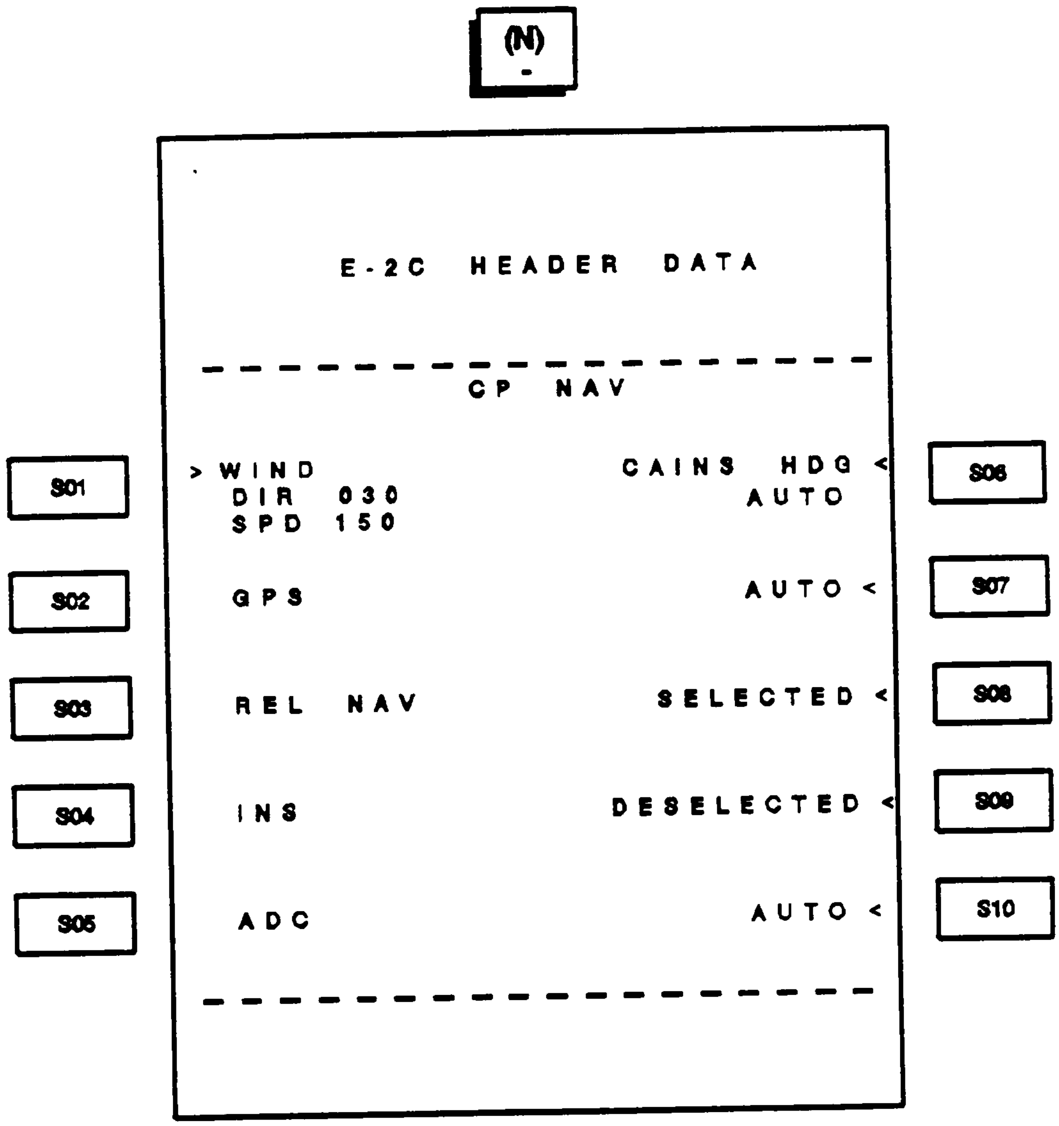


Figure 15 MFCDU CP NAV Menu

Source: Jackson, R. et.al., MFCDU Operator's Manual, VEDA Inc., 300 Exploration Drive, Lexington Park, MD, 20670, Jan 1992, pg 11-3.

Table V

Computer Navigation Menu

COMPUTER NAVIGATION MENU

Table 11-1

KEY	Selection	Purpose
S01	>WIND DIR 000 SPD XXX	Enter a estimated wind, when in a degraded mode. The softkey will allow access to the wind direction (DIR 000° to 359°). Enter a value then press ENT. Enter the wind speed and press ENT. TO ENTER WIND ALL NAVIGATION SENSORS MUST BE DESELECTED.
S06	XXXXX HDG < XXXXXXXXX	Possible selections are: CAINS, HARS or AUTO. If AUTO is selected heading will default to CAINS; if the CP heading history test fails, a CAINS/HARS HDG alert will be posted. When this occurs switch to HARS.
S07	GPS XXXXXXXXX <	Configure the GPS sensor.*
S08	REL NAV XXXXXXXXX <	Configure the REL NAV sensor.*
S09	INS XXXXXXXXX <	Configure the INS sensor.*
S10	ADC XXXXXXXXX <	Configure the ADC.*

* Make three available selections, SELECT, DESELECT OR AUTO by toggling the appropriate softkey. When AUTO is selected data from the specified sensor will only be used if the C-P determines that the sensor is providing valid data. SELECT will cause the data to be used regardless of the acceptance criteria and DESELECT will not use.

Source: Jackson, R. et.al., MFCDU Operator's Manual, VEDA Inc., 300 Exploration Drive, Lexington Park, MD, 20670, Jan 1992, pg 11-2.

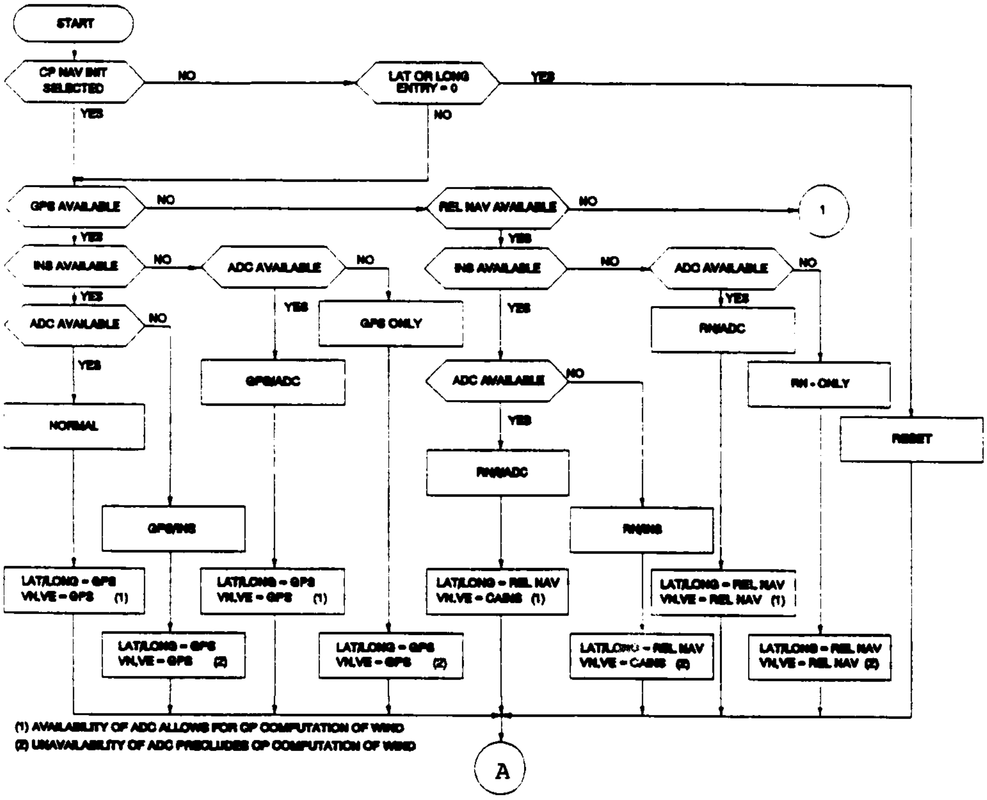
Additionally, the heading source may be manually selected by the operator, via activation of the HDG softkey on the CP NAV screen. Initially, the HDG source is set to AUTO, indicating that the heading source will be determined by the availability of INS and HARS (INS is first choice).[9]

1. The first activation of the HDG softkey changes the heading source to CAINS - magnetic and true heading from CAINS will be used.

2. The second activation changes the heading source to HARS - magnetic and true heading from HARS will be used.

Automatic NAV Mode Selection

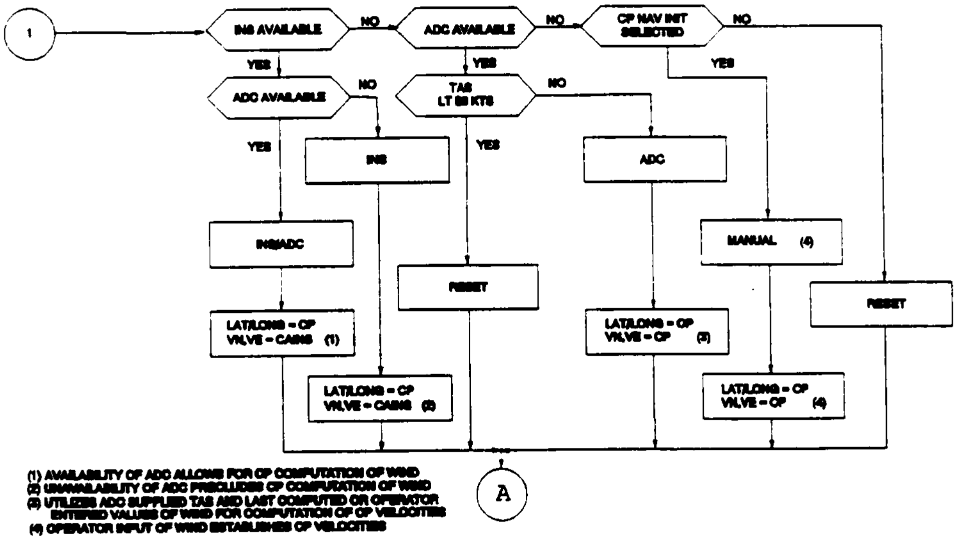
If the pilot has not selected a NAV mode using CP NAV INIT and non-zero ownship latitude and longitude have been entered, the CP program monitors the status of the five sensors to determine the best available operating mode. If GPS or REL NAV are available, or CAINS is operating in the Inertial - Air Data or Inertial mode, the CP program automatically selects the highest mode based on sensor availability and immediately starts navigating. If GPS and REL NAV are not available, and CAINS is not in either of those two modes and the aircraft's true air speed is greater than 80 knots, the Air Data mode is selected by the CP program. If none of the above conditions exist, no mode will be selected by the CP program and pilot action is required to select a NAV mode.[9] (See figure 16 and 17).



A = Pilot Action Required.

Figure 16 Criteria for Selection of Nav Mode (1 of 2)

Source: Systems Operational Manual for Airborne Tactical Data System E-2C, PD-32001-J, Grumman Aircraft Systems, Bethpage, New York, Nov 1992, pg 2-47.



A = Pilot Action Required.

Figure 17 Criteria for Selection of Nav Mode (2 of 2)

Source: Systems Operational Manual for Airborne Tactical Data System E-2C, PD-32001-J, Grumman Aircraft Systems, Bethpage, New York, Nov 1992, pg 2-48.

4.3.5 Automatic Downgrade/Upgrade

Once a NAV Mode has been selected, the navigation program will monitor navigation sensor status and evaluate their inputs. If a sensor or its inputs to the navigation program are determined to be bad, the program will downgrade to the highest available mode. If at a later time, the status of the sensor or its inputs are determined to be valid, the program will upgrade.[9]

4.3.6 Air Data True Air Speed

The automatic mode selection process and the automatic downgrade process could combine to cause the navigation program to begin drifting while on deck. This would be caused by a GPS, REL NAV OR INS mode being selected as unavailable. To prevent this inadvertent drift, the Air Data Computer velocity is checked. If the reported ADC velocity is less than 80 knots, the ADC mode will not be automatically selected by the NAV program.[9]

4.3.7 Operator Interface

Once the most accurate navigation mode has been determined, the various computational routines and I/O tests listed previously are initiated automatically under navigation subprogram control. Operator interface and control of the program, other than mode selection, are accomplished via the MFCDU and ADU function switches and involve data entry and display. The MFCDU entries and readouts consist of the following:[9]

1. Latitude and longitude of ownship position.
2. Wind speed and direction.
3. Ground track and speed.
4. Sensor Selection/Deselection.
5. Heading Source.
6. Sensor Availability (for GPS, INS, ADC, and HARS).

The Track field displayed on the MFCDU E-2C Airborne Header reflects ownship magnetic ground track. The course readout on the ADU reflects ownship heading. As an extreme example, a direct headwind causing a negative ground track would result in a track readout on the navigation control indicator 180 degrees different from ownship heading.[9]

The NAV FIX function interacts via the tactical program with the MFCDU and ADU. The program accepts updates from either source; therefore, geo point symbols jump when an ownship position entry is made (via function switch or MFCDU), or upon translating a Nav Fix. A Nav Fix translate or lat/long entry while the nav mode is a GPS or REL NAV mode (i.e. NORMAL, GPS/INS, GPS/ADC, GPS-ONLY, RN/I/ADC, RN/I, RN/ADC, RN-ONLY) will cause the GPS and REL NAV sensors to be DESELECTED automatically, and the program will attempt to downgrade to INS/ADC.[9]

4.3.8 Coordinate System

Upon initialization, a ground stabilized coordinate system (GSCS) is established. This is essentially a 2048 NM square grid with its center designated as the system tracking reference point (STRP). All computations are done in X, Y from STRP. The latitude and longitude of STRP is stored upon its establishment and is equal to ownship position only upon initial selection of a navigation mode. Thereafter, ownship will navigate away from STRP at the aircraft's calculated course and speed over the ground. Because meridians of longitude, which in actuality converge at the poles, were previously represented as parallel vertical lines in the GSCS, distortions were introduced, particularly at high latitudes. However, the new coordinate conversion system utilizes a tangential projection technique to effectively bend or reshape the display grid to more accurately approximate the earth's curvature and this meridian convergence. This will substantially lessen the error difference between calculated NAV position and MDU symbol position. Each time ownship position is updated either by NAV FIX translation or manual entry at the ADU or MFCDU, new ownship X and Y values are calculated by comparing the new and old ownship latitudes and longitudes. Any geographic points previously entered will have their track file coordinate values of X and Y recomputed to values consistent with this new ownship position. The points will retain their original latitude and longitude and will be repositioned on the MDU.[9]

5. FLIGHT TEST

5.1 INTRODUCTION

The GPS integration and verification flight tests were conducted from 13 April, 1990 through 13 August, 1990 on five dedicated flights, totaling 11.2 hours.[16] In addition, the GPS and MFCDU installation was evaluated during the E-2C Update Development Program Group II Technical Evaluation conducted from October, 1991, to April, 1992.[12]

5.2 INSTRUMENTATION

5.2.1 Control and Display Unit

The Control and Display Unit (CDU) accomplished all of the display and control functions necessary for the operation of the GPS receiver during flight testing. The CDU indicates, via a four line CRT, the operational mode of the receiver, while a keyboard and two rotary knobs allow selection of parameters for control and display. The CDU was connected to the GPS receiver by a standard ARINC-429 Data Bus. The CDU was installed in the aircraft for instrumentation purposes only.[16]

5.2.2 High Density Digital Recorder System

The High Density Digital Recorder (HDDR) System consists of an AMPEX AHBR 1700i tape recorder, Digital Processing Unit (DPU), Digital Acquisition Formatter (DAF), CICO Control Panel, DAF Cable Driver, CP Data Extraction Module (L-304 DX) and Pulse Coded Modulation (PCM) assembly. The Ampex AHBR 1700I is a 28 track recorder with 22 digital tracks recording 400K words/second in a parallel format. Seventeen of the 22 tracks are for formatted message type data and the remaining 5 tracks are designated for synthetic videos. Six tracks are used for internal tape system overhead which consists of: error correction and coding, ICS, voice, and IRIG A serial time code. Record time is approximately 2 hours at 15 IPS. The HDDR System provides in-flight performance monitoring for fault isolation and troubleshooting in addition to receiving input data from various asynchronous avionic system sources on the aircraft. The data is arranged into a format suitable for recording on the HDDR. The PCM sub-system allows a 16 channel input serial stream record capability.[12]

5.2.3 High Speed Recorder System

The High Speed Recorder (HSR) system consists of an AMPEX AHBR 1700i tape recorder, Digital Processing Unit (DPU), HSR Formatter, HSR Control Panel, HSR Cable Driver, Common Bus Cable Driver and DAF Cable Driver. The Ampex 1700i is a 28 track recorder with 24 parallel digital data tracks recording 5M words/second. Four tracks are used for internal tape system overhead and error correction and coding. Record time is approximately 21 minutes at 115.5 IPS. The HSR was designed to acquire synchronous data during flight from the radar and IFF subsystem for post flight playback and analysis.

The HSR system also has the capability of routing one display video to the MDU through the Long Pulse Video line. The HSR system has the capability to provide seven different modes which are operator selectable.[16]

5.2.4 Film Camera System

Nikon F-3 35mm cameras with oversized magazines (250 frame bulk pack) were used for simultaneously photographing MDU and ADU displays along with ancillary information such as IRIG time, calendar date, aircraft number, frame number, CIG location(ACO, CICO, RO), radar filter number, threshold number and range (sample) number. The cameras may be operated in manual mode or synchronously from the CICO control panel in an automatic mode where a "Stagger Mark" knob controls the azimuth at which the camera shutter is opened to start the 10-second time lapse photograph. The Cameras used a 24mm wide angle lens with motor drive and high speed black and white Kodak 2475 film (ASA 1000).[12]

5.2.5 TV Camera System

Two Pulnix T34K closed circuit TV cameras mounted at the ACO CIG were used for recording the MDU and ADU, MDU and Spectrum Analyzer or full screen Spectrum Analyzer displays as a function of operator selection through a video camera control unit (VCU). The MDU camera is fitted with a 4.8mm lens. The VCU inserts time of day and date on the video signal and also supplied the Pulnix cameras with a sync signal. The composite video signal is routed from the VCU to a TEAC V-1000AB-N Video Cassette Recorder (VCR). The VCR recorded and played back 30 minutes of video data with appropriate RO or ACO ICS crew compartment voice annotations, selectable via the Instrumentation voice processor, on a 3/4 inch U-matic video cassette.[12]

5.2.6 Strip Chart Recorder

A modified Astro-Med Model W303XL 3-channel strip chart recorder was used to provide real time recording of selected radar signals. The recorder had three main data channels and two event (discrete) channels. Three of ten signals may be marker and time (Slow Code Format) are recorded on the left and right events pens, respectively; 5mm/second or 25mm/second paper speed are available.[12]

5.2.7 Spectrum Analyzer

A Tektronix 492 Spectrum Analyzer is used to display the Radar IF over the channel bandwidth to assess EMI and/or jammer characteristics. The spectrum analyzer may be used with or without a TV video camera depending upon test requirements.[16]

5.2.8 Cockpit TV Camera

The Cockpit MFCDU Display was recorded using a 12 volt Pulnix TM 540 video camera mounted on the glare shield. The MFCDU is located on the cockpit pedestal. On takeoff the camera was in a stowed position, out of the pilots line of sight. Prior to use, the camera was rotated 90 degrees into the operating position by releasing a spring loaded pull pin. A control panel, located within the reach of the copilot, contains power on/off and standby/recorded switches in addition to an end of tape (EOT) lamp. A TEAC Video Cassette Recorder (VCR) was used for recording and time was recorded via a Datum Time Inserter synchronized with the instrumentation IRIG Time Code Generator. The recorder used 3/4 inch U-matic format tapes permitting 1/2 hour record time. The MDU and ADU, MDU and Spectrum Analyzer or MFCDU Displays were switches selectable for viewing on the TV monitor located in the CIC compartment.[16]

5.3 TEST METHODS AND DATA ACQUISITION

Digital and video data were recorded for evaluation of GPS integration into the E-2C weapon system. The digital data, on HDDR tape, was subsequently reformatted and computer processed post flight into plots. These plots compared various navigational modes (Normal, INS/ADC, ADC), navigational inputs (CAINS, ADC) and ground based truth data (CTR, navigation reference points) with GPS inputs to the CP

NAV solution. The video data, stored on 3/4 inch U-matic cassettes, was taken to evaluate the performance of the MFCDU and provide a "quick look" comparison of GPS and CP NAV data. This "quick look" comparison was used by the engineers to evaluate GPS integration while waiting for post flight data reduction.[16]

5.4 TEST FLIGHTS

The objectives of the test flights consisted of integration and verification goals. Integration objectives consisted of basic test flights over closed loop navigation courses, as well as accuracy flights against the Chesapeake Test Range (CTR), to evaluate L-304 Mission Computer use of GPS data. Verification objectives were conducted to show that other navigational sensors (CAINS, HARS, ADC) suffered no degradation due to GPS installation.

Five dedicated flights, totaling 11.2 flight hours, were flown during this test program. Of these five flights, two flights were flown at NAWCAD, Patuxent River, MD, using the Chesapeake Test Range (CTR). The remaining three flights were flown out of GASD, Bethpage and Calverton, NY, over closed loop navigation courses. The flight profiles are illustrated in figures 18 through 20.

During the flight test period, numerous navigation modes were selected to evaluate the hardware (GPS and MFCDU) integration and proper implementation of GPS algorithms into

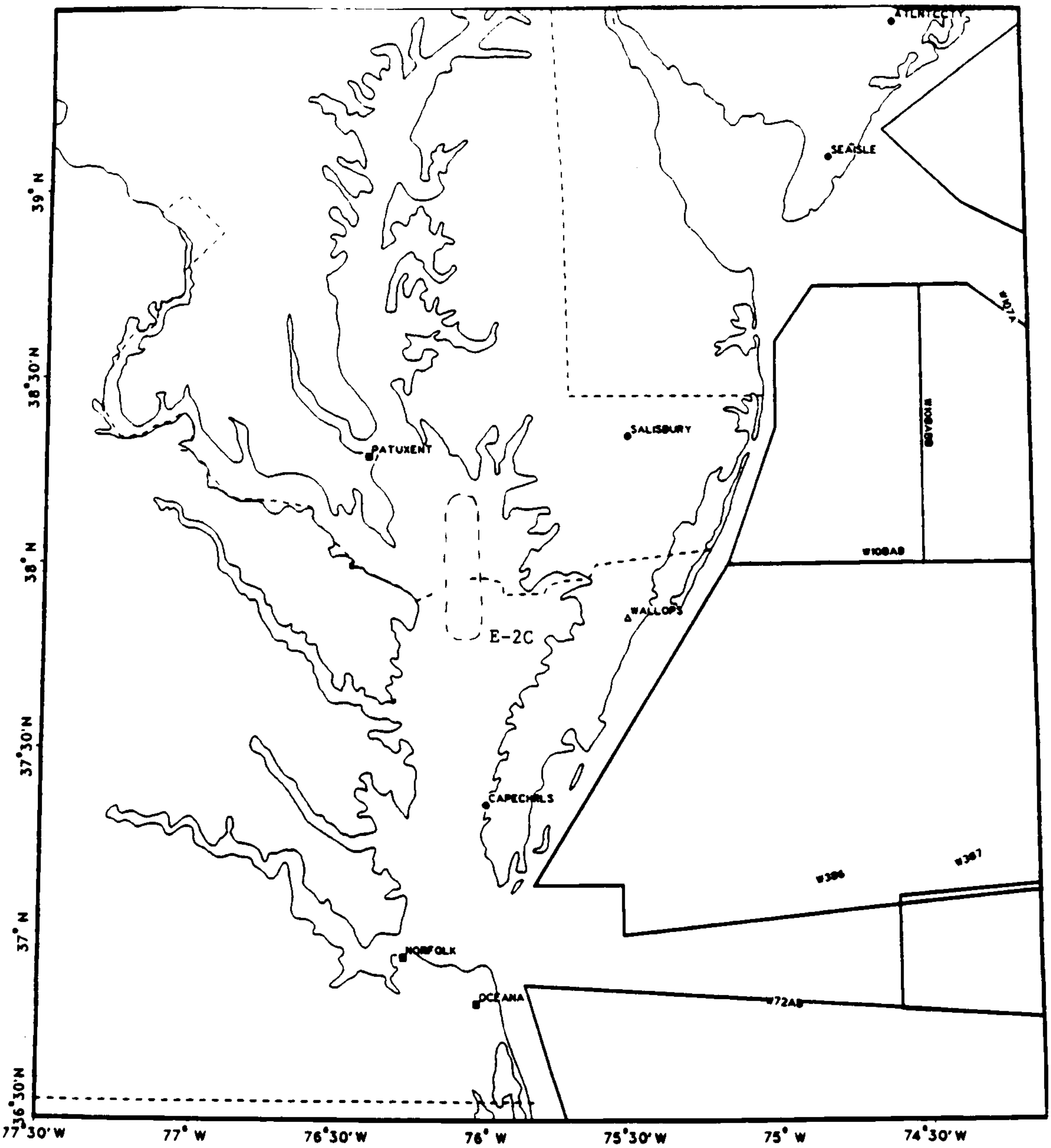


Figure 18 GPS Flight Profile 1

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 32.

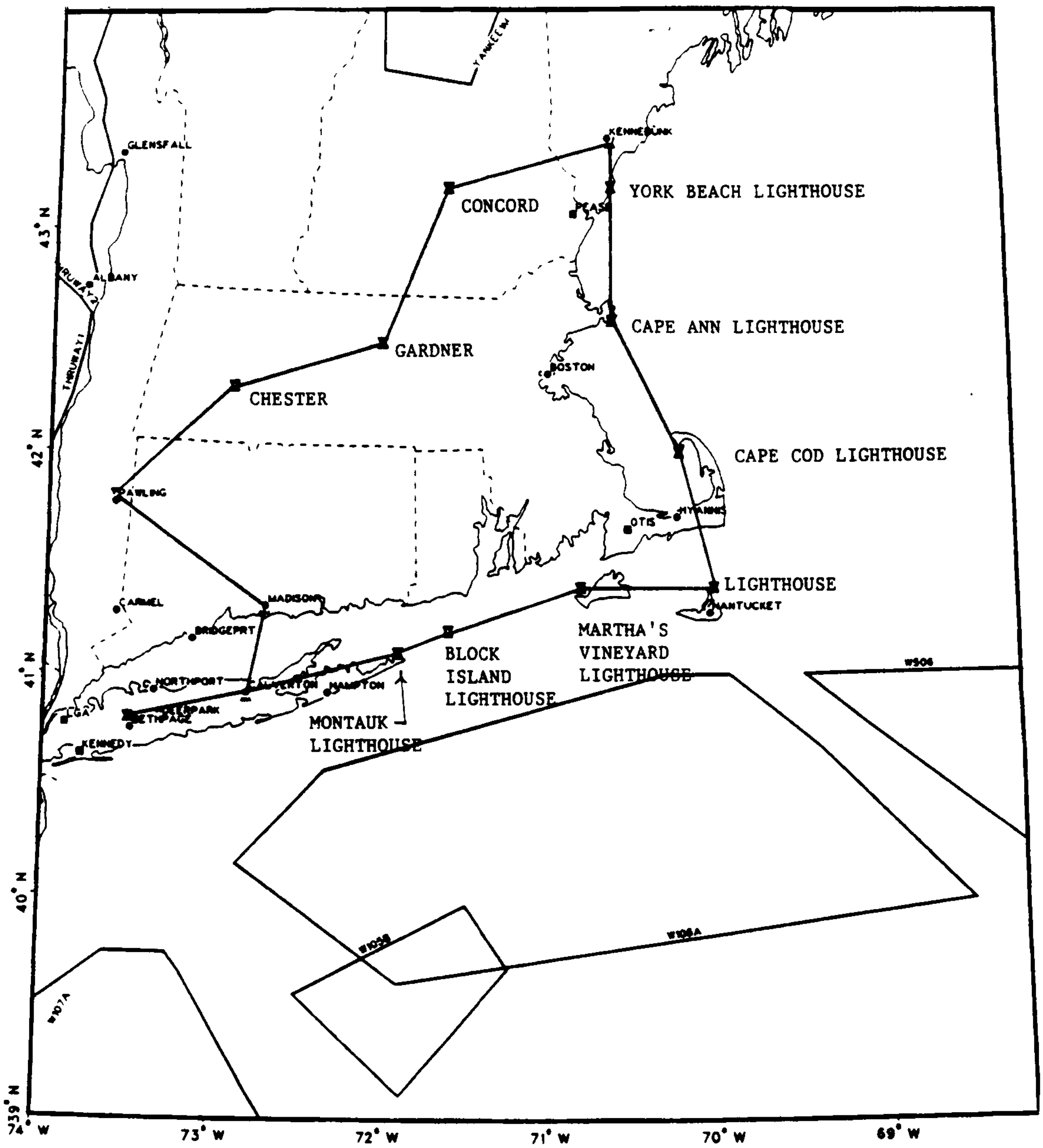


Figure 19 GPS Flight Profile 2

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 33.

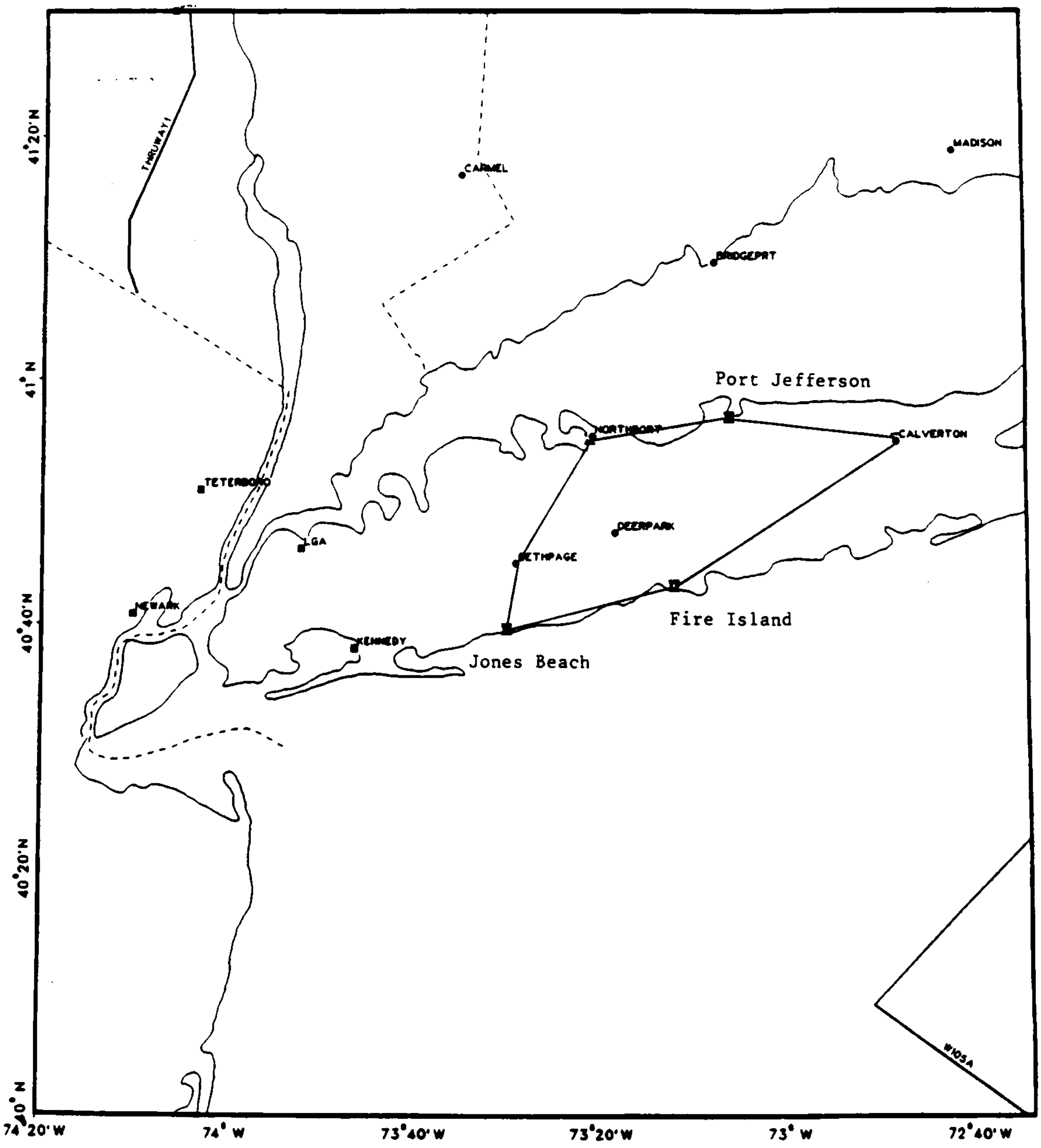


Figure 20 GPS Flight Profile 3

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 34.

the L-304 Mission Computer software. The CP NAV solution was closely monitored for proper response to degraded system performance (i.e. failure of one or more navigation sensors). The limited window of GPS satellite visibility greatly aided in the test scenarios. This provided an involuntary downgrade which occurred gradually, allowing the test engineers an opportunity to verify correct response over time.[16]

5.5 TEST RESULTS

The digital (HDDR) data from the test flights were combined for each of the appropriate test points to provide composite plots of aircraft navigation mode vs. GPS vs. CTR (if applicable). The resulting plots from flight #649 are presented in appendix A, figures 1 through 19, and offer the best representation of GPS integration due to the highly accurate truth data generated by the Chesapeake Test Range. The data from the other dedicated GPS flights have not been presented due to the lack of adequate truth data to warrant submission to this report. However, the results of all test points have been compared to confirm their "reasonableness".[16]

Figure 21 compares GPS, CP NAV and CTR data over the duration of flight 649. As an overview, these data shows the overall quality of CP NAV solution while in the Normal mode.[16]

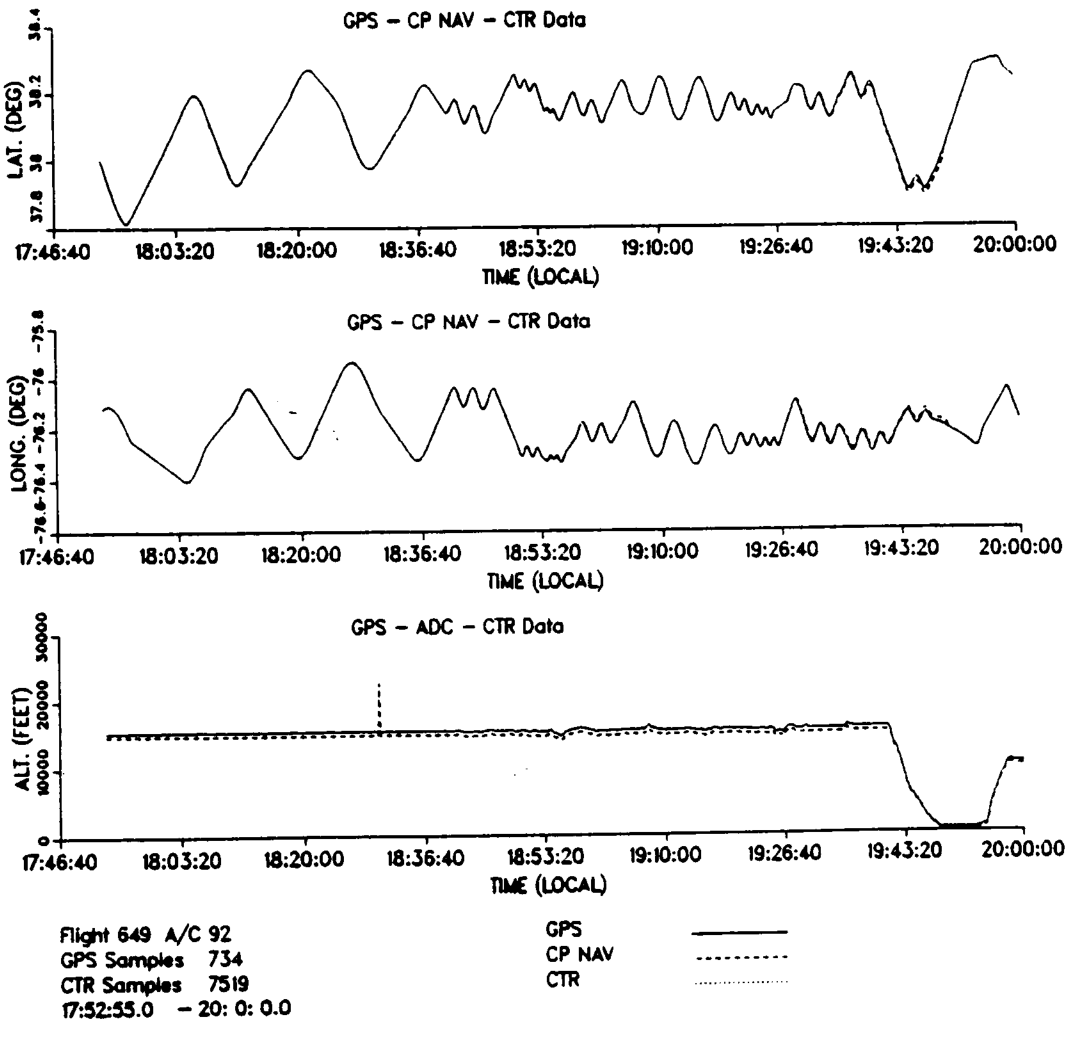


Figure 21 Comparison of GPS, CP NAV, and CTR over the duration of the flight.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 10.

While operating in the Normal mode (GPS, CAINS, ADC), the CP NAV solution tracked precisely with the truth data from CTR. The correlation of the CP NAV solution with CTR data verifies the uses of GPS input (appendix A, figure's 2, 3, 8, 9, 17, and 18). This high degree of accuracy demonstrates the proper selection, by the L-304 Mission Computer, of sensor input to CP NAV solution based on an accuracy weighing factor.[16]

Downgrading to the next navigation mode, INS/ADC shows proper tracking response, but a lesser degree of accuracy (appendix A, figure's 5 and 6). The offset between CPNAV and CTR typically seen is approximately 0.015 minutes (1/8 NM). This is consistent for a CP NAV solution based on CAINS velocity inputs.[16]

The selection of the lowest navigation mode - ADC, shows an altitude offset of approximately 700 - 800 feet from CTR truth data (appendix A, figure 4). The ADC output is based on pressure altitude, not baro corrected altitude. Therefore, this difference is probably due to temperature and pressure variations and position error within the Pitot Static System.[16]

The CP NAV solution in Normal mode, during a 30 degree bank turn, shows a slight difference from CTR over time. This was due to a momentary nav mode downgrade to INS/ADC mode. This downgrade was the result of GPS data invalidity caused by the blanking of the GPS antenna with the fuselage or rotodome of the aircraft. This momentary reduction in the number of satellites visible or figure of merit caused the L-304 Mission Computer to automatically downgrade to the INS/ADC mode. The difference seen in appendix A, figures 11 and 12, is consistent with results of INS/ADC mode test points. Upon reacquiring valid GPS inputs, the L-304 automatically switched back to the Normal nav mode. This nav mode change was only seen at 30 degrees bank turns, where as 60 degree bank turns were uneventful due to the reduced time spent in the turn, therefore reducing the duration of antenna blanking (appendix A, figure's 14 and 15). A contributing factor to this antenna blanking condition may have been the limited satellite constellation available for use during this flight. If any of the four satellites required for a GPS based CP NAV solution were low enough on the horizon, the fuselage or rotodome would have blocked the reception by the GPS antenna. This condition should be eliminated as soon as the full GPS satellite constellation is in place and available for use.[16]

Plots comparing GPS - ADC - CTR for altitude (appendix A, figure's 4, 7, 10, 13, 16, and 19) show a delta between GPS and CTR truth data. This is due to the use of radar based tracking by CTR for this specific flight. Subsequent GPS accuracy tests flown used laser based tracking, showed a much smaller delta between GPS altitude and CTR truth data. This was due to the greater accuracy of the laser based tracking system.[16]

6. DISCUSSION AND CONCLUSIONS

The integration of GPS and MFCDU into the E-2C Hawkeye was successfully completed. Flight crew evaluations, substantiated by digital and video data, confirmed the proper use of GPS data and algorithms in the E-2C.

The cockpit crew, pilot and co-pilot, now have a highly accurate means of navigation with an easy to use graphic interface (MFCDU). The CIC crew, RO, CICO, and ACO, have a reliable and highly accurate navigation input to the CP NAV solution which will not drift over time. GPS can be utilized by the E-2C Hawkeye to provide strike and traffic control, area surveillance, and search and rescue guidance, with precision accuracy. The E-2C in combination with other GPS equipped platforms will be able to improve target detection and handoff, and enhance Naval Tactical Data System (NTDS) gridlock. GPS can also be used to stabilize the JTIDS relative navigation grid and the GPS PTTI output can provide precise time to JTIDS for passive synchronization. As the aircraft that patrols Naval task force defense perimeters and warns of approaching hostile aircraft, the E-2C/GPS integration will tremendously benefit airwing operations. This addition to the aircraft will serve it well into the 21st Century.

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APPENDIX

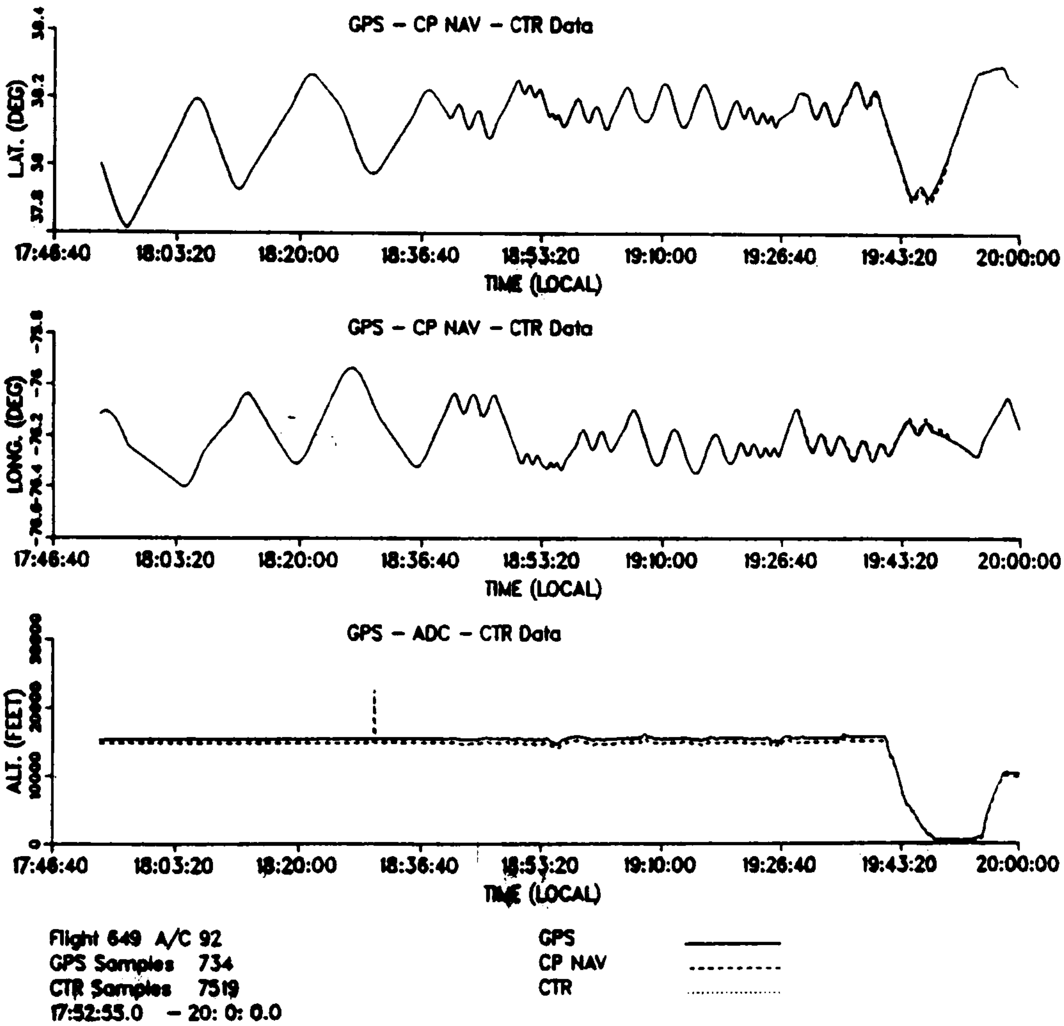

Figure 1 Comparison of GPS, CP NAV, and CTR over the duration of the flight.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 10.

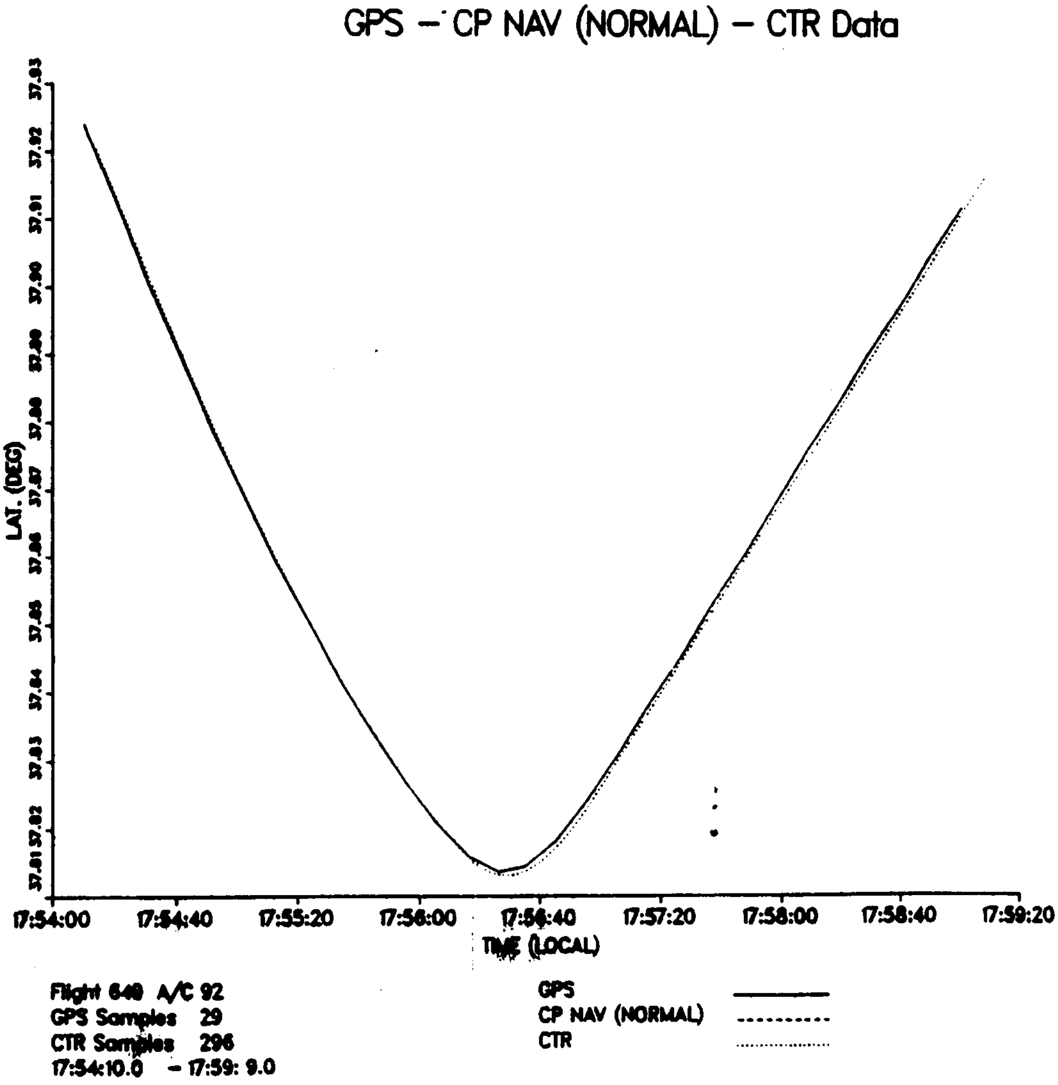

Figure 2 Comparison of GPS, CP NAV (Normal), and CTR Latitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 11.

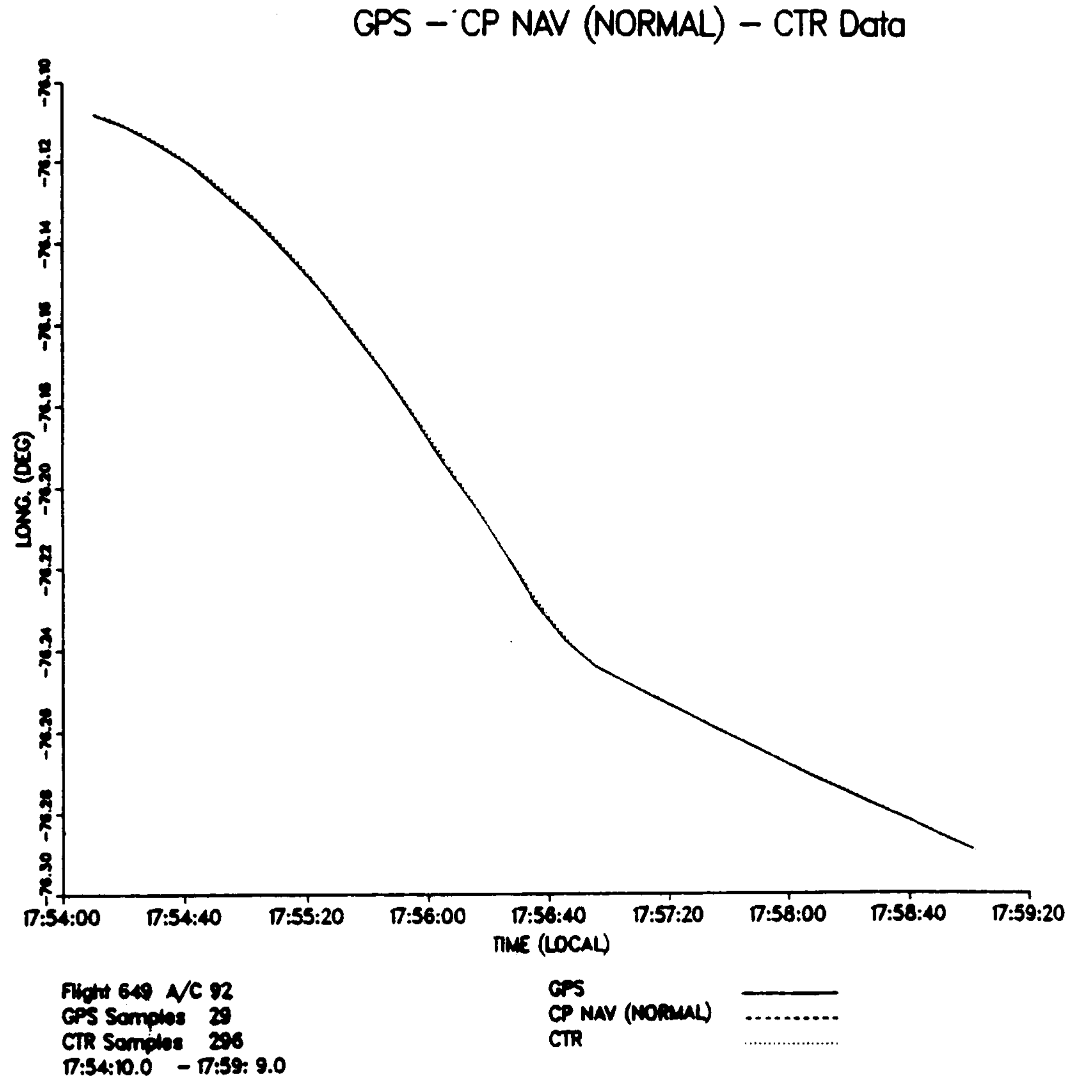

Figure 3 Comparison of GPS, CP NAV (Normal), and CTR Longitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 12.

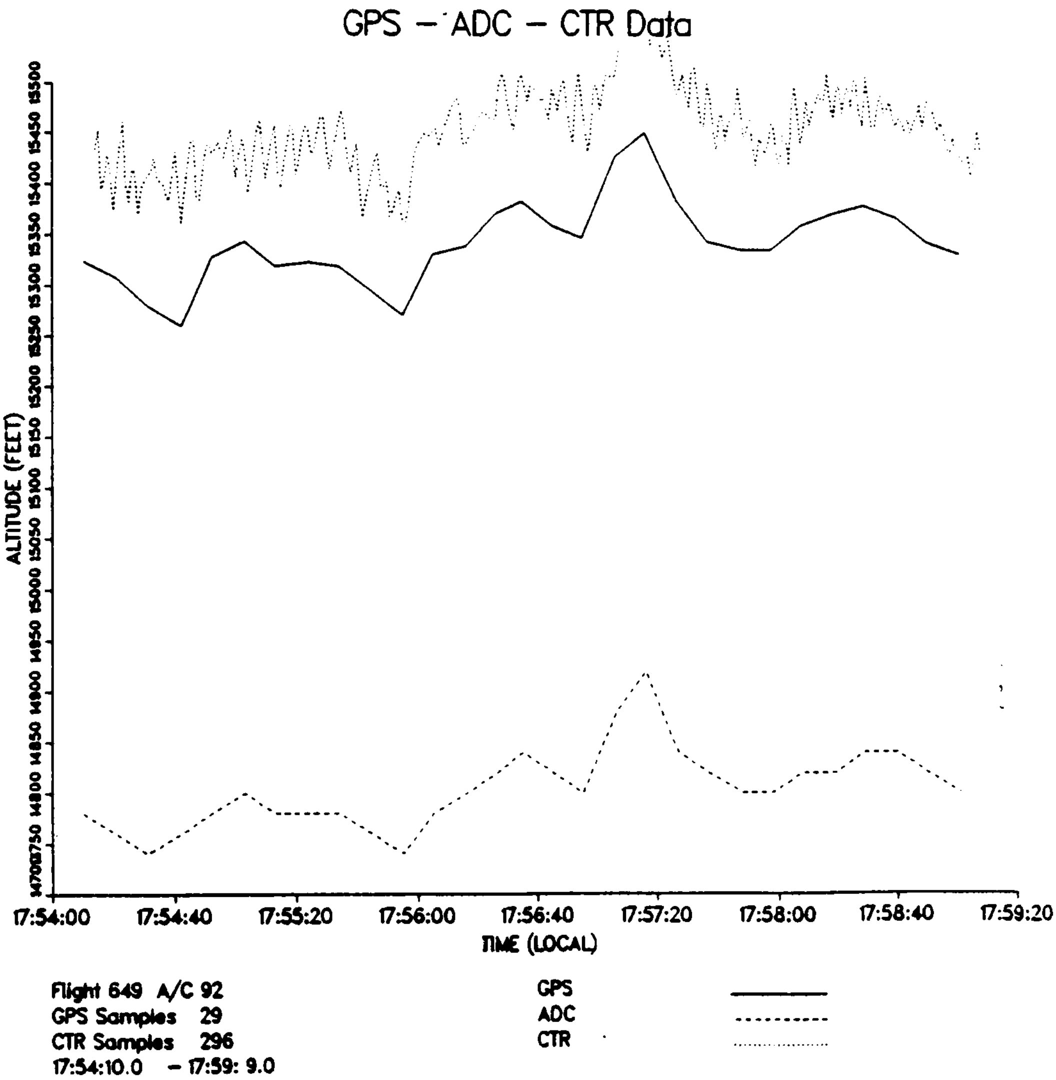

Figure 4 Comparison of GPS, ADC, and CTR Altitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 13.

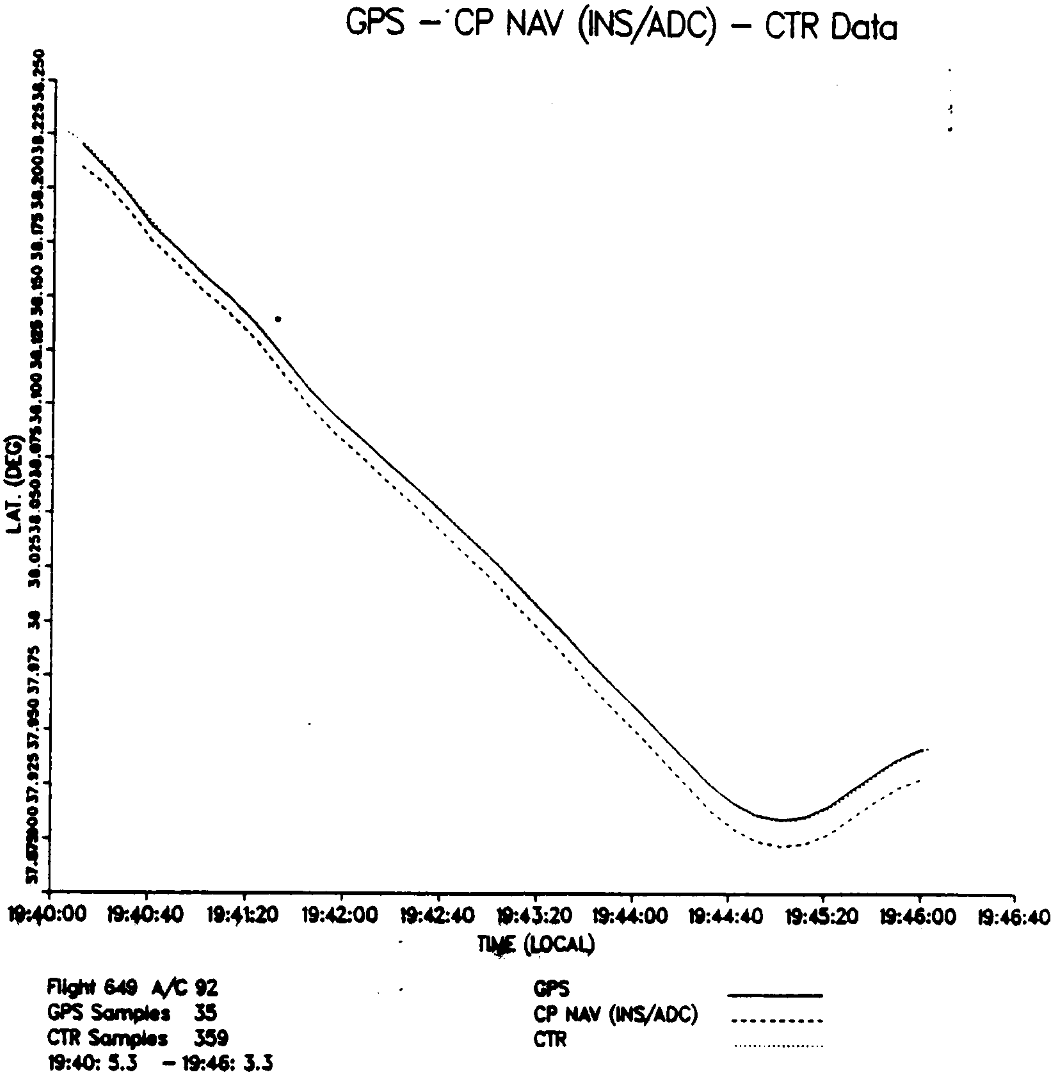

Figure 5 Comparison of GPS, CP NAV (INS/ADC), and CTR Latitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 14.

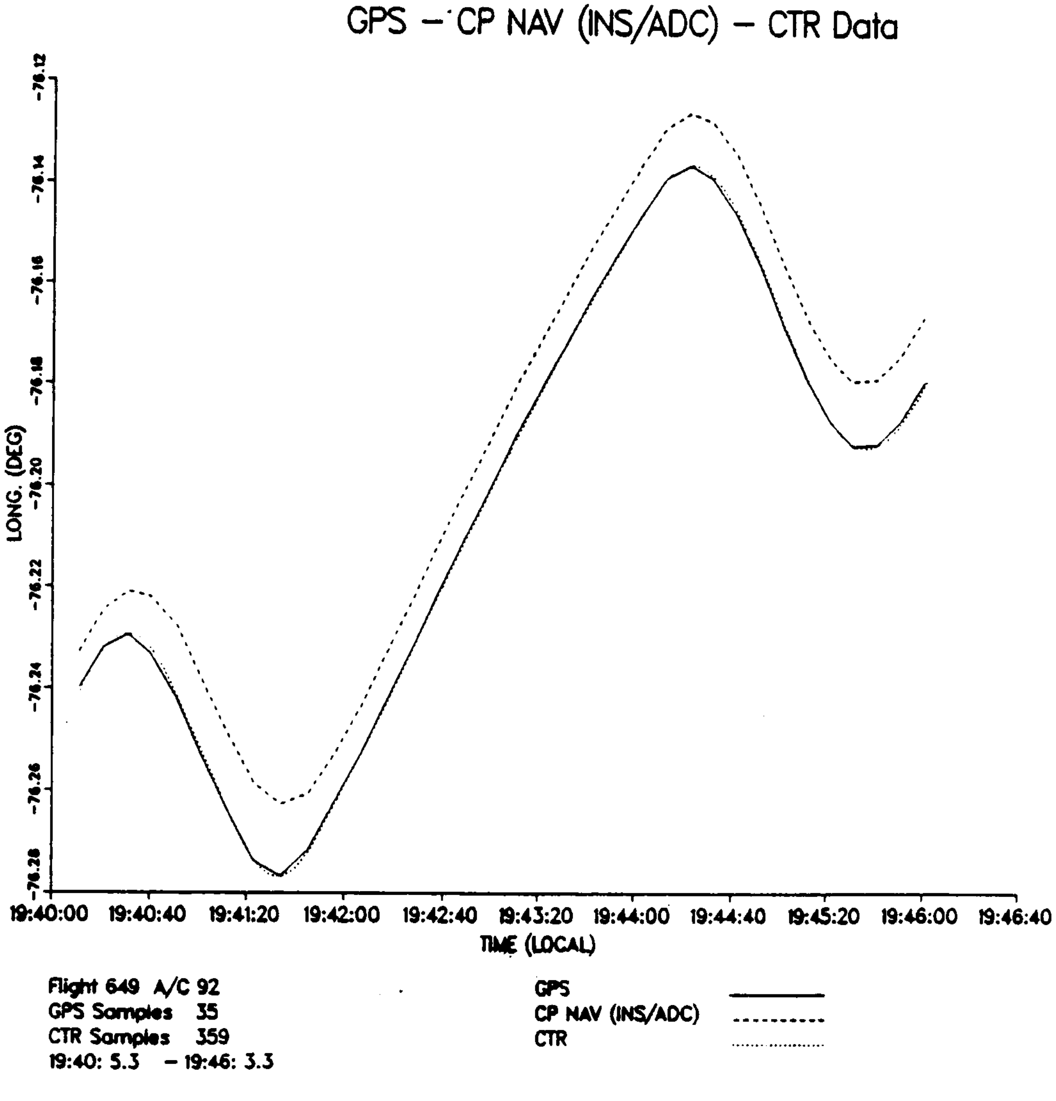

Figure 6 Comparison of GPS, CP NAV (INS/ADC), and CTR Longitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 15.

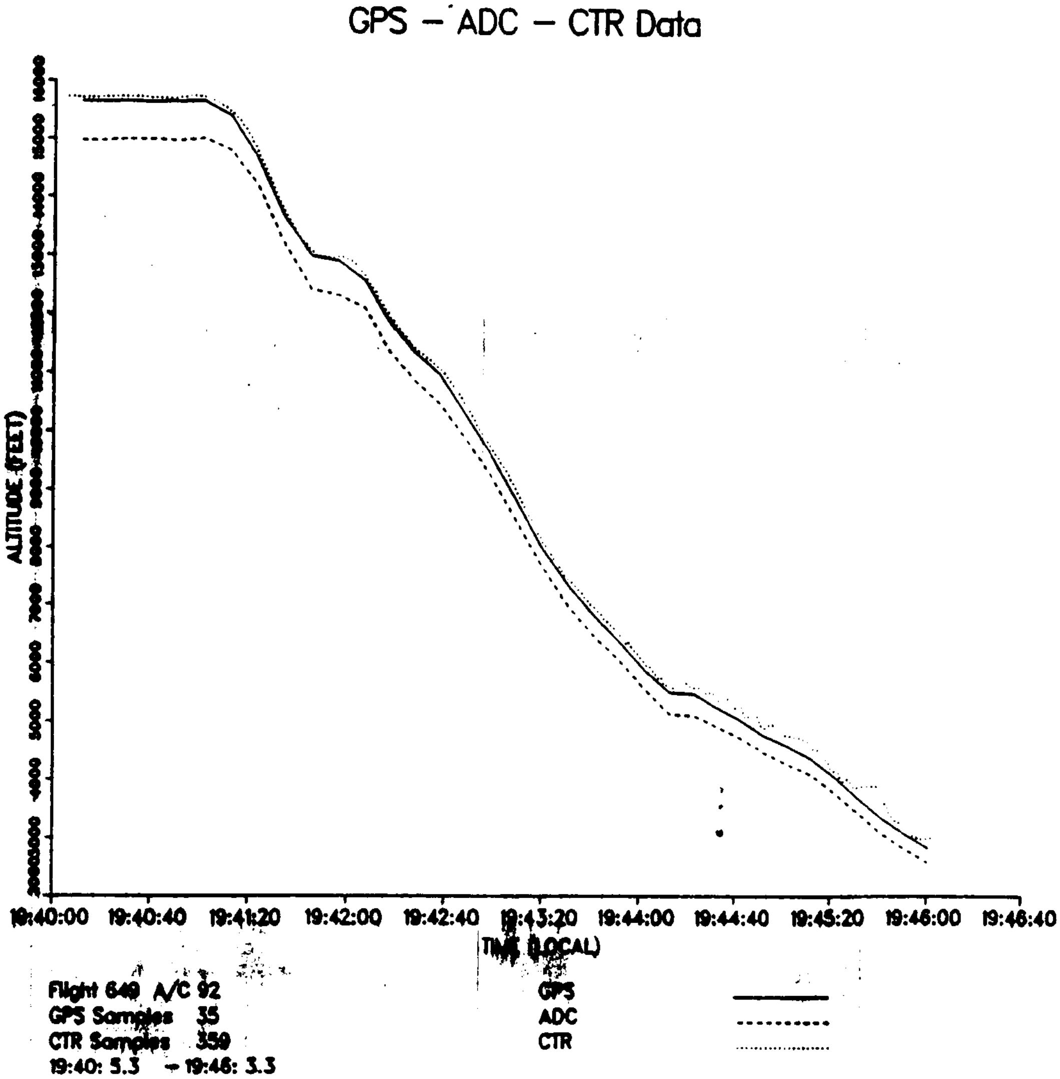

Figure 7 Comparison of GPS, ADC, and CTR Altitude. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 16.

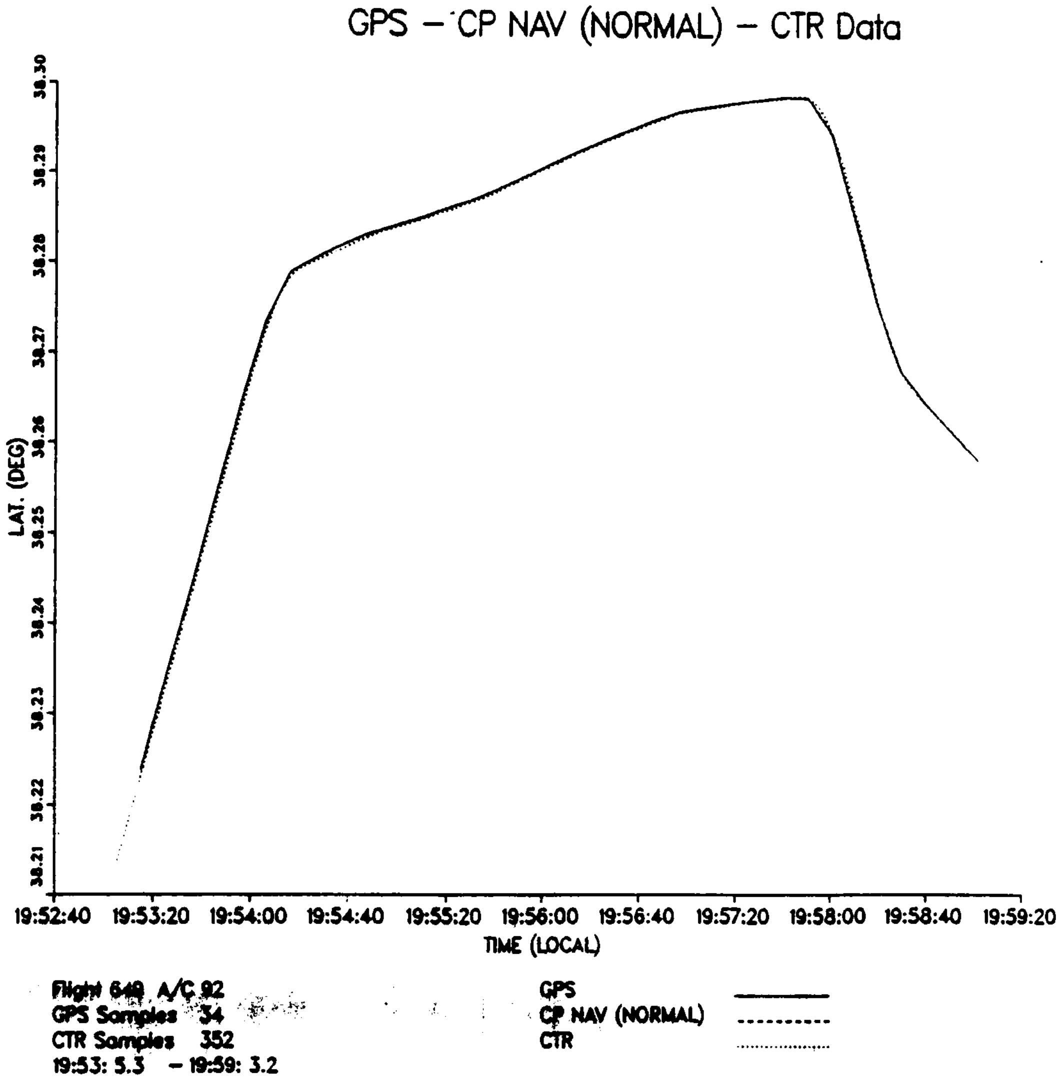

Figure 8 Comparison of GPS, CP NAV (Normal), and CTR Latitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 17.

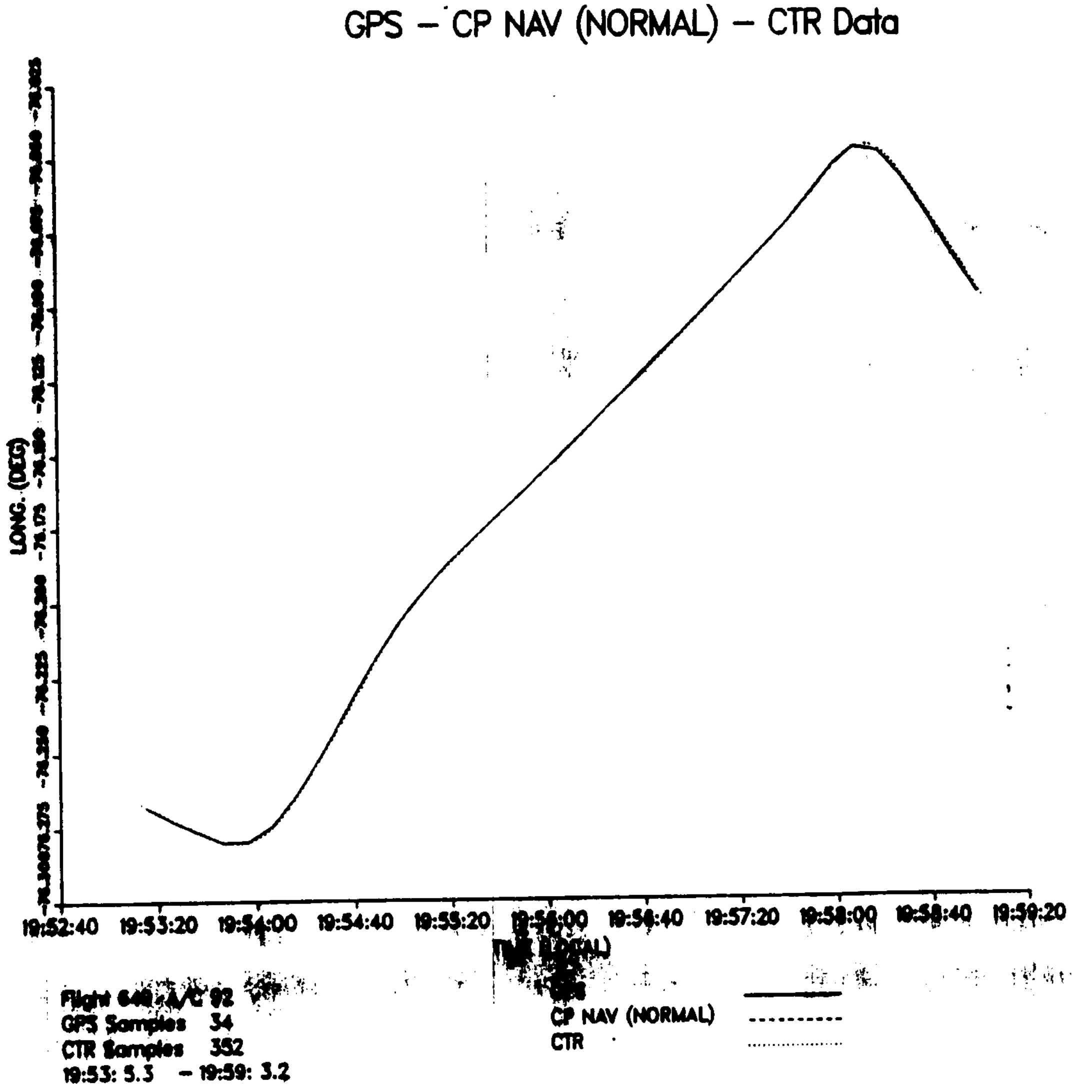

Figure 9 Comparison of GPS, CP NAV (Normal), and CTR Longitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 18.

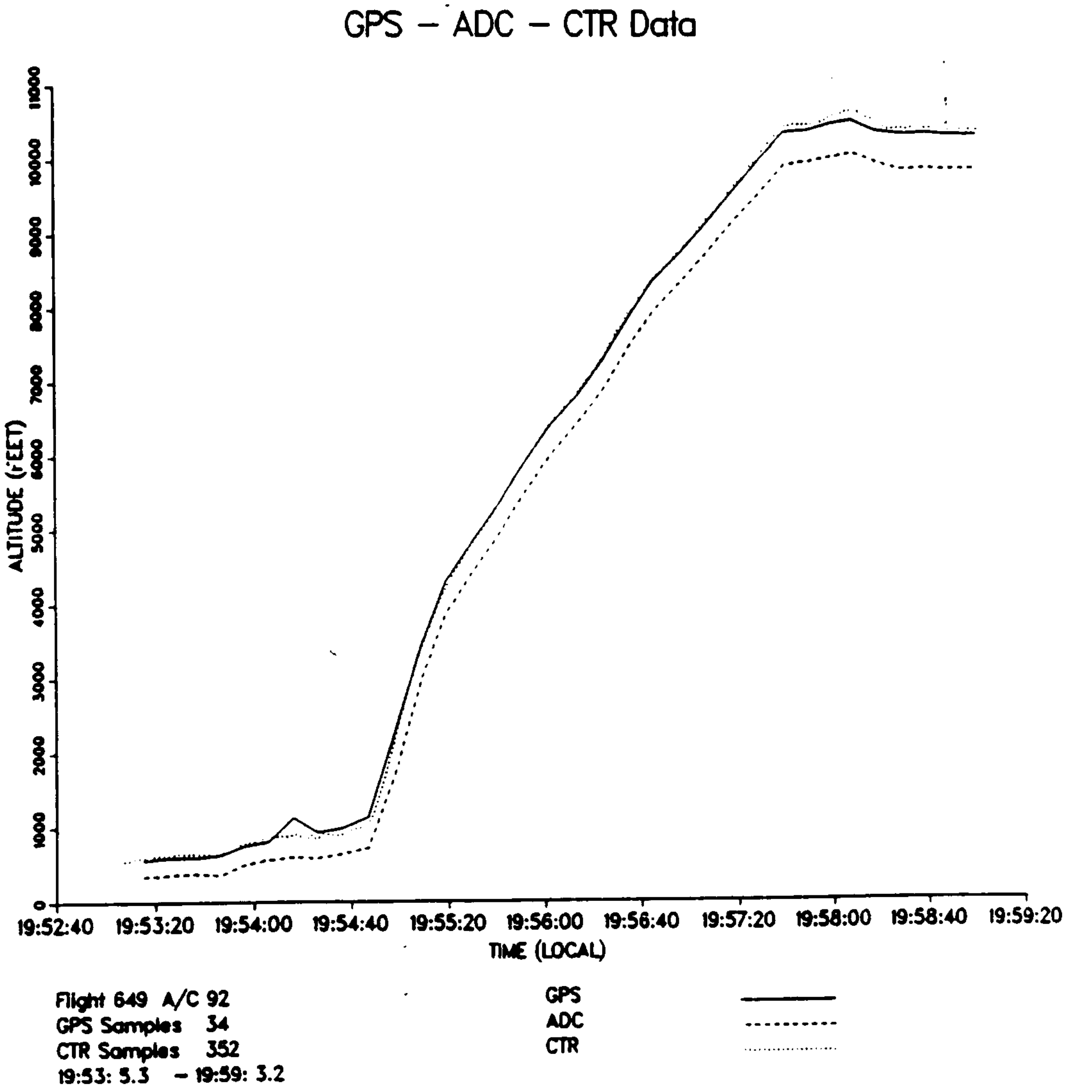

Figure 10 Comparison of GPS, ADC, and CTR Altitude. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 19.

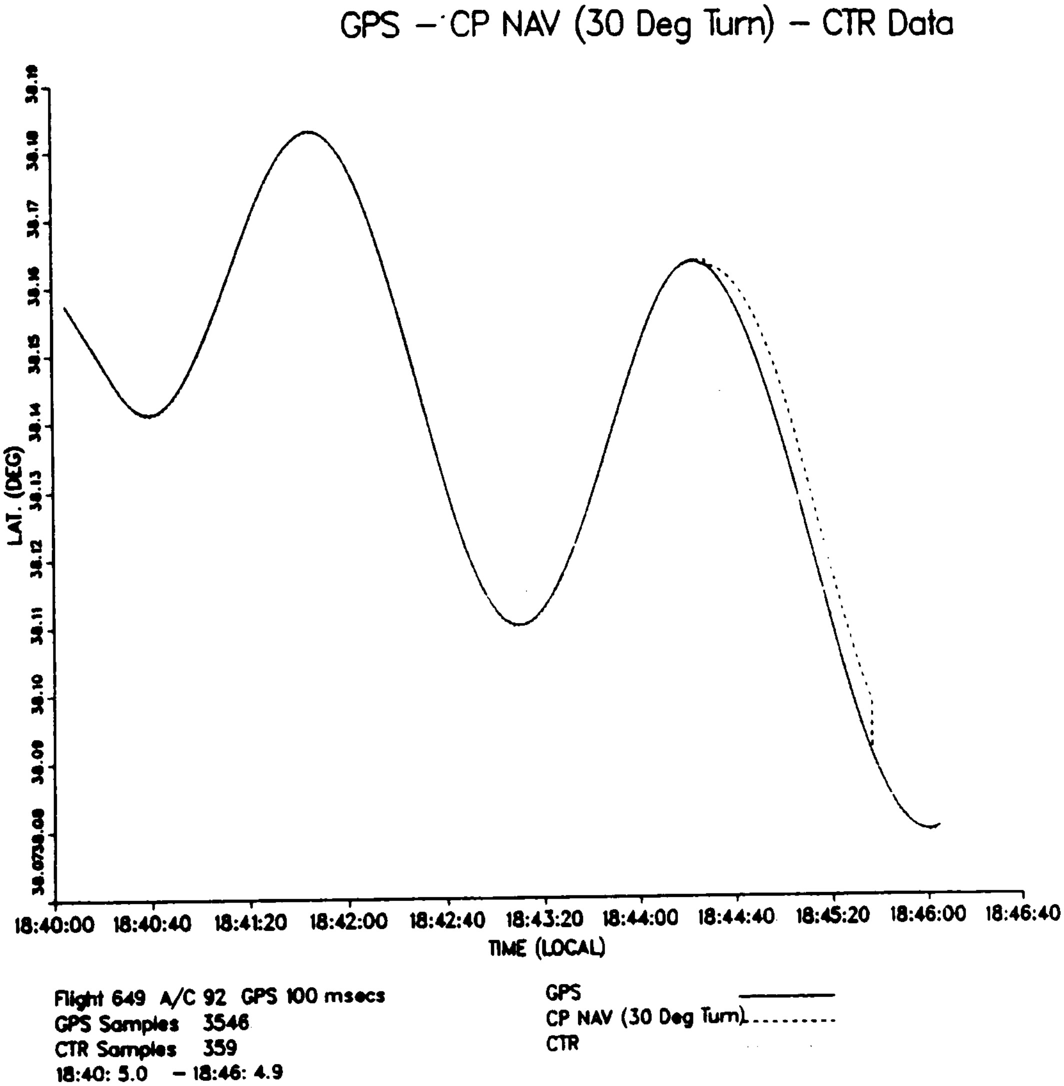

Figure 11 Comparison of GPS, CP NAV (30 Deg Turn), and CTR Latitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 20.

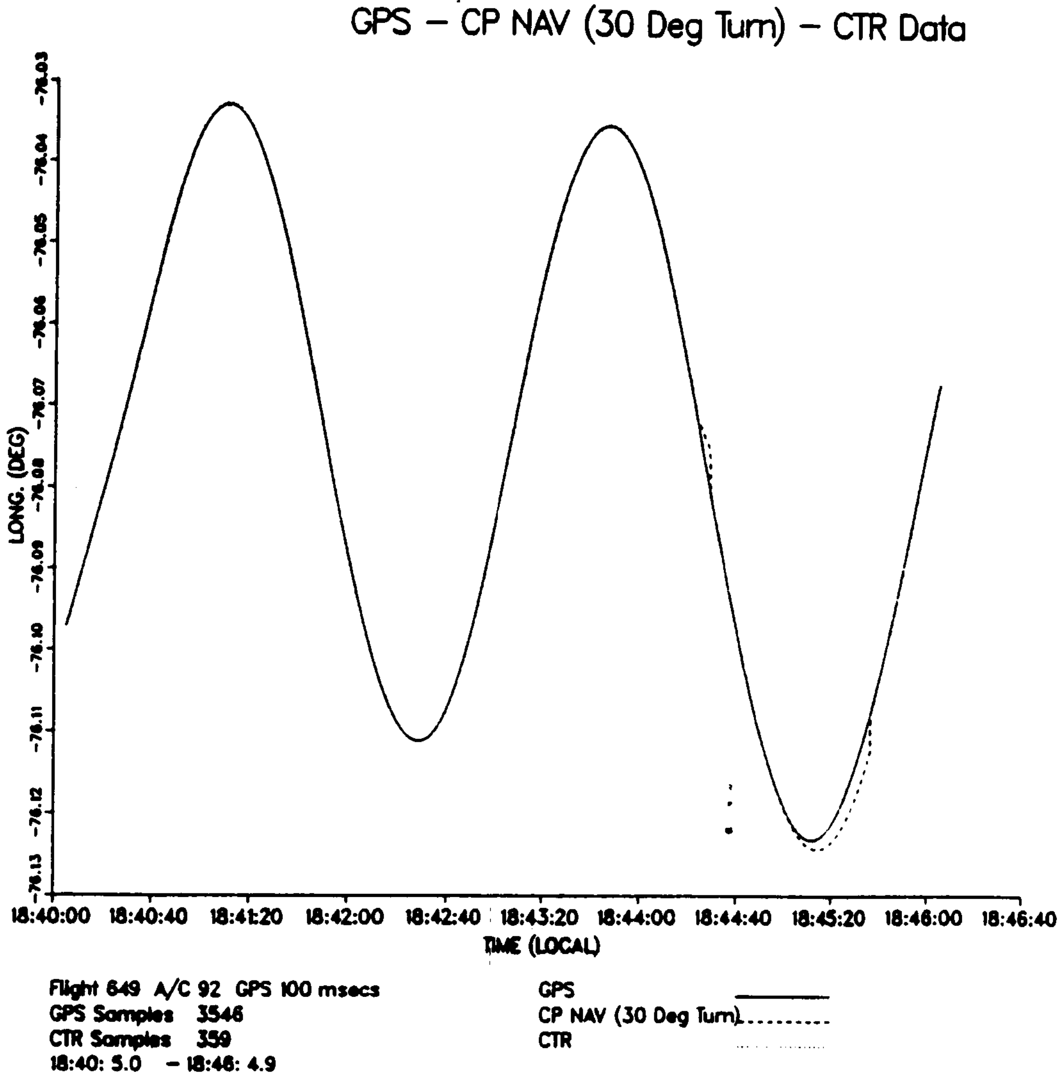

Figure 12 Comparison of GPS, CP NAV (30 Deg Turn), and CTR Longitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 21.

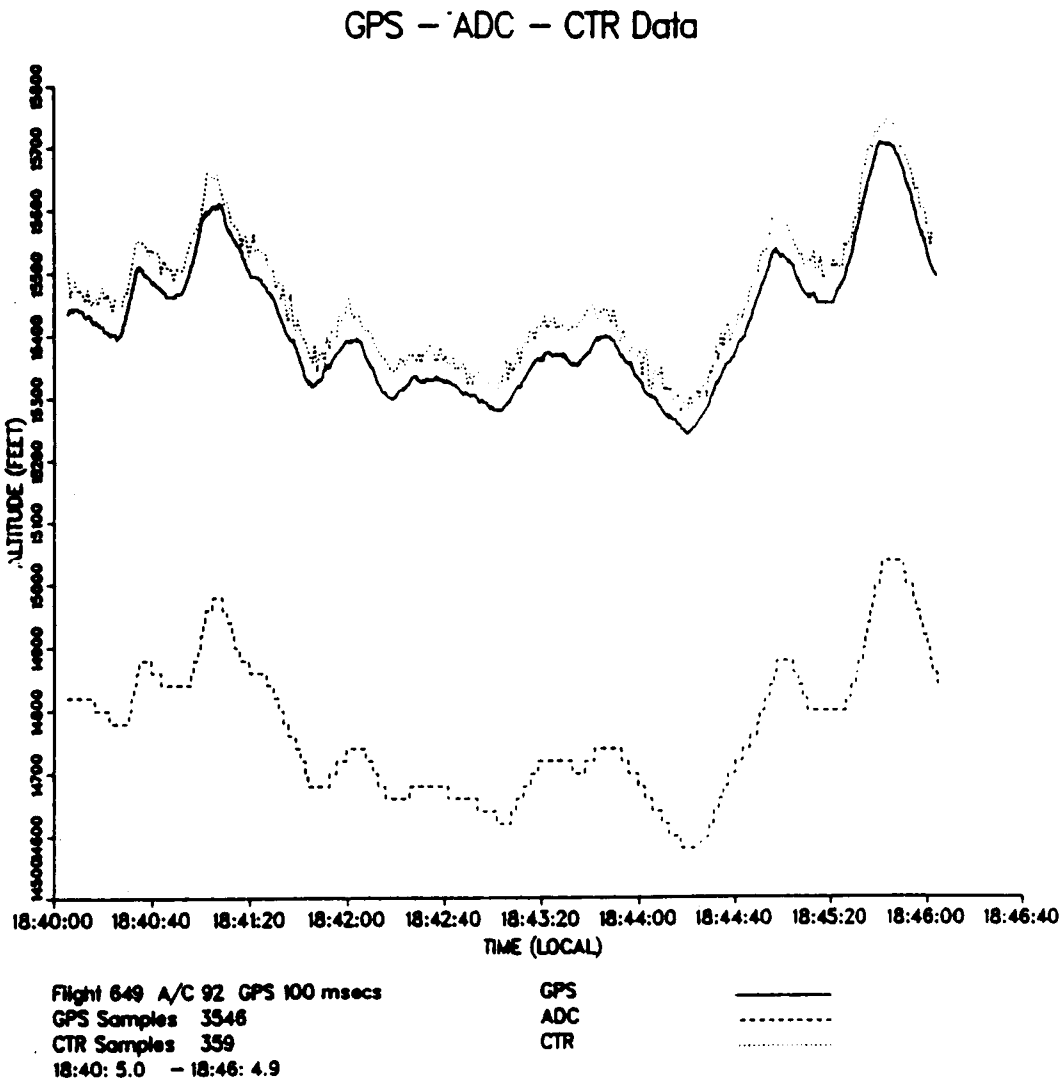

Figure 13 Comparison of GPS, ADC, and CTR Altitude. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 22.

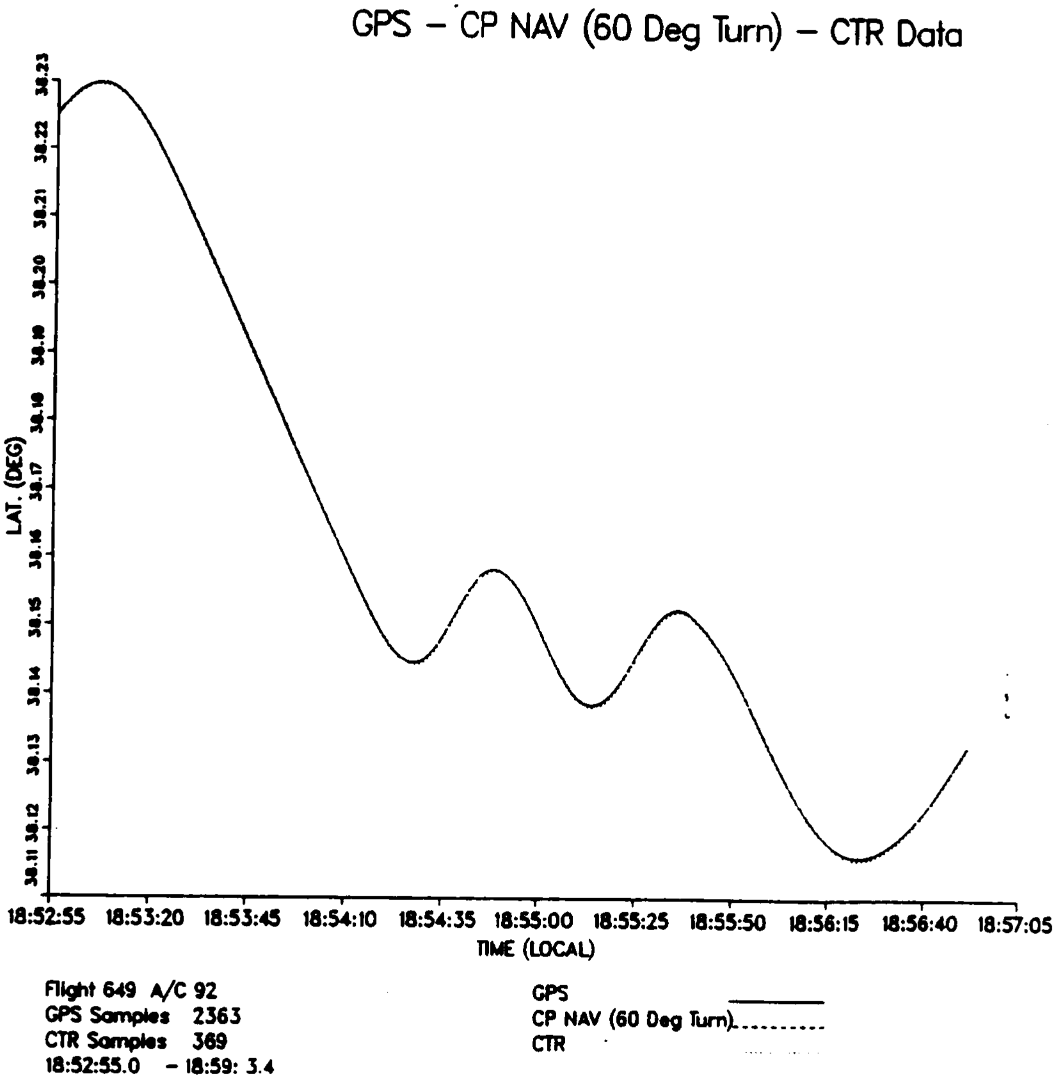

Figure 14 Comparison of GPS, CP NAV (60 Deg Turn), and CTR Latitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 23.

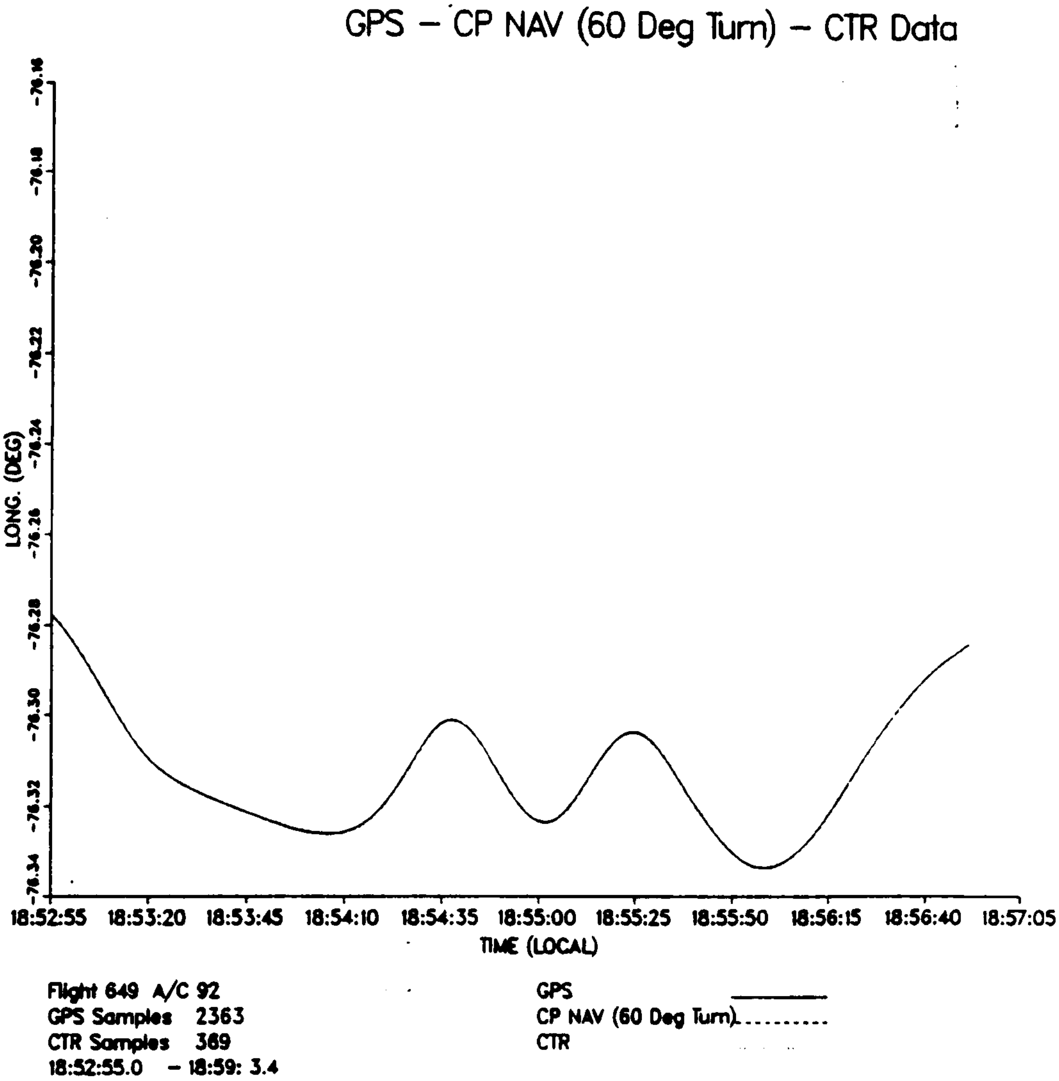

Figure 15 Comparison of GPS, CP NAV (60 Deg Turn), and CTR Longitude.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 24.

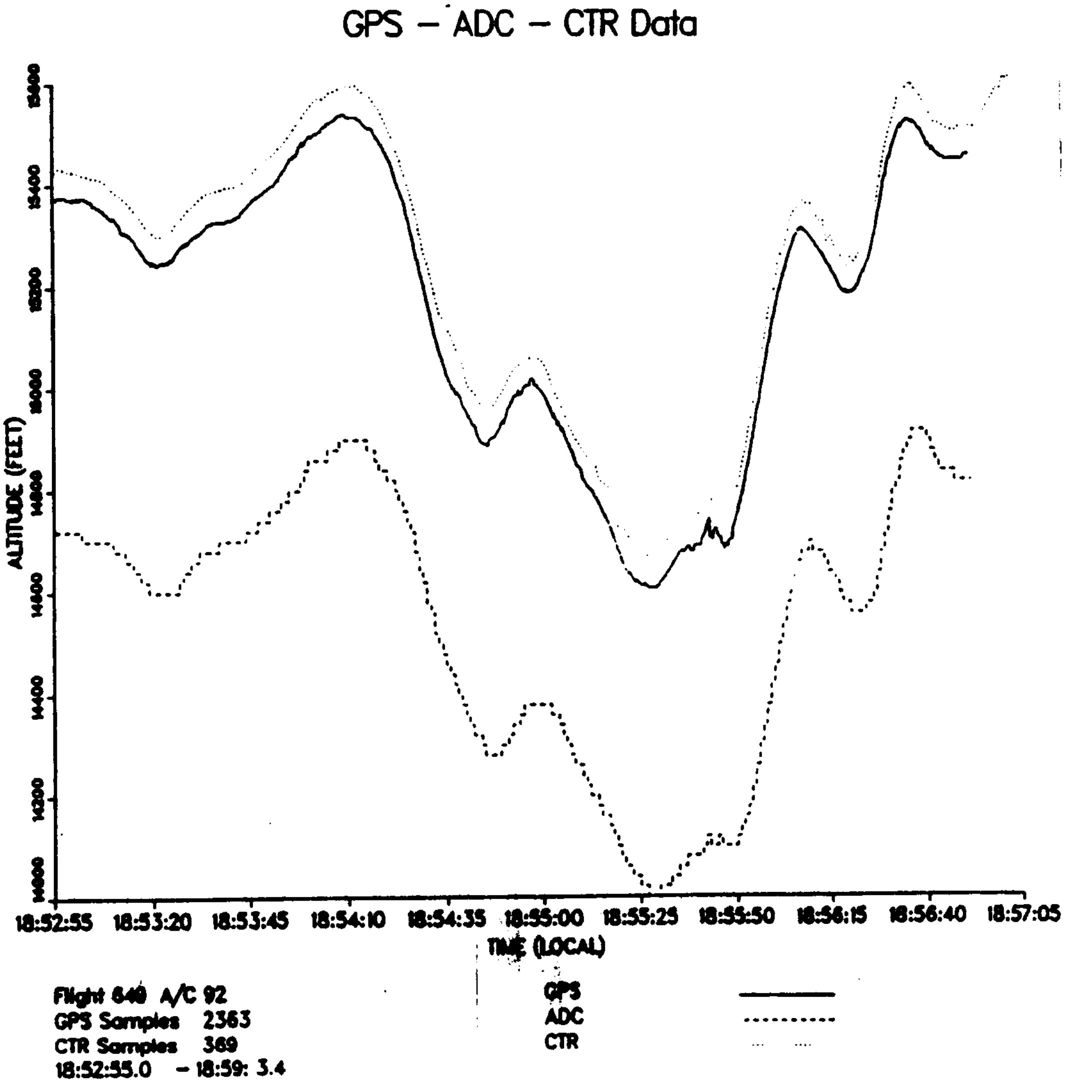

Figure 16 Comparison of GPS, ADC, and CTR Altitude. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 25.

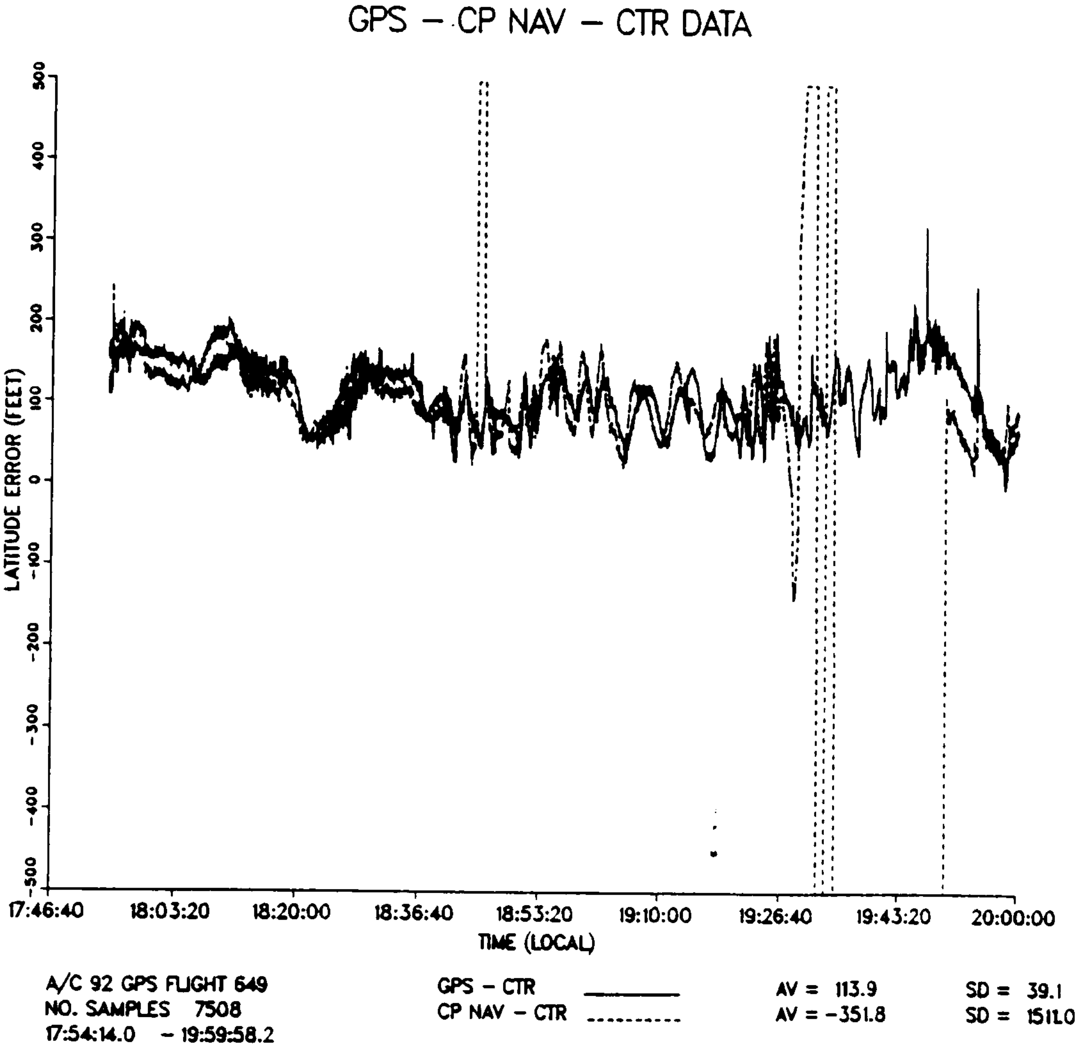

Figure 17 Comparison of GPS, CP NAV, and CTR Latitude Error.

Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 26.

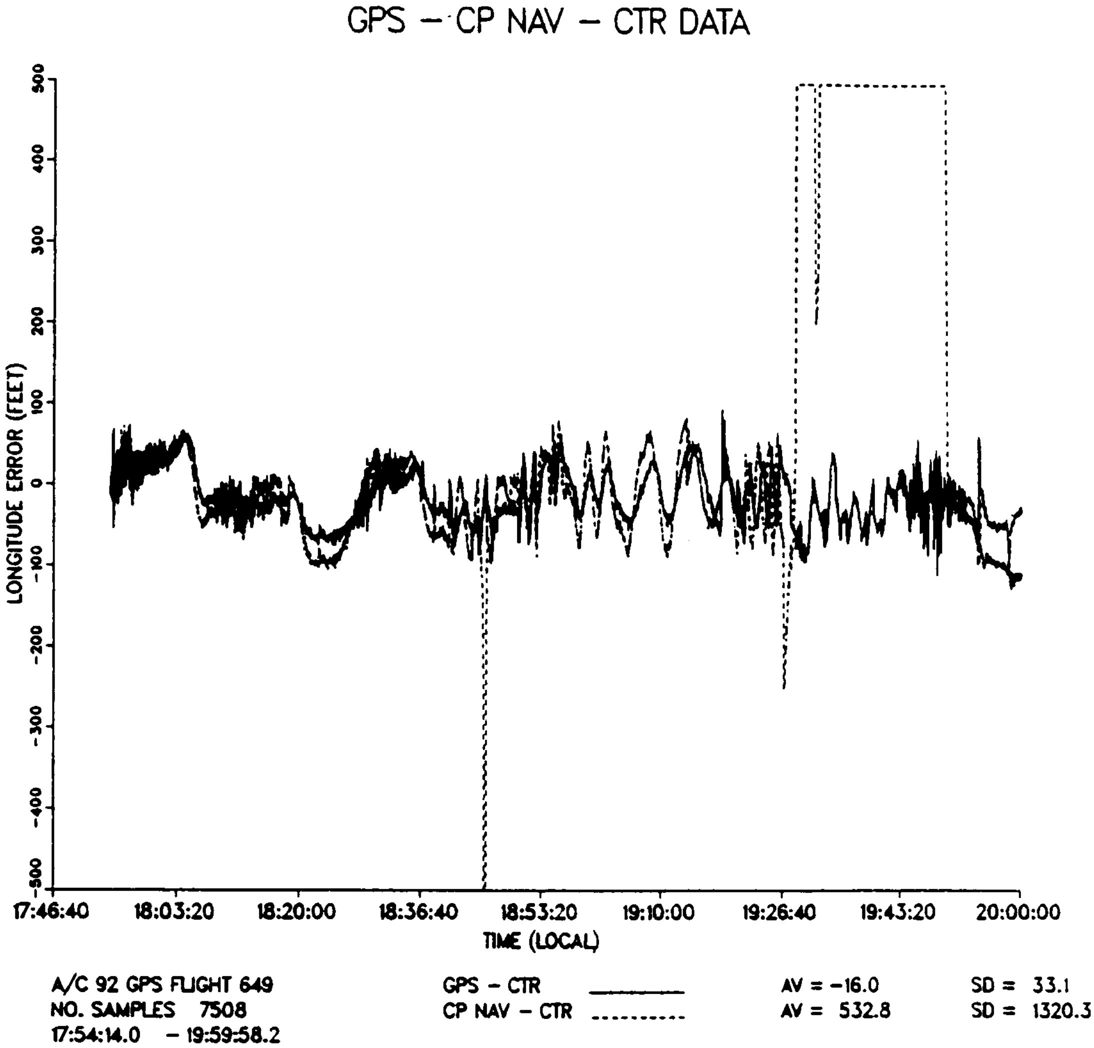

Figure 18 Comparison of GPS, CP NAV, and CTR Longitude Error. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 27.

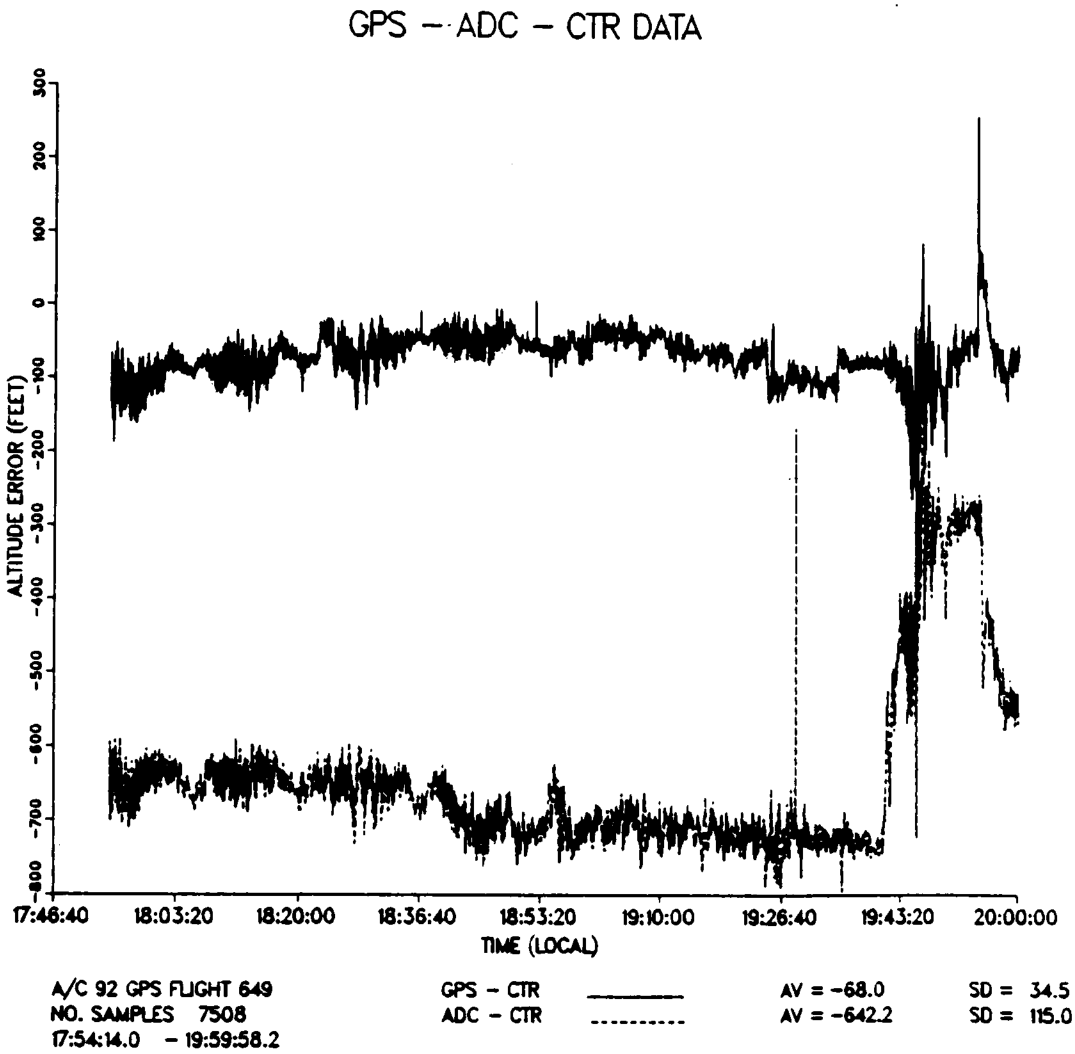

Figure 19 Comparison of GPS, ADC, and CTR Altitude Error. Source: E-2C GPS Integration Final Report, TED-123-3.85, Grumman Aerospace Corp., Bethpage, New York, 24 October 1991, pg 28.

VITA

Edward J. Najmy was born in Brooklyn, New York on 5 December 1959. He graduated from Monsignor Farrell High School in May 1977. The following September he became an undergraduate at Stevens Institute of Technology in Hoboken, New Jersey, and in May, 1981 received the degree of Bachelor of Engineering in Metallurgical Engineering and Material Science. In October, 1984 he entered the U.S. Navy's Aviation Officer Candidate School and received a commission as an U.S. Naval Officer in February, 1985. In March, 1985 he began basic flight training as a Naval Flight Officer and received his "Wings of Gold" in June, 1986. In August, 1986 he completed flight training in the Navy's E-2C Hawkeye airplane and reported to VAW-115 aboard the USS Midway stationed in Yokosuka, Japan for duty. In February, 1989 he transferred duty stations to VAW-110 at NAS Miramar, San Diego, California as an Naval Flight Officer Instructor. In June, 1990 he reported to Naval Air Warfare Center Aircraft Division at NAS Patuxent River, Maryland to attend the U.S. Navy Test Pilot School and completed the course in June 1991.

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