HC-130H GPS Upgrade: A Case Study In Incorporating Digital Avionics Into the Cockpit

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ABSTRACT
When designed in the late 1970's, the avionics suite for the US Coast Guard's HC-130H fleet contained state of the art components. Although the rapid advancement of electronics technology soon surpassed that employed in some of these units, the suites remained highly functional and economically feasible into the late 1980's. A desire by government officials to improve joint operability between the various military services coupled with the opportunity to capitalize on the advanced characteristics of current avionics components combined to enhance the viability of the Coast Guard's wish to upgrade the capabilities of its fleet. Working in conjunction with the US Navy and the US Marine Corps, the Coast Guard finalized the plans and designs which incorporated digital avionics into a suite which formerly contained only analog components. The nonrecurring engineering necessary to perform this integration included the design of several new subsystems to allow for the interface between existing components and the new digital data bus. This case study reviews the project which encompassed the specification, engineering, testing, prototyping, and fielding of this combined system. In addition, it shall also review the documentation, simulation, and training associated with a project of this scope.

BACKGROUND
Coast Guard aviation works within a structure defined by the Federal Aviation Administration (FAA), the Department of Transportation (DOT), commercial aviation, Department of Defense (DOD), and commercial and recreational maritime concerns. All of these serve to place certain requirements, limits, or needs on the limited resources allotted. Among these is the need for the most precise, accurate, repeatable navigation source available. This plus the requirement for interoperability with the US Navy led to the development of the combined US Coast Guard and US Marine Corps HC/KC-130 Global Positioning System (GPS) installation project.

Global Positioning System
The Navstar Global Positioning System is a space-based radio positioning, navigation system designed to provide highly accurate continuous worldwide position, velocity, and time information to suitably equipped users anywhere on or near the Earth. System features include passive operation, accessibility by an unlimited number of users, and high jamming resistance [1]. The GPS constellation consists of 24 satellites in various orbital planes 10,900 nm above the earth broadcasting a pseudorandom code timing signal and data message that the airborne equipment processes to obtain satellite position and status data as well as a measurement of how long a radio signal takes to reach the receiver from each satellite. These messages radiate on two frequencies. The Link 1 (L1) signal broadcasts on 1575.42 MHz and the Link 2 (L2) signal frequency is 1227.60 MHz. L1 and L2 together provide authorized users with the precise positioning service (PPS), whereas L1 alone is used for the standard positioning service (SPS) [2].

U. S. Coast Guard
The U. S. Coast Guard (CG) divides its aviation resources into three categories: short range recovery, medium range recovery, and long range recovery (LRR). The HC-130H aircraft fleet provides the entire LRR capability for the service. The USCG commenced purchase of these aircraft in the late 1970's to supplant an already aging HC-130B fleet. At the time of purchase the aircraft came equipped with then state-of-the-art avionics. These components included HF, UHF, and VHF communications radios and VHF and TACAN navigation radios. The CG opted not to pursue an integrated flight
management system on these aircraft and, instead opted for an array of control heads located at the pilot's, copilot's and the communications operator's stations.

**Department of Defense**

In September 1991 the DOD promulgated the Minimum Avionics Requirements (MAR) document which provided policy and technical guidance for integrating GPS equipment into DOD aircraft. The services developed the MAR and it had their unanimous approval through the GPS Phase-In Steering Committee. Unfortunately, advancing technology and diverging service needs resulted in cancellation of the MAR and the need for each branch of the service to prepare their own integration documents. The Navy generated the GPS Integration Guide (GIG). In order to foster inter-service compatibility, the Navy accepted responsibility for the integration of GPS into CG aircraft and agreed to provide initial assets for the engineering, prototyping, and testing, as well as the long term logistical support.

**ARCHITECTURE**

Engineers from Naval Air Warfare Center (NAWC) Warminster combined requirements from the CG, FAA, Navy, and the Air Force-sponsored GPS Joint Program Office to delineate the architecture for the HC-130H GPS suite. Among the prerequisites were:

- Flight planning with automatic sequencing up to 50 waypoints.
- GPS sole means navigation with reversionary capability.
- On-line 20,000 waypoint database accessible from a data cartridge.
- Local 200 waypoint database maintained within nonvolatile memory.
- Guidance computations for all phases of flight.
- Computer generated pattern and offset flight capability.
- Rendezvous with moving waypoints.

**CDNU**

The Control Display Navigation Unit (CDNU) provides the control display processing and interface capability to meet the flight and navigation requirements established for this system. Using deviation, range, and bearing displays, the CDNU provides all navigation and steering functions for enroute operations, terminal area operations, and non-precision approaches.

The CDNU interfaces with the GPS receiver, Standard Altitude Heading Reference Systems (SAHRS), Standard Central Air Data Computer (SCADC), Mission Data Loader (MDL), two additional CDNU systems, and two Interface Ship Sets (ISS) (Figure 1). Data to drive flight instruments is transmitted via an ARINC-429 output to a digital-to-analog signal data converter (SDC). Two spare ARINC inputs and one spare ARINC output are provided for future growth.

**CDNU Hardware**-The CDNU system is comprised of one hardware configuration item (HWCI). The HWCI provides for user input via
the CDNU keyboard (full alphanumeric plus special function keys), system display (standard text display is 8 lines of 22 characters), and interface to external equipment. The external interfaces include MIL-STD-1553B Data Bus (the CDNU operates as either the bus controller or a remote terminal terminal/backup bus controller), ARINC-429 Data Bus (two serial data inputs and two serial data outputs), discrete (16 ground/open inputs, 4 ground/open outputs, and an ON/OFF control), and a power (28 VDC, 35 W max; 0 to 5 VAC keyboard lighting power, 10.2 VA max) interface.

CDNU Software-The CDNU system contains two computer software configuration items (CSCI). The fixed CSCI provides the internal built in test (BIT) function and loads the alterable CSCI, also called the operation flight program (OFP). The fixed CSCI, which resides in write protected PROM, allows the CDNU to assume the role of BC and load an OFP as directed by the operator. In addition, the fixed CSCI implements three levels of BIT. These include continuous (a background task which runs during null times between execution of other tasks), initiated (executed only after specific crew action), and power up (executed only on application of power) BIT. The fixed CSCI also serves to alert the crew of CDNU or MDL failure or operator entry errors. The alterable CSCI includes the OFP which performs waypoint and flight plan management, RNAV/flight plan execution, navigation computations, flight display interface, GPS control, MDL control, SAHRS and SCADC control, MIL-STD-1553B data bus control, status annunciation, and system test and status monitoring.

GPS System

The GPS system installed in aircraft consists of three components; the antenna system, the antenna amplifier, and the GPS receiver. Current technology and current components in the CG inventory proved to be key factors in determining the final configuration for the GPS system in the HC-130H.

FRPA System-The antenna used on the HC-130H GPS suite is a fixed reception pattern antenna (FRPA) system. The FRPA-3 antenna and AE-4 antenna amplifier comprise the FRPA system. The FRPA antenna is a right hand circularly polarized omnidirectional antenna which provides at least 0 dBIC gain at the L1 and L2 frequencies over at least a 160° cone. The AE-4 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 [3].

GPS Receiver-The GPS receiver installed with the HC-130H GPS suite is the RCVR3A, a five channel GPS receiver with multiple interfaces designed for use in high dynamics host vehicles. It is a full function PPS-capable receiver with five independent space vehicle signal tracking channels, each able to continually track L1 or L2 [4]. The RCVR3A receives the L1 and L2 signals, attempts to synchronize with the signals from the satellites it has chosen for navigation, measures pseudo-range and delta range when synchronized and uses these measurements in the navigation Kalman Filter. The Kalman Filter is dual-tuned for high dynamics operation in either an aided or unaided mode. In the aided mode with external inputs from an inertial navigation system (INS), the 12 Kalman filter states are: user position and velocity in three axes, CB, CD, altimeter bias error, and three inertial platform tilt errors. In an unaided mode, the 12 states are: user position, velocity, and acceleration in three axes, CB, CD, and altimeter bias error. In addition to its position, velocity, time, and navigation functions, the RCVR3A provides input to the external LTN-72 INS to support in-air alignment and reset of the inertial platform.

Interface Shipset

Two CMA-2074MC Mission Computers operate in tandem as the HC-130H GPS avionics suite Interface Shipset (ISS), which is a stored program, real-time digital computer designed to interface HC-130H avionics equipment with the MIL-STD-1553 digital data bus. A 1750 processor bus, comprised of a 16-bit address/data bus and a control bus, performs internal data and control flow operations. The address/data bus is a parallel bidirectional bus used to transfer the memory location of data. The control bus consists of unidirectional signals to control data transfer and I/O on the 1750 processor bus. The architecture of the CMA-2074MC includes the chassis, a wiring harness, a power supply, and motherboard assembly and up to 12 plug-in shop replaceable units (SRU). These SRU include the discrete I/O, the serial I/O, the synchro I/O, and the power supply assemblies as well as growth potential. The HC-130H radios the CMA-2074MC provides interface control for include the ARN-118 TACAN, the ARN-123 VOR/ILS, the ARC-182 VHF/UHF AM/FM, and the 618M-3A VHF.
Digital Data Set

The AN/ASQ-215 Digital Data Set (DDS) is an advanced, high capacity solid-state military airborne data storage and retrieval system. The DDS consists of two basic units: the MU-1053/A Data Transfer Module (DTM) and the CP-2092(p)/A DDS Interface Receptacle Unit (IRU). The DTM is a transportable, compact, nonvolatile random access storage device with 2MB (expandable to 6MB) memory capacity with growth to 32MB. The DTM possesses a rapid data erase function and its user-programs background execution capability provides the GPS suite with a reversionary operations feature. The IRU is an aircraft mounted, intelligent receptacle for the DTM which manages exchange of mission information via the MIL-STD-1553 data bus. It contains a 32 kiloword EEPROM for operational program storage and 128 kiloword RAM. The high memory capacity of the DTM and IRU supports high density transfer of the CDNU alterable CSCI.

GPS SYSTEM OPERATIONS

Integration Guidance

The Navy's GIG placed constraints on the manner by which the GPS suite should be integrated into the cockpit. Primary among these was the ability to use of GPS as the sole means of navigation within the national airspace. To comply with this requirement, NAWCAD Warminster made the GPS independently selectable on either the pilot's or the copilot's NAV select switches. Another demand imposed by the GIG is the requirement for the GPS to emulate TACAN navigation guidance. To accomplish this, the GPS steering data is displayed on the pilot's and copilot's HSI and ADI. In addition, this output can be coupled to the autopilot. Also in the style of TACAN navigation guidance, the GPS had to generate TO/FROM navigation information. As well as complying with this condition, the suite provides TO/TO and DIRECT TO guidance, all referenced to either true or magnetic north.

The GIG also outlined the manner by which navigation waypoints were to be stored, recalled and sequenced. By incorporating an algorithm into the CDNU baseline software which processes the waypoints in these manners, the Navy insured all of their platforms which employ the CDNU will comply with this precept of the GIG. The display of GPS navigation data on the flight instruments was an additional unique requirement imposed by the GIG. This directed the inclusion of course deviation, waypoint bearing, and the TO/FROM arrow displayed on both the pilot's and copilot's HSI.

The addition of a single set of lights on the instrument panel which displays the flight mode (enroute, terminal, approach) combined with the NAV INVALID flag which appears on the HSI insure compliance with the GIG constraint requiring flight modes and failures be announced in the pilot's primary field of view. Additional annunciations appear on selected CDNU pages.

Integration Engineering

NAWCAD Warminster engineers placed three CDNU in the cockpit of the HC-130H aircraft. They positioned them at the pilot's, copilot's, and navigator's stations. The CDNU serves as the primary control center for the GPS system and each has equal access and equal control. All three serve as either the bus controller (BC) or as a remote terminal/backup bus controller (RT/BBC). The CDNU, when operating as the BC, performs all navigation computations, builds all page displays, communicates with all associated equipment, and performs all other computations to support the communications/navigation management system. As the BC, the CDNU provides input for and controls the output from the ISS, SDC, and the INS. The CDNU provides control input for both the communications and navigation radios via the dual ISS, which split the redundant radios. This insures the loss of one ISS does not equate to a total loss of radios.

The CDNU/INS interfaces allows the transfer of position, velocity, heading and status information from the INS to the CDNU. In addition, the INS communicates with the GPS RCVR3A over an ARINC-429 data bus. In this manner, the GPS is able to bound the INS error by providing long-term navigation for the system and continuously update the INS position. This helps overcome the inherent 0.8 nm/hr drift rate of the INS. During those occasions when the GPS tracks less than four satellites, the INS aids the GPS by providing short-term position updating. With the addition of the GPS to the HC-130H, the original equipment manufacturer provided a software update which allowed for the use of GPS information from the RCVR3A. This upgrade also allowed these two components to communicate in a manner that allowed for the inflight alignment of the INS.
The SDC performs as the digital to analog converter for the communications/navigation management system. It receives input from the BC and converts it to an analog format which the flight instrument can then display.

Radio Systems-As part of the CDNU installation, the TACAN (ARN-118) and the multiband transceiver (ARC-182) control heads were removed to allow for integration and provide the necessary room on the center pedestal to install the pilot’s CDNU. This requires all control functions be performed by the CDNU except for volume and guard frequency selection. The communications system uses the existing ICS panel to control radio volume. The CDNU may be used to transmit and receive the guard frequency on the ARC-182 transceiver or the pilot or copilot may use an added panel on the center pedestal to select it.

Area Navigation

The CDNU prepares an area navigation (RNAV) solution which allows the aircraft to perform point-to-point navigation. Although originally designed to emulate the TACAN TO-FROM navigation scheme, the preferred navigation mode is the TO-TO option. RNAV maintains an estimate of the present horizontal position and velocity through an integrated navigation computation method. The exact method used to determine the RNAV position is dependent on availability of sensor data. Using the automatic waypoint sequencing mode, two sources of heading reference are available to the suite, GPS and INS. With the full complement of sensors available and GPS selected to provide the heading reference, the CDNU will use the GPS and INS input to determine the RNAV solution. Selecting INS as the heading reference precludes the use of GPS input for a navigation solution, and restricts the information to INS input only. In the manual mode, automatic waypoint sequencing is discontinued and both the CDNU ignores both GPS and INS input. True airspeed and heading are still available as a backup.

GPS/CDNU Integration Functions

Present Capabilities-The Coast Guard and the Marines both requested the retention of several present navigation system functions. Included in these were the ability to provide roll steering output to the flight director, generate search patterns, and allow for waypoint crossfill. Waypoint crossfill allows operator selection of either a flight plan or a manual waypoint data list. The flight plan "TO" waypoint is always loaded into the INS as waypoint #1. A maximum of nine waypoints may appear in either data list. In addition, the CDNU continuously supplies the operator selected data list.

Enhanced Capabilities-In addition to the retained functions, several operational enhancements were requested. These included:

- INS input as alternate to CDNU RNAV
- Vertical navigation
- Additional flight patterns
- Sweep width calculator
- Computed air release point (CARP)
- Stored routes
- Operator entered waypoint storage

Implementation-NAWCAD Warminster served as the prime integrator for the three different software algorithms necessary to meet the specified operational requirements. They directed the integration of the CDNU 6.0 baseline software with a combined Navy/commercial package as well as a Rockwell Collins generated module. When completed, extensive testing was needed to validate this integrated software package which was to become the combined CG/USMC HC-130H CDNU operational flight program. Prior to the availability of a GPS-modified aircraft in which to test the software, NAWCAD Warminster developed a software integration laboratory (SIL) consisting of a dual PC-based ARINC-429/575 and MIL-STD-1553 simulator with the ability to perform a flight profile simulation. Included in the SIL are all relevant HC-130H avionics to include radios, GPS, INS, altimeters and flight instruments. The SIL contains all communications and navigation test sets and provided the capability to test and support the newly developed CDNU software functions. During initial SIL testing, NAWCAD Warminster engineers uncovered several software problems which included the inability of the CDNU to read two simultaneous ARINC inputs, the incorrect validity annunciation of the first navigation message, and improper scaling of the TAS input scaling. After correction of these problems, NAWCAD Warminster was able to verify the proper operation of the CDNU software as well as the interface of the ISS with each non-1553 device.

TESTING

Developmental Testing

Ground Testing-By agreement with the Navy, NAWCAD Patuxent River performed the devel-
opmental testing on the HC-130H GPS suite. Navy policy requires a two phase testing prior to implementation of any new project. The first phase is developmental testing, designed to evaluate the technical aspects of the project to determine the ability of the project to safely, accurately, and correctly perform the assigned mission. The initial portion involved ground tests which included electromechanical compatibility (EMC) test, integrated logistic support, and CDNU/GPS functionality checks. With no discrepancies noted during any of these, the testing proceeded to the flight portion.

**Flight Testing**-NAWCAD Patuxent River supported by CGAS Elizabeth City conducted flight testing during three sorties which totaled 12.1 flight hours. Among the items tested were the operator defined refueling pattern, all search patterns, CARP, GPS non-precision approach capabilities with autopilot coupled, and the GPS' ability to download waypoint data and INS. As a result of this testing, NAWCAD Patuxent River identified one Part I deficiency related to the possible outcome of inadvertent activation of the SDC built-in test (BIT) in flight. A Part I deficiency is one which adversely affects safety of flight or mission accomplishment. The USCG and the Navy intend to insert a warning into the Operator's Manual as well as install a placard warning against activation of the BIT during flight in response to this finding.

**Operational Testing**

Coast Guard Air Station Clearwater assumed responsibility for the performance of the operational testing to determine if the installation met the specified mission requirements and if operational units could effectively use the system. The Coast Guard initiated this testing in April 1995 and it continued through August 1995. The final results were unavailable for this report, but initial responses from the aircrew were positive.

**CONCLUSION**

The Coast Guard and Navy executed a major digital avionics project when they integrated a GPS navigation suite into the HC-130H aircraft. The lack of a digital data bus and its ancillary support equipment increased the challenge dramatically. A team effort using the strengths and inputs from a highly varied group combined into an innovative and effective navigation suite which proves extremely responsive to the Coast Guard mission. As the interim Developmental Test report states, "HC-130 CDNU and GPS showed excellent potential to accomplish USMC and USCG missions. With the GPS CDNU providing steering cues to the flight director, the pilots were able to more accurately navigate the required search patterns. When the GPS CDNU was coupled to the autopilot system, the pilots workload was greatly reduced which resulted in a more efficient and effective visual search."

**REFERENCES**