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TECOM Project No. 7-CO-M92-AVD-004

METHODOLOGY INVESTIGATION

FINAL REPORT

GLOBAL POSITIONING SYSTEM INTEGRATION

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TECHNICAL TEST SUPPORT AND LOGISTICS DIVISION

UNITED STATES ARMY AVIATION TECHNICAL TEST CENTER

FORT RUCKER, ALABAMA 36362-5276

DECEMBER 1992

Prepared for:
Commander
U.S. Army Test and Evaluation Command
ATTN: AMSTE-TC-D
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ATTENTION OF

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MEMORANDUM FOR Commander, U.S. Army Aviation Technical Test Center, ATTN: STEAT-MP-P, Fort Rucker, AL 36362-5276

SUBJECT: Final Report, Global Positioning System Integration (GPS), TECOM Project No. 7-CO-M92-AVD-004

1. Subject report is approved.

2. Point of contact at this headquarters is Mrs. Cyndie McMullen, AMSTE-TC, amstetcd@apg-9.apg.army.mil, DSN 298-1469.

FOR THE COMMANDER:

Kenneth R. Balliet

KENNETH R. BALLIET
Acting Chief, Tech Dev Div
Directorate for Technology

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Testing at U.S. Army Aviation Technical Test Center (ATTC), Fort Rucker, Alabama, requires nap-of-the-earth time space position information (TSPI) of rotary-wing aircraft integrated with other aircraft parameters. The Global Positioning System (GPS), integrated with other sensors, is expected to meet the TSPI requirements. This methodology investigation explored the requirements and the problems encountered in using the GPS for this purpose.

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TABLE OF CONTENTS

Paragraph | Page

SECTION 1. SUMMARY

SECTION 2. DETAILS OF INVESTIGATION

NOT USED

SECTION 3. APPENDICES

SECTION 1. SUMMARY

1.1 BACKGROUND. To provide time space positioning information (TSPI) of rotary-wing aircraft for technical tests, the U.S. Army Aviation Technical Test Center (ATTC) procured commercial airborne Global Positioning System (GPS) hardware. This hardware, marketed by Cubic Defense Systems, consists of six-channel Course Acquisition (CA) code GPS receivers, antennas, and preamplifiers.

1.2 PROBLEM. Testing at ATTC requires nap-of-the-earth TSPI of rotary-wing aircraft integrated with other aircraft parameters such as airspeed, barometric altitude, platform attitude, platform attitude rates, and platform accelerations. In particular, the TSPI requirement is typically in the range of a ± 20 feet spherical error. ATTC does not have an instrumented test range and is therefore expecting GPS, integrated with other sensors, to meet the TSPI requirements.

1.3 OBJECTIVES. The objectives of this portion (Fiscal Year (FY) 92) of the methodology investigation were: (1) provide a first-order surveyed location for the GPS reference station; (2) provide a post-mission capability to generate corrected Differential GPS (DGPS) TSPI; (3) integrate the ring laser gyro inertial navigation data through a Kalman filter with the GPS data to fill in periods where the GPS data are less accurate; (4) integrate the GPS data with the remainder of the airborne flight test data; and (5) ensure that the accuracy of the GPS data is known at all times.

1.4 PROCEDURES.

a. Provide a first-order survey for the DGPS reference station. To provide a first-order survey at Cairns Army Airfield, Fort Rucker, Alabama, would require either contracting a surveyor or obtaining the services of the Corp of Engineers from Mobile, Alabama. The site chosen for the reference receiver processor antenna was the top of building 30602 (data reduction building). Another important factor (in surveying in the reference receiver) was that ATTC intended to use DGPS with their mobile data van. This would require a survey for the reference receiver each time the data van moved to a new location. To recontract for a survey each time the data van moved was not a workable solution. Analysis of the procedures used by surveyors to get a first-order survey indicated that ATTC could possibly use their own GPS receivers to survey sites for the reference receiver. A quick test could be done to verify this by contracting for a first-order survey and using the GPS to survey in the same site. If the data were accurate enough, all subsequent surveys would be accomplished using ATTC's GPS equipment.

b. Provide post-mission DGPS capability. The GPS receivers ATTC purchased from Cubic Defense Systems are capable of processing DGPS in real time; however, they are unable to process DGPS in a post-mission mode. Since ATTC at Fort Rucker processes 70 percent or more of its data post-mission, a requirement exists to process DGPS post-mission. Further, the DGPS requirement is for processing raw GPS measurements (pseudorange measurements), not just correcting the receiver's navigation solution. To accomplish this, a Kalman Filter algorithm would have to be implemented in a host computer for GPS data previously collected (both airborne and reference receiver).

c. Integrate inertial navigation system data with GPS. Through Quick Reaction Methodology project in FY91, it was determined that GPS without some type of sensor aid would not fulfill ATTC's instrumentation requirements. ATTC currently owns two Honeywell H423 Inertial Navigation Systems (INS) and expects to acquire three additional systems or their equivalent in FY93. It was determined that the GPS operating with INS aid would meet ATTC's requirement for accurate TSPI data. Since the GPS and INS are not amenable to hardware integration, it was determined that for the initial effort, GPS data would be integrated with INS data via a Kalman Filter in a post-mission processing mode. Technical support was coordinated through the GPS Range Applications Joint Program Office (RAJPO) at Eglin AFB, Florida (Department of Defense established tri-service office for the development of range instrumentation GPS). This decision was partially based on the experience level of the contractors working for the RAJPO and because the contractor could modify any software written when the RAJPO GPS equipment becomes available to ATTC.

d. Integrating GPS data with the remainder of the flight test data involved building an interface to the GPS for the data collection system used by ATTC. The GPS output was via the RS-232 interface which operates at 9600 baud and implements no control lines. ATTC's data acquisition system is a BASE 10 Systems Inc., Programmable Data Acquisition System (PDAS), Model 7-184-1. This system has a digital parallel input instead of the RS-232 interface. The required interface would accept the RS-232 from the GPS and convert the data to an 8-bit parallel for output to the PDAS.

e. Another problem discovered in the FY91 Quick Reaction Methodology was the inaccuracy of the Figure-of-Merit (FOM) for the receiver. The FOM was not a reliable predictor of the GPS accuracy. As a matter of fact, on some documented occasions, accuracy of the GPS had degraded to less than a three-dimensional solution; yet the FOM indicated the GPS was outputting an accurate three-dimensional solution. ATTC had to be able to quantify the accuracy of the GPS TSPI solution if the GPS was to be used as TSPI instrumentation. In past research on GPS, it was observed that the accuracy of the system was usually expressed differently in the xy plane from that in the z or vertical axis. A generally accepted expression of accuracy was the dilution of precision (DOP) which is further quantified by VDOP (vertical) and HDOP (horizontal). The DOP value is a measure of the GPS receiver's capability to achieve a certain accuracy based solely upon the geometry of the satellite constellation. If VDOP and HDOP were used in conjunction with a measure of the receiver's induced error, a system accuracy (both the receiver and satellite) could be developed that would give a dynamic picture of how the system performed. To accomplish this, software would have to be written to calculate the DOP based upon the satellites used in the position solution and to characterize the error of the receiver.

1.5 RESULTS

a. The investigation, to attain a first-order survey for the reference receiver antenna and a second survey as a calibrated point to check the operation of the DGPS, started with the Directorate for Engineering and Housing (DEH), Fort Rucker, Alabama. They did not have the capability necessary to perform a first-order accuracy survey and could not give a projected response time for the engineers at Mobile, Alabama. The only alternative was to contract a local company to accomplish the surveys.

(1) In considering utilization of the Cubic GPS to accomplish the survey, two points were noted. First, the Cubic GPS output resolution was only 1.2 meters, accuracy far below ATTC's requirement. Second, while collecting data, a software bug was discovered in the Cubic receiver position solution that introduced a 1 to 10 meter step change in position.

(2) During a GPS users group meeting at Headquarters, U.S. Army Test and Evaluation Command (TECOM), a representative from Redstone Technical Test Center (RTTC) volunteered the use of their system (Ashtech Surveying GPS equipment and software) to ATTC. With the borrowed system, we were able to survey both the reference receiver location and several calibration points for the airborne GPS receivers.

b. ATTC contracted the post-mission software to perform Method Three* DGPS calculation of position. AMCOMP, Torrence, California, will write the software, with delivery scheduled for January 1993. The software will run on an IBM PC AT compatible, mission planner included.

c. Integration of INS/GPS data required an extensive knowledge of the system and GPS errors, as well as how one system complemented the other. This expertise was not available at ATTC; however, the RAJPO had a number of support contractors who could provide it in different areas. One such contractor, The Analytical Sciences Corporation (TASC), assists the RAJPO in testing and evaluating various GPS and the components that make up the systems. They had extensive expertise in using INS to aid GPS for range applications. The RAJPO was assigned the task and ultimately TASC developed the requirements for the GPS INS integration. From these requirements, a subsequent contract would be awarded to design and write the software to integrate the GPS/INS data and provide a smooth position prediction that would not degrade rapidly due to GPS tracking dropouts. The requirements document should be completed by January 1993. The software contract for implementation of the requirements was scheduled for March 1993; however, funding for the software has not been provided.

d. Helicopter flight testing requires many types of flight test data. For most tests, attitude, attitude rates, attitude accelerations, airspeed, and altitude along with TSPI of the aircraft are required. Integrating these data into a single data collection system that will output a composite data stream is desirable. The BASE 10 PDAS used at ATTC, Fort Rucker, was designed to collect analog and discrete data and format it into a Pulse Code Modulated (PCM) serial data stream. The Cubic GPS has an RS-232 output of ASCII characters and is not directly compatible with the BASE 10 PDAS inputs. The discrete or parallel inputs of the PDAS provided the most logical means of inputting the GPS data but would require that the RS-232 output be converted to parallel and that timing between the GPS and PDAS be synchronized. A WYNTEK 6809 (microprocessor) single board computer (SBC) with serial and parallel ports was chosen as the interface between the PDAS and GPS. Software for the WYNTEK SBC, written in assembly language, consists of two main algorithms. The first algorithm (interrupt driven) accepts data from the GPS and moves the data into the SBC memory. The second algorithm takes the memory saved by the first algorithm and outputs it in parallel to the PDAS discrete inputs. The first algorithm has been written and tested; the second algorithm has been designed and partially written. This portion of the project was halted before completion due to funding constraints.

e. As a system, GPS was designed for navigation, not as instrumentation for TSPI. As a navigation system, GPS was designed to degrade in accuracy gracefully (continuing to give a solution with the available sensor information although accuracy not at a maximum). This was a two-edged sword in that graceful degradation is good for navigation but not for TSPI. The two characterizations of the GPS that try to quantify the position solution accuracy are the (1) FOM (quantifies the receiver accuracy due to the internal tracking algorithms) and (2) positional dilution of precision (PDOP) (quantifies errors due to the geometry of the satellites and the receiver near the ground). In tracking, one could give a reasonable estimate for the dynamic GPS TSPI solution with the error due to geometry and a crude measure of the receiver performance.

1.6 ANALYSIS. The data analysis is presented in order by the stated objectives of the investigation.

a. Four surveys were accomplished using borrowed (from RTTC) GPS equipment: three calibration points (static locations over which the aircraft can be parked to observe if the DGPS gives the correct position), and the reference receiver antenna location. The ambiguity in position for the four points ranges from 3 to 10 inches. This bias error in position will be negligible in comparison to the overall system accuracy of the DGPS.

b. The software (being designed and written by AMCOMP) should be specific to ATTC applications (for the Cubic GPS receivers) and a Kalman Filter solution using the pseudorange (range calculated by the time it takes the GPS satellite signal to reach the GPS receiver) and range rate measurements. The software should consider pseudorange bias errors such as satellite clock errors, ephemeris errors, and atmospheric delays. The errors should be removed using the standard DGPS technique of placing a reference receiver over a known point and correcting common mode errors present at the reference and airborne receivers. The software should provide an output of general information (time, date, reference location, run number, and mission ID), receiver and satellite information (satellites tracked, satellite azimuth and elevation, signal to noise of the received satellite signal, satellite navigation data, satellite health, differential corrections calculated, FOM), and position information (calculated position of the airborne GPS, position dilution of precision, and horizontal dilution of precision).

c. No analysis of integration of INS with GPS data can be accomplished until requirements for the integration method have been established.

d. At ATTC Fort Rucker, flight test data are recorded on 14-track magnetic tape or telemetered to a ground station for real time reduction. In either process, the data are available in digital form as PCM data. This is a serial synchronous data stream defined in time by its format (called a frame of data) and is repetitive at its sampled frequency (frame rate, e.g., once-per-second). The PDAS system used to collect data at ATTC Fort Rucker was primarily designed to collect analog signals (transducer or sensor output), digitize, and format them for transmission as PCM. To collect GPS data with the PDAS required converting the GPS data to a signal type that could be read by the PDAS and appropriate timing so that data transfers occurred at synchronous times. Since neither the Cubic GPS receiver nor the PDAS implemented control lines on their communications ports, design of a smart interface between the devices was required. An SBC, utilizing a Motorola 6809 microprocessor, was chosen because of its size (small single board application). The SBC consisted of four, 8-bit parallel ports (two were required to output data to the PDAS in a ping pong or alternating fashion) and two serial RS-232 ports (one required to talk to the GPS and the other to allow on-line communications while debugging the application software). The software for the SBC was designed around two tasks. Upon interrupt, one would read the GPS serial communications and store the data in memory; the other would continuously perform memory management and output, in parallel, the stored memory location to the PDAS. The only timing available was the interrupt generated when a serial word was transferred into the SBC, and the frame and word flags generated by the PDAS as it transmitted serially the PCM data. The two tasks, an interrupt handler and the other a totally separate software module, were designed; the interrupt handler has also been written. Coding of the second module and integration testing of the two tasks running together were not accomplished due to funding constraints.

e. Static and dynamic testing of the Cubic GPS provided several unexpected problems.

(1) The FOM (the gage of how well the GPS receiver was tracking and calculating position) produced erroneous outputs in certain instances. This would prove to be a problem if GPS was to be used as truth for TSPI of a test article. Some measure of accuracy of the TSPI data would have to be known; otherwise, someone might accept the altitude as correct when the GPS TSPI solution had degraded to the point that it could not predict in three dimensions.

(2) The second part to understanding the accuracy of the GPS TSPI solution was that regardless of how well the GPS receiver was tracking and processing the GPS signals, if the satellites used in the solution were not in good geometric angular position the multi-lateration used to find the GPS receiver's position would have sizable errors. These errors associated with geometry are characterized by GPS manufacturers as geometric dilution of precision (GDOP). The GDOP could be broken down into position dilution of precision (PDOP) negating time element of the error and broken further into horizontal and vertical dilution of precision (HDOP and VDOP). As stated earlier, these are characterizations of geometric error. This error could become dynamic as the airborne platform instrumented by GPS moves with the platform blocking view of first one and then another satellite, thus changing which of the GPS satellites are used by the receiver. The two estimations or characterizations of error must be used together to determine the usefulness of the GPS TSPI solution. One cannot advertise the GPS TSPI as being accurate to ± 20 feet when one or the other or a combination of the two of these error estimates is too large. A quantization of the indicators to accuracy would be achievable only by using the total integrated DGPS against a truth system and empirically measuring the error. For the present, this is beyond the scope of this project, but is needed to provide a confidence level in the GPS TSPI solution.

1.7 CONCLUSIONS

a. The only feasible way to collect TSPI on flight tests at ATTC Fort Rucker is through the use of GPS. This is driven by the realization that with no real estate to position tracking radars or optical systems, the only alternative is a space-based system such as GPS. With the GPS, there are no requirements for large areas of land to be dedicated as a range and no restriction as to where the aircraft must fly to be tracked.

b. To use DGPS as TSPI for aircraft, some obstacles must be overcome. First, GPS is a line-of-sight transmission system; i.e., line-of-sight must be maintained between the GPS antenna and satellites used. This is impossible to accomplish because maneuvering the aircraft will eventually cause the airframe to block or shade one or more of the satellites from the antenna. In flight tests at ATTC, this phenomenon was experienced time and again with the Cubic GPS and Ashtech GPS used by RTTC. When one or more of the satellites was blocked from view, tracking of the satellite by the GPS receivers was lost. With the loss of satellite tracking, the GPS receiver must degrade in accuracy or track an alternative satellite. The acquisition time associated with dropping one or more satellites from tracking and beginning tracking on alternative satellites could be less than a second for the loss of one satellite to multiples of seconds if several satellites had to be reacquired. The loss of track and reacquisition of events created gaps of missing data in the TSPI solution. This is unacceptable in many of the technical tests that ATTC conducts.

c. The second obstacle to overcome is that the accuracy of GPS is a function of how well the receiver is tracking the satellites, whether the receiver is tracking enough satellites, and whether the satellites tracked are in an orientation in space that would produce good geometry. Any one or more of these three factors degrades GPS accuracy. If the GPS is to be used for TSPI a means of quantifying the degradation must be established to ensure the test customer of the confidence in the test data.

d. To use the GPS as a TSPI system for helicopters, it is imperative that an inertial sensor be used to augment the data. ATTC utilizes INS as another sensor for flight test data. It is only logical that the two sensors (GPS and INS) be integrated and complement each other. This would prevent the dropout of GPS data and could be used to help remove the characteristic longterm errors of the INS data. ATTC must accomplish further work in this area before GPS can dependably be used as TSPI.

e. Finally, TSPI data at ATTC consists of three data points (longitude, latitude, altitude) of 100 to 500 parameters that would be collected on a technical test. It may be possible to treat the TSPI data totally separate at test ranges but this is not the case at ATTC. Typically, the position is an integral part of a maneuver and would need to be merged with aircraft attitude, airspeed, and altitude to get a total picture.

SECTION 2. DETAILS OF INVESTIGATION

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SECTION 3. APPENDICES

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