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Honeywell's Differential GPS Satellite Landing System

By George Lewison

As we approach the year 2000, the FAA and other aviation agencies throughout the world are looking to replace the existing obsolete ILS landing systems and VOR navigation systems with higher technology navigation systems and greater precision landing systems.

The great majority of the world's ILS systems are only operational to Category 1 or Category 2 standards. Very few are good to Category 3 with autoland capability. GPS with its 100 meter accuracy is already becoming the new world standard for long range navigation systems. Now it appears we are on the verge of exploiting the GPS Satellite technology to create an entirely new system of providing precision approach and landing information to all types of aircraft.

Honeywell has for years been extremely interested in navigation utilizing the Global Positioning Navigation satellites. In the early 1980s Honeywell began development of a GPS receiver autonomous integrity monitoring algorithm called (RAIM). This Honeywell-developed algorithm allows for the automatic detection and exclusion of faulty satellite data from the GPS navigation solution without requirement for action by the crew. In 1987, Honeywell developed the first integrated Inertial Reference and Global Positioning System in order to conduct testing of autoland systems for NASA. A Honeywell-equipped NASA Boeing 737 performed the first GPS guided automatic landing proving that DGPS landings were possible. In the fall of 1990, Honeywell and NASA made 34 Category III landings using the Honeywell IRS/DGPS integrated landing system.

Honeywell then teamed with the FAA to determine the feasibility of providing position accuracies sufficient for non precision and precision approaches using commercially available GPS sensors. Honeywell instrumented their GIV aircraft with a complete GPS/IRS navigation and data acquisition system. The aircraft was flown at the FAA test center where the approaches were monitored with a laser tracker.

The results of these tests were presented at a conference in 1992. Much useful data was gathered during these flight tests but the FAA was only willing at that point in time to consider a non-precision approach with the use of GPS.

In 1993, Honeywell was the first to certify GPS as a sole means of landing with a non-precision approach at Aspen, Colo. on an ATR-72 aircraft. The data generated in this program was used by the FAA and the satellite office to establish certification procedures for non-precision GPS approaches.

Subsequently, from 1993 through 1994, the FAA and Honeywell jointly demonstrated DGPS precision approaches using a prototype Honeywell-equipped aircraft and ground reference station. These demonstration flights were accomplished at Washington National, Chicago Midway and Ontario, Calif.

Honeywell had been teamed for some time with Canadian Marconi to develop an ARINC 743 twelve channel GNSSU for commercial aircraft. This sophisticated GPS sensor system was designed to provide information to flight management systems. It was certified for use on general aviation aircraft in January of 1994 and subsequently certified on both Boeing and Airbus aircraft in early 1995.

The Honeywell/CMC Global Positioning Sensor system was certified on the first flight of the new Boeing 777 aircraft in mid 1995.

The original Honeywell GPS receiver, installed on many corporate aircraft, was a three channel unit and did not have the required integrity monitoring to satisfy FAA requirements. While it provided much higher resolution navigation solutions most of the time than the positions provided during long term inertial system drift, the FAA would not allow it to become part of the navigation solution.

We were allowed to display the GPS position for the edification of the flight crew, but it could not be used as part of the navigation solution on the aircraft. For a brief period of time during the Gulf War, of necessity the DoD allowed military resolution of position to be resolved on civil systems. We made numerous flights during that period of time and were astounded by the accuracy of the GPS solution on this early equipment. The FAA at this point in time was still not convinced that GPS could be relied on as a stand alone navigation system.

I had been working for Gulfstream Aerospace during the event of the early GPS sensors and the introduction of the Honeywell/CMC 12 channel Global Positioning Sensor system. The new integrity monitored GPS system made a tremendous difference in the accuracy of the flight management systems on the Gulfstream IV aircraft by bounding the inertial systems with an extremely high resolution update of position on a worldwide basis. At this particular point in time, numerous GPS manufacturers had begun producing GPS navigation receivers and sensors with 100 meter accuracy for civilian installations.

As mentioned previously, the navigation data from the GPS system was allowed to be displayed by the FAA before the event of integrity monitoring, but was not allowed to be a sole means of navigation or to effectively bound the inertial systems on large aircraft to the extent that the navigation accuracy over the basic inertial position was improved.

With the event of the integrity-monitored Global Positioning Sensor Units and receivers, the FAA then allowed considerable weight from the Global Positioning Sensor Unit to modify the inertial position of the flight management systems on board large corporate aircraft to provide a far more precise long range navigation solution for these aircraft. Because this update was available over oceanic areas as well as land masses, GPS soon became the preferred method of navigation over previous long range systems on all types of aircraft.

In January of 1995, Honeywell and Pelorus Navigation Systems Inc. of Calgary, Canada, joined forces to develop and manufacture a Differential GPS (DGPS) Ground Station to be called the Satellite Landing System. The ground station equipment is available in two configurations, the SLS-1000 and the SLS-2000. Both systems are comprised of three major subsystems:

1) Ground Reference Station
2) Remote Satellite Measurement Units
3) VHF Data Link Transmitter

The SLS-1000 ground station is a fail safe system that is designed to continually perform self test of its operation. If it detects a problem, it will notify the ground station operator and any aircraft in the area that it is not capable of furnishing accurate navigation data.

The SLS-2000 is a fail operational system that is not affected by single component failures. The ground station operator is notified of a component failure and can call for service. Because it is totally redundant in its capability, the SLS-2000 will continue to operate with accurate approach navigation data. Both the SLS-1000 and the SLS-2000 are self calibrating and do not require periodic flight tests of the systems.

The Teaming of Honeywell and Pelorus Navigation Systems of Canada was a good choice as Pelorus had an extensive background in installation and training for approach aid technology. With this type of background, the Honeywell team participated in Boeing's Category III-b flight test evaluation program in July and August of 1995. NASA supplied the 757 aircraft and flight test facility. Boeing supplied the pilots, ground crew, maintenance, flight test personnel and performed the aircraft modifications for the flight tests. The flight tests were accomplished at NASA's Wallops Island, Virginia, flight test facility. A total of 75 Category III-b automatic landings were accomplished during this phase of flight testing.

The Honeywell DGPS landing system replaced the standard ILS instrument landing system for these test flights. The DGPS landing system provided equivalent lateral and vertical guidance signals to the aircraft's autopilot. The autopilot used the DGPS to guide the aircraft to a landing and then continued to use the DGPS signals to provide lateral guidance to keep the aircraft centered on the runway during roll out. Preliminary performance data of these flight tests showed that the Honeywell DGPS landing system achieved the predicted system accuracy of one to two meters.

The analysis of these results have been used to help create the requirements for the impending certification of the DGPS precision landing system.

It should be kept in mind that the certification of a differential DGPS landing system involves the development of both the ground facility systems as well as the airborne equipment. To provide for the early implementation of DGPS approach and landing systems, RTCA Special Committee 159 has published the Minimum Aviation System Performance Standards for a DGPS approach and landing system to Special Category I standards. This is the type of approach to certification that the FAA can live with as they want to see active demonstration of repeated Category I approaches before attempting to certify Category II or Category III approach systems.

There is no question that the capability of providing CAT II and CAT III landings with the Honeywell DGPS System is possible. It has already been demonstrated. Likewise it is prudent to begin operation of the system as a Category I system until the standards for CAT II and CAT III are developed as well as providing for the accumulation of experience with an operating Category I DGPS system.

Even though the capability to land CAT III has been demonstrated on a test vehicle, the Honeywell DGPS approach and landing system goes far beyond the capabilities of the current ILS systems. Due to the fact that the Honeywell system provides multiple approach data to all of the airports runways there is a complexity that must be explored over a period of time by utilizing the special Category I approach with multiple aircraft utilizing the system. Since the Honeywell/Pelorus DGPS landing system is one of the most advanced systems proposed for utilizing the satellite system for precision approaches, there is an excellent possibility that it will be the precision airport landing system for the future.

The other factor that cannot be ignored is the fact that a common system is needed on a worldwide basis. Aircraft cannot be equipped for one type of system in the United States and a different type in Europe or Asia. For many years, the European community has been wary of the GPS system since it is controlled entirely by the United States. The dedication of ground facilities in the U. S. for DGPS operation would certainly remove a great deal of this concern from the European Aviation community. As a matter of fact, comments are now being heard from both England and the continent as to when such a system could be activated.

Honeywell has chosen to implement a carrier smoothed code tracking DGPS for their initial SCAT 1 certification program as this is the most robust of the numerous DGPS solutions that are possible for the Category 1 certification program. Its accuracy exceeds the requirements of SCAT I and may be compatible with the developing Category II requirements. This architecture makes very modest demands on the differential correction datalink.

Honeywell will utilize their SLS-2000 Fail Operational DGPS Ground Station in the certification program. The ground station is equipped to perform two major functions: First, to determine all of the necessary differential corrections to the satellite signals; and, two, to transmit the corrected information to the approaching aircraft utilizing a DO-217 defined data link. In addition, the aircraft itself must be equipped with a differential GPS receiver and a VHF data link receiver.

It should be noted that the DGPS Ground Based System is capable of handling multiple approaches to different runways on the field. It is able to transmit through the DO-217 data link the exact decent data to multiple aircraft. On the approaching aircraft, the differential GPS receiver applies the differential corrections that have been transmitted to the aircraft through the datalink to provide a GPS smoothed Pseudo range corrected flight path to provide a precision approach path for landing the aircraft.

The VDL-500 is a datalink receiver. Since the ground station continuously transmits data for all of the runways at the airport, the pilot only needs to select the specific runway and the type of approach that will be accomplished to that runway. The DGNSSU then strips the specific approach data from all of the approach data being transmitted from the ground station and utilizes that data to create a look-alike ILS decent path to the landing.

For a single runway, their can be five or six approach paths being transmitted. For example, a straight in approach, a left turn approach, a right turn approach, and in addition several different vertical angles of approach to accommodate different types of aircraft. As a result, the ground station may be transmitting continuously as many as 60 or more approach scenarios at any given airport. As a result the complexity and the capability of this installation far exceeds that of any of the approach and landing systems that are currently in use.

It should be noted that the corrected approach path ILS look-alike data is generated by the DGNSSU utilizing the data from the GPS satellite system and modified by the data for the specific type of approach to the selected runway by the Honeywell ground station. This data currently is furnished directly to the flight director and autopilot system on the aircraft from the DGNSSU just as the current ILS approach information is furnished by an ILS receiver.

In the future, if integrity could be guaranteed, it would provide a seamless hand off if the approach data could be furnished through the flight management system, but that would require additional qualifications to approve the system which adds another link in the sensitive data path.

In order to understand how the Honeywell Ground Station can handle all of the complex requirements of multiple approaches at any specific airport, it is necessary to look at the architecture of the system. The physical equipment consists of a Differential Reference Ground Station which is housed in an environmentally-controlled shelter. In addition, there are three spatially located DGPS receivers that are installed at extremely accurate surveyed locations. These receivers are called RSMU's. The RSMU receivers at their surveyed locations are the key to enabling the differential ground station with its processors to correct for all types of errors in the GPS navigation signals.

The Differential Ground Station also contains the datalink transmitter and the omni directional datalink antenna. The control tower will have a remote status unit that gives continuous information on the integrity of the system operation. Data from all three of the RSMU receivers is furnished to the fail operational computer in the Differential Reference Ground Station. The ground station has three differential correction processors.

The three differential processors are synchronized by fault tolerant clocks resident in each processor function. Each of these processors receives data from the RMSU's, from the datalink wrap-around and from the interface function. The synchronization assures that all three processors operate on the same input data. The differential processors calculate the differential corrections and also RSMU integrity checks using identical RMSU data sets. The differential corrections and other output data is then compared bit by bit by the fault detection circuits. Upon successful comparison, the information is routed to the datalink transmitter and broadcast to the aviation users.

In addition to providing the flight path information for all of the various approaches to the airport, the primary function of these differential corrections in the Honeywell Ground Station is to remove the selective errors that are intentionally induced by the GPS control segment and the system errors that are common between the Satellite signals and the airborne and ground receivers. These errors are tropospheric errors and clock errors. The removal of these errors increases the accuracy and the integrity of the aircraft's GPS navigation solution to the point that the accuracy of the navigation enables it to be used for aircraft guidance during Category I approaches.

These corrections are made possible because the DCP's calculate a differential correction for each satellite vehicle that is in view and considered valid. It is possible to do this because the DCP's psuedo ranges are predicted using the surveyed positions of the RSMU station antennas and the

RSMU output of each satellite vehicles position. The predicted pseudo ranges are then differenced with the RMSU's measured value. Removal of clock error and satellite propagation errors from the solution are then possible.

The performance required for the SCAT-1 specification is described in the RTCA document DO-217. This document defines the SCAT-1 approach through four measures. They are: integrity, availability, accuracy and continuity of function. The Honeywell Ground Station is designed to exceed these requirements for each of these measures. A table showing the Honeywell Ground Station capability versus the RTCA DO-217 document laying out requirements for the SCAT-I approach shows that the SLS-2000 ground station well exceeds the DO-217 requirements in all areas.

Integrity

The integrity level provided by the Honeywell SLS-2000 Differential Satellite Ground station for the SCAT-1 requirements is provided mainly by the systems major design components.

The first is the use of three RSMU's with fault tolerant architecture and redundant components to provide a measurement consistency check to identify multi-path errors and detect other erroneous measurements.

The second is the use of Cyclic Redundancy Check (CRC) codes on the messages transmitted to the aircraft from the ground. The CRC ensures the end to end integrity of the differential corrections datalink and eliminates the datalink as a potential system integrity failure point. A separate CRC is used to ensure the integrity of the uplinked path points. The integrity level of the Honeywell SCAT-1 ground equipment is 1 X $<10^{-8}$ approach.

Availability

The availability of the SCAT-1 is a function of the satellite constellation, the MTBF of the ground equipment and the integrity requirements of the system. A study has shown that the availability of the DGPS ground station equipment with the fail operational equipment is 99.9%.

Accuracy

The accuracy of the Honeywell SCAT-I system is the function of the differential corrections, sensor measurements and the satellite geometry. The resulting vertical system accuracy of the SCAT-I is currently one to two meters. This accuracy will be enhanced in the future by upgrades to the equipment as requirements for Category II and III are defined.

Continuity of Function

The continuity of function of the SCAT-I system is the function of the failure rates of the DGPS ground station and the satellite constellation. System outages resulting from constellation limitations do not affect the continuity of function, but do affect availability. The continuity of function computed for the Honeywell SLS-2000 Ground Station is 5.5 X 10^{-7} / approach.

The Honeywell SCAT-I ground stations include a monitoring system for configuration, control, fault isolation and system status. The monitoring consists of both power up and continuous built in test. In addition, each ground station is furnished with a local maintenance monitor. The local maintenance monitor consists of a personal computer configured with a software program that allow it to communicate with the ground station through an RS-232 interface.

The local maintenance monitor provides for system configuration, system control and fault isolation. In addition, it allows the system operating parameters to be initialized and or changed. It has a user friendly software program that allows the operator to request system status and to aid in fault isolation and repair. The following parameters can be configured by use of the local maintenance monitor: RMSU locations, datalink frequency, datalink transmitting power, fail safe versus fail operational configurations, multi-path information, pathpoint data, modem auto dial numbers and enable/disable system.

It is easy to understand that the sophistication of the DGPS ground station technology will allow airports with terrain limitations that make it difficult for a standard ILS system to provide a safe approach will be able to provide almost any approach scenario that is necessary to increase the safety of flights into that area. This is the result of the flexible capability of the DGPS ground station to provide variations in approach navigation data that will meet the specific requirements for the particular terrain surrounding the field.

In order to simplify the certification of the first Honeywell ground station for DGPS approach and landings, the first certification will take place at a field where an existing ILS is in operation that can be used as a comparison for the operation of the DGPS. Since the Honeywell Ground Station transmits information used by the airborne GNSSUs, it will create a look-alike ILS glide path for the final segment of the approach. In order to accomplish this the ground station will transmit to the aircraft the following information in addition to the other data being furnished.

1) The datum point which is the latitude, longitude and the altitude of the threshold of the runway.

2) The datum point which is the latitude and longitude of the departure end of the runway.

3) The threshold crossing altitude.

4) The specific glidepath angle for the type of airborne vehicle.

Once the requirements for Cat-II and Cat-III approaches has been established for DGPS, it should be relatively simple to upgrade any previous installed Cat-I DGPS ground station to these requirements as Category III capability has been the goal for creating this new approach and landing system since the program was initiated.

The first Honeywell DGPS ground station was installed in Minneapolis and has been used for some time to test the system with a Honeywell Gulfstream IV aircraft. Currently, a ground station is undergoing construction at the Newark Airport in New Jersey. This ground station will be the first to be certified with the FAA and initially will be utilized by Continental Airlines which is equipping a Douglas MD-80 series aircraft to run the certification tests with the ground station.

Newark is a particularly interesting field for the first DGPS approach and landing system installation as it is located in an area that has air traffic from other large metropolitan areas that tend to interfere with many normal ILS approaches. The flexibility of the DGPS approach and landing system should hopefully allow approaches to Newark that will avoid much of the air traffic that is generated by adjacent airports.

The certification of this first Differential Global Positioning ground station is going to be of great interest to all in the aviation community. It could well portend the beginning of a whole new era in terminal navigation. The fact that it can be installed and operated without the immediate decommissioning of the existing ILS system means that it can provide a smooth transition from the current approach system to the new satellite based concept. The important factor of being able to operate with both the old and the new system will ease the economics for all operators in purchase of the new airborne equipment.

What is the future of DGPS for general aviation? I think it is very bright since in many ways the equipment that was developed for this program has already flown on general aviation aircraft. Honeywell estimates that the cost of their airborne DGNSSU navigation receiver will be approximately $15,000.00 each. This is not out of line with some of the equipment being installed in many general aviation aircraft today.

The Honeywell DGPS Approach and Landing System is a new approach to terminal navigation but in many ways is actually an enhancement of the current enroute navigation equipment that is more or less universally in use today. The important factor is the precision that it provides for the approach in terminal areas.

The fact that Honeywell has worked with the FAA and the RTCA committee during the development of the SCAT-1 specifications as well as the design capability that is included in the existing equipment to allow for upgrades to whatever standards are set for Category II and III seems to indicate that it may well be the successor to the current ILS Instrument Approach System.

In addition, the Lockheed / Martin Autonomous Instrument Approach and Landing system which was discussed in a previous article has been designed so that it can readily be interfaced to utilize any certified DGPS ground station that is adopted by the FAA. There is no question that if the Honeywell DGPS ground station concept should be the selected system for future installation on the airports of the world, that all the current manufacturers of airborne navigation equipment could very quickly begin the manufacture of navigation receivers and datalink units that could be installed at a very reasonable price in small aircraft.

The qualification of the new DGPS approach system would definitely offer a new product line for general aviation aircraft that would enhance the productivity of AEA members. ❑