

# **IMPLEMENTATION OF DGPS AS A FLIGHT TEST PERFORMANCE MEASUREMENT TOOL**

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## **ABSTRACT**

The accurate determination of test aircraft position and velocity is a very strong requirement in several certification and development flight test applications. This requirement often requires availability of test ranges properly instrumented with optical or radar tracking systems, precision time for data reduction and dependency on environmental and meteorological conditions. The capabilities of GPS (Global Positioning System) technology, in terms of data accuracy, speed of data availability and reduction of test operating cost, moved Bombardier Flight Test Center to make an investment and integrate a system utilizing GPS for extensive use in flight and ground test activity. Through the use of differential GPS (DGPS) procedures, Bombardier Flight Test Center was able to implement a complete system which could provide real-time data results to a very acceptable output rate and accuracy. Furthermore, the system was capable of providing post-processed data results which greatly exceeded required output rate and accuracy. Regardless of the type of aircraft testing conducted, the real-time or post-processed data could be generated for the same test. After conducting various types of testing, Bombardier Flight Test Center has accepted the DGPS as an acceptable and proper flight and ground test measurement tool for its various aircraft test platforms.

## **KEY WORDS**

DGPS (Differential Global Positioning System), real-time processing, post-processed data, data acquisition, telemetry, ARINC 429, Flight Test.

## **INTRODUCTION**

A collaborative project was conducted between the Bombardier Aerospace Group and the National Research Council Canada in order to explore the application of differential GPS position measurement to type certification flight and ground test maneuvers. The project

yielded accurate post-processed results, yet real-time data accuracy did not meet the desired specifications. Due to the large amount of real-time data processing during certification and development programs, Bombardier Flight Test Center felt it was a requirement to improve the real-time accuracy of differential GPS positioning, particularly in the vertical plane. The National Research Council Canada undertook an investigation in which they compared a recently developed differential GPS receiver to an airworthiness authority approved differential GPS system for flight testing. In a report provided by the National Research Council Canada, the newly developed differential GPS met the manufacturer's performance specification for real-time and post-processed position solutions.

With the results obtained from the collaborative project, the Bombardier Flight Test Center initiated the procurement and integration of a differential GPS system into its existing test aircraft instrumentation package. This system would be designed to provide accurate real-time aircraft position for all airfield performance testing on any of the Flight Test Center's flight test aircraft. The design of the system included the capability of quickly relocating the system from one aircraft model to other models, depending upon which aircraft required the system. The Flight Test Center felt that differential GPS real-time data merged directly with the onboard aircraft data acquisition system, would provide the complete solution for its airfield performance test activities. A secondary solution, for those tests which required higher output rate could be accomplished with an implemented post-processing software package. After trial testing on a Learjet 60 test aircraft, the system was utilized on the Learjet 45 for its certification test program.

This paper will describe the equipment procured, the implementation of several types of data acquisition equipment, the design of data protocol between differential GPS ground station, test aircraft, and telemetry station and the final results of the system obtained.

## **THEORY OF OPERATION**

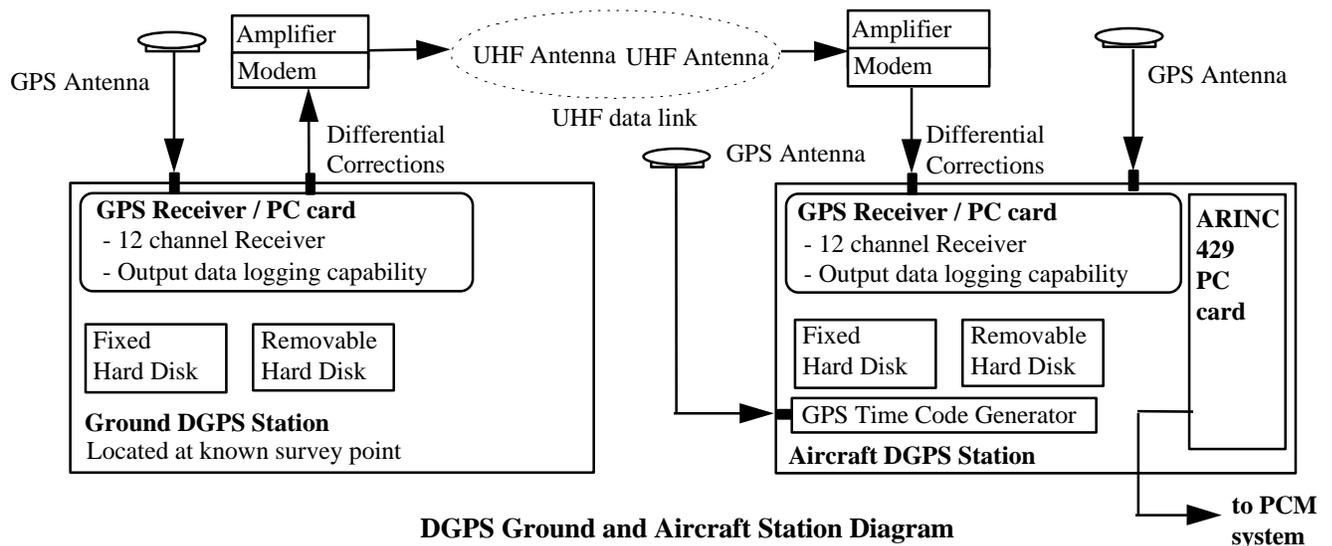
Due to the inherent position measurement errors associated with a non-differential Global Positioning System (GPS), Bombardier Flight Test Center adopted a system utilizing differential correction techniques in order to help eliminate these errors. A system designed to eliminate satellite clock error, ionosphere and troposphere delays (baselines less than 50 km), ephemeris prediction errors and selective availability could allow for position accuracy in the order of one to five meters in real-time and less than twenty centimeters in post-processed solutions. In order to obtain a better real-time (static and kinematic) solution, a system utilizing floating ambiguity resolution techniques was obtained. This technique, which has been utilized by post processing packages for some time, determines on which cycle the phase angle is being measured along the L1 carrier frequency. To further improve position solutions, the system combines carrier phase measurements with double differencing techniques. Double differencing utilizes a combination of observation

differences between satellites and receivers. For baselines less than 10 km, the double differencing techniques virtually eliminate all system biases, except for multipath errors. With proper multipath elimination techniques, the system would provide a 10 to 30 centimeter real-time kinematic accuracy solution with a position update rate up to 5 Hz maximum, regardless of the differential data link rate. The system would be further capable of providing uncorrected raw ephemeris and channel measurement data for post-processed data routines, in order to provide a higher data output rate. Depending on the type of testing encountered the real-time or post-processed data could be used to determine aircraft position, velocities and accelerations.

In order to operate in differential GPS mode, two stations are required, one in the aircraft (remote) and one at a known position (monitor). In order to properly obtain double difference carrier phase solutions, a minimum of four common satellites need to be tracked by the monitor and remote stations. For real-time solutions, the remote and monitor stations need to be initialized and linked by some form of data link in order for the monitor station to transmit its reference position, as well as differential observation data, to the remote receiver.

### SYSTEM DEFINITION

The system in Figure 1 was procured and configured in order to provide differential GPS capability.



Each system consisted of a rack mountable AT personal computer chassis, a 12 channel L1 frequency C/A code Global Positioning PC card and a UHF 9600 baud data radio modem and 35 watt amplifier. The Aircraft DGPS Station configuration differs only in an ARINC 429 Transmitter/Receiver card housed within the computer chassis. Ground

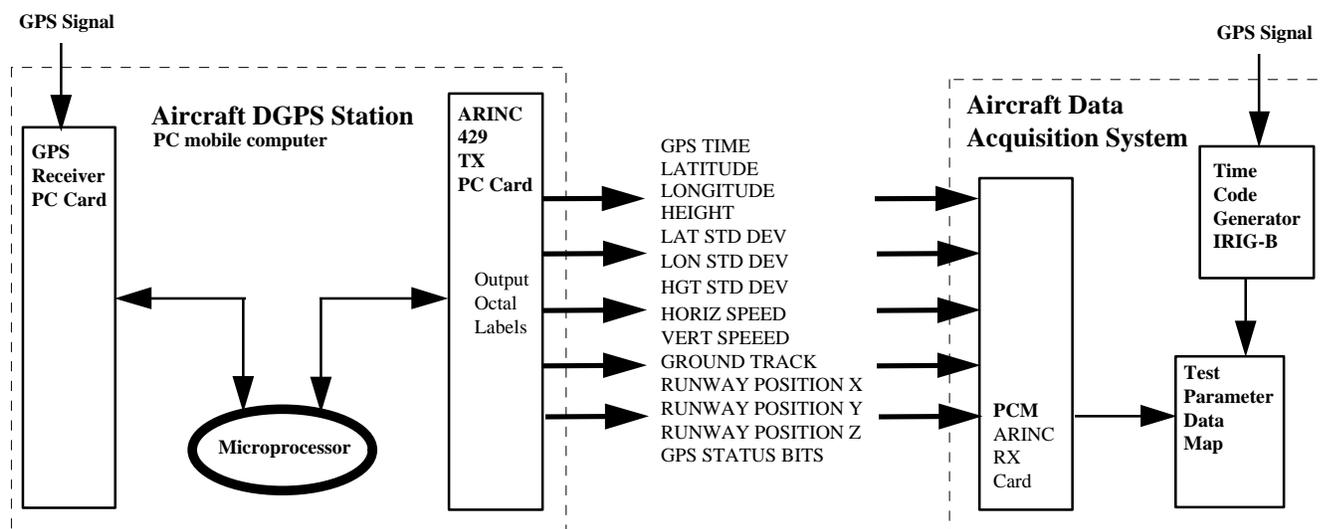
station mobile and aircraft station mounted antennas for both UHF modem datalink and GPS satellite signals completed the configuration.

For real-time differential GPS capability, the two systems operate as a team in which the Ground DGPS Station transmits corrections to the Aircraft DGPS Station. By placing the Ground DGPS Station antenna on a known or surveyed reference point and allowing the system to acquire GPS satellite information, the GPS receiver can calculate the difference between the known location and GPS determined position. The Ground DGPS Station then passes this difference, in the form of RTCM (Radio Technical Commission for Maritime Services) standard differential correction logs, through the GPS receiver communication port and along the UHF datalink. The Aircraft DGPS Station then receives the UHF differential corrections via its' GPS receiver communication port and applies the corrections in order to obtain high accuracy real-time position and velocity solutions.

In order to provide post-processed differential GPS capability, the two systems operate separately, logging raw uncorrected data to the PC hard disks. Data is collected and processed utilizing post-processing software algorithms in order to obtain differentially corrected data. In some areas of aircraft testing (brake performance, high speed airspeed calibrations), a higher output rate (up to 20 Hz) is required to accurately depict the positions, velocities and accelerations of the aircraft. For this reason the option of storing and post-test combining and correcting the remote GPS data is required.

In order to add the differential GPS system into the Bombardier Flight Test Center existing test aircraft instrumentation package, a method to record and store the corrected and uncorrected GPS data on the test aircraft was needed. The system was designed to be a low maintenance tool for the technician ground crews on a day to day basis. By allowing for the acquisition and recording of the GPS data on the test aircraft, the ability to transmit GPS aircraft data via telemetry was also possible. Through the use of software programs, the aircraft runway position coordinates were calculated using corrected Latitude, Longitude and Height. Along with all required runway information (Heading, Magnetic Variation, Geoidal separation (height to WGS-84 ellipsoid), Runway reference point) an accurate position solution could be computed and included as differential GPS corrected data to be recorded on the test aircraft.

Figure 2 depicts the data flow from the Aircraft DGPS station to the Aircraft Data Acquisition System.



**DGPS Aircraft Station and Data Acquisition Diagram**  
**Figure 2**

The software program used to receive differential GPS information, records uncorrected and corrected data on the Aircraft DGPS station removable hard disk for backup and post-processing use. The software program also calculates aircraft runway position from differential corrected Latitude, Longitude and Height. All corrected and calculated data is then transmitted to the Aircraft Data Acquisition System via an ARINC 429 PC card. The ARINC 429 card is used to provide acquired differential GPS data to the Aircraft Data Acquisition System. All ARINC 429 parameters are transmitted as octal labels on a own dedicated ARINC bus. Parameters describing differential fix state, solution status and degree of accuracy status are all transmitted. The Aircraft Data Acquisition System receives and records the data as it does any other digital bus available on the aircraft. Since the data acquired on the differential GPS system is asynchronous to the Aircraft Data Acquisition System, a method to synchronize the GPS data to the aircraft data system clock is required. The time tagged GPS data is recorded along with GPS time from the GPS PC card. In order to run from the same GPS time source, the Aircraft Data Acquisition System is synchronized using the same GPS time information through the data system time code generator IRIG-B input. By having time recorded as parameters on the acquisition system, as well as, synchronizing the time code generator to the same time, the difference in time between acquired and recorded GPS data could be determined, from test point to test point. In order to properly transmit data from the ARINC 429 card the card is setup in burst mode, allowing for all octal labels to be transmitted at the same time to eliminate time lags between parameters (Horizontal speed versus X runway position, etc.).

## TEST APPLICATIONS

Trial tests were conducted on a Learjet Model 60 test aircraft in order to confirm that the complete system operated per design. Testing was conducted to verify the datalink capability, GPS parameter recording and acquisition, data validity during low and high speed maneuvers and also ease of system use was evaluated. All testing scenarios were visited during the trial tests. These tests included takeoff/landing performance, minimum radius turn maneuvers, rejected takeoff performance, centerline taxis, low level flybys and climb to altitude tests. Data validation was conducted to ensure the real-time telemetry, data acquisition playback and post-processed GPS solutions yielded the same results.

The only adverse result from the trial test, was the intermittent reception of UHF differential corrections from the GPS ground station at certain areas of the testing runway. Due to declination of the runway, the UHF datalink became intermittent and caused the differential correction information to be lost. After reacquisition of the datalink, full position solution convergence began and operation was normal. In order to avoid this situation, the ground station antenna was moved to a more advantageous position. Analysis of standard deviation outputs resulted in errors in the range of 10 to 25 centimeters for all testing conducted. After corrections for ground station antenna locations and data validation tasks the system was accepted for use by all Bombardier Flight Test Center aircraft.

To date the differential GPS system has been used by the Learjet 45 certification test program in various applications. The system was used to determine highly accurate position solutions for noise measurement testing. Aircraft positions were referenced to microphone measurement locations. Differential GPS horizontal and vertical speeds were used to determine if the aircraft satisfied required configurations. The largest use for the differential GPS system has been in the area of brake, landing and takeoff performance. The rapid data availability of highly accurate GPS solutions, has provided the Flight Test Center the ability to test and confirm test points in a timely manner.

Differential GPS data is available for the engineering community in the same format and system as all other test aircraft acquired data, ensuring ease, timeliness of data collection and analysis. Table 1 depicts sample data output of the differential GPS system.

A/C #45001	Flight 356	Run 002	Bombardier Flight Test Center				Test Date: 04/28/97			
Time hh:mm:ss.sss	X Distance on runway (feet)	Y Distance on runway (feet)	Z Distance on runway (feet)	# of Satellites	Latitude Position (degrees)	Longitude Position (degrees)	Horizontal Speed (knots)	Ground Track (degrees)	Vertical Speed (knots)	
6:35:04.508	9938.09	-7.81	-31.73	7	33.3053990	-104.5141880	125.280	226.614	1.283	
6:35:04.646	9895.65	-8.98	-31.34	7	33.3053190	-104.5142890	125.280	226.614	1.283	
6:35:04.784	9895.65	-8.98	-31.34	7	33.3053190	-104.5142890	125.682	226.652	1.190	
6:35:04.922	9853.08	-10.13	-30.94	7	33.3052390	-104.5143900	126.096	226.676	1.145	
6:35:05.059	9810.51	-11.29	-30.58	7	33.3051590	-104.5144920	126.096	226.676	1.145	
6:35:05.197	9810.51	-11.29	-30.58	7	33.3051590	-104.5144920	126.388	226.722	1.067	
6:35:05.335	9767.61	-12.47	-30.26	7	33.3050780	-104.5145940	126.788	226.728	1.011	
6:35:05.473	9724.71	-13.66	-29.89	7	33.3049970	-104.5146960	127.142	226.704	1.044	
6:35:05.610	9724.71	-13.66	-29.89	7	33.3049970	-104.5146960	127.142	226.704	1.044	
6:35:05.748	9681.73	-14.66	-29.47	7	33.3049160	-104.5147980	127.142	226.704	1.044	
6:35:05.886	9638.57	-15.83	-29.04	7	33.3048340	-104.5149010	127.818	226.587	1.281	
6:35:06.024	9638.57	-15.83	-29.04	7	33.3048340	-104.5149010	127.818	226.587	1.281	
6:35:06.161	9595.40	-16.87	-28.52	7	33.3047530	-104.5150030	128.147	226.539	1.557	
6:35:06.299	9551.96	-17.88	-27.93	7	33.3046700	-104.5151060	128.460	226.520	1.744	

**Processed DGPS data output  
Table 1**

**CONCLUSIONS**

The major ongoing investigation involves the process of merging post-processed differential GPS data with aircraft processed data. The ability to obtain high output rate and high accuracy solutions is the ultimate goal for the differential GPS system. Bombardier Flight Test Center is currently coordinating with airworthiness authorities regarding the use of differential GPS airfield performance data for certification testing reports. Bombardier Flight Test Center is currently looking at all the possible scenarios for the use of the differential GPS system. Due to the ease in data acquisition, recording and processing, the differential GPS system has proven it will provide the most accurate and time-saving solution for our test center requirements.

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## NOMENCLATURE

ARINC	Aeronautical Radio Incorporated standard
GPS	Global Positioning System
IRIG-B	Inter-Range Instrumentation Group standard
RTCM	Radio Technical Commission for Maritime Services
UHF	Ultra High Frequency
VMCG	Minimum Control Ground Speed

## AUTHOR BIOGRAPHY

Albert Pedroza graduated from California State Polytechnic University, Pomona in 1988 with a Bachelor of Science degree in Aerospace Engineering. Albert worked as an Engineer for McDonnell Douglas in Long Beach, California, from 1988 through 1996, on the MD-11 and C-17 Flight Test departments prior to transferring to his current position as Senior Engineer at the Bombardier Flight Test Center in Wichita, Kansas. The Bombardier Flight Test Center is responsible for the certification and on-going flight testing of all Bombardier Corporation aircraft (Canadair, de Havilland and Learjet).

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