A Differential Global Positioning System for Determining Time Space Position Information in Support of Aircraft Noise Certification

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BIOGRAPHY

Mr. Fleming and Mr. Roof of the John A. Volpe National Transportation Systems Center's (Volpe) Safety and Environmental Technology Division work primarily on national and international transportation-related noise and emission issues. Mr. Fleming oversees all transportation noise and emissions work within the division. Mr. Roof's work includes measurement, modeling and analysis of transportation noise. Their work often includes flight tests related to noise certification. Mr. Ruggiero of Volpe's Airport Surface Division, Mr. Geyer of Volpe's Surveillance and Sensors Division and Mr. Kim of Volpe's Safety and Environmental Technology Division were instrumental in the design and implementation of the hardware and software system, including graphical user interface (GUI) described herein. Mr. Connor and Mr. Skalecky, of the Federal Aviation Administration's Office of Environment and Energy, oversee the technical and regulatory aspects of aircraft noise certification in the U.S.

ABSTRACT

Federal Aviation Regulation (FAR) Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification," requires that measured aircraft noise certification data be corrected to a nominal reference-day condition. This correction process which can be quite rigorous is typically done for sequential ½-second acoustic data records measured for a given aircraft noise certification event. Consequently, the process requires precise time-space-position-information (TSPI) for each acoustic data record within each event. Traditionally, noise certification applicants have used optical positioning systems such as still cameras and video cameras, radar, or in rare instances, laser tracking systems. The accuracy of these systems is typically on the order of 10 to 20 ft., although the accuracy of laser tracking systems can be much better. In addition, many of these traditional systems only provide TSPI data over a relatively limited time interval in the vicinity of aircraft overhead, thus requiring extrapolation of TSPI data to sufficiently define aircraft position for each acoustic data record within each certification event. With the advent of differentially corrected global positioning systems (dGPS), the accuracy and limitations associated with traditional TSPI systems are easily overcome. This paper describes a dGPS TSPI system developed by the U.S. Department of Transportation (DOT) Volpe Center Acoustics Facility (Volpe). The paper includes descriptions of both the hardware and software components of the system. It also details the static and dynamic system performance.

1. INTRODUCTION

Federal Aviation Regulation (FAR) Part 36, " Noise Standards: Aircraft Type and Airworthiness Certification",[1] requires that measured aircraft noise certification data be corrected to a nominal reference-day condition. This correction process, which can be quite rigorous, is typically done for sequential ½-second acoustic data records measured for a given aircraft noise certification event. Consequently, the process requires precise time-space-position-information (TSPI) for each acoustic data record within each event. Traditionally, noise certification applicants have used optical positioning systems, such as still cameras or video cameras, radar, or in rare instances laser tracking systems. The associated accuracy of these systems is typically on the order of 10 to 20 ft., although the accuracy of laser tracking systems can be much better. In addition, many of these traditional systems only provide TSPI data over a relatively limited time interval in the vicinity of aircraft overhead, thus requiring extrapolation of TSPI data to sufficiently define aircraft position for each acoustic data record within each certification event. With the advent of differentially corrected global positioning systems (dGPS), the accuracy and systematic limitations associated with traditional TSPI systems are easily overcome.

The genesis of Global Positioning System (GPS) technology in the United States dates back to the 1970s. GPS was designed and developed by the U.S. Department of Defense (DoD) as a worldwide navigation and positioning resource for both military and civilian use. The nominal constellation consists of 24 satellites (28 were operational on March 7, 2000) in medium earth orbits (altitude approximately 11,000 miles). Satellites repeat their ground tracks with a period of approximately 23 hours and 56 minutes. The system segment consists of a master control station in Colorado Springs, Colorado, five monitoring stations and three data up-loading stations. Because of the national security issues potentially associated with a high-precision, universally-available tracking system, DoD initially introduced random error into the GPS signal. This error, referred to as selective availability (SA), purposely degraded the performance of the GPS system such that the specified position accuracy was on the order of 328 ft. 95 percent of the time. Although acceptable for many applications (e.g., hiking, leisure boating, and some land-based navigation applications), an accuracy of 300 ft. is not acceptable for determining TSPI during aircraft noise certification. It should be noted that since the development of the system described herein began, DoD has eliminated the presence of SA. Although this has resulted in a substantial improvement in the accuracy of stand-alone GPS-based TSPI data (from approximately 300 ft. to only about 100 ft. after the elimination of SA), it still does not provide for sufficient accuracy with regard to aircraft noise certification tests.

However, by introducing a second, localized, fixed-position GPS receiver, which is properly set-up to communicate with a roving GPS receiver, a substantial improvement in accuracy can be achieved. Such an arrangement is referred to as a differential GPS (dGPS) system. The fixed-position GPS receiver, often referred to as the base station in a dGPS configuration, effectively eliminates the error associated with a stand-alone GPS receiver. The introduction of a properly configured differential base station into a conventional GPS TSPI system can result in a position accuracy of 5 ft. or better in some instances. Such high precision TSPI information is extremely desirable for use in aircraft noise certification tests.

In support of the Federal Aviation Administration's (FAA's) Office of Environment and Energy (AEE), the Acoustics Facility at the United States Department of Transportation (DOT) John A. Volpe National Transportation Systems Center (Volpe) has developed a turn-key, fully integrated, high-precision TSPI system for use in FAR 36-type aircraft noise certification tests. This system, based on dGPS technology, can be used for determination of aircraft position during dynamic flight conditions, and can be used to accurately survey static test positions critical to aircraft noise certification tests, as well as for other tests. This paper describes the dGPS TSPI system developed by Volpe. It includes a description of both the hardware and software components of the system. It also details the static and dynamic performance of the system.

2. SYSTEM DESCRIPTION

The dGPS TSPI system described herein is designed around two single-frequency (commonly referred to as L1) NovAtel Model RT20E GPS receivers and two GLB Model SNTR 150 transceivers (radio transmitter / receivers) which facilitate communication between the two GPS receivers. A detailed discussion of single and dual frequency GPS receivers can be found in Reference 2 and is therefore not presented here. The two 25-Watt GLB radio transceivers are tuned to a frequency of 136.325 MHz.

An integral component to the dGPS TSPI system is the graphical user interface (GUI) and supporting software which is tailored for use during aircraft noise certification tests. The following two sections individually describe the hardware and software system in detail. For a more detailed discussion of the system's basic operation, readers are directed to Reference 3.

2.1 SYSTEM HARDWARE

Figure 1 presents the components and related interconnections which constitute the Volpe dGPS TSPI hardware system as they would be arranged for final deployment (i.e., for collection of real-time TSPI data).

The system is basically designed around two individual GPS receivers which are linked by a dedicated pair of radio transceivers. One GPS receiver and radio transceiver combination comprise the base station

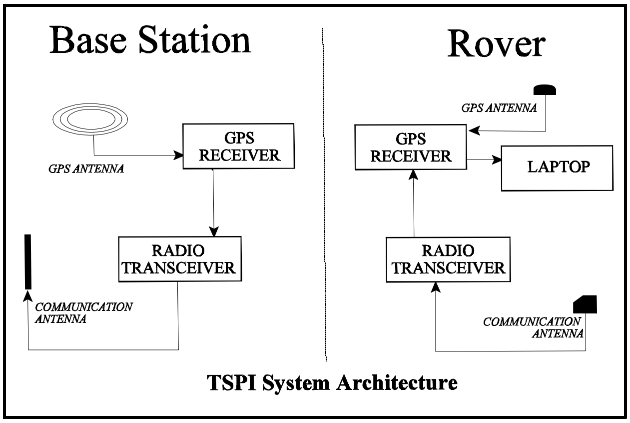

Figure 1: Block Diagram of System Hardware

which transmits differential corrections. The other GPS receiver and radio transceiver combination, referred to as the rover, is typically secured inside an aircraft or at a land-survey point, and is responsible for determining the precise TSPI data by applying the differential corrections transmitted from the base station to its own TSPI data.

Other integral components of the hardware system include two GPS antennae, two communication antennae, and an IBM Thinkpad Model 770 laptop which is used for system initialization, real-time position display and data storage. The base station GPS receiver is connected to a NovAtel Model GPS-503 L1/L2 antenna with a choke ring adapter. The use of a choke ring adapter on the base station GPS antenna is necessary to help minimize system inaccuracies associated with multipath effects, which are discussed in Section 2.2.2. The rover GPS receiver is connected to either a NovAtel Model GPS-501 L1 antenna with GPS-A031choke ring (in land-survey mode); or a NovAtel Model GPS-511 L1 or GPS-512 L1/L2 antenna (in aircraft mode). Because of the dynamic nature of the rover, it is assumed that any associated multipath will be high-frequency in nature (characteristic times on the order of seconds, versus a few minutes for base station multipath). Consequently, multipath at the rover quickly averages to almost zero and can be neglected; therefore, a choke ring adapter is not utilized on the rover GPS antenna when installed on aircraft. The base station communication antenna is an Antenex FG1360 while the rover system utilizes either a Dorne and Margolin (D&M) C63-1/A or C63-2 antenna. Both D&M antennae are designed for installation on aircraft. However, the C63-2, essentially a "bent" version of the C63-1/A, allows for installation on smaller aircraft with less ground clearance.

Although the system's current GPS receivers are single frequency, several of the antennae currently utilized are dual frequency. This will allow for easy migration to a true dual frequency system in the future. The transition to a true dual-frequency system, as would be possible with the integration of NovAtel Model RT-2 receivers, would result in a more robust system with some resultant improvement in position accuracy.

2.2 SYSTEM SOFTWARE

2.2.1 FUNCTIONALITY

Figure 2 presents the main screen of the Volpe-developed system software, entitled *TSPI* (current Version 1.20, dated 7/7/2000).

Figure 2: TSPI Software Main Screen

During field data collection, *TSPI* performs five primary functions. The purpose of these functions is described below:

Base Station Multipath Test

The purpose of a base station multipath test is to establish whether multipath affects reception of GPS satellite signals at the test site. It is important to perform this test during the hours of expected use of the TSPI system (i.e., typically early morning hours for most aircraft noise certification flight tests). A dGPS TSPI system's accuracy can, under certain circumstances, be greatly compromised by the presence of multipath at the base station. Specifically, a GPS antenna may receive both a direct signal from a given GPS satellite as well as a reflected signal (or several reflected signals) which can compromise the signal and possibly cause inaccurate TSPI data. Multipath issues are discussed in further detail in Section 2.2.2. As stated previously, it is assumed that multipath is not an issue for the rover system. The multipath test in *TSPI* is currently hardwired to operate over a 24-hour period, but it need not be conducted for 24 hours if a specific test period can be identified. It is sufficient to assess multipath for the anticipated test period time of day with a safety factor of about one hour at both the beginning and end of the anticipated test period. To help further guard against multipath, *TSPI* rejects all satellite signals at the base station below an elevation angle of 10 degrees. Signals from these low-elevation satellites are more susceptible to larger multipath errors as compared with signals from overhead satellites.

Base Station Position Averaging
The purpose of base station position averaging, in lieu of a known, surveyed site marker, is to accurately determine the absolute location of the base station. This step in the field data collection may be abbreviated if a simple, site-relative coordinate system is all that is required. In other words, if absolute latitude and longitude position information is not needed, the full base station position averaging is not necessary. Simply initializing the system with an approximate position read from a map or a hand-held GPS receiver is sufficient. If performed, the base station position averaging should be conducted over an entire satellite orbit cycle, i.e., effectively 24 hours. If the site-relative approach is all that is necessary, base station position averaging can of course be performed over a shorter time period to obtain an approximate position.

Deploying the Base Station
The base station is deployed to transmit differential corrections to the rover, typically installed on an aircraft for a flight test. Deploying the base station is as simple as entering a latitude, longitude and altitude into the base station GPS receiver and initializing it to transmit differential corrections. Precise position information resulting from the base station averaging process can be used, or an approximate location can be entered if an absolute coordinate system is not required.

Defining the Coordinate System
The local coordinate system is defined by separately positioning and collecting data with the rover at two points which define the X axis, one being the coordinate system's origin.

Deploying the Rover (TSPI Data Collection)
The rover is deployed at positions for which TSPI data are desired. This may include aircraft position data or land-based survey data. Figure 3 presents the software window which appears during typical TSPI data collection. In addition to altitude, latitude and longitude, the display includes real-time X, Y and Z position information relative to the local coordinate system. A fairly detailed set of system diagnostics are also presented. These include RT20 solution status (see Section 3), number of satellites being tracked and standard deviations for all position information.

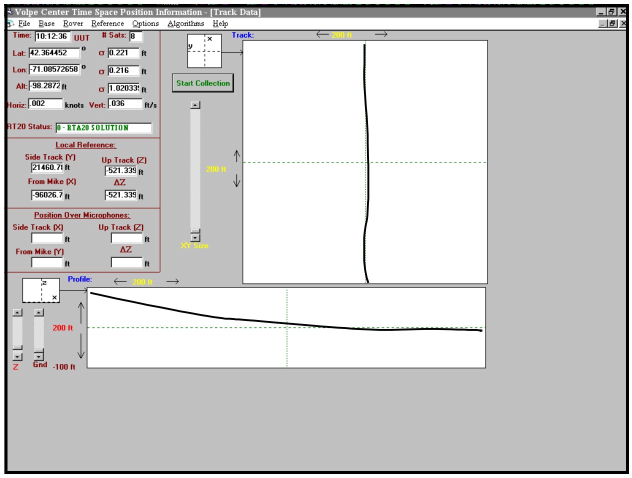

Figure 3: Example Software Display During Data Collection

In addition to the options pertaining to field data acquisition, the software also includes a diagnostic tool for converting absolute latitude and longitude data into local X-Y data. After entering the latitude, longitude and altitude data for the origin of a given coordinate system (X=0, Y=0, Z=0) and a second point, the X, Y and Z values of the second point are computed and displayed along with pertinent diagnostic information.

It is anticipated that this system will be used at various locations throughout the U.S., both in Volpe-led tests as well as in joint test programs with other organizations which may follow a different field measurement protocol as compared with that of Volpe. Consequently, system time base synchronization is deemed critical. The dGPS TSPI system allows data to be time stamped in various ways including GPS time (with or without a local offset) or universal coordinated time (UTC) either with or without the local time offset. In addition to the local time zone offset capability, the GPS versus UTC time switch allows the software to account for the difference in handling of leap seconds between the two time bases (currently GPS time is ahead of UTC by approximately 14 seconds). This is crucial because an error in timing of this magnitude may effectively render any associated TSPI data useless.

2.2.2 OUTPUT DATA FILES AND MULTIPATH ANALYSIS
During data collection, *TSPI* stores the raw data and any computed data in a set of ASCII-formatted files. Separate files are created for base station multipath tests, base station position averaging, defining the coordinate system, and data collection (both position and velocity).

To assist in data management and to avoid an inadvertent deletion of good data, every filename includes the date when it was collected and each of the five file-types maintains a unique prefix. Also, every file has a numeric extension which *TSPI* automatically increments each time data collection is initiated.

The multipath data base files contain all of the data necessary to determine if the test site is susceptible to multipath at specific times-of-day. For reasons discussed in Section 2.1, it is assumed that multipath at the rover may be neglected.

There are two general ways by which a system's multipath error may be minimized: instrumentation and site selection. On the instrumentation side, there are three specific options. First, incorporation of a device such as a choke ring adapter as part of the base station antenna (the GPS-503 in the Volpe system utilizes such a device) greatly minimizes the reception of satellite signals reflecting off objects (e.g., the ground) below the plane of the antenna. Second, an elevation angle cutoff algorithm may be implemented in conjunction with the GPS receiver such that only signals above that angle with respect to the horizon will be processed (a 10 degree cutoff angle is utilized in TSPI). Finally, dual-frequency receivers and antennae (commonly referred to as L1/L2) are available which effectively eliminate multipath. Choosing the proper location of a base station GPS receiver antenna is also important for mitigating the effects of multipath. Ideally, the antenna should have a clear view of the sky down to the horizon in all directions. There should be no large, reflective objects (i.e., buildings, bunkers, cars, etc.) within 500 to 1000 ft. of the antenna. In lieu of a choke ring adapter, or a similar device to minimize ground reflection multipath, the antenna should be placed as close to ground level as possible.

Although no universally accepted way of measuring/ calculating multipath exists, there is one relatively common method for determining whether multipath error is potentially a problem at a particular site for a given time period during the day[4]. After multipath data is collected at a given site, it must be analyzed on a satellite-by-satellite basis. This analysis was purposely considered during the development of *TSPI*. The *TSPI* software first saves individual data files for each satellite tracked during the multipath test. The data included in the files allow for relatively simple analysis methods to determine if multipath is of concern at a given test site.

One analysis method is to plot the difference "Pseudo Range minus Carrier Range" versus time for the time period of interest, (i.e., the anticipated test period). These two parameters are available directly in the multipath output files. An example of this analysis over a relatively short time period is shown in Figure 4. In general, the plot will appear as a slow, time-varying curve with a higher frequency "noise" component superimposed on that curve. A multipath error will likely be represented by a rise and fall (or "scalloping") of the lower-frequency curve, inconsistent with the remainder of the curve.

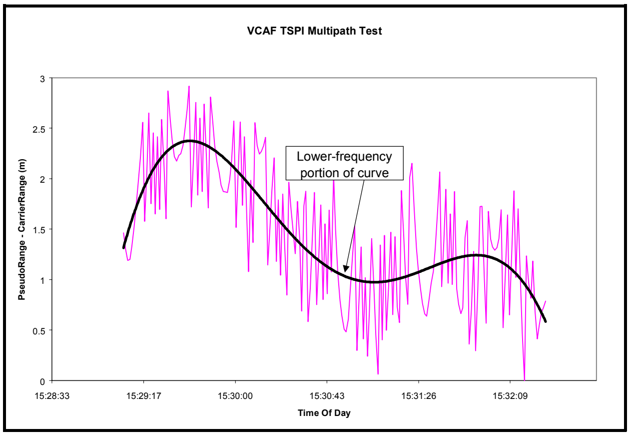

Figure 4: Example Multipath Analysis #1

Analysis of multipath can also be performed by examining the associated signal-to-noise ratio (carrier strength over wideband noise spectral density, C/No, measured in units of dB-Hz) as a function of elevation angle for each satellite and time. These parameters are also available in the multipath output file. A noticeable scalloping effect coinciding with a sharp drop in C/No is an indication of multipath. Figure 5 presents an example of this type of analysis. Utilizing the plots for both of these relationships, one can determine what periods of the day the system may be vulnerable to multipath. This type of analysis would be required for all satellites tracked during the hours of expected use of the system. The base station multipath output files provide all the data necessary to perform a complete system multipath test.

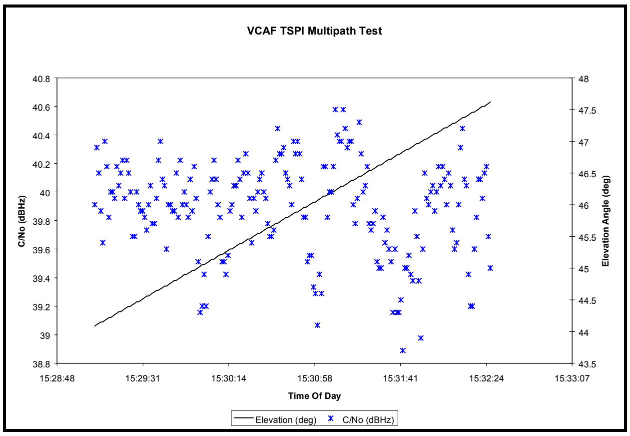

Figure 5: Example Multipath Analysis #2

In addition to the multipath data, *TSPI* saves all relevant information to ASCII text files. Survey base data files contain data pertaining to the absolute position of the dGPS base station. Survey point data files contain data pertaining to the absolute position of the points surveyed to define a local coordinate system. Track position data files contain data collected during: (1) surveying of positions after a local coordinate system is established, and (2) flight tests.

3. SYSTEM PERFORMANCE FLIGHT TESTS

When implemented properly into a differentially-based dGPS system, the NovAtel Model RT-20 receiver has manufacturer-specified accuracy as shown in Table 1. The RT20 solution status allows the TSPI user to know in real-time the expected system accuracy. For collection of static survey data, the position standard deviation data is helpful in determining the stability of the position information.

Table 1: Manufacturer Specified RT-20 Accuracy

RT20 Solution Status	System Accuracy
0	20 cm
1	30 cm
2	variable
8	100 m (No Differential)

The RT-20 solution status shown in the table is a data quality indicator which is saved on a record-by-record basis for all data collected by *TSPI*. If the RT-20 is receiving differential corrections, the solution status should converge to 2, 1, and finally to 0 given optimum conditions. If the system does not converge to either a 0 or 1, experience has shown that there is a functional problem with the system. Any TSPI data which are collected under a solution status other than 0 or 1 are considered "bad"as well as any associated data events.

With the possible exception of a laser tracking system, no TSPI system is known to exist which consistently provides greater theoretical accuracy than a differentially-based GPS. (Dual frequency dGPS systems using full resolution of carrier-phase ambiguities can achieve accuracies of a few centimeters. Dual-frequency was not initially selected for this application due to the significantly higher cost involved and lack of robustness in an aircraft environment.) As such, it was not plausible to independently verify the manufacturer-specified accuracy of the system components. However, it was possible to examine the system from the standpoint of reasonableness. It was felt that as long as dGPS-based field-measurement data compared reasonably well with a known, less accurate system, it was likely that the manufacturer's specifications were being met. Further, recent third-party tests conducted with a similar system and compared with a laser tracker indicate the RT-20 differential system to be more accurate than a laser tracker[5]. Consequently, Volpe conducted several field tests to examine the reasonableness of the implemented system. The results of those tests are described below.

3.1 FITCHBURG MUNICIPAL AIRPORT

On July 15, 1999, Volpe conducted a flight test at Fitchburg Municipal Airport in Fitchburg, MA, to examine the performance of the dGPS TSPI system. The objective of the test was to determine the dynamic performance of the system (specifically, accuracy and reliability) installed on an aircraft operating under conditions considered typical of those encountered in aircraft noise certification. Version 1.10 of the TSPI software (dated 5/29/99) was used for the flight test.

Fitchburg Municipal Airport is located about 50 miles west of Boston, MA. For the tests, the differential base station was located at the airport control tower (currently unused). The electronics were housed within the top floor control room, while the GPS and communication antennae were placed on top of the building's roof.

The aircraft used for the test was a Piper Aztec F (PA-23-250, tail number N327DR). The Piper Aztec is a twin-engine, 6-passenger craft, about 31 ft. nose-to-tail. The electronics for the rover system were secured in the middle row of seats on the aircraft. The GPS antenna was mounted on top of the nose of the aircraft approximately 3.5 ft. from the tip of the nose, and the communication antenna was mounted on the belly of the aircraft approximately 10 ft. from the end of the tail.

In addition to the dGPS, a digital video camera tracking system (Video Time-Space-Position-Information System: VTSPI) was used to track the aircraft. Two Canon Optura digital video cameras were placed about 400 ft. southwest of Runway 32. Data taken from the two cameras were used to verify aircraft position using a traditional triangulation technique. The data collected by the VTSPI system were used to gauge the accuracy of the dGPS system. More detail on the VTSPI system can be found in its associated Volpe User's Guide.

A local coordinate system was set up for the flight test. The origin was located approximately 560 ft. south-west of Runway 32. The x-axis of the coordinate system was parallel to runway 14/32. Figure 6 presents a plan view of the measurement site with the coordinate system superimposed.

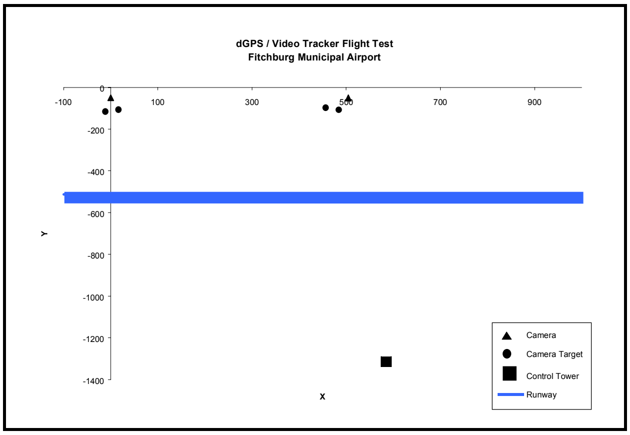

Figure 6: Plan View of Fitchburg Measurement Site

During the flight test, level flyovers (LFOs), takeoffs and approaches were flown. In addition, system range tests were performed along with antenna shielding tests where the aircraft pilot made "hard" and "soft" banks to assess the performance of the communication data link providing differential corrections. Two level flyovers were each flown at 100 ft. increments between 100 ft. and 400 ft. along with four takeoffs (2 actual and 2 "touch and go") as well as two approaches and two system range tests in opposite compass directions.

Results of the test indicated that the system proved to be extremely reliable. In general, an RT20 status of "0" was maintained throughout the tests. The RT20 status did briefly switch to "1" when the aircraft banked to return to the test area between events, and at large distances from the airport during the system range tests (between 8.5 and 14 miles). For the periods when the RT20 status toggled to 1 due to the aircraft banking, it generally returned to 0 again within 10 to 30 seconds. However, when the status of 1 was due to the large distance from the base station, it took several minutes to return to 0.

The system also proved to be very accurate, as determined from comparisons with the video-based tracking system. There appeared to be no data anomalies in the dGPS data. Further, when the TSPI data are compared with the VTSPI data, very good agreement is seen as presented in Figure 7 for a typical single event. As can be seen in the figure, the difference in X-Y-Z position (TSPI - VTSPI) is less than 4.5 ft. throughout the duration of the event. Figure 8 presents XY distance and RT20 solution status versus time for the first of the two system range tests.

	TSPI Data			VTSPI Data			TSPI - VTSPI		
T.O.D.	X (ft)	Y (ft)	Z (ft)	X (ft)	Y (ft)	Z (ft)	△X (ft)	△Y (ft)	△Z (ft)
13:01:56.5	-231.1	-522.0	138.8						
13:01.57.0	-123.0	-523.3	135.8	-123.9	-524.6	139.6	0.9	1.3	-3.8
13:01:57.5	-15.0	-524.2	133.4						
13:01.58.0	92.8	-524.9	131.6	93.3	-524.8	135.3	-0.5	-0.1	-3.6
13:01:58.5	200.5	-525.4	131.1						
13:01.59.0	307.9	-525.7	131.8	310.5	-525.9	133.4	-2.6	0.1	-1.6
13:01:59.5	414.8	-526.0	133.5						
13:02.00.0	521.2	-526.3	136.2	525.6	-526.4	135.6	-4.4	0.1	0.7
13:02.00.5	627.2	-526.6	140.3						
13:02.01.0	732.7	-526.7	144.8	733.8	-528.9	144.9	-1.1	2.1	-0.1
13:02.01.5	837.7	-527.0	148.8						

Figure 7: Comparison of TSPI and VTSPI Data

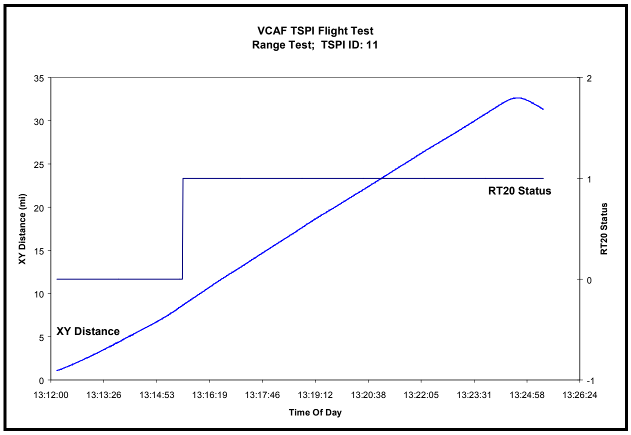

Figure 8: RT-20 Solution Status as a Function of Time

3.2 VALLE AIRPORT, ARIZONA

On September 15, 1999, Volpe conducted a flight test at Valle Airport near Grand Canyon, AZ, to further examine the performance of the dGPS TSPI system. The primary objective of the test was to examine the stability of the system with a particular goal of determining the time required to collect accurate survey data at a given location. A secondary objective was to conduct a test of dynamic system performance as a follow-up test to the Fitchburg study. Version 1.13 of the TSPI software (dated 8/22/99) was used for the study.

The primary objective was attained by collecting data with the rover in a fixed survey position for approximately fifteen minutes. As outlined in Figures 9 through 11, the latitude and longitude stabilized within approximately six to nine minutes. Latitude and longitude stabilization appears to correlate with associated standard deviations of between 0.07 and 0.08 ft. The altitude data was not stabilized after the full 15 minutes, but appeared to be in the process of converging. It should be noted that the RT20 solution status equal to 0 for the duration of the fifteen minute period which, per the manufacturer's specifications, indicates better than 20 cm accuracy. GPS altitude accuracy is usually poorer than horizontal accuracy (average error is 1.6 times larger) due to the system's basic technique of measuring range to satellites. There is more "sky" (solid angular area), and thus on-average more satellites, near the horizon than overhead. The greater density of measurements results in greater accuracy.

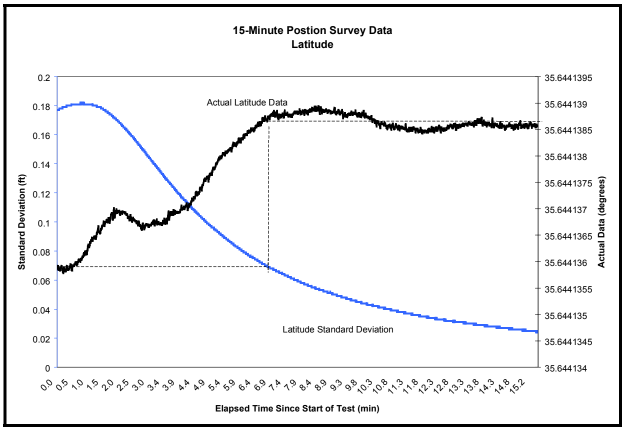

Figure 9: Latitudinal System Stability

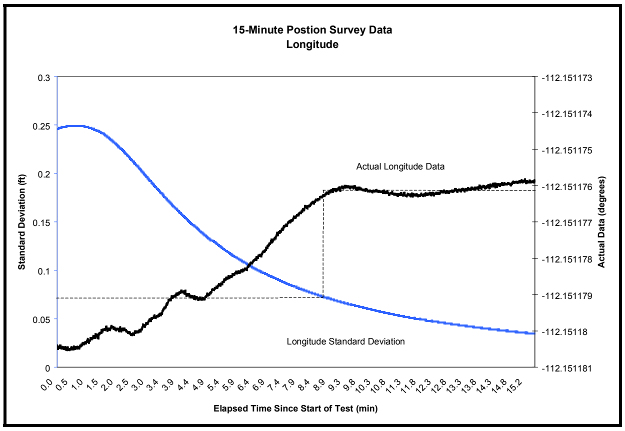

Figure 10: Longitudinal System Stability

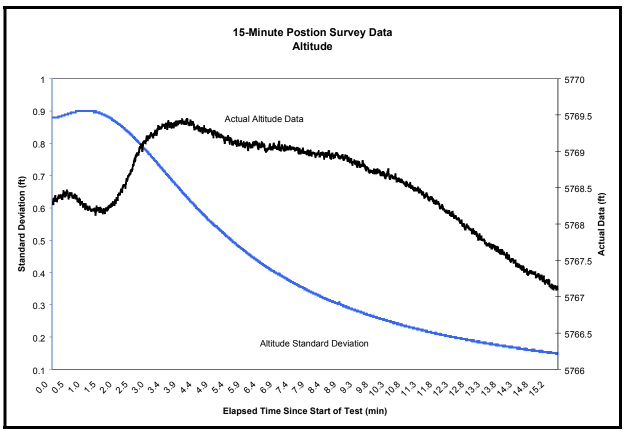

Figure 11: Altitudinal System Stability

Inspection of these data indicates no anomalies and very good correlation with observations made visually on-site, thus satisfying the second objective. Additionally, tracking data were also collected during this flight using the VTSPI system. If deemed necessary, further comparison of these TSPI and VTSPI data may be undertaken.

3.3 WICHITA, KANSAS

During October 12 through 14, 1999, Volpe participated in a flight test with Cessna Aircraft near Wichita, KS. During this flight test, Volpe collected both TSPI and VTSPI data. Additionally, Cessna collected single-point altitude data at closest point of approach (CPA) using an FAA-approved photo-scale technique. Comparing the dGPS to the Cessna system, differences in altitude were typically less than or equal to 5 ft. and always less than or equal to 13 ft. For the profiles flown, these differences represent approximately 1 to 2 percent error in altitude (i.e., excellent correlation).

4. SUMMARY

The Volpe Center Acoustics Facility, in support of FAA/AEE, has developed a high-precision time-space-position-information (TSPI) system based on dGPS technology. The system includes a complete hardware implementation as well as a comprehensive, user-friendly software to ease system use. Also developed to complement the system is a complete User's Guide. The system has been shown to be at least as accurate as modern optical tracking techniques -- although it is likely the system is far more accurate in comparison if measurement resolution of the optical system allowed for such comparison. The system has also been shown to be quite reliable, operating over distances between base station and rover of up to 15 miles in an aircraft application. The system has been successfully used for conducting highly accurate land surveys. It is anticipated that it could be easily adapted to most situations where high precision position information is required.

5. REFERENCES

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