Use of Leica Differential Global Positioning System (DGPS) as an Aircraft Precision Tracker

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16. Abstract

The Leica (formerly Magnavox) Differential Global Positioning System (DGPS) is a two-receiver GPS system which permits the collection of highly accurate positions of Federal Aviation Administration (FAA) aircraft. While the William J. Hughes Technical Center has excellent aircraft tracking assets at its Atlantic City International Airport (ACY) location, obtaining tracking services at other locations has proven costly and problematic.

This report details the results of flight testing performed at the William J. Hughes Technical Center to demonstrate that the Leica DGPS provides a flexible and reasonably accurate replacement for other forms of aircraft tracking. Aircraft equipped with the Leica DPGS system flew a series of approaches to ACY and data collected from the Leica DGPS system was compared to a highly accurate GTE Precision Automated Tracking System (PATS) Laser Tracker. The Leica DPGS system was found accurate to better than 13 feet.

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EXECUTIVE SUMMARY

This report details a system which can save money and reduce delays during Federal Aviation Administration (FAA) flight testing. The Leica Differential Global Positioning System (DGPS) is a Commercial Off-the-Shelf (COTS) Global Positioning System (GPS) which permits the collection of highly accurate positions of FAA aircraft. The two-receiver GPS system and related post-processing software create once-per-second tracks of the aircraft's flight path. The system can be used worldwide, and is intended to support testing which occurs beyond the range of the FAA William J. Hughes Technical Center's existing tracking radar assets.

The Leica DGPS uses a GPS receiver on each aircraft under track and a GPS base station installed in the vicinity of the flight path. Data from each receiver is logged to a personal computer (PC). At the conclusion of testing, the data from each airborne receiver is postprocessed with data from the base station by the Leica NAVREF V1.10a postprocessing software package (NAVREF). The final output of NAVREF is a highly precise track of the aircraft's flight path. The system can track an unlimited number of aircraft, provided each is equipped with the proper GPS receiver.

The system was evaluated by conducting a series of approach flights to the Atlantic City International Airport (ACY). The aircraft was tracked by both the Leica DGPS system and the FAA Technical Center GTE Precision Automated Tracking System (PATS) laser tracking system. The Leica DGPS system was found to be accurate to better than 13 feet.

1. OBJECTIVES.

This report presents flight data which demonstrates the application of the Leica (formerly Magnavox) Differential Global Positioning System (DGPS) in the place of a precision tracking radar. This system can provide high accuracy tracking services in areas where tracking assets would be unavailable or prohibitively expensive.

2. BACKGROUND.

Precision tracking radars have been used to evaluate the performance of search radars for decades. A tracking radar typically is a radar which acquires and follows a single target. They can be cooperative or non-cooperative. In a non-cooperative system, pulses of radio frequency (RF) energy are reflected from a target to determine its range, azimuth, and elevation. In a cooperative system, equipment on the target is used to reflect or retransmit the energy back to the tracker. Cooperative trackers are generally more accurate than non-cooperative trackers because the track position is always relative to the same point on the target, while a non-cooperative tracker is subject to shifts in return amplitude across the target as the target aspect changes.

2.1 ATLANTIC CITY TRACKING RADARS.

The Federal Aviation Administration (FAA) William J. Hughes Technical Center, located at the Atlantic City International Airport (ACY) in New Jersey, has three cooperative tracking systems. Two are X-band transponder trackers and the third is a laser tracker. When testing must be conducted at locations other than Atlantic City, a portable X-band tracker is available that can be shipped to the test site. This is generally expensive and time consuming, and does not support testing involving multiple aircraft. In the past, it has been necessary to lease equipment for multiple aircraft tests.

The laser tracker, which was used for this evaluation is a GTE Precision Automated Tracking System (PATS) Laser Tracker. Its azimuth and elevation accuracy are +/- 20 ArcSeconds @ all ranges. Its range accuracy is:

+/- 1 foot for ranges < 5 nautical miles (nmi).
+/- 2 feet for 5 to 10 nmi.
+/- 5 feet for ranges at 25 nmi.

The PATS laser tracker is a monopulse-type tracking system. It uses quadrant detection from a (near) infrared (1.06 micrometer (μm)) frequency laser as a source. The azimuth and elevation encoders are 18 bits (just under 5 arcseconds/bit). The range resolution is 1 foot.

2.2 GLOBAL POSITION SYSTEM (GPS).

The GPS system consists of 24 satellites: 21 navigational satellites and 3 active spares orbiting the earth in 12-hour orbits. These satellites orbit the earth, covering the same ground track as the earth turns beneath them. They travel in six orbital planes (with nominally four satellites in each), equally spaced (60° apart), and inclined at about 55° with respect to the equatorial plane. This makes anywhere between five and eight satellites visible from any point on the earth.

The system is capable of 66-foot horizontal and 90-foot vertical accuracy, but this accuracy is limited by the Department of Defense (DOD), which controls the system. With a single GPS receiver, a user can obtain a position with 100 feet of horizontal accuracy and 450 feet vertical of accuracy. This additional error which is added by DOD is referred to as Selective Availability (SA).

There are additional potential sources of error, and their type and magnitude is detailed in table 2.2-1.

TABLE 2.2-1. GPS ERROR SOURCES

Source	Magnitude	Type
Selective Availability	300 feet	Bias error
Ephemeris Error	3 feet	Bias error
Satellite Clock Error	3 feet	Bias error
Propagation Delay Error (Ionospheric)	30 feet	Bias error
Receiver Noise Error	5 feet	Random error
Atmospheric Scattering (Tropospheric)	3 feet	Random error
Satellite Encoding Error	3 feet	Random error

The bias error components will be the same for two receivers in the same general geographic area (within 60 miles of each other), which are using the same group of satellites. This is the basis for DGPS. If one receiver is placed at a well surveyed location, the amount of these bias errors can be determined and used to remove the bias error from another receiver.

The random errors will vary between receivers using the same satellite sets, so the DGPS method will not reduce these errors. To further reduce the error, Carrier Phase Tracking can be employed. This involves using GPS receivers which are capable of detecting and recording the incoming phase of the two GPS carrier signals. If the receivers and satellites were to remain stationary with respect to each other, the distance between them would remain constant, and the incoming phases would remain constant. By tracking the change in carrier phase of the received signal from a satellite, a stationary receiver can determine the change in distance between the receiver and the satellite. For example, if the L1 (1575.42 megahertz (MHz)) signal is known to shift one full cycle, then the distance between the receiver and satellite has changed 7.5 inches (one wavelength). Theoretically, receivers that can track fractions of a cycle change could produce accuracies of fractions of an inch, but before that can be obtained, differences in the paths of the satellite signals through the Ionosphere become significant. Two receivers using this method for the same satellite set can produce accuracies of approximately 3 feet.

3. SYSTEM CONFIGURATION.

The Carrier Phase Tracking DGPS system under evaluation consists of a Leica Model MX9112 Differential Reference Station and a Leica Model MX9212 Differential Navigator. The Reference Station was connected to a personal computer (PC) and a GPS antenna, which is placed on a stand atop a fixed survey monument on the roof of the FAA Technical Center Hanger Facility at the Atlantic City International Airport. The Navigator was connected to a laptop PC and installed on an avionics shelf in the FAA's Convair 580, tail number N39. The Navigator was connected to a GPS antenna mounted on the upper fuselage centerline 256 inches aft of the aircraft's forward bulkhead. The aircraft has a laser tracker reflector installed on the lower fuselage centerline 4 inches aft of the forward bulkhead.

Raw data from the GPS receivers is logged to both PCs during the flights. After the flights, the raw data files are processed using Leica's NAVREF V1.10a DGPS Postprocessing software in two steps. In the first step, the NAVREF software uses the MX9112 data to create corrections. In the second step, the NAVREF software applies the correction to the corresponding report from the MX9212, and then uses the carrier phase information contained in both the MX9112 and MX9212 data to further refine the corrected position.

4. TEST METHOD.

A set of six approaches were flown while data was collected by the Laser Tracker, the Differential Reference Station on the Hanger and the Differential Navigator aboard N39. The approaches consisted of :

a. A standard Instrument Landing System (ILS) approach to ACY Runway (RW) 13.
b. An ILS approach to RW 13 flown 2 ILS dots left of center.
c. An ILS approach to RW 13 flown 2 ILS dots right of center.

d. An ILS approach to RW 13 flown in a zigzag pattern alternating between 2 ILS dots left and 2 ILS dots right.
e. An ILS approach to RW 13 flown 2 ILS dots high of glideslope
f. An ILS approach to RW 13 flown 2 ILS dots low of glideslope

As the aircraft approached the threshold of RW 13, the approach would be broken off, and the aircraft would circle back to the outer marker.

5. RESULTS.

Figures 5-1 through 5-4 detail the raw accuracy results just comparing the position reports of the Laser Tracker and the Leica System.

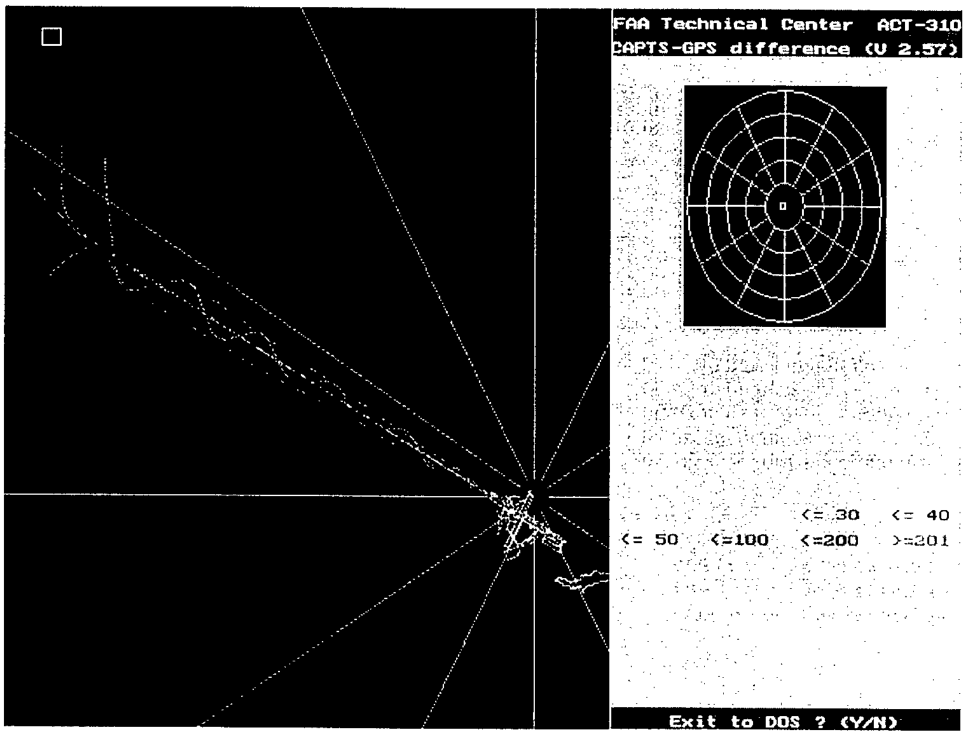

FIGURE 5-1. POST-CORRECTED DGPS POSITION, COLOR-CODED TO SHOW DISTANCE FROM LASER TRACKER POSITION

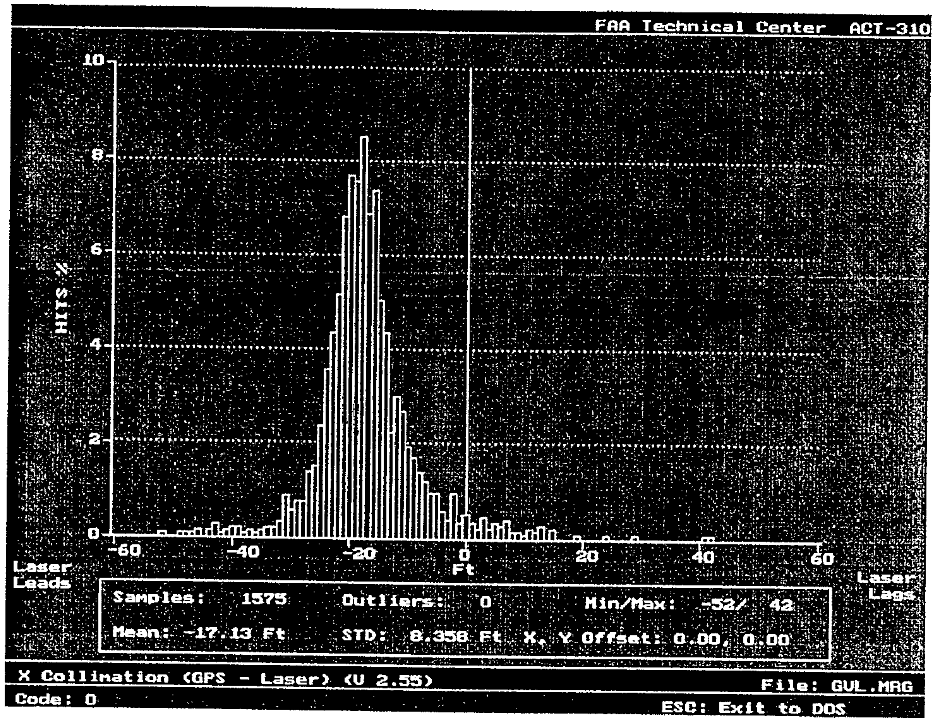

FIGURE 5-2. LASER VERSUS POST-CORRECTED DGPS, X-AXIS COLLIMINATION

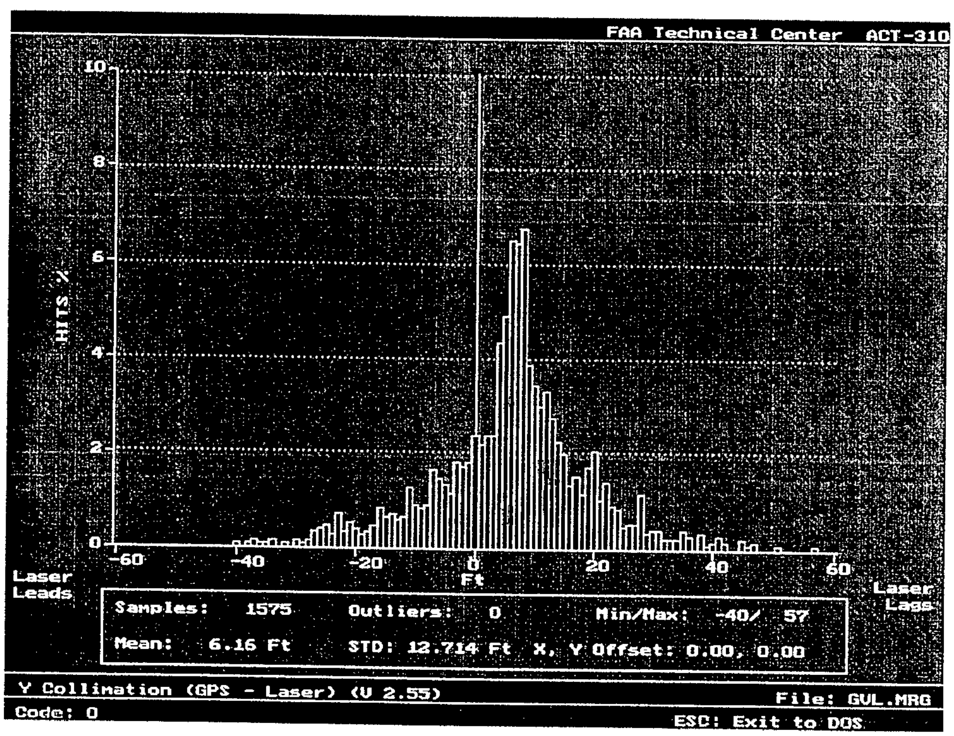

FIGURE 5-3. LASER VERSUS POST-CORRECTED DGPS, Y-AXIS COLLIMINATION

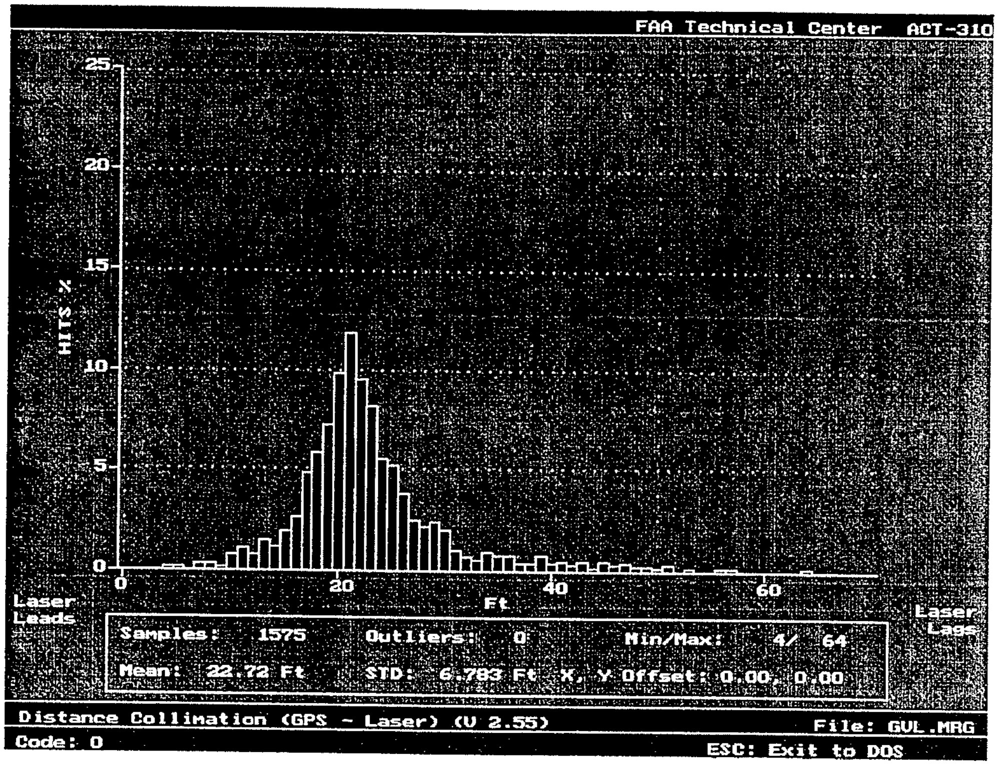

FIGURE 5-4. LASER VERSUS POST-CORRECTED DGPS, DISTANCE COLLIMINATION

Since the Laser Reflector and GPS antenna are not colocated on the aircraft, it is necessary to remove the bias caused by this separation. The GPS antenna was located 256 inches aft of the first bulkhead on top of the aircraft. The Laser Reflector was located 4 inches aft of the first bulkhead on the underside of the aircraft. The two antennas are vertically separated by 99.5 inches. The aircraft heading during the approaches was 116.0° true north, and the approaches were flown with a 3° nose down attitude. It is not possible to compensate for aircraft motion in each position report, as complete pitch, roll and yaw data could not be recorded. Of these three, yaw maneuvers have the greatest impact on XY separation, while pitch and roll cause very small shifts in the XY plane. The maneuvering can be considered negligible as the approaches were generally straight, and even the zigzag approach consisted of roll maneuvers which did not substantially separate Reflector and Antenna in the XY plane. Similarly, the 3° nose down pitch causes negligible shift in the XY plane and is disregarded here. As shown in figure 5-5, this would place the GPS antenna

sqrt(256**2+99.5**2) inches,

or 274.66 inches behind the Laser Reflector along the forward direction of motion. The X and Y components of the bias would be:

X = 274.66 inches * COS (116°-90°)

Y = 274.66 inches * SIN (116°-90°)

X =246.86 inches = 20.57 feet

Y = 120.40 inches = 10.03 feet

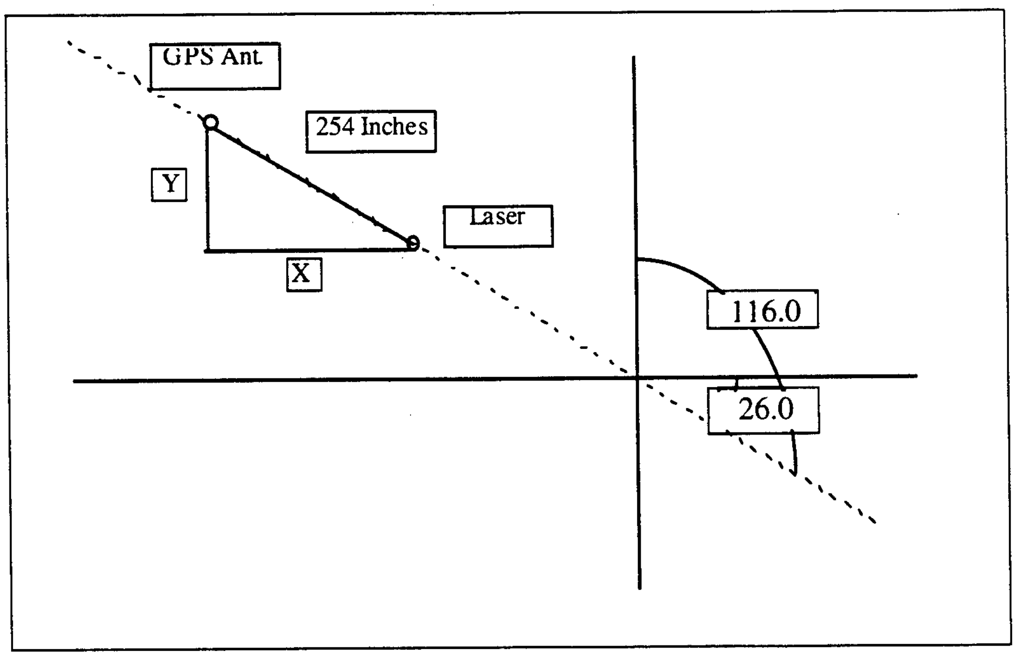

FIGURE 5-5. XY BIASES DUE TO SEPARATION OF LASER REFLECTOR AND GPS ANTENNA

Therefore to unbias the GPS reports, we must add 20.57 feet to each X position and subtract 10.03 feet from each Y position.

The data was adjusted to remove the bias and the results are detailed in figures 5-6 through 5-8.

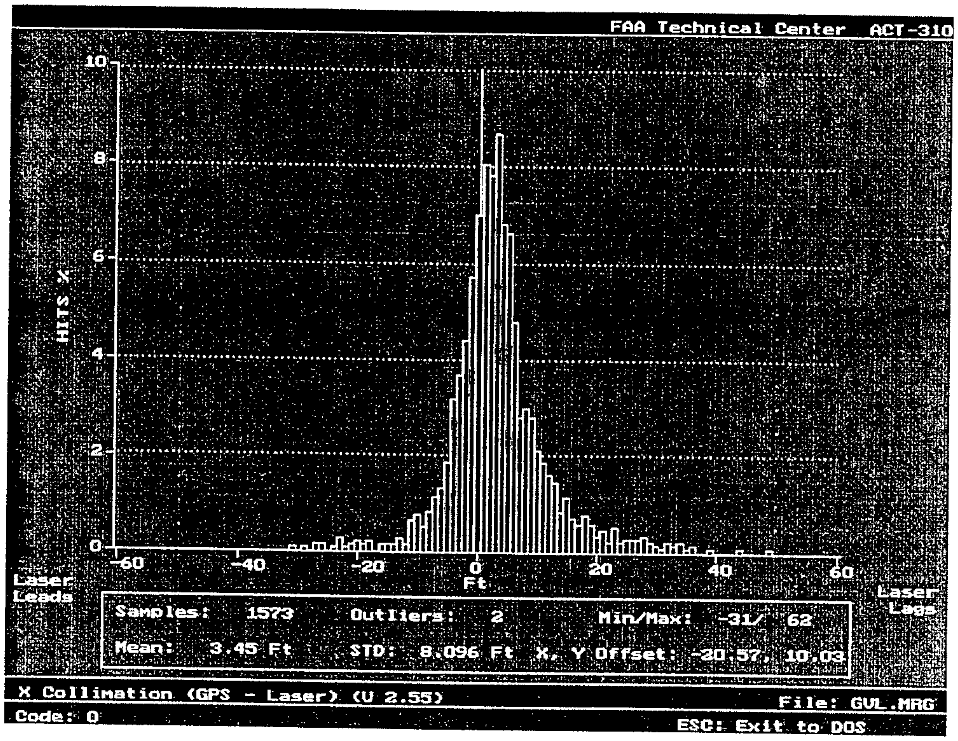

FIGURE 5-6. LASER VERSUS POST-CORRECTED DGPS, X-AXIS COLLIMATION ANTENNA POSITION BIAS REMOVED

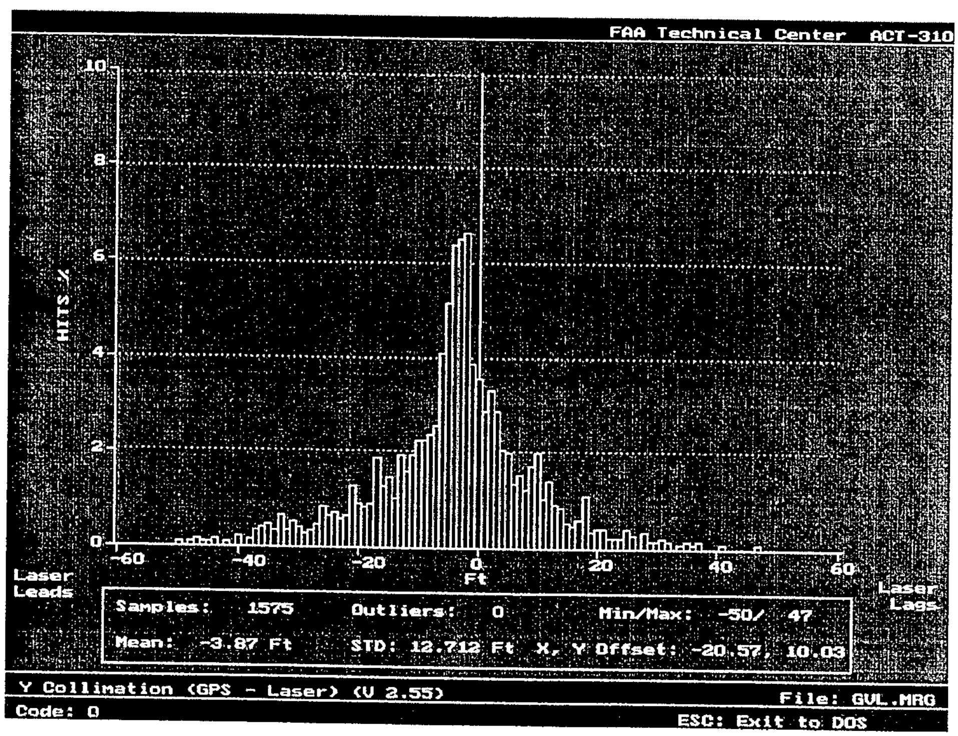

FIGURE 5-7. LASER VERSUS POST-CORRECTED DGPS, Y-AXIS COLLIMATION ANTENNA POSITION BIAS REMOVED

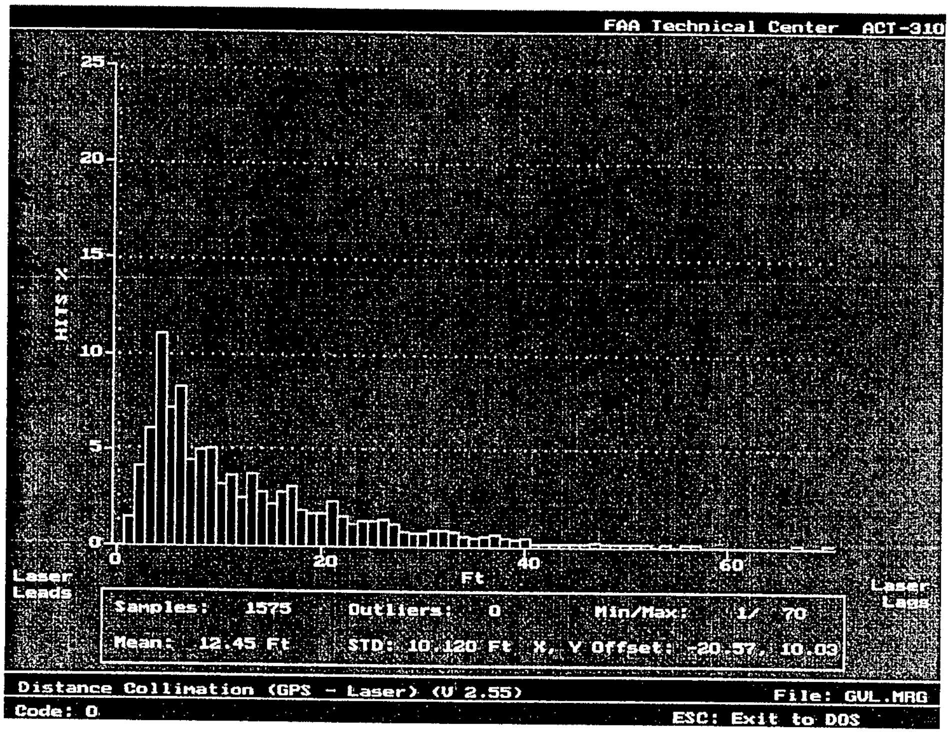

FIGURE 5-8. LASER VERSUS POST-CORRECTED DGPS, DISTANCE COLLIMATION ANTENNA POSITION BIAS REMOVED

6. CONCLUSIONS.

The Leica Differential Global Position System (DGPS) system demonstrated performance that makes it a good alternative to a conventional tracking system. It does not provide all of the accuracy of a Laser Tracker, but in any application where 13 feet of accuracy is sufficient, it can be superior. It can provide the ability to track any number of targets, provided each is properly equipped. It has greater range and is generally impervious to weather.

7. ACRONYMS AND ABBREVIATIONS.

ACY	Atlantic City International Airport
DGPS	Differential Global Positioning System
DOD	Department of Defense
DOT	Department of Transportation
FAA	Federal Aviation Administration
GPS	Global Positioning System
ILS	Instrument Landing System
MHz	megahertz
μm	micrometer
NAVREF	Leica NAVREF V1.10a Postprocessing software package
nmi	nautical mile
PATS	Precision Automated Tracking System
PC	personal computer
RF	radio frequency
RW	runway
SA	Selective Availability
US	United States