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FAA /WILCOX PRECISION APPROACH FLIGHT TEST

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EXECUTIVE SUMMARY

Recent technological advancements in Global Positioning System (GPS) receivers have resulted in an increased level of accuracy than previously attainable with commercially available receivers. Narrow correlator spacing techniques in conjunction with differential corrections demonstrated accuracies in these tests beyond that required for a Category I precision approach.

Wilcox uses a narrow correlator differential GPS (DGPS) receiver card mounted in a personal computer (PC). Features of the narrow correlator spacing technique are the drastic reduction of tracking errors in the presence of both multipath and noise [1].

Laser tracking provided truth data. Straight in "ILS look-alike" approaches were flown to runway 13 at Atlantic City International Airport. All of the approaches were completed during a four day period starting November 30,1992 and ending December 3,1992.

The table 1 below provides data for an estimate of the 95% error (|mean| + 2SD) of the sensor and total system errors. Note: all 95% error values given are the |mean| + 2SD(standard deviation) which is taken as a conservative estimate of the expected 95% probability of error. The VDOP for 35 approaches was less than or equal to 3 and HDOP was less than or equal to 2.3. When compared to the Federal Radionavigation Plan (FRP), the International Civil Aviation Organization (ICAO) Collision Risk Model (CRM), or the Satellite Operational Implementation Team (SOIT) Tunnel the flight test data is within the requirements for a precision approach down to the 200' decision height (DH) (Category I). The crosstrack sensor error of 1.03 m meets the FRP CAT I, II, and III requirements. Additionally, the vertical sensor accuracy of 2.4 m is well below the FRP requirement of 4.1 m for CAT I and comes close to the category II accuracy requirement of 1.7 m.

Table 1. Summary of Results for 35 Approaches

	HIGHEST ERROR OVER FINAL 2 NMI	ERROR AT 200' DH (0.5 NMI FROM RWY THR)	1991 FRP RQMTS. AT 200' DH	ICAO CRM RQMTS. AT 200' DH	SOIT TUNNEL RQMTS. AT 200' DH
Vertical Sensor Error (95%)	2.4 m	2.01 m	4.1 m		
Crosstrack Sensor Error (95%)	1.4 m	1.03 m	17.1 m		
Vertical FTE (95%)	14.6 m	7.2 m			
Crosstrack FTE (95%)	35.9 m	24.6 m			
Total System Vertical Error (95%)	15.5 m	9.08 m		11.6 m	9.75 m
Total System Crosstrack Error (95%)	36.0 m	24.0 m		32.8 m	33.52 m

1. INTRODUCTION.

The FAA Satellite Program Office invited Wilcox Electric to flight test a precision approach system they developed based on differential GPS (DGPS). Wilcox recently presented results of their flight test program at the Institute of Navigation (ION)-GPS 92' conference. Wilcox uses a state-of-the-art narrow spacing correlator Novatel GPS receiver card. The ability of the Novatel receiver to reduce multipath and make low noise measurements provides for accurate pseudo-range measurements of each satellite used in the position solution. Additionally, a Novatel card is used to determine the corrections for the differential GPS ground station.

This report covers the test configuration, the flight test, and provides complete results with a brief analysis. All of the approaches were completed during a four day period starting November 30,1992 and ending December 3,1992.

2. DESCRIPTION OF TEST.

2.1 TEST EQUIPMENT.

The test bed for flying the Novatel GPS receiver is a Wilcox owned Beech King Air 300. Wilcox uses a VHF data link transmitting at 136.2 MHz. Differential corrections are transmitted at a 1200 baud rate. All satellite differential corrections are updated approximately once each second, and the average age of the corrections when used are 2 seconds. Wilcox provides guidance commands to the course deviation indicator (CDI) at a 5 Hz rate. The guidance is angular and replicates what an Instrument Landing Sytem (ILS) would look like (i.e. +/- 0.7° vertical deviation = 150 mV and +/- 1.8° horizontal deviation = 150 mV).

The DGPS ground station uses a Novatel GPS receiver and transmits the corrections continuously with all satellites updated approximately every second. To help reduce multipath, the GPS antenna was placed an inch above a surveyed point on the ground in a clear area, approximately 2500 feet to the side of the runway midpoint.

2.2 FLIGHT SCENARIO.

All of the approaches were flown to runway 13 at the Atlantic City Intemation Airport. The King Air has a flight inspection rack in the cabin which allows the flight test engineers to monitor the guidance commands from the ILS and the GPS.

Typically the aircraft is established on the extended runway centerline 7 nmi from the airport at 1800 ft. Once the 3 degree glide path (based on DGPS) is intercepted, the pilot will begin to descend the aircraft based on the CDI information provided by DGPS. The final approach fix (FAF) is 4.3 nmi from the runway threshold. Before the FAF point is reached, the aircraft should be configured for landing; gear down, engines spooled, etc.,. All approaches are flown with the pilot under the hood.

The satellite vertical dilution of precision (VDOP) constraint provides that VDOP < 3 is acceptable otherwise the data is disregarded. This is a prior constraint used for all DGPS precision approach flight tests at the Technical Center. Additionally, the mask angle is set at 5 degrees. VDOP greater than 3 is considered and the results of those tests will be presented.

2.3 TRUTH SOURCE.

The FAA Technical Center's Laser tracker is the truth source for precision approach tests, accurate to .1 milli radians in azimuth and elevation and 1 ft in range out to 5 nmi. The aircraft is tracked via a retroreflector mounted on the nose of the aircraft. Additionally, Wilcox provided theodolite tracking on the ground. Refer to appendix A for details on the location of the retroreflector and the GPS antenna on the test aircraft.

3. DATA REDUCTION.

Ensemble means and standard deviations are computed at 0.1 nmi increments from the runway threshold out to the FAF point (4.3 nmi). The upper limit for the 95 percent confidence interval is based on the number of approaches. The test plan includes a graph of the confidence interval generated by MITRE. Statistical analysis is provided in terms of total system and sensor errors.

4. DATA ANALYSIS AND RESULTS.

4.1 FLIGHT TEST RESULTS FOR 35 APPROACHES, VDOP < 3.

4.1.1 SENSOR ERRORS.

Vertical sensor errors in the final 2 nmi are less than 2.4 m, |mean| + 2 standard deviation (SD) (an estimate of the 95% error). Both along-track and crosstrack sensor errors are less than 1.4 m (95%). Mean errors are small because the DGPS removed nearly all bias errors in the signal e.g., ephemeris, ionospheric, tropospheric, and satellite clock errors. Also the small along-track error indicates good time synchronization in the data. The sensor accuracies for vertical sensor and crosstrack sensor are well within the Federal Radio Navigation Plan requirement for a CAT I approach at the DH (4.1 m vertical and 17.1 m lateral). CAT II sensor error requirements at DH are 1.7 m vertical and 5.2 m lateral. Below are figures 1 and 2 which show the error trajectory for all 35 approaches for vertical sensor error and crosstrack sensor error from 2 nmi to the runway threshold. Figure 3 shows the |mean| + 2 SD from the final approach fix (FAF), which is at 4.2 nmi, to the runway threshold. Note in figure 3 that beyond 2 nmi (where the laser tracker is less accurate), the largest error is only 3.5 m.

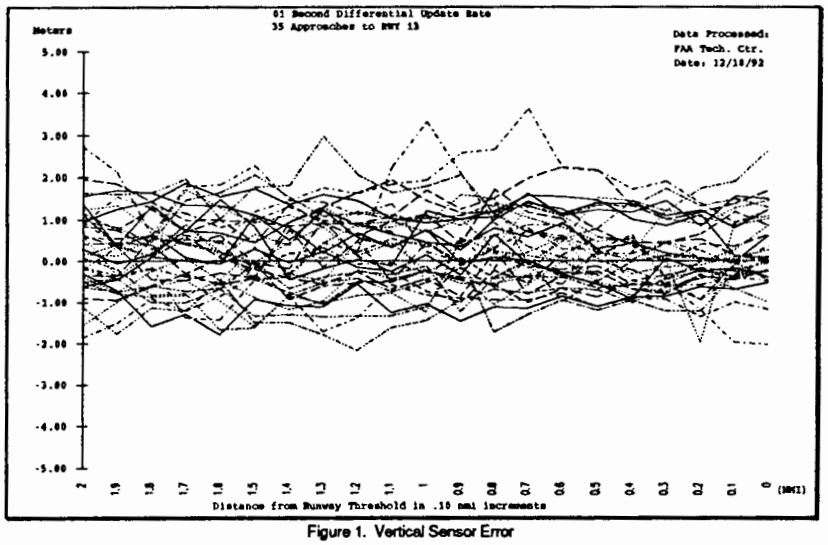


Figure 1. Vertical Sensor Error

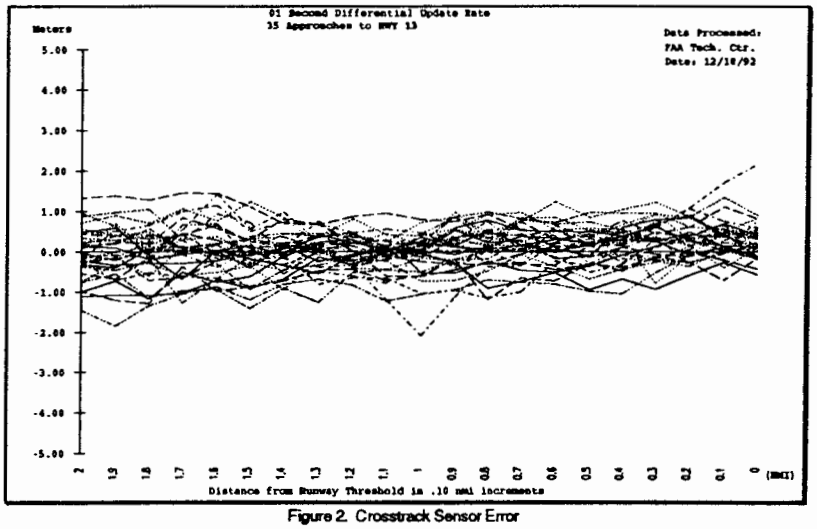


Figure 2. Crosstrack Sensor Error

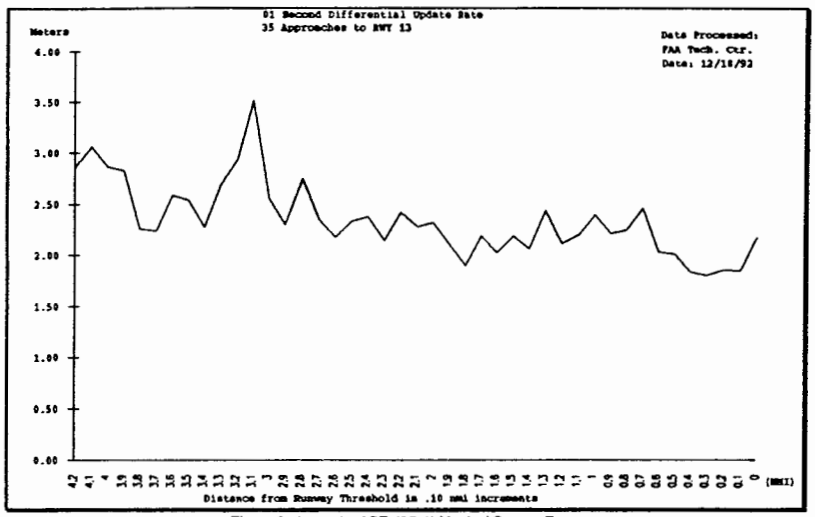


Figure 3. |mean| + 2SD (95%) Vertical Sensor Error

4.1.2 FLIGHT TECHNICAL ERROR.

Flight technical error (FTE) is presented as a measure of the deflection of the needle on the CDI as derived from GPS positions. Vertical FTE is 23.7 ft (95%) 0.5 nmi from the runway threshold (approximately the 200 ft DH). Crosstrack FTE is 80.6 ft (95%) at the same location. A 23.7 ft vertical error is approximately a 2 dot deflection on a 5 dot CDI. An 80.6 ft lateral error is less than 1 dot on a 5 dot CDI. Also, the deflection of the needle from an ILS generated signal closely matched the GPS with a vertical error of 25.2 ft (95%) and 87.8 ft (95%) 0.5 nmi from the runway threshold.

Figures 4 and 5 below show the error trajectories from 2 nmi to the runway threshold for vertical FTE and crosstrack FTE. The test pilot may be considered better than average (due to his experience in flight inspection). All approaches were flown to RWY 13 over a 4 day period and thus various wind conditions were encountered. The FTE observed in figures 4 and 5 indicate that DGPS was able to provide guidance that was flyable and furthermore, the pilot rarely had deflections that were more than 3 dots.

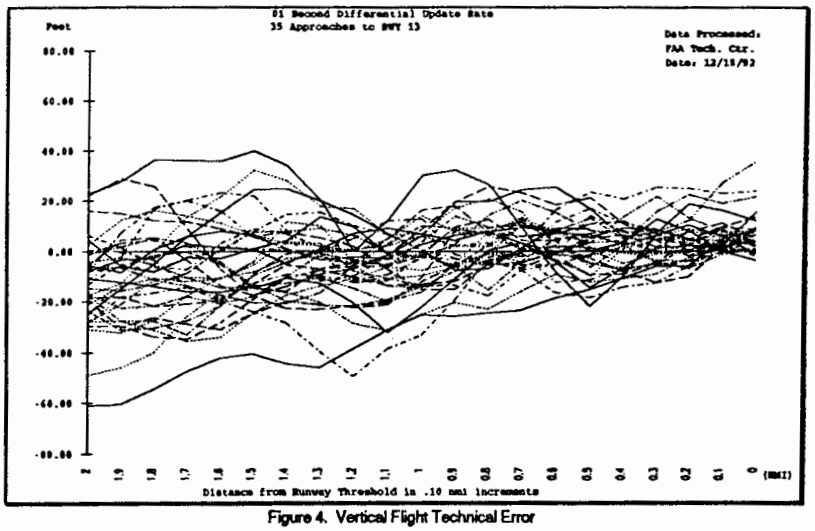


Figure 4. Vertical Flight Technical Error

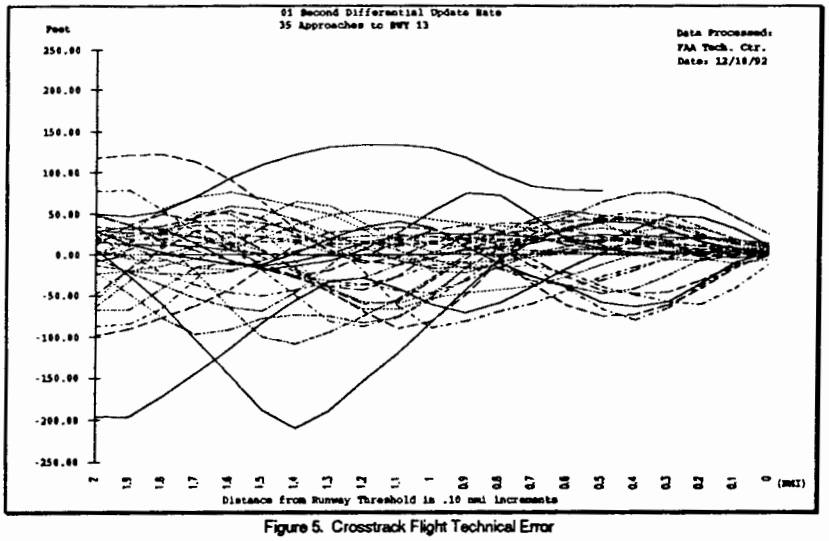


Figure 5. Crosstrack Flight Technical Error

4.1.3 TOTAL SYSTEM ERRORS.

Total system errors are derived from the laser tracker truth referenced to the desired flight path. Since all the approaches were manually flown, the total system vertical error is expected to be larger than if autocoupled or flight director flown. At 0.5 nmi from the runway threshold (approximately the 200 ft DH), the total system vertical error is 9.08 m (95%) or 29.8 ft. While this is well within the CRM requirement of 11.6 m, there is less of a margin when compared to the developing SOIT "tunnel" [2] requirement of 32 ft. The total system crosstrack error is 23.96 m (95%) or 78.6 ft at 0.5 nmi from the runway threshold. At a CAT I DH, the CRM requires 32.8 m and the SOIT tunnel requires 110 ft. Thus, as expected, the crosstrack total system errors easily fall within either the CRM or SOIT tunnel requirements.

Figures 6 and 7 below show the error trajectories from 2 nmi to the runway threshold for total system vertical errors and total system crosstrack errors. Additionally, figures 8 and 9 show the 95% total system vertical and crosstrack error for all approaches combined (35 total) from the FAF point down to the runway threshold.

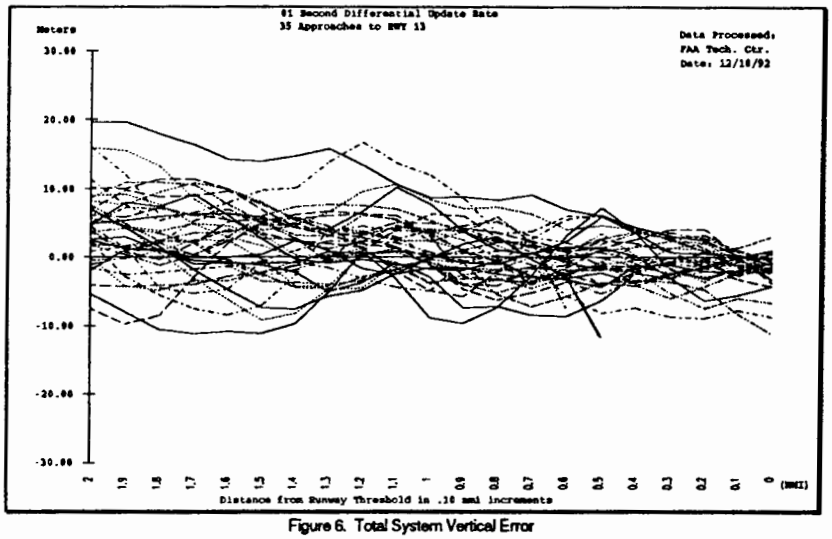


Figure 6. Total System Vertical Error

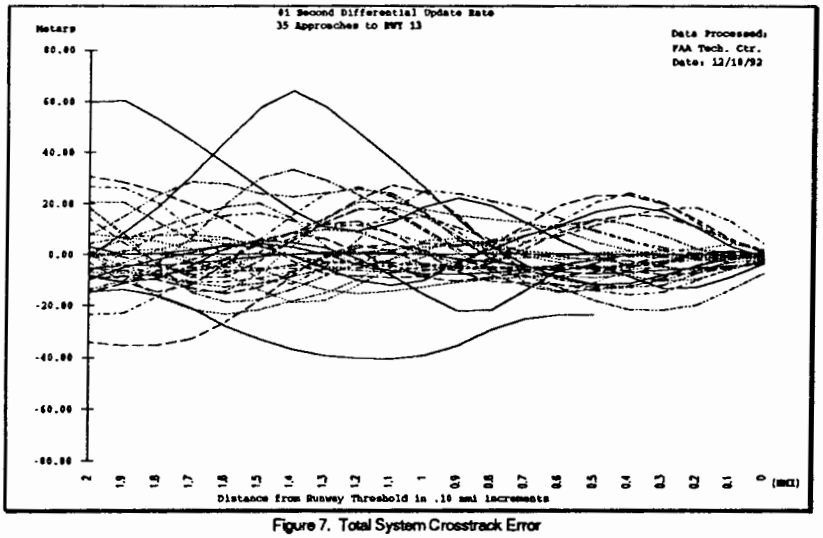


Figure 7. Total System Crosstrack Error

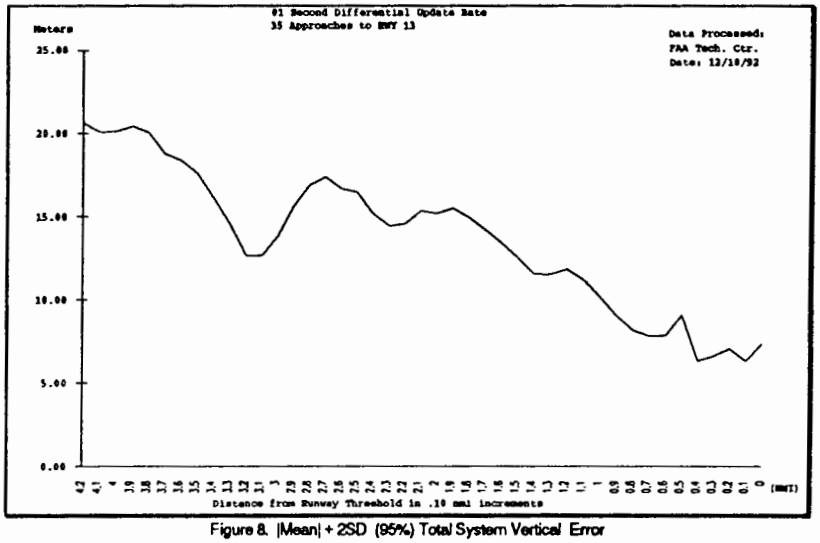


Figure 8. |Mean| + 2SD (95%) Total System Vertical Error

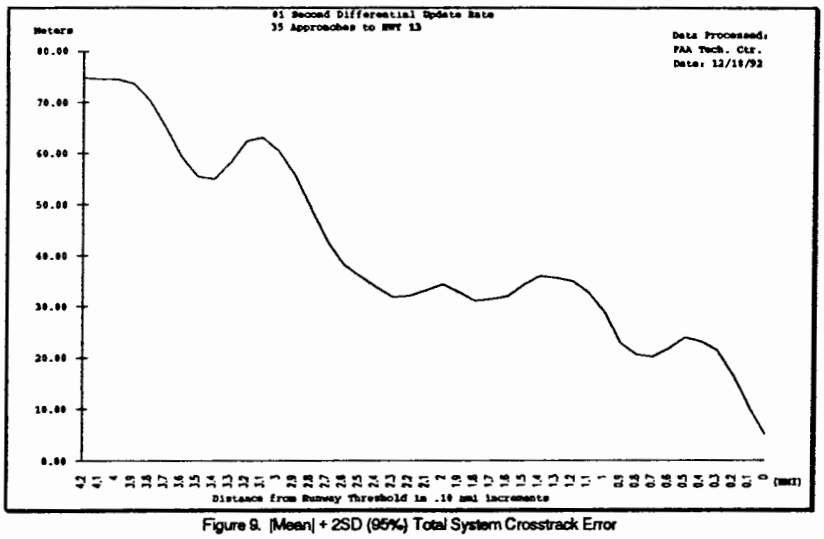


Figure 9. |Mean| + 2SD (95%) Total System Crosstrack Error

4.2 FLIGHT TEST RESULTS FOR 9 APPROACHES AT 3 < VDOP < 10.

Nine approaches with high VDOP provide a "look" at what effect the geometry of the satellites can have on the accuracy of the GPS position. Three satellites are intentionally set unhealthy within the receiver to permit use of satellites with VDOP above 3. Six approaches are separated out where the VDOP is 3 < VDOP < 5.7. At 0.5 nmi from the runway threshold, the vertical sensor error is 5.4 m (95%). However, for some unknown reason, it is observed from the data that the errors are unusually large at the point were the receiver switched to use another satellite in the solution position. Wilcox is investigating to find out what caused this as it is not an expected phenomena and presumably the error can be traced to a source. Thus, removing the approach in which the errors are unusually large improves the vertical sensor error to 2.3 m (95%) for 5 approaches . No other data on the above 9 approaches is presented here as vertical sensor error is the primary objective for looking at higher VDOP. However, the results are promising and would indicate that VDOPs up to 6 may still provide Category I sensor accuracy. Note: Crosstrack errors are about 1 m (95%) for the 9 approaches mentioned above.

REFERENCES

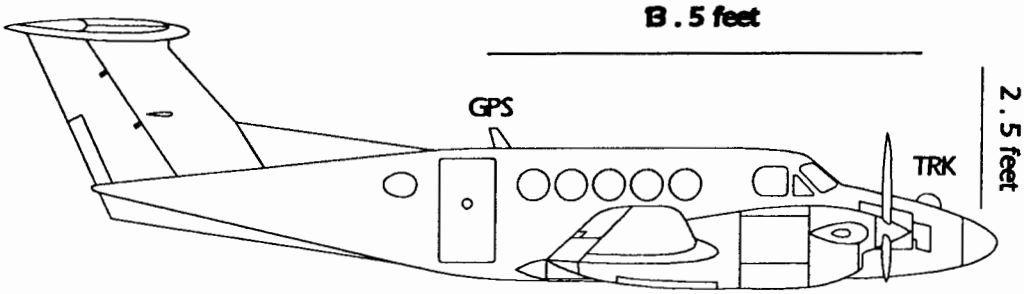
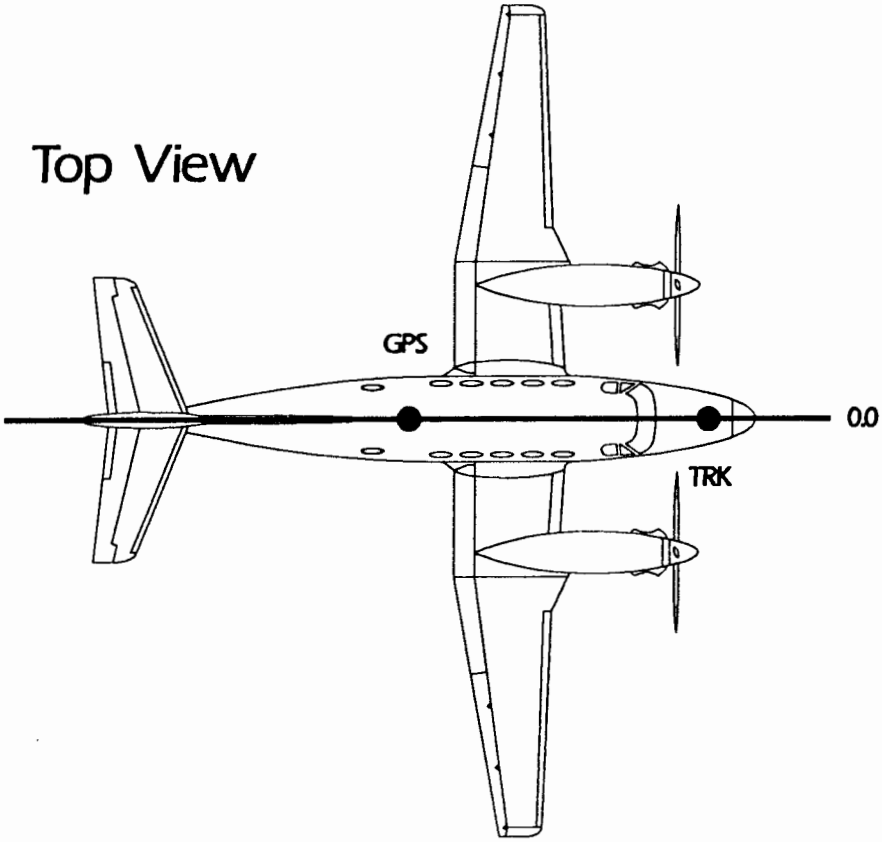
1. Van Dierendonck, A.J., Fenton, P., Ford, T., *Theory and Performance of Narrow Correlator Spacing in a GPS Receiver,* NAVIGATION, Journal of The Institute of Navigation, Vol. 39, No. 3, Fall 1992, pp. 265-283.

2. Federal Aviation Administration (FAA) Satellite Operational Implementation Team (SOIT) Special Technical Committee (STC), *The Tunnel Concept, The Path to the Future; A RNP Standard for Precision Approaches,*paper approved by FAA SOIT STC on 11/19/92.

APPENDIX A

WILCOX Flight Test

Side View



Top View