COMMERCIAL AVIATION NAVIGATION SYSTEMS ANALYSIS TOOLSET

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BIOGRAPHIES

Ian Longstaff

Ian Longstaff has recently joined NAVSYS Corporation as the Integrated Product Team Leader for GPS/Inertial products and services. He has more than 25 years experience in developing Inertial systems and Inertial measurement units. He was most recently Lead System Engineer at Litton Space Systems, Goleta, CA, on their Precision Hemispherical Resonant Gyro program, for space-based applications. Previous to this he was Systems Engineer for the Litton ZLG™-based LN100 systems from 1986-1994 at Litton Guidance and Control Systems in Woodland Hills, CA. Prior to this Mr. Longstaff was a Systems Engineer at Litton Italia in Rome, on the LISA 2000 and Tornado Nav HARS. Mr. Longstaff started his professional career as an Assessment Engineer at British Aerospace's Precision Products Group working on testing and designing gyroscopes for tactical applications.

Gengsheng Zhang

Gengsheng Zhang is an engineer at NAVSYS Corporation. He has more than ten years experience in GPS and INS applications. Mr. Zhang received his first MS degree from Northwestern Polytechnical University, China, and a second MS degree from the University of Calgary, Canada, both with specializations in navigation.

Alexander J. Brown, PE

Al Brown has more than 25 years experience, primarily in the areas of research and development of aerospace communications systems. He has worked with GTE Sylvania, Martin Marietta, GE Aerospace and Loral Command & Control Systems. He supports NAVSYS Corporation in the areas of systems engineering and program management. He has a BSEE degree from the University of New Mexico and an MBA degree from the University of Utah. Mr. Brown is the owner of Colorado Corporate Library, a market research and consulting firm.

ABSTRACT

NAVSYS Corporation has developed a set of Commercial Aviation Navigation Systems (CANS) tools that allow post-flight analysis of various reference aids and systems used in aircraft en-route navigation and landing approaches. These tools were developed to provide qualification capability for civil aviation navigation and landing systems, and they can be used to compare any new navigation or landing aid to existing systems. This toolset provides a cost-effective method of integration, validation and verification of new systems. They were developed using the flexible open architecture of the MATLAB programming environment.

These tools allow the on-board GPS, Differential GPS, VOR/DME, and Inertial Navigation systems performance to be compared and analyzed for an aircraft enroute scenario, against each other, against a GPS base station, airborne rover station, post-processed "Truth" solution, and against the performance of other on-board systems, such as the Flight Management System (FMS) and the Automatic Dependent Surveillance (ADS). The approach segment of a flight can also be analyzed with the CANS software suite. In this flight segment, the on-board GPS and Differential GPS performance can be analyzed and compared to Radar and Instrument Landing System (ILS) approach data and compared to a base station Differential GPS rover station "Truth" solution. The suite can also compare the differential corrections from different base stations and determine the accuracy levels of the differential corrections for a particular time slice.

This toolbox allows evaluation of Differential GPS against conventional accepted civil aviation navigation and landing aids and analysis of its performance against these aids, and thus qualify Differential GPS systems for civil aviation use.

This software suite has been used by an avionics manufacturer to evaluate a differential GPS navigation and landing approach system developed by them for civil aviation. This paper discusses the analysis capability of the NAVSYS CANS software and relative performance characteristics of the different commercial navigation and landing approach systems analyzed by NAVSYS.

INTRODUCTION

There is an ongoing multifaceted drive within the aviation community to apply Global Positioning System (GPS) technology in a safe and cost beneficial manner to enroute navigation, non-precision, and precision approach. Participation in this effort includes the FAA, NASA, various universities and industrial organizations. Flight tests have been conducted to determine the performance of GPS-based precision approach systems and demonstrate their ability to provide enroute navigation, non-precision, and precision approach capability to the specified accuracy.

In order to determine the performance of a GPS-based navigation precision approach system, data from GPS-based systems and other standard navigation and landing systems was recorded for post-flight analysis. Usually, a laser tracking system or a post-processed carrier-phase-based Differential GPS (DGPS) system is also employed as the independent test reference system. The test reference system provides true aircraft position data for post-flight analysis. During post-flight analysis, the accuracy of the tested system for enroute navigation, non-precision and precision approach is evaluated against the true aircraft position to determine if the tested system satisfies the demanding standards of accuracy. The tested GPS-based system is also compared with the standard enroute and non-precision approach navigation facilities, and the conventional landing system.

THE CANS ANALYSIS TOOLBOX

NAVSYS Corporation has developed a post-flight analysis toolbox to provide qualification capability for civil aviation navigation and landing systems. The CANS Analysis Toolbox analyzes recorded test data to determine the accuracy of the tested system and compare any new navigation or landing aid to existing systems. This analysis toolbox was implemented in MATLAB, and is a cost-effective method of integration, validation and verification of new navigation and landing systems.

The CANS Analysis Toolbox analyzes recorded test data from onboard data collection systems and supporting ground systems. The recorded test data comes from various sources, including GPS/DGPS, Instrument Landing System (ILS), Very High Frequency Omnidirectional Range (VOR), Distance Measuring Equipment (DME), Primary Surveillance Radar, Secondary Surveillance Radar, Flight Management System (FMS), Automatic Dependent Surveillance (ADS), and the test reference system.

Aircraft attitude data is used for the lever arm computation and converting aircraft position obtained from different systems to the center of mass of the aircraft for comparison. All the recorded data must be time tagged using a common time reference.

The Graphical User Interface (GUI) implemented in the CANS Analysis Toolbox provides an effective way to use this analysis toolbox.

The precise antenna locations of all related airborne equipment must be given in the aircraft body coordinate system. The CANS Analysis Toolbox provides the Aircraft Information Screen to enter the antenna locations of ILS Localizer, ILS Glideslope, VOR/DME, GPS receiver, and GPS receiver of the test reference system. The entered antenna location data is stored in the Aircraft Information File for use in data processing.

Information about test-related systems at each airport is required for data processing. The CANS Analysis Toolbox provides the Airport Information Screen to enter runway bearing, theoretical glideslope, magnetic variation, and the locations of ILS Localizer, ILS Glideslope, runway start, runway end, and Glidepath Intercept Point (GPIP). All the locations are given in Earth Centered Earth Fixed (ECEF) WGS-84 latitude, longitude, and altitude coordinates. The airport data is stored in the Airport Information File for use in data processing.

The locations of VOR/DME stations in ECEF WGS-84 latitude, longitude, and altitude coordinates must be known to compute aircraft position from VOR/DME bearing and distance measurements. The CANS Analysis Toolbox provides the VOR/DME Information Screen to enter locations of VOR/DME stations. The VOR/DME data is stored in the VOR/DME Information File for use in data processing.

The locations of navigation radar stations in WGS-84 latitude, longitude, and altitude coordinates must be known to compute aircraft position from radar azimuth, elevation, and range measurements. The CANS Analysis Toolbox provides the Radar Information Screen to enter locations of radar stations. The radar data is stored in the Radar Information File for use in data processing.

The CANS Analysis Toolbox provides the Flight Plan Information Screen to enter locations of waypoints. The waypoint data is stored in the Flight Plan Information File for use in data processing.

The CANS Analysis Toolbox provides the Configuration Screen to enter configuration data. Configuration data describes how the analysis toolbox is configured to process test data. Configuration data includes Airport Information File name, Aircraft Information File name, Flight Plan Information File name, test flight data directory, selection of navigation systems to be evaluated, the analysis time period selection, and result logging ON/OFF status. The analysis results can be stored by turning on the Result

Logging File. The previously logged results can be redisplayed. Configuration data is saved in the Configuration File for use in data processing.

The CANS Analysis Toolbox performs enroute analysis, approach analysis, and differential correction verification. The Analysis menu is designed to activate either enroute analysis or approach analysis. The CANS Analysis Toolbox allows the GPS/DGPS, VOR/DME, FMS, ADS and radar performance to be compared and analyzed for an aircraft enroute scenario. The CANS Analysis Toolbox also allows the GPS/DGPS, ILS, and radar performance to be compared and analyzed for an aircraft approach and landing scenario.

The CANS Analysis Toolbox provides the following data processing capabilities:

1. Compute aircraft position from VOR/DME bearing and distance measurements using the recorded barometric altitude measurements and the locations of VOR/DME stations stored in the VOR/DME Information File.

2. Compute aircraft position from radar azimuth, elevation and range measurements using the locations of radar stations stored in the Radar Information File.

3. Calculate lever arms and transform antenna positions relative to the center of mass of the aircraft using the antenna locations stored in the Aircraft Information File.

4. Compute aircraft position from ILS localizer and glideslope deviation measurements using the along-track distance to the runway start point provided by the test reference and the locations of ILS localizer and glideslope stored in the Airport Information File.

Based on the true aircraft position from the test reference, Navigation System Error (NSE), Flight Technical Error (FTE), and Total System Error (TSE) are calculated. NSE is the difference between the aircraft position as indicated by the tested navigation system and the true aircraft position as indicated by the test reference. FTE is the difference between the aircraft position determined by the tested navigation equipment and the aircraft position defined by the desired flight path. TSE is the displacement of the true aircraft position as indicated by the test reference from the desired aircraft position. The Power Spectral Density (PSD) of Navigation System Error is also calculated to assess the noise characteristics of the flight test data.

The desired flight path for approach analysis is generated from the glideslope stored in the Airport Information File. This is usually the standard straight-in three-degree glideslope path. The desired flight path for enroute analysis is generated from the Flight Plan Information file.

The enroute analysis capability provided by the CANS Analysis Toolbox is designed to determine the system enroute navigation performance. The performance of airborne GPS/DGPS can be determined by comparing recorded GPS/DGPS position data to the true aircraft position as reported by the "Truth" system.

The approach analysis capability provided by the CANS Analysis Toolbox is designed to analyze the data collected in the approach and landing segment of a test flight and determine the system non-precision and precision approach performance. The performance of airborne GPS/DGPS can be determined by comparing the true aircraft position to radar and ILS approach data. To present data and results in a meaningful format, all positions, errors and differences are transformed into the runway coordinate system. The runway coordinate system is convenient for approach analysis since x is approximately the range to the runway, y represents the lateral deviation from the extended runway centerline, and z is approximately the altitude above the runway. Aircraft position is transformed from ECEF WGS-84 latitude, longitude, and altitude coordinates to the runway coordinate system using the location of runway start and the runway true bearing stored in the Airport Information file.

The CANS Analysis Toolbox calculates the mean and standard deviation values of resultant errors and differences for both enroute and approach analysis. The statistics are calculated over the time period of the displayed data. For approach analysis the statistics are expressed in the runway coordinate system, which shows the system glideslope/localizer tracking performance.

The Graphics menu provides access to the various analysis charts. For enroute charts, aircraft position is presented in ECEF WGS-84 latitude, longitude, and altitude coordinates. Errors and differences are provided in north, east and up. For approach charts, aircraft position is presented in the runway coordinate system and can be displayed by either two- or three-dimensional plots. Errors and differences are expressed in along-track, cross-track, and vertical distances. The mean and standard deviation values of errors and differences are tabulated for both enroute and approach analysis. All the plots and charts may be printed for further analysis.

The CANS Analysis Toolbox can also compute differential corrections from GPS range measurements and ephemeris recorded from a GPS receiver located at a surveyed site, compare differential corrections from different ground stations, and determine the accuracy levels of the differential corrections. An algorithm was developed to remove the effects of any clock bias between the different ground stations so that differential corrections from the ground stations can be meaningfully compared.

APPLICATION OF THE CANS TOOLBOX

NAVSYS recently used the CANS Analysis Toolbox to determine the performance of a differential GPS navigation landing system which an avionics manufacturer is developing for civil aviation. Data from ADS, FMS, ILS, and Differential GPS navigation systems was recorded by an onboard data collection system during flight tests. An Ashtech Z-XII Truth System, which is a post-processed carrier-phase-based DGPS system, was used as the test reference system. Data from the airborne and ground-based Ashtech Z-XII GPS receivers was recorded simultaneously. The differential corrections from the DGPS ground station were also recorded to determine the accuracy of the differential corrections.

The analysis system for these calculations is called the Post-Flight Analysis System. This section discusses the capabilities of the Post-Flight Analysis System.

SYSTEM OVERVIEW

The Post-Flight Analysis System analyzes navigation data recorded by aircraft and supporting ground systems. The data consists of system configuration and navigation parameters recorded simultaneously from airborne VOR, DME, and ILS systems, a GPS-based navigation system, and a GPS-based Ashtech Truth Reference System. The system also analyzes ground-based radar position reports.

The components of the system are illustrated in Figure 1. The Aircraft Data describes the position of the various navigation systems in the aircraft. Precise knowledge of the locations of the navigation antennas is necessary to take full advantage of the precision offered by GPS-based navigation systems. Similarly, Airport Data describes the runway being used as well as the supporting ground-based navigation systems. The Airport Data is saved in several computer files. Configuration Data describes how the system computer is configured to process Test Data Files resulting from a flight test.

An operator prepares for a test sequence by entering the locations of the navigation antennas on the test aircraft and on the ground, runway information, and flight plan data into formatted displays. He then enters flight data stored on a disk drive during the test flight. Upon command, the system generates graphical displays that depict the performance of the navigation system(s) being evaluated. The analysis reports may be viewed on the computer screen and also printed for further analysis.

BASIC SYSTEM REQUIREMENTS

The Post-Flight Analysis System is designed to operate on a lap-top computer using the Windows 95 Operating System. Here are the required computer components:

- IBM (or compatible) 486/33 or better.
- Windows 95 Operating System.
- MATLAB Version 4.2c.1. Note: The system has been optimized for this version of MATLAB. It can be adapted to other versions.
- 500-MB (or greater) hard drive.
- 8-MB (or greater) internal memory.
- 3.5-in. Floppy drive and a 100-Megabyte ZIP drive.
- Mouse pointer.
- Standard keyboard.
- VGA color display.
- Color printer (optional).

An operator must have a basic knowledge of computer operations and the Windows 95 Operating System to use the Analysis program. It is not necessary for the operator to know or use MATLAB.

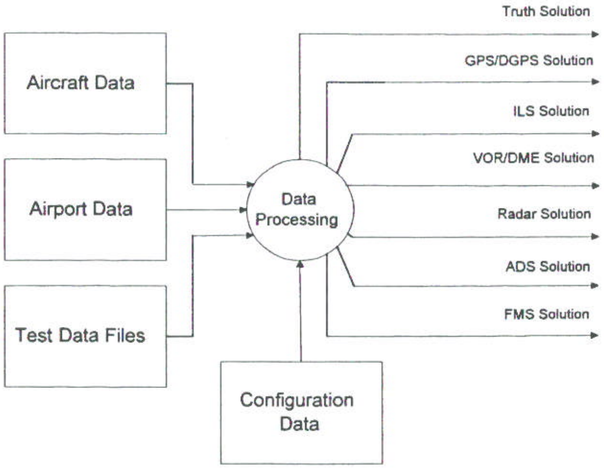
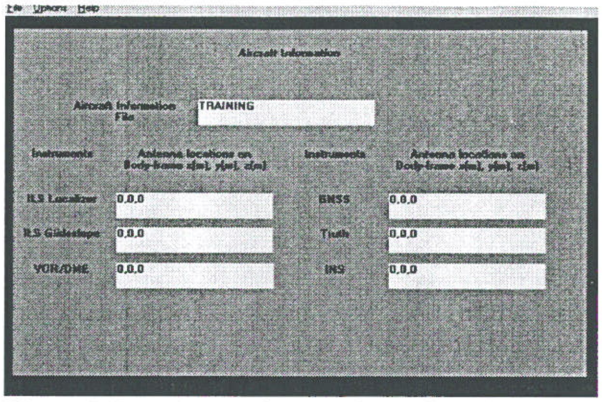


Figure 1 Post-Flight Analysis System Block Diagram

AIRCRAFT INFORMATION

The system captures the locations of the on-board navigation antennas using an Aircraft Information data entry screen. An operator enters the position of each navigation antenna in meters relative to the center of gravity of the test aircraft. +x is in the direction of flight, +y is to the starboard and +z is downward. The data entry screen for Aircraft Information is shown in Figure 2.



Aircraft Information

Aircraft Information File: TRAINING

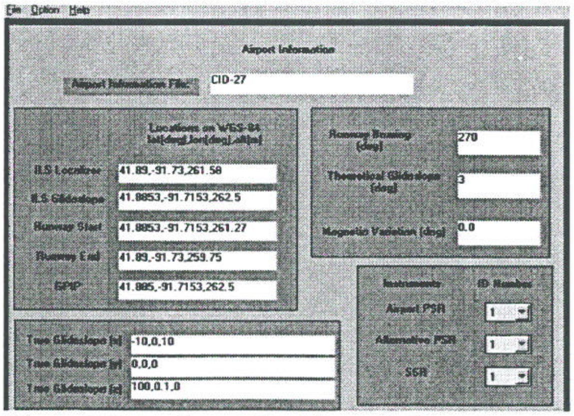
Instruments	Antenna locations on Body-frame x[m], y[m], z[m]	Instruments	Antenna locations on Body-frame x[m], y[m], z[m]
ILS Localizer	0,0,0	GNSS	0,0,0
ILS Glideslope	0,0,0	Truth	0,0,0
VOR/DME	0,0,0	INS	0,0,0

Figure 2 Entry Screen for Locations of Navigation Antennas Onboard the Test Aircraft

AIRPORT INFORMATION

The system captures the locations of key runway points and ground-based navigation systems using an Airport Information data entry screen. As stated above, the system assumes that the positions are entered using WGS-84 surveyed data. The Airport Information screen is shown in Figure 3. The points shown in the figure describe Runway 27 at Cedar Rapids, Iowa. The numbers shown in the Locations portion of the screen are the locations for the ILS antennas, the runway endpoints, and the intersection of the glidepath and the runway.

The system also allows entry of true glideslope coordinates derived from FAA certification flights.



Airport Information

Airport Information File: CID-27

	Locations on WGS-84 lat[deg],lon[deg],alt[m]
ILS Localizer	41.89,-91.73,261.58
ILS Glideslope	41.8853,-91.7153,262.5
Runway Start	41.8853,-91.7153,261.27
Runway End	41.89,-91.73,259.75
GPIP	41.885,-91.7153,262.5

Runway Bearing (deg): 270

Theoretical Glideslope (deg): 3

Magnetic Variation (deg): 0.0

Instruments	ID Number
Airport PSR	1
Alternative PSR	1
SSR	1

True Glideslope [x]: -10,0,10

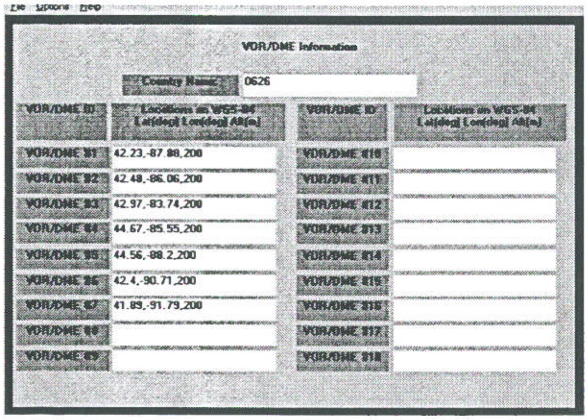
True Glideslope [y]: 0,0,0

True Glideslope [z]: 100,0.1,0

Figure 3 Entry Screen for Airport Information

WAYPOINT INFORMATION

The flight plan for a test flight is defined in terms of the VOR/DME stations and waypoints to be crossed during the flight. The system allows for entry of up to 36 points within an area of interest. A particular flight plan is defined by entering the identification numbers in order of the VOR/DME and waypoint locations to be overflown. For example, Leave Point #1, Fly to VOR/DME #3, Fly to VOR/DME #5, Fly to Waypoint #4, Return to Point #1. As before, the locations of the VOR/DME and waypoints are entered in WGS-84 coordinates. The entry screen for VOR/DME and waypoint locations is shown in Figure 4.



VOR/DME Information

Country Name: 0626

VOR/DME ID	Locations on WGS-84 Lat[deg] Lon[deg] Alt[m]	VOR/DME ID	Locations on WGS-84 Lat[deg] Lon[deg] Alt[m]
VOR/DME #1	42.23,-87.88,200	VOR/DME #10	
VOR/DME #2	42.48,-86.06,200	VOR/DME #11	
VOR/DME #3	42.97,-83.74,200	VOR/DME #12	
VOR/DME #4	44.67,-85.55,200	VOR/DME #13	
VOR/DME #5	44.56,-88.2,200	VOR/DME #14	
VOR/DME #6	42.4,-90.71,200	VOR/DME #15	
VOR/DME #7	41.89,-91.79,200	VOR/DME #16	
VOR/DME #8		VOR/DME #17	
VOR/DME #9		VOR/DME #18	

Figure 4 Entry Screen for VOR/DME and Waypoint Locations

FLIGHT DATA FILES

Data collected during a test flight is captured in several files. The format and content of each file are defined in an Interface Control Document. Separate files capture data from two channels of ILS, two channels of VOR/DME, primary and secondary surveillance radars, GPS, DGPS, ground truth, ADS and FMS. All records are time tagged so that the system will accurately sort and correlate the many inputs.

SYSTEM ANALYSIS RESULTS

ENROUTE ANALYSIS OPTIONS AND RESULTS

Figure 5 shows the screen used by an operator to select the graphs and charts that will best display the results of the nroute analysis. Check marks in the first column result in graphs of latitude (deg), longitude (deg) and altitude (m) vs time (sec) for the portion of the test flight that is being analyzed. Checks in the second column result in plots of the differences in the selected parameters vs time. Finally, checks in the third column result in tabular displays of the selected statistics.

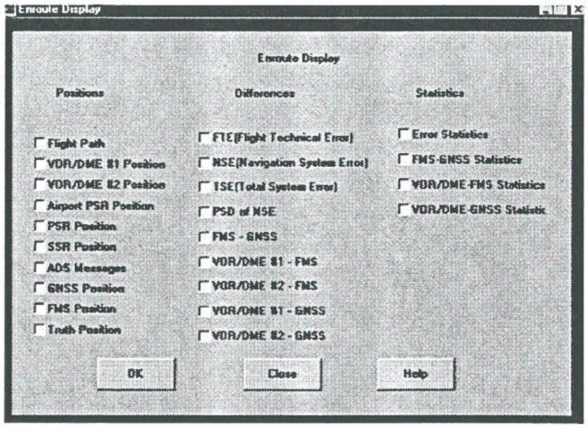


Figure 5 Selection Screen for Displaying Results of Enroute Analysis

Figure 6 shows a sample plot from the enroute analysis. Data from the GNSS navigation system and the Ashtech ground truth system is displayed on the chart.

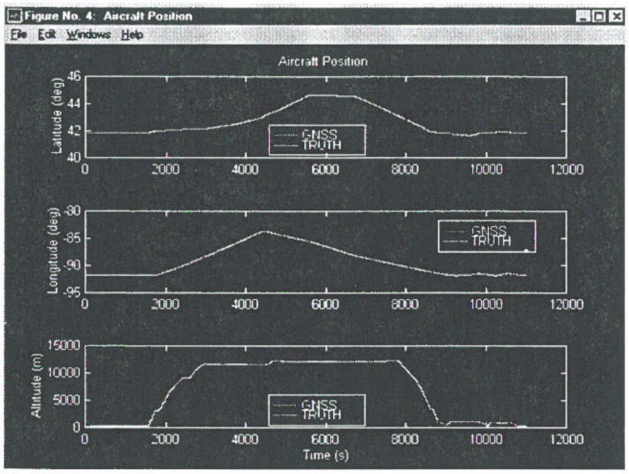


Figure 6 Plot of Aircraft Latitude, Longitude and Altitude during Flight Test

APPROACH ANALYSIS OPTIONS

Figure 7 shows the screen used by the operator to select the graphs and charts that will best display the results of the approach analysis. This screen is similar to Figure 5, but with the additional capability to display the approach data using a 3-dimensional display. The approach parameters are plotted as functions of distance from the glidepath intercept point.

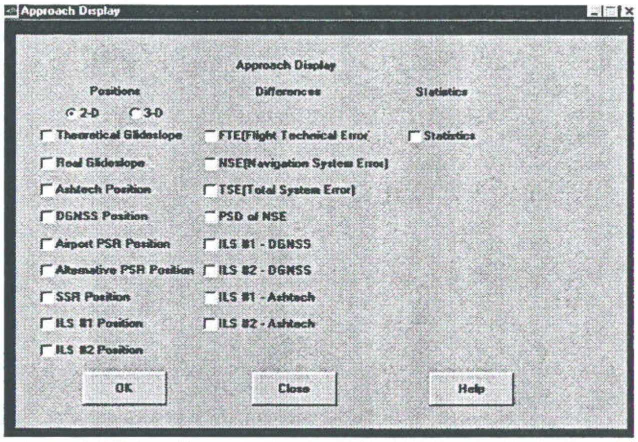


Figure 7 Selection Screen for Displaying Results of Approach Analysis

SUMMARY

The NAVSYS Commercial Aviation Navigation Systems (CANS) Analysis Toolbox provides a flexible and cost-effective means of analyzing flight navigation system. By comparing data collected from on-board navigation systems with high-precision ground truth positional data, an operator can quickly determine the accuracy of the systems of interest. This is particularly important for aviation management officials who are considering upgrading or replacing in-place navigation systems.