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MLS Angle Accuracy of the MIAS Flight Test*

H. Inokuchi*1, M. Zaayer*2, J. K. Sridhar*2, J. A. Mulder*2

Abstract

The Multi-mode Integrated Approach System (MIAS) is under development at Delft University of Technology (DUT), the Netherlands. The system is an advanced approach system based on the Microwave Landing System (MLS) and the Differential Global Positioning System (DGPS). Since the MIAS uses two independent systems, the availability of the system and the maintainability of each subsystem can be increased.

Flight tests were performed at Amsterdam's Schiphol airport in 1994 to evaluate the performance of the system. This report describes the flight test results of the MIAS in 1994. Especially the MLS data was compared with true reference obtained from carrier phase DGPS.

In the case of a straight approach, the accuracy of the MLS elevation angle in this flight test equipment was approximately 0.015 degrees (1σ) except for a bias. The mean of the bias was approximately 0.025 degrees. The accuracy of the MLS azimuth angle was approximately 0.015 (1σ) degrees except for a bias. The mean of the bias was approximately −0.075 degrees. In the case of take off and steep turn, the accuracy of the MLS angle decreased.

Keywords : MLS, GPS, terminal area navigation, guidance, flight testing

概　要

オランダのデルフト工科大学で開発を進めている Multi-mode Integrated Approach System (MIAS) は，マイクロ波着陸誘導システム (MLS) およびディファレンシャル全世界測位衛星システム (DGPS) を利用した着陸援助システムである。MIAS では，2 種類の独立したシステムを利用するため，有効性およびそれぞれのシステムの保全性を増加させることが出来る。

MIAS 飛行試験は，システムの能力を評価するために1994年にアムステルダムのスキポール空港で行われたので，その結果を報告する。特に MLS データは，搬送波位相方式の DGPS により得られた基準データと比較した。

直線進入の場合，MLS の仰角精度はバイアス分を除くと，今回の飛行試験装置の場合，約 0.015 度 (1σ) で，バイアスの平均値は約 0.025 度であった。方位角精度は，バイアス分を除くと約 0.015 (1σ) 度で，バイアスの平均値は約 −0.075 度であった。また，離陸および急旋回のときは，精度が劣化した。

Acronyms

ADW	Auxiliary Data Word
AHRS	Attitude and Heading Reference System
AM	Amplitude Modulation
BDW	Basic Data Words
CAT	Category
CDU	Control Display Unit
DME	Distance Measuring Equipment
DME/p	DME/precision
DGPS	Differential GPS
DUT	Delft University of Technology
FMS	Flight Management System
GPS	Global Positioning System

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*1 Flight Research Division
*2 Delft University of Technology

ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
Inmarsat	International Maritime Satellite
MIAS	Multi-mode Integrated Approach System
MLS	Microwave Landing System
NLR	Nationaal Lucht-en Ruimtevaartlaboratorium (dutch)
NovAtel	NovAtel Communications Ltd.
RAIM	Receiver Autonomous Integrity Monitoring
RPU	Receiver Processor Unit
RVR	Runway Visual Range
SD	Standard Deviation
SPS	Standard Positioning Service
TFT	Thin Film Transistor
TU	Technische Universiteit (dutch)
UTC	Coordinated Universal Time
VHF	Very High Frequency
WGS84	World Geodetic System 1984

1. Introduction

These days a demand for transportation by air is increasing rapidly. Major airports are congested, however, it is difficult to build more runways because the airports are usually located in densely populated areas. Almost all major airports have the Instrument Landing System (ILS) on their runways for the final approach phase. One of the disadvantages of this system is the single approach path the airplane can follow. Every aircraft has to approach the runway in the same part of the final approach area, which means unnecessary delays for the fast airplanes. This problem could be solved by using a Microwave Landing System (MLS), a system with a wide coverage in the landing area. Finally this system seems to have reached the level where it can be certified and implemented in civil air liners as a replacement for ILS. However, the MLS installation is expensive and in case of using only MLS as an approach system, enough redundant parts are required for preserving reliability. As the redundant parts of MLS are also expensive, the cost for maintenance is increased. The Global Positioning System (GPS) can be utilized for aircraft navigation using an inexpensive receiver. This system is not qualified for precision approaches in its original set-up. The Differential GPS (DGPS) can be used as an approach system in order to solve the problem. The GPS was originally developed for military purposes of the United States of America. It is possible that the GPS is stopped or restricted use of it without notice by the United States of America. The availability of the GPS is not obvious.

The Multi-mode Integrated Approach System (MIAS) is under development at Delft University of Technology (DUT) the Netherlands. The MIAS utilizes MLS and DGPS for a hybridized navigation solution. Since the MIAS uses two independent systems, the availability of the system and the maintainability of each subsystem can be increased, while the landing requirements are still maintained.

In order to examine the experimental equipment of the MIAS, the flight test was carried out at Amsterdam's Schiphol airport. The MIAS equipment, software for navigation and accuracy of subsystems were examined in the flight test. Every equipment was checked the adaptation as a part of on board system. The software for navigation calculates and displays real time position of aircraft using subsystems. The software was tested the suitability for the MIAS processor. Subsystems for navgation include a MLS, a GPS and gyros. Real time GPS positioning and measured MLS angles were compared with true reference. As the gyros were conventional equipment, the accuracy and character were already informed.

This report describes the flight test results of the MIAS in 1994. Especially the author focused on MLS angle accuracy and the data were compared with the true reference by the DGPS. Close to the threshold of a runway the MLS angles have a great influence on the position accuracy. The MIAS respects MLS data for a final approach phase and uses for a navigation solution in terminal area. The MLS originally is designed that it has enough accuracy as a landing system by itself. However, it is necessary to find out the measurement accuracy of every subsystem using MIAS equipment. Because the MIAS processor considers the weight of measured data according to the accuracy of each subsystem in order to calculate hybrid navigation solution. It is important that the accuracy of MLS angle is examined for implementation of the MIAS. This result was compared with result of Japanese similar flight testing. As a detail process of the MIAS is not decided yet, main purpose of the flight testing is acquisition of basic data for the implementation of the MIAS.

2. The MIAS project

MIAS is designed to satisfy the most demanding landing system requirements which is CAT Ⅲ automatic landing of ICAO. At CAT Ⅲ conditions the landing system has to operate to and along the surface of the runway with an external visual reference during the final phase of the landing down to a Runway Visual Range (RVR) value of 200 m (CAT ⅢA), 50 m (CAT ⅢB) or 0 m (CAT Ⅲ C). All categories set their own special constraints to the airborne equipment, number of pilots and the ground equipment.

Several landing systems are able to satisfy the CAT Ⅲ landing requirements. The present landing system is the Instrument Landing System. ILS could be replaced by the Microwave Landing System in combination with Distance Measuring Equipment (DME).

MIAS is an integrated approach system based on MLS and DGPS. The total MIAS concept is shown in figure 2.1. The DGPS corrections are transmitted to the airplane using the Auxiliary Data Word (ADW) channel of MLS. With the MLS azimuth and elevation angles and the DGPS range measurements a hybrid position of the aircraft is calculated. If the aircraft is located out of the MLS coverage, no DGPS corrections are received for GPS. The aircraft uses only GPS data for navigation. If the aircraft is located in the MLS coverage zone, the MIAS extracts the DGPS corrections from the ADWs of MLS. The aircraft uses DGPS data for approach. In the case of GPS data is not available, the MLS is used instead of the DGPS. Close to the threshold of a runway the MLS angles have a great influence on the position accuracy rather than DGPS. The aircraft uses MLS data for automatic landing. When both MLS and DGPS are available, a MIAS processor estimates present position of the aircraft from the previous position data. The estimated position data are used for navigation and guidance. If measured position data by a subsystem deviate from the estimated position data, the MIAS processer recognizes that the subsystem is abnormal and removes the data from the position calculation process. Since the MIAS takes advantage of two independent systems, the measurement acuracy and the availability of the system can be increased. As the redundant parts of the MLS can be omitted by using the DGPS, the maintainability of the MLS can be increased.

It is possible to extend the MIAS position calculation with DME/precision (DME/p) and Radar altimeter measurements to improve integrity and accuracy. The DME/p is a ground equipment which measures the distance between aircraft and runway more accurate

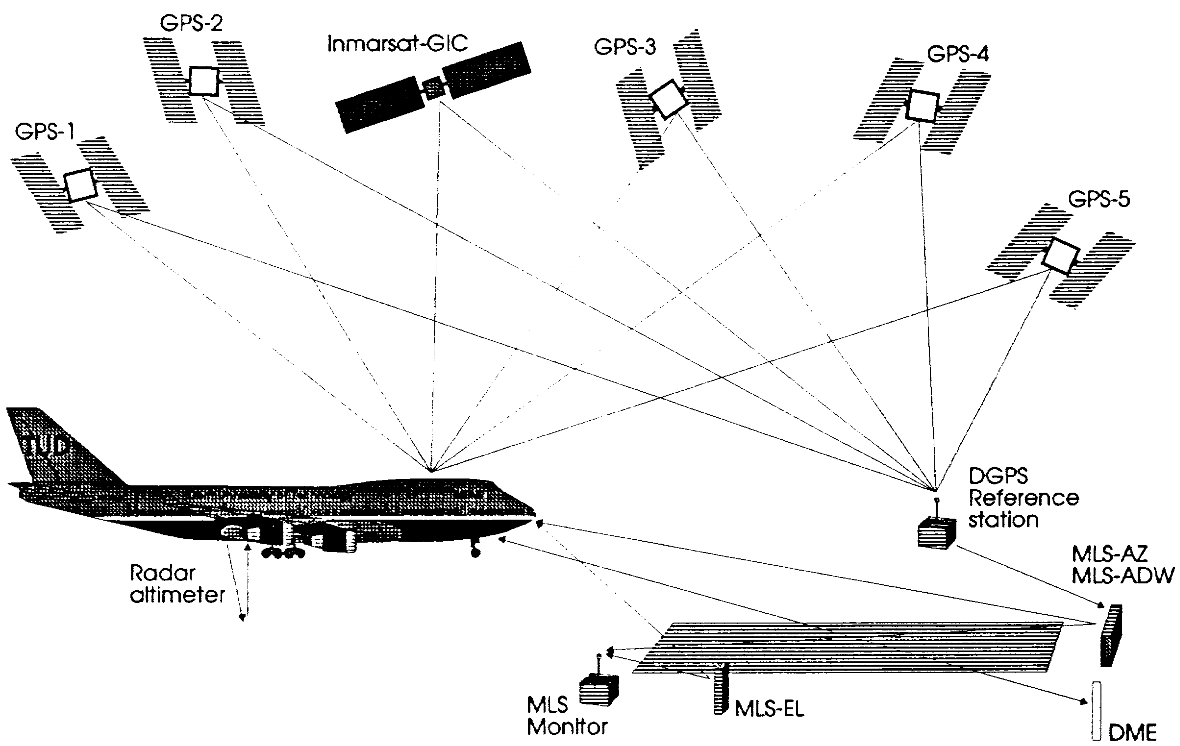

Figure 2.1 MIAS Comcept

than DME. MIAS integrity can also be improved by sending GPS satellite health information over an Inmarsat satellite, international maritime satellite, data link.

2.1 MIAS subsystems

2.1.1 MLS

The Microwave Landing system basically consists of an azimuth angle measurement for guidance in the horizontal plane and an elevation angle measurement for guidance in the vertical plane. The distance between aircraft and runway is measured with Distance Measuring Equipment (DME). For the azimuth measurement a fan shaped beam is generated, which is narrow in horizontal plane and wide in the vertical plane. This beam sweeps on a predefined time between the horizontal borders of the coverage zone, with a constant angular speed. From the time difference between the scan signals the azimuth angle can be calculated. The elevation angle is measured with the same principle, only now a beam narrow in the vertical and wide in the horizontal plane is swept up an down in the vertical plane.

The transmission of the MLS functions and MLS data words are time division multiplexed. These data words, transmitted by the azimuth antenna, can be divided in two categories: the Basic Data Words (BDW) and the Auxiliary Data Words (ADW). The BDWs are reserved for MLS specific information, but most of the ADWs are still available for DGPS and other usage.

The coverage of the MLS signals basically is divided in three sectors:

- proportional coverage area,
- fly left and right clearance area,
- out of coverage zone.

Figure 2.2 shows the MLS coverage zones in a horizontal view and vertical view.

The advantage of MLS with respect to ILS are:

- since MLS measures angle with respect to the run way, it is possible to approach the runway from any direction, which means that every aircraft can choose its own optimal approach,
- less constraints are made on the area around the antenna because MLS uses a high frequency (about 5 GHz) with a small beam width (about 1.5 degrees), MLS suffers less from multipath effects.

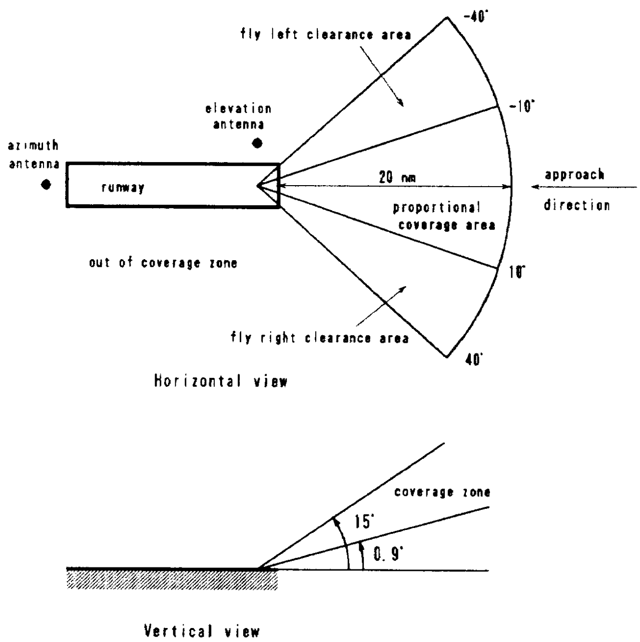

Figure 2.2 The coverage zones of MLS

2.1.2 GPS

A GPS receiver receives the signal from GPS satellites, measures the time arrival of the signal and demodulates the time information and satellite orbit. Since we know the transmission time, it is possible to calculate the range from the GPS receiver to the satellite. We use four satellite ranges for the calculation in order to solve the position in three dimensions[4].

2.1.3 DGPS

The DGPS[5] system is an extension of the GPS. GPS with the Standard Positioning Service (SPS) has pseudo range accuracy of 30 meters (1σ). The error is correlated over a wide area. If we measure this error on a known location and send this error to a user, we are able to correct the pseudo ranges the user has measured. Depending on the distance between the reference station and the user, and correction update rate, it is possible to get a pseudo range accuracy of about 1.5 meters (1σ)[1]. This principle is called Differential GPS (DGPS). A disadvantage of the DGPS is the need of an extra data link.

2.1.4 AHRS

Generally, the MLS and GPS antennas are not located in the center of gravity of an aircraft. To correct the MLS and GPS measurements, the roll, pitch and heading angle of the aircraft are required. The Attitude Heading Reference System (AHRS)[2] measures these angles using gyros. The gyro used to measure the roll and pitch angle are slaved to gravity of the earth, the gyro used to measure the heading is slaved to the magnetic north. The true heading, variance from the true north, is obtained by adding deviation from magnetic north. The AHRS data were used only drawing time histories for attitude of aircraft. Its data were not used for correction of antenna position in this study.

3. Flight Testing

The flight tests were performed at Amsterdam's Schiphol airport, where runway 01R (52.28N, 4.78E) is experimentally equipped with MLS. The purpose of the flight tests is to gather new data for development of the MIAS.

3.1 Experimental system

Since the MLS installation at Schiphol airport is not equipped with a dynamic ADW channel, the DGPS corrections were transmitted with a VHF data link. This implies that the conversion form ADW's to DGPS corrections could not be tested in real time. This, however, is not a critical operation of MIAS. The experimental system is shown in figure 3.1.

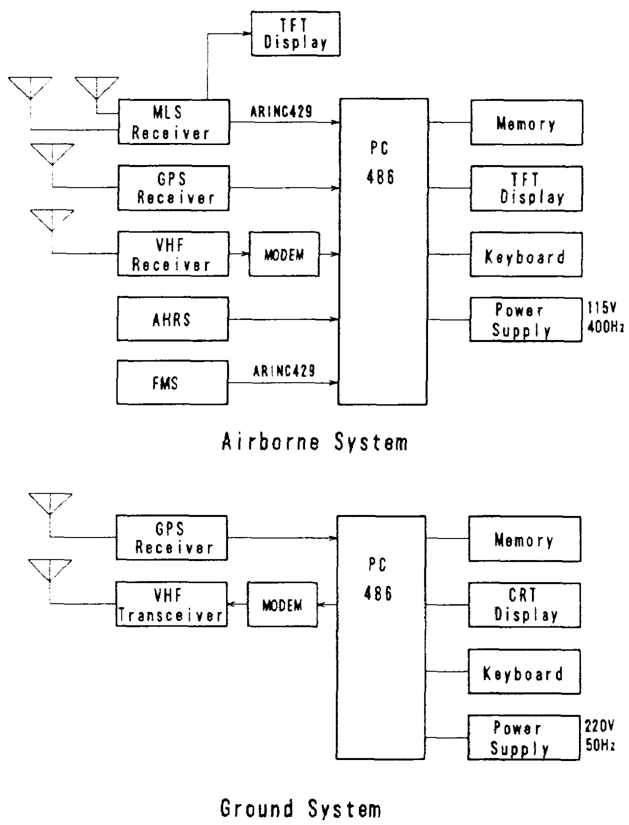

Figure 3.1 The experimental system

The experimental equipment consists of the following:

The GPS receiver - The NovAtel PC951R GPS card is a high performance GPS receiver. The receiver has 10 channels available for tracking of satellites.

The MLS receiver - The Canadian Marconi CMA-2000 MLS receiver consists of a Receiver Processor Unit (RPU), a Control Display Unit (CDU) and up to three antennas. The RPU is the primary component of the MLS receiver. It receives and processes C-band signals generated by any MLS ground facility which uses the ICAO format. The CDU is the interface between the pilot and up to two MLS RPUs. For the flight tests two of the possible antennas were connected to the RPU. The tail antenna which is located near the tail at the bottom side of the aircraft, and the landing antenna which is located at the top side of the aircraft nose.

The VHF data link[6] - The VHF data link used to transmit DGPS messages consists of two parts, the ground station part and the airborne part. Both parts contain a PC, a modem unit and a transceiver unit. The PC units communicate with the modems through a RS232 interface. The modems are connected to the VHF transceivers Collins VHF 22B. It is able to transmit within the frequency range of 118.00 to 139.95 MHz. The frequency used was 136.95 MHz (license from NLR). The transceiver AM modulates the signal and transmits with a maximum power of 25 Watts.

The Attitude and Heading Reference System - Two gyro's are used as an AHRS. The first gyro is used to measure the attitude of the aircraft. The roll and pitch angle of this gyro are measured with a synchronizer. The second gyro is pointing North, when it is slaved by flux valve. However a (secondary) flux valve was not available in the Citation, meaning that the heading was not available from the gyro but from the Flight Management System (FMS). The AHRS data was not used for correction of antenna position in this study. The data was used only drawing time history for attitude of aircraft.

The Navigation display - The position calculated by the airborne system was made visible on a TFT display in the Citation. The display is showed the horizontal position of the aircraft relative to the runway.

DGPS reference station - The DGPS reference station on the ground has two functions. The first function consists of the calculation of DGPS corrections and transmission of these corrections to the airborne system. The DGPS corrections are calculated by the GPS receiver on ground. The second function is the data collection for the calculation of the true reference performed during the postprocessing. For these calculations the carrier phase of the airborne system and the DGPS station are used.

3. 2 Cessna Citation

The airplane used for the flight tests is the Citation, an aircraft from the manufacturer Cessna. The aircraft has two jet engines and gives place to a maximum of 11 passengers and two pilots. The maximum Indicated Air Speed of the aircraft is 262 knots (135 m/s), the landing speed is 100 knots (51 m/s).

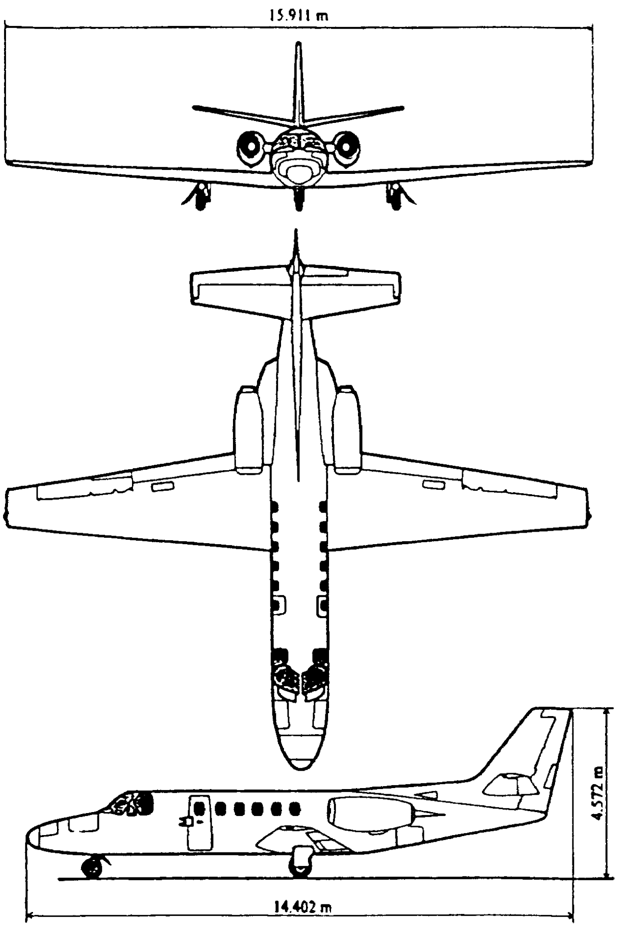

Figure 3.2 Cessna Citation

Maximum altitude of the aircraft is approximately 43,000 feet (14,000 m) and the maximum take off weight is 14,600 lb (6,622 kg). Three-view of the Citation is shown in figure 3.2. The aircraft is jointly owned and operated by TU Delft and NLR Amsterdam.

3. 3 Flight test procedures

Several flight tests are performed to examine all the possible situations that could occur when MIAS is used. During the flight tests a sequence of the following procedures is made. Figure 3.3 shows the flight test pattern.

Straight approach - The straight approach is the landing procedure as it is until now with ILS. In this procedure azimuth is continuously 0 degrees and a chosen glide path of 3 degrees. As the straight approach is the most simple procedure, it will still be used by many aircraft, if MIAS is used.

Curved approach - During the curved approach the aircraft approaches the runway with a curved track in the azimuth plane. The curved approach can be used by small and slow aircraft to gain a fast approach procedure, not slowing down the bigger and/or faster aircraft.

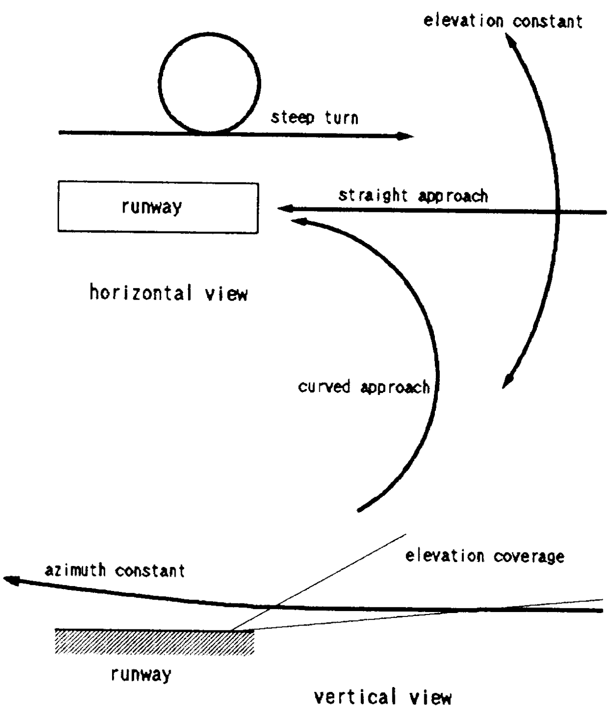

Figure 3.3 flight test pattern

Elevation constant - The procedure where the elevation is constant and the azimuth angle is changing from one boundary of the coverage zone to the other, is called the Elevation constant procedure. The elevation constant procedure is a fictitious procedure and is probably only used under test conditions.

Azimuth constant - The procedure where the azimuth angle is constant and the elevation angle changes between the two outer boundaries of the elevation coverage, is called the Azimuth constant procedure. This procedure is used during a low pass procedure for a missed approach.

Steep turn - During the steep turn procedure GPS satellites are shielded by the aircraft fuselage and wings, so the GPS receiver losses track of the signal of the satellites. A 60 degrees bank was chosen as a steep turn procedure.

3.4 Data acquisition

The follow data were acquired on the airborne system.

GPS data: pseudo range, carrier phase, lock time, channel status, GPS time

DGPS data: correction, correction rate

MLS data: elevation angle, azimuth angle

AHRS data: roll angle (ϕ), pitch angle (θ)

4. Results from flight test

In this report, the MLS data in two different flight patterns are treated. The MLS data was compared with the true reference by DGPS and the variance was analyzed.

4.1 True reference

The necessary true reference was based on carrier phase DGPS[7]. This technology is different from DGPS of MIAS subsystem and already developed on field of surveying about still position. In order to derive the position solution, post flight analyzing is required. Both on the ground and in the air carrier phase data were collected and they were processed by a software package called TOPAS 3.1e. This program is able to process the carrier phase data and provide positions with decimeter accuracy by resolving the cycle ambiguities on the fly[8]. The accuracy of the DGPS position for maneuvering or fast flying aircraft is not obvious since the technology is under developing.

4.2 Data processing

The used definitions are shown in figure 4.1.

A convenient software package called Matlab was used in order to calculate, analyze and display.

Flight profiles were calculated from the true reference and the AHRS data. This data consists of GPS time, latitude, longitude, altitude, roll angle (ϕ) and pitch angle (θ). The other data were calculated as follows.

$$\begin{bmatrix} X \\ Y \end{bmatrix} = \begin{bmatrix} -\cos\psi r & -\sin\psi r \\ -\sin\psi r & \cos\psi r \end{bmatrix} \begin{bmatrix} N \\ E \end{bmatrix}$$

where

X : position along runway direction,

Y : position cross runway direction,

ψr : runway direction, = 0.05546828039706 radians

N : position along meridian,

E : position cross meridian,

N and E are calculated from latitude and longitude of the true reference,

Location of the MLS antennas (WGS84 co-ordinates) are shown in table 4.1.

$Vg = \sqrt{dX^2 + dX^2} / dt$: ground speed.

$\psi = \tan^{-1}(dY/dX)$: heading, however it is flight direction rather than heading since the side slip angle (β) was neglected.

$ROC = dH/dt$: rate of climb.

$\gamma = \tan^{-1}(dH/(Vg \times dt))$: flight path angle.

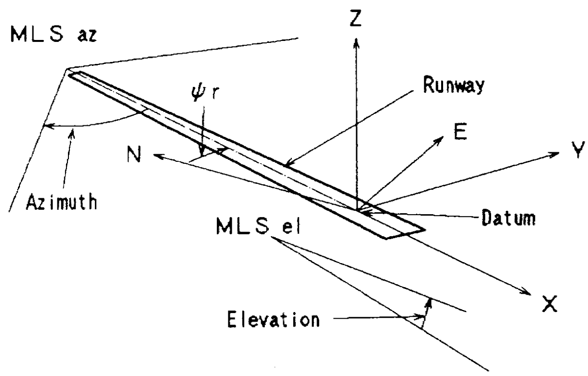

Figure 4.1 Definition

Table 4.1 Location of the MLS antennas (WGS84 co-ordinates)

	longitude(deg)	latitude(deg)	altitude(m)
azimuth	4.78039743725692	52.32376395325756	40.518
elevation	4.77640929696727	52.29335530160628	40.923
datum point	4.77757679378156	52.29331469443991	39.731

The MLS elevation angle was derived from MLS data by a MLS receiver. The true elevation angle was calculated from true reference positions by the DGPS.

The MLS azimuth angle was derived from MLS data by a MLS receiver. The true azimuth angle was calculated from true reference positions by the DGPS.

The elevation error is the difference between MLS elevation angle and true angle.

The azimuth error is the difference between MLS azimuth angle and true angle.

The distance is measured between the on-board antenna position and the ground antenna position.

The bias and standard deviation (SD) were calculated dividing each one kilometer in distance. The bias is the mean of each dividing part. standard deviation (SD) is the standard deviation of each dividing part.

4.3 Flight pattern and time history

The flight pattern and basic data time history of the two tests which were used for analysis are shown in figure 4.2 and 4.3. Figure 4.2 shows the case of the ILS-approach. Figure 4.3 shows the case of Take-off (T/O) and steep turn. The time means GPS time described by second in these time histories. The GPS time starts every 0 hour on Sunday of UTC time and increments during one week. These figures help to understand the flight pattern of the tests. These results were calculated from the true reference by the DGPS and the AHRS data. Contents of these figures are explained in table 4.2.

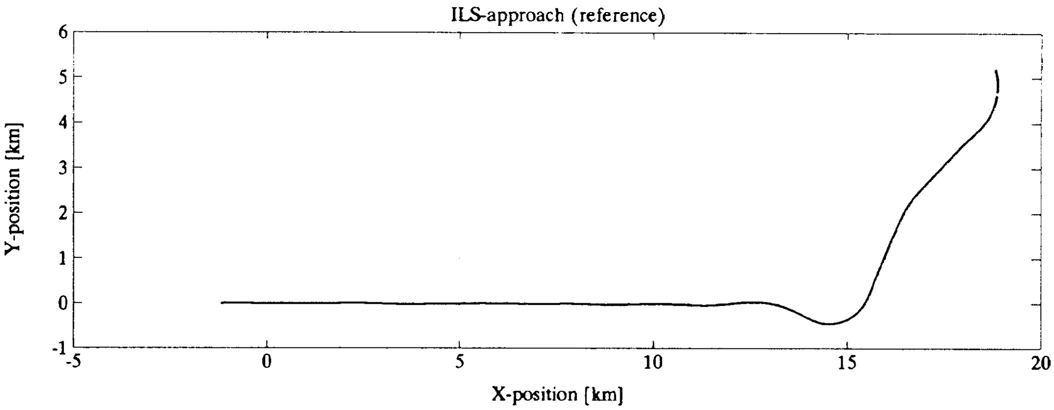

Figure 4.2 (a) Flight pattern and time history

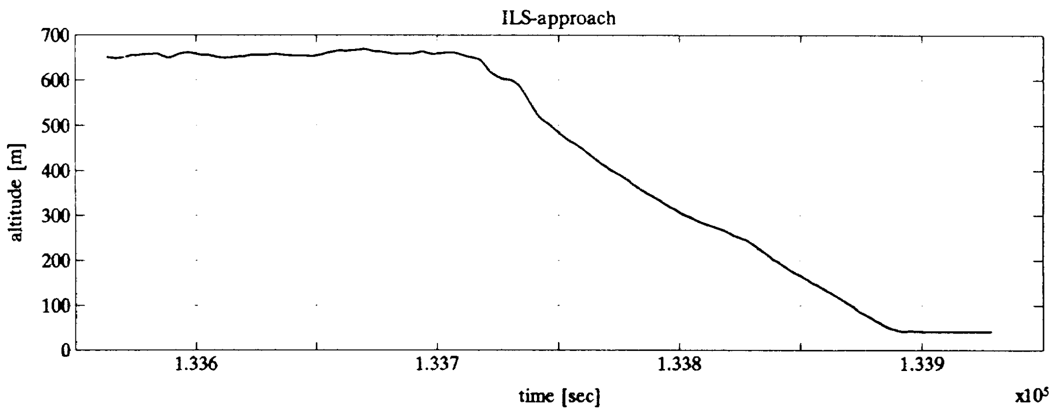

Figure 4.2 (b) Flight pattern and time history

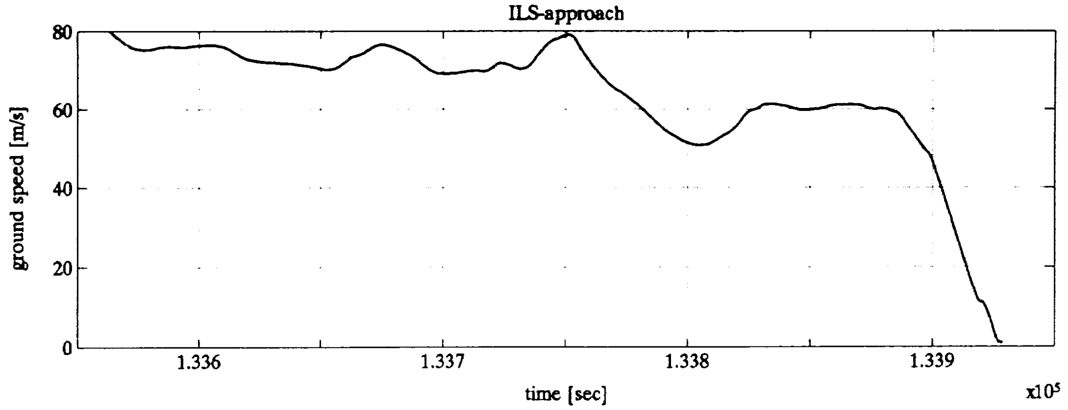

Figure 4.2(c) Flight pattern and time history

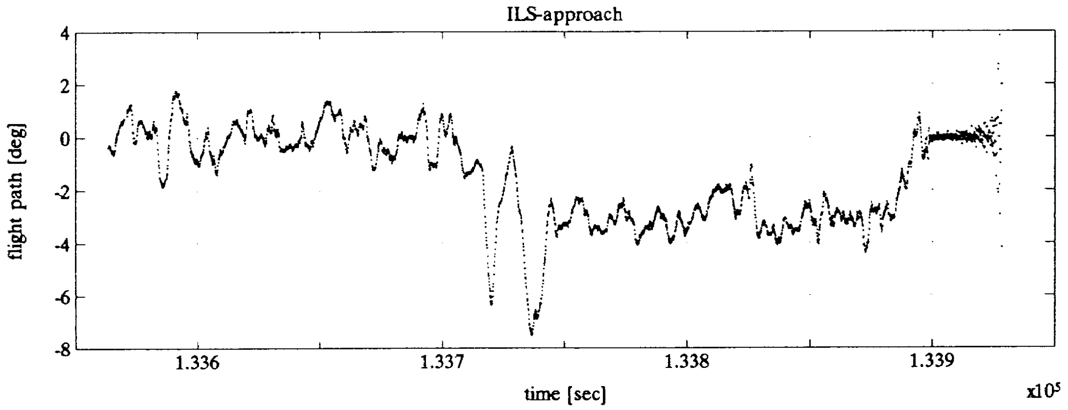

Figure 4.2(d) Flight pattern and time history

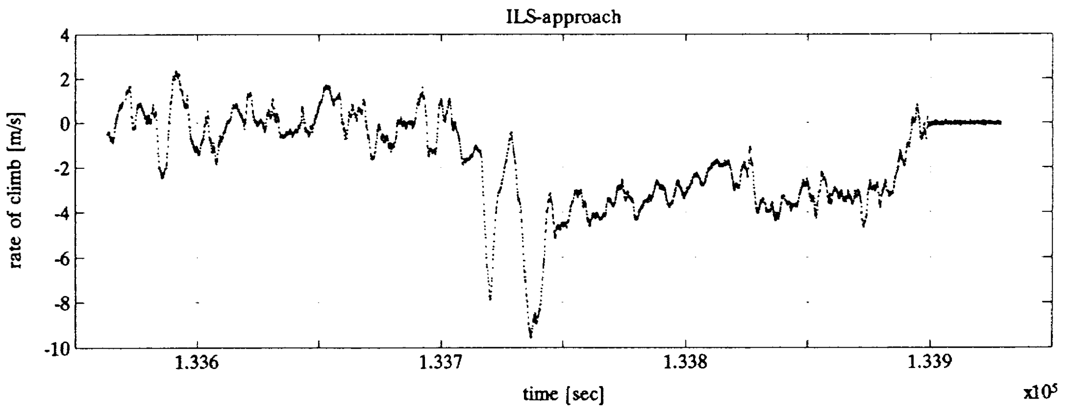

Figure 4.2(e) Flight pattern and time history

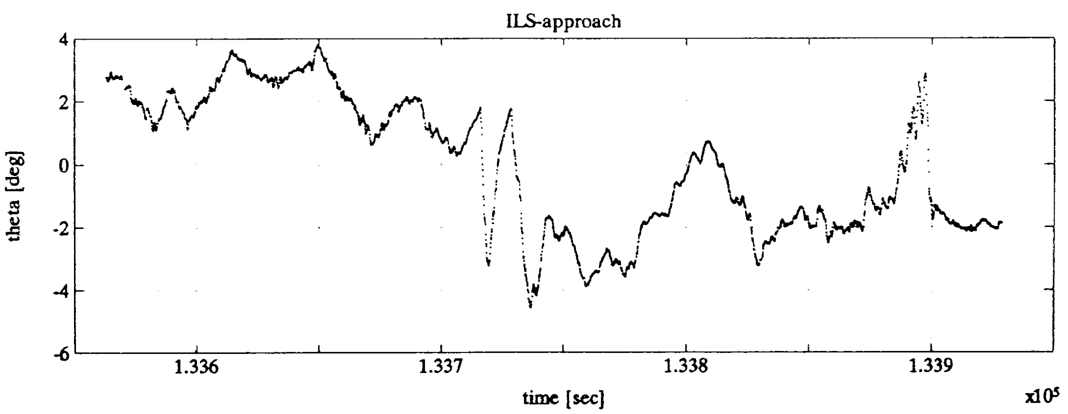

Figure 4.2(f) Flight pattern and time history

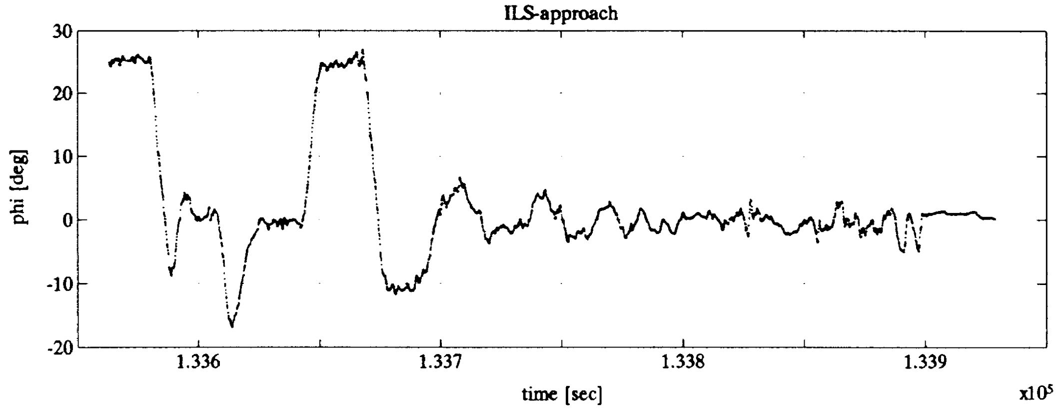

Figure 4.2 (g) Flight pattern and time history

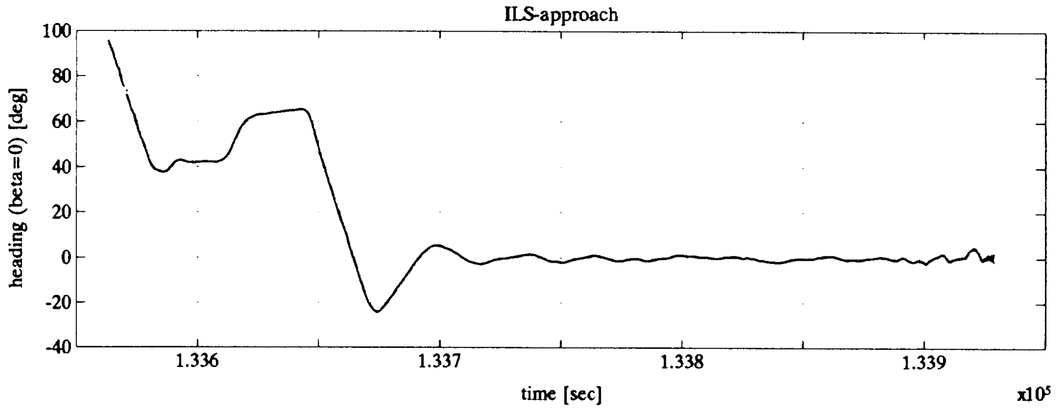

Figure 4.2 (h) Flight pattern and time history

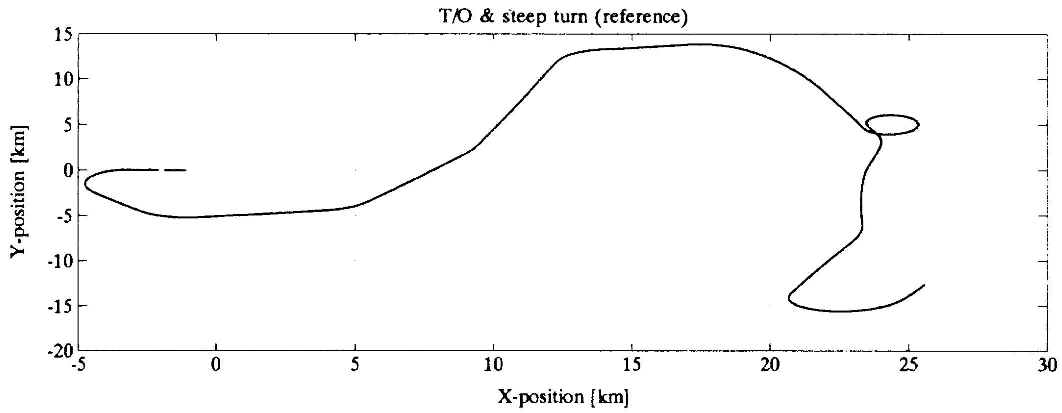

Figure 4.3 (a) Flight pattern and time history

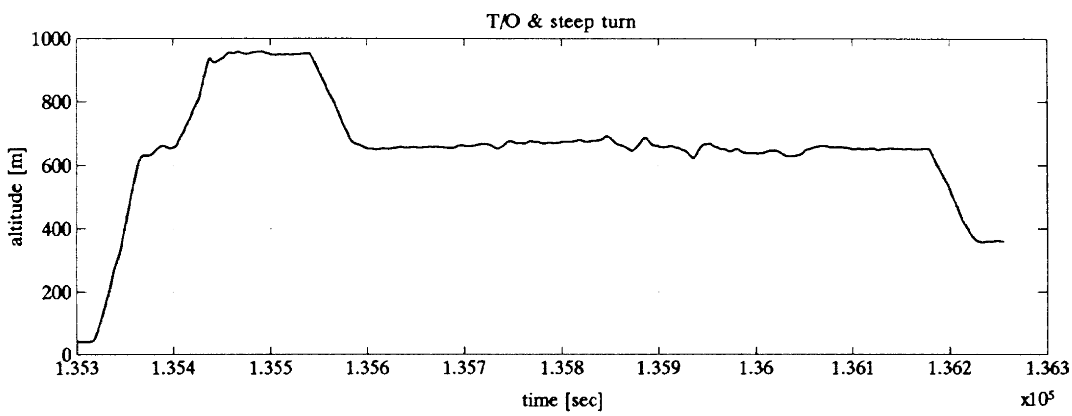

Figure 4.3 (b) Flight pattern and time history

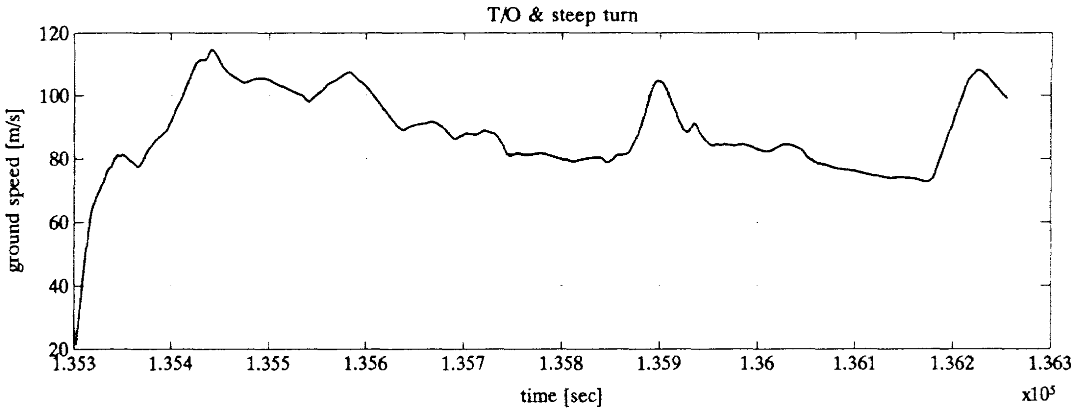

Figure 4.3(c) Flight pattern and time history

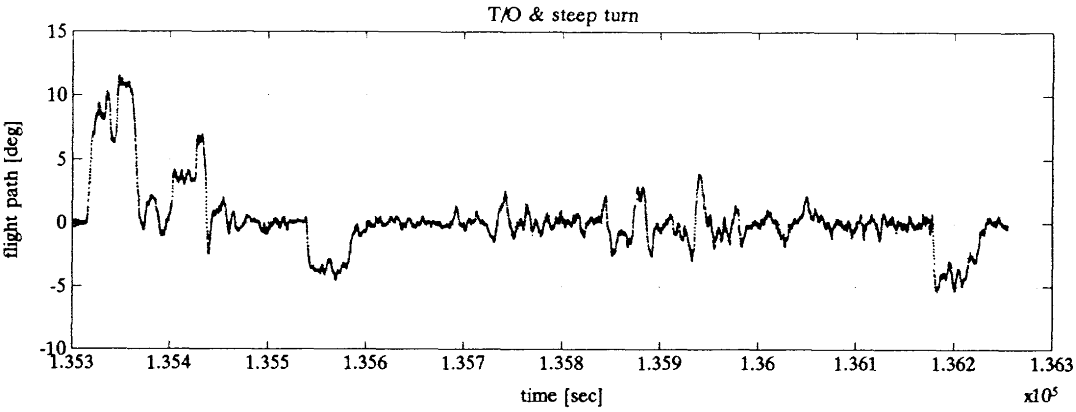

Figure 4.3(d) Flight pattern and time history

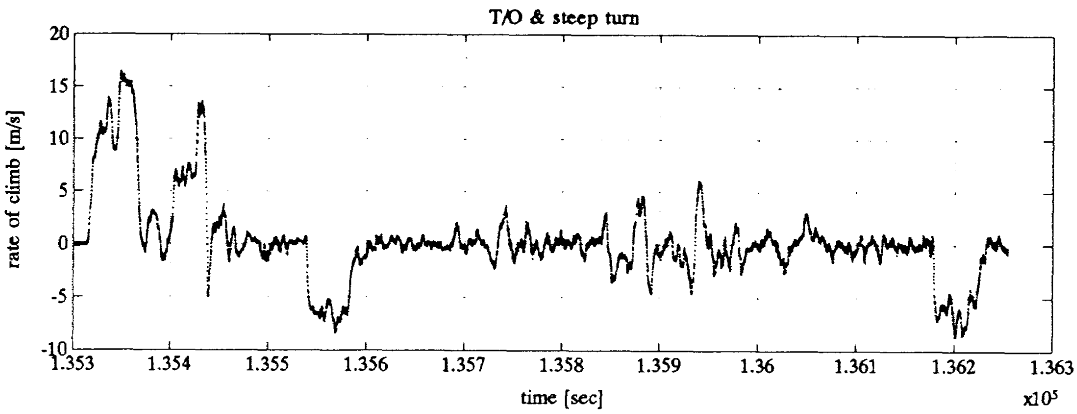

Figure 4.3(e) Flight pattern and time history

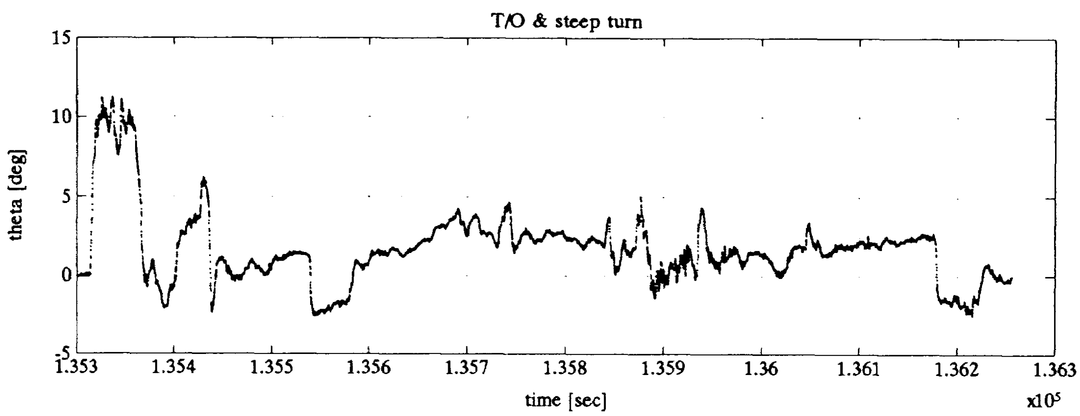

Figure 4.3(f) Flight pattern and time history

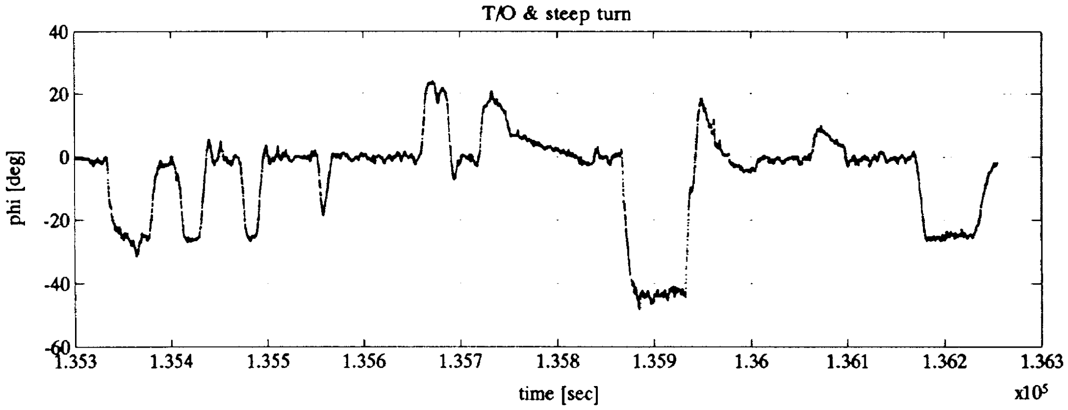

Figure 4.3 (g) Flight pattern and time history

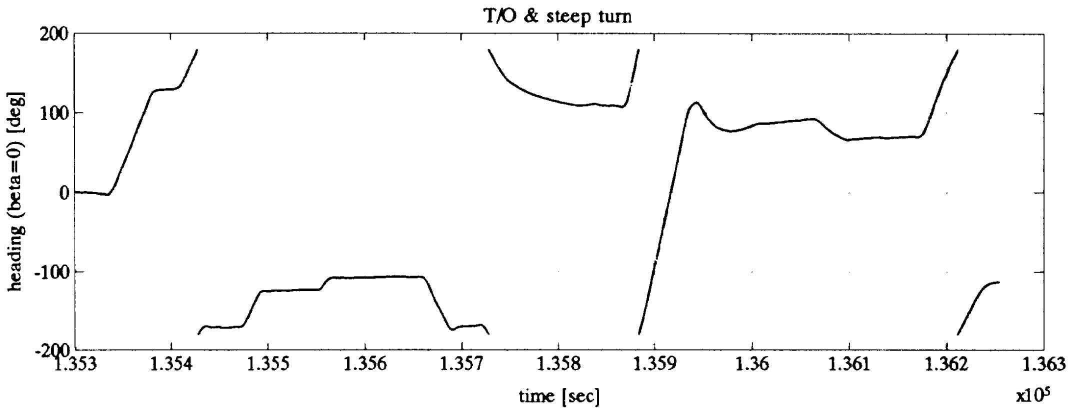

Figure 4.3 (h) Flight pattern and time history

Table 4.2 Flight pattern and time history

Test Case	Fig. No.	Contents
ILS-approach	4.2 (a)	flight pattern in horizontal view
	4.2 (b)	aircraft altitude
	4.2 (c)	ground speed of the aircraft
	4.2 (d)	flight path angle, γ (Gamma)
	4.2 (e)	rate of climb
	4.2 (f)	pitch angle, θ (Theta)
	4.2 (g)	roll angle, ϕ (Phi)
	4.2 (h)	heading, ψ (Psi)
T/O & steep turn	4.3 (a)	flight pattern in horizontal view
	4.3 (b)	aircraft altitude
	4.3 (c)	ground speed of the aircraft
	4.3 (d)	flight path angle, γ (Gamma)
	4.3 (e)	rate of climb
	4.3 (f)	pitch angle, θ (Theta)
	4.3 (g)	roll angle, ϕ (Phi)
	4.3 (h)	heading, ψ (Psi)

4.4 Evaluation MLS data comparing with true reference by DGPS

Real flight test data of MLS is shown in figure 4.4 and 4.5. Figure 4.4 shows the case of the ILS-approach. Figure 4.5 shows the case of Take-off (T/O) and steep turn. The definition and data processing were explained in previous section. The time means GPS time described by second in these time history. Contents of these figures are explained in table 4.3.

4.4.1 Angle Accuracy

Accuracy of the MLS angle in this flight test equipment is shown in table 4.4.

In case of ILS-approach, the mean of SD for elevation is approximately 0.015 degrees. The mean of the elevation bias is approximately 0.025 degrees. The mean of the SD for azimuth is approximately 0.015 degrees. The mean of the azimuth bias is approximately −0.075 degrees. The MLS angles contains bias. It is possible that the alignment of the MLS antennas is not complete.

In case of take off and steep turn, the mean of the SD for elevation is approximately 0.03 degrees. The elevation bias is too large and not constant. The mean of SD for azimuth is approximately 0.04 degrees. The azimuth bias is too large and not constant. It is possible follows. Position correction of the on-board MLS receiver antenna is neglected in this study, MLS signal reaches through multi-path cause of reflection of the aircraft body.

The accuracy of the DGPS position for maneuvering or fast flying aircraft is not obvious since the technology is under developing.

4.5 Comparison with Japanese testing

Similar flight test of the MIAS was carried out by National Aerospace Laboratory in Japan[9), 10)]. They have a MLS and a DME/p equipment at Sendai airport. A laser tracker was used in order to get true references. The laser tracker is a ground equipment that can track an aircraft automatically. It is able to get aircraft positions with decimeter accuracy.

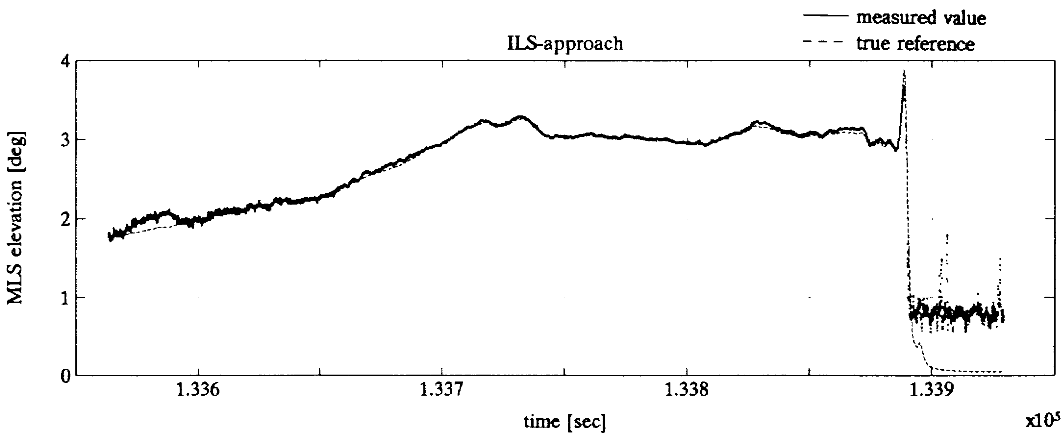

Figure 4.4 (a) MLS data comparing with DGPS

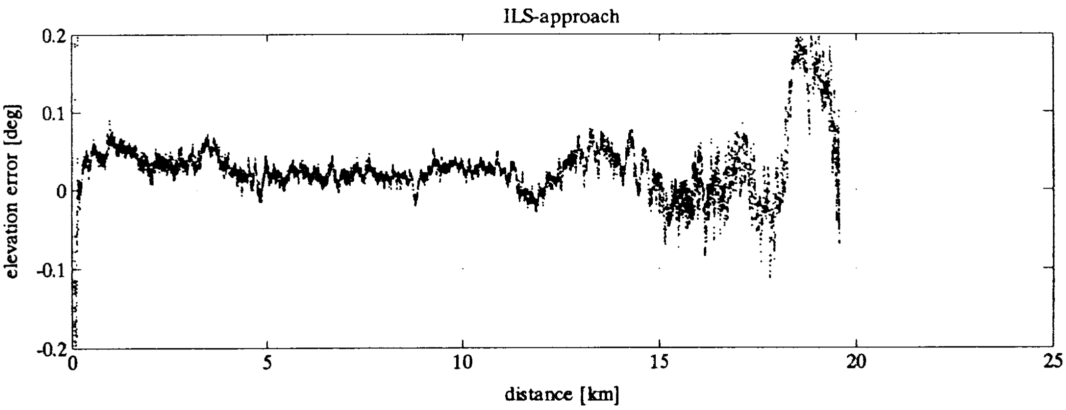

Figure 4.4 (b) MLS data comparing with DGPS

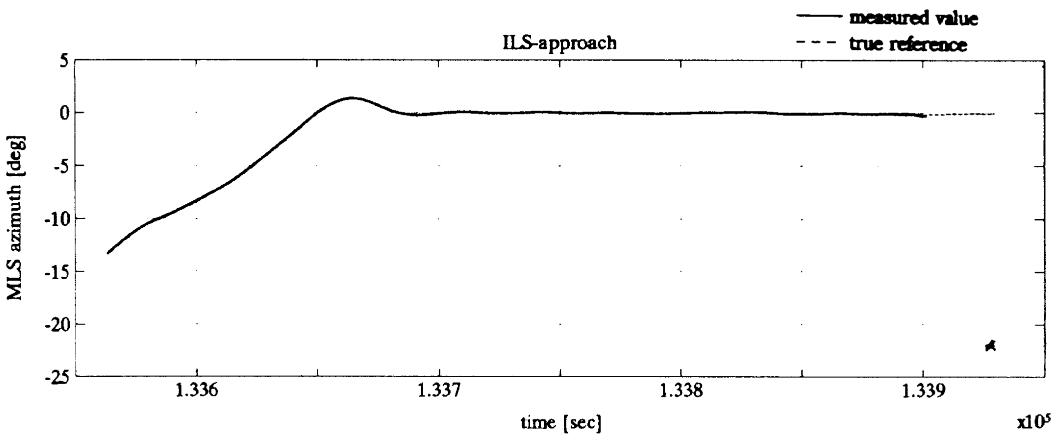

Figure 4.4(c) MLS data comparing with DGPS

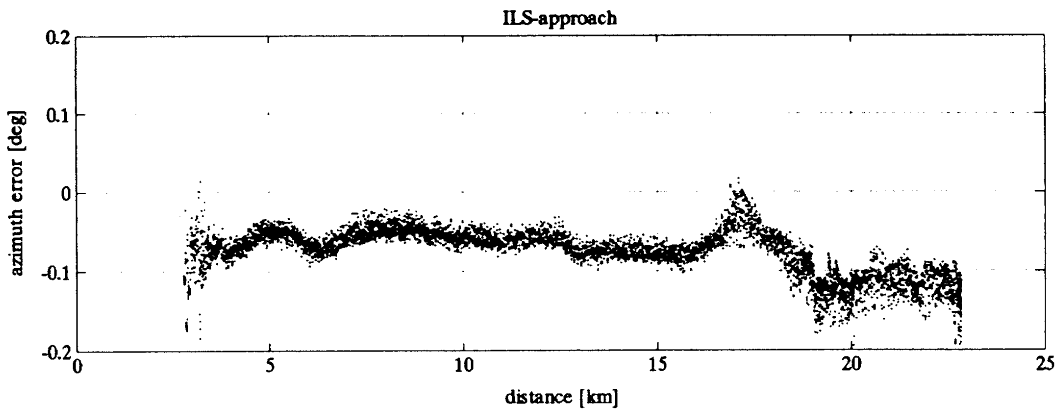

Figure 4.4(d) MLS data comparing with DGPS

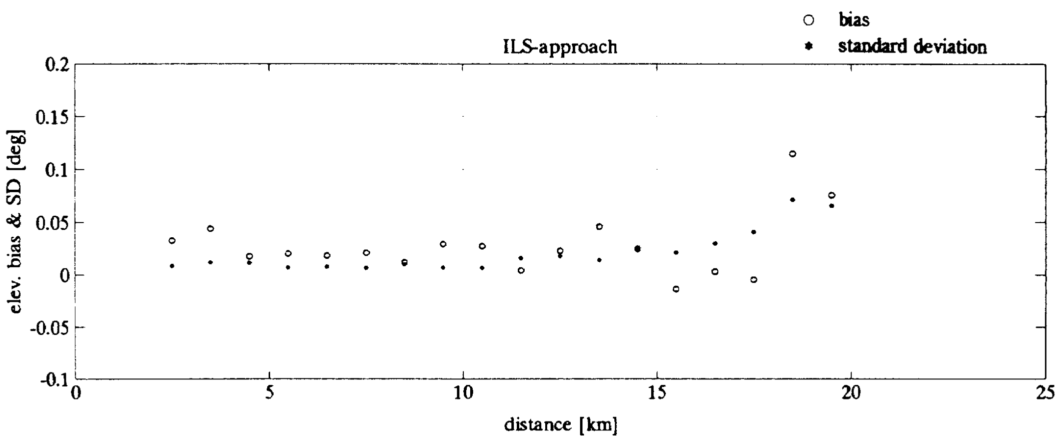

Figure 4.4(e) MLS data comparing with DGPS

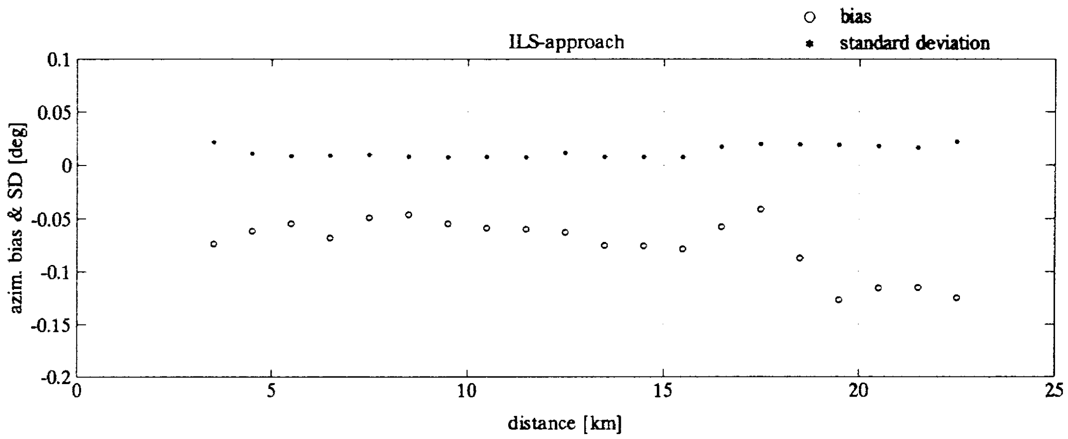

Figure 4.4 (f) MLS data comparing with DGPS

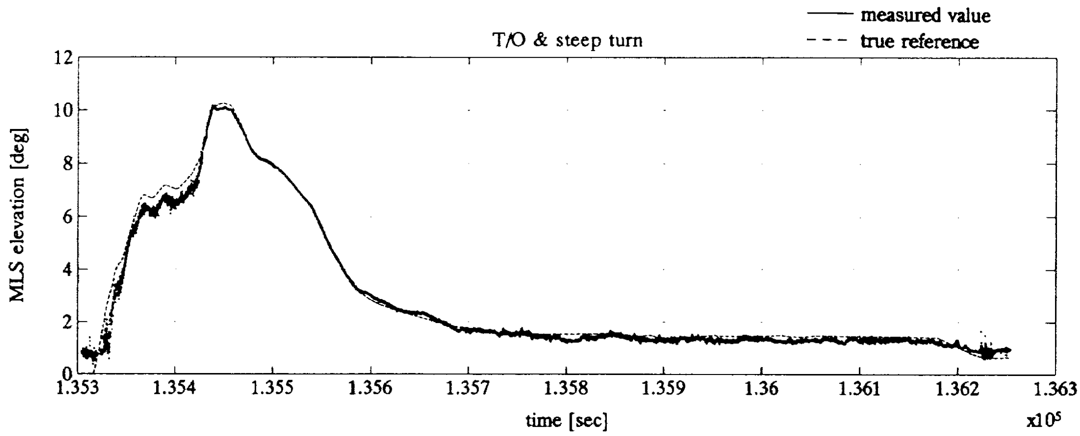

Figure 4.5 (a) MLS data comparing with DGPS

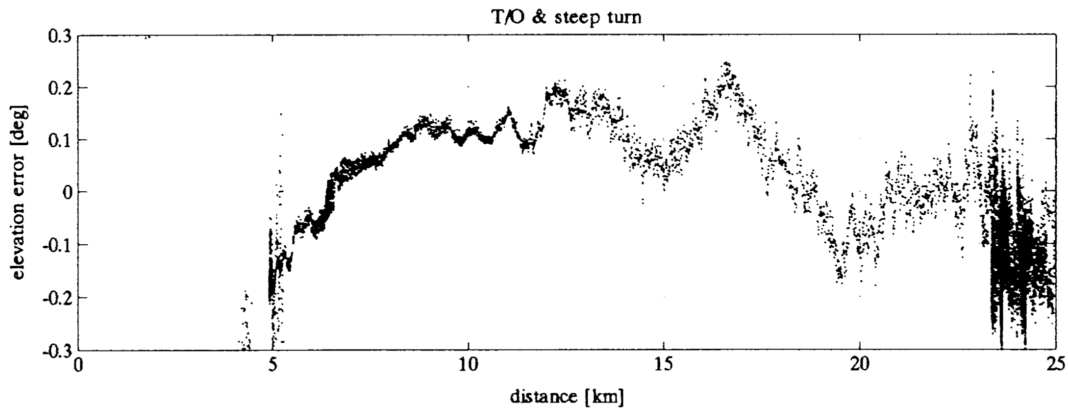

Figure 4.5 (b) MLS data comparing with DGPS

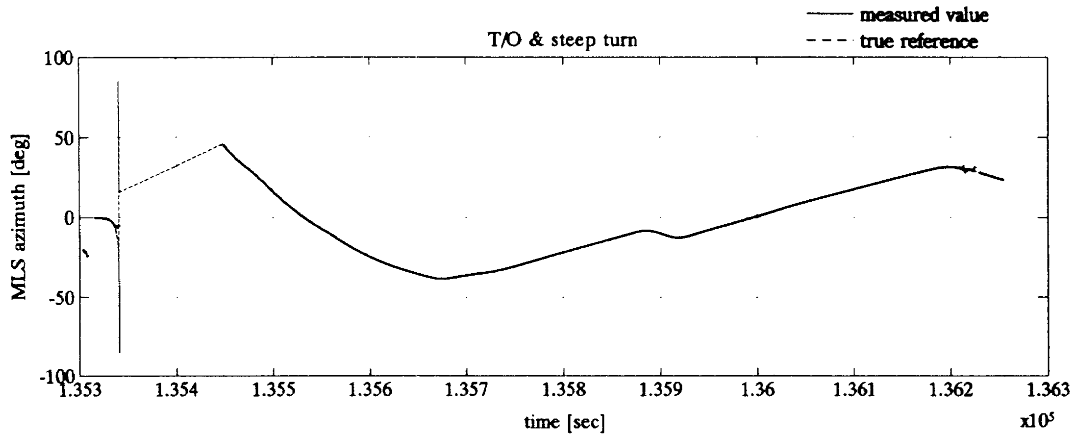

Figure 4.5(c) MLS data comparing with DGPS

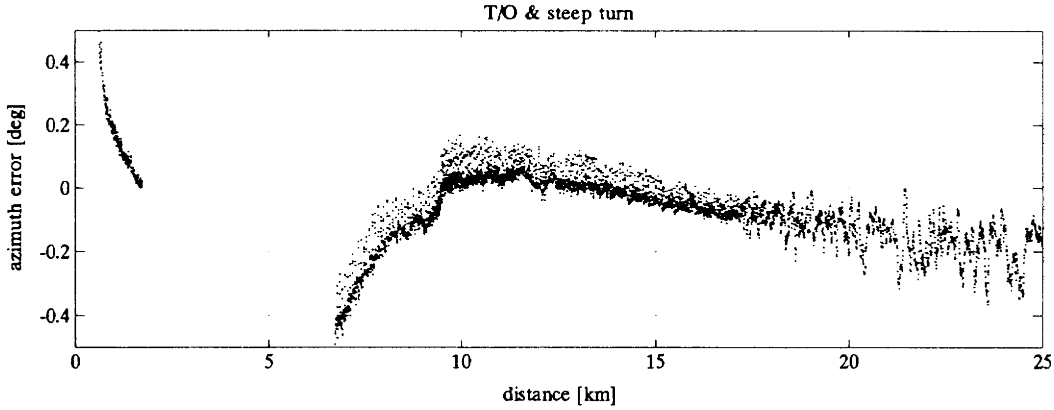

Figure 4.5(d) MLS data comparing with DGPS

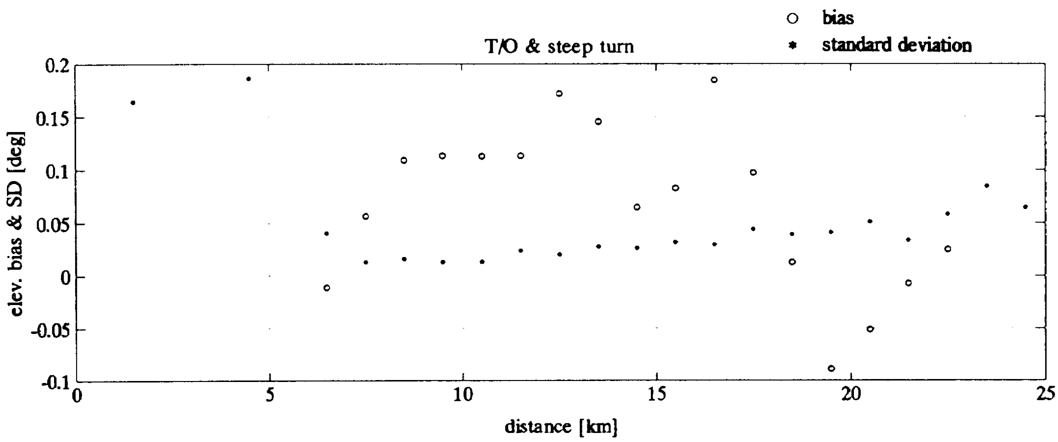

Figure 4.5(e) MLS data comparing with DGPS

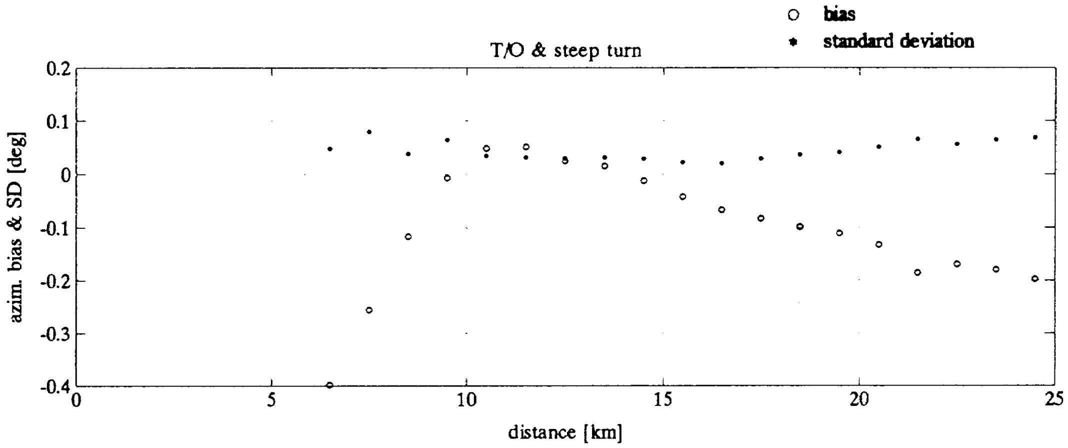

Figure 4.5(f) MLS data comparing with DGPS

A part of these flight test results is shown in figure 4.6. This flight case is a straight approach on a 6 degree glide path. The case is similar to ILS-approach case in the MIAS flight test. Some data were dropped out around 80 seconds because of tracking error of the laser tracker. Accuracy of the MLS elevation angle is approximately 0.015 degrees (1 σ) except for a bias. The bias of the elevation angle is approximately 0.03 degrees and the bias is constant during all time and all distances. Accuracy of the MLS azimuth angle is approximately 0.02 (1 σ) degrees except for a bias. The bias of the azimuth angle is approximately 0.02 degrees and the bias is constant during all time and all distances. Accuracy of the MLS angle in Japanese testing is shown in table 4.5. This result almost comparable with the ILS-approach case of the MIAS flight test result.

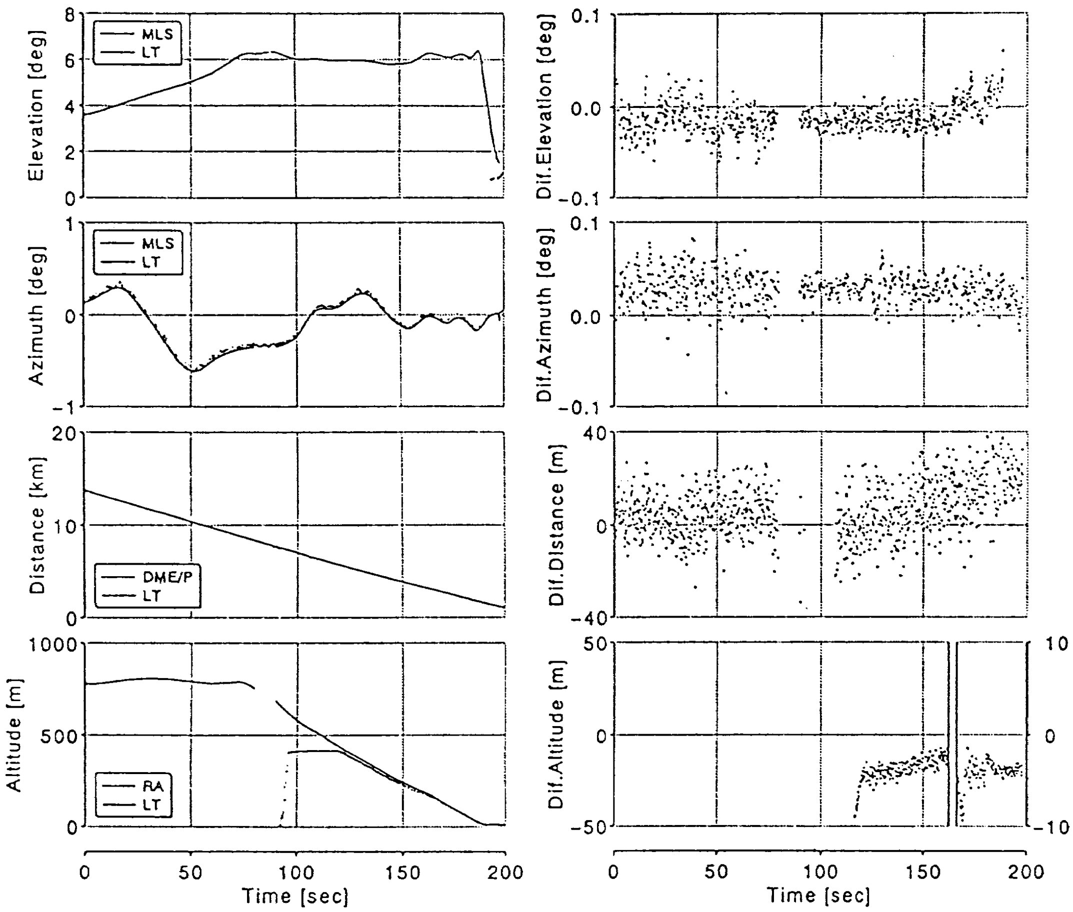

Figure 4.6 Japanese testing

Table 4.3 MLS data comparing with DGPS

Test Case	Fig. No.	Contents	Comment
ILS-aproach	4.4 (a)	elevation angle	The values agree almost completely with each other. The aircraft is out of coverage zone of MLS in the last noisy part because the aircraft already landed.
	4.4 (b)	elevation error	Before distance is about 15 kilometers, the aircraft was turning.
	4.4 (c)	azimuth angle	The values agree almost completely with each other.
	4.4 (d)	azimuth error	The azimuth error contains bias.
	4.4 (e)	bias and SD elevation angle	The mean of the SD is approximately 0.015 degrees except for a bias. The mean of the bias is approximately 0.025 degrees.
	4.4 (f)	bias and SD azimuth angle	The mean of the SD is approximately 0.015 degrees except for a bias. The mean of the bias is approximately 0.075 degrees.
T/O & steep turn	4.5 (a)	elevation angle	The values agree almost completely with each other in this elevation scale.
	4.5 (b)	elevation error	The aircraft was turning around 24 kilometers of distance. The elevation error contains bias and the bias is not constant. The bias and the deviation are growing large over 12 kilometers of distance. The cause of the error is not obvious as the aircraft was not maneuvering intensely in this range.
	4.5 (c)	azimuth angle	MLS angle data were dropped out over 40 degrees because it is out of coverage zone of MLS.
	4.5 (d)	azimuth error	The azimuth error contains bias and the bias is not constant.
	4.5 (e)	bias and SD elevation angle	The mean of the SD is approximately 0.03 degrees except for a bias. The bias is too large and not constant.
	4.5 (f)	bias and SD azimuth angle	The mean of the SD is approximately 0.04 degrees except for a bias. The bias is too large and not constant.

Table 4.4 MLS angle accuracy in MIAS flight test

	elevation(deg)		azimuth(deg)	
	bias	SD	bias	SD
ILS-approach	0.025	0.015	-0.075	0.015
Take-off and steep turn	--- *	0.03	--- *	0.04

* not constant

Table 4.5 MLS angle accuracy in Japanese flight tes

	elevation (deg)		azimuth (deg)	
	bias	SD	bias	SD
Straight approach	0.03	0.015	0.02	0.02

5. Conclusions

In the MIAS project, strict request for accuracy of each subsystem is not obvious yet. However, data characteristics about each subsystem such as the MLS is required in order to design the MIAS. As the result of the MIAS flight test, follow items were found out.

1) It was shown in chapter 4, bias and SD of the MLS measured angles were obtained by flight tests using the MIAS equipment. As a weight of the MLS data for position calculation is decided for hybridized navigation solution, the flight test results are useful for implementation of the MIAS.

2) In the case of an ILS-approach, the acuracy seems to be enough for approach but the MLS angles contains bias. However, the bias is not so critical for approach because every aircraft receive same signal.

3) In the case of take off and steep turn, the bias is too large and not constant, however it is difficult to indicate the cause of the bias because both MLS and DGPS have error factors. In order to investigate into the error factors, further experiments using other test equipment is required.

4) In the case of an ILS-approach, the result is almost comparable with the result of Japanese testing. The test case in Japanese testing is a straight approach which is similar to the ILS-approach.

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