MLS Performance and Evaluation of ALFLEX

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ABSTRACT

The MLS of ALFLEX navigation system is outlined and the performance in the ALFLEX trials is evaluated. The results are satisfactory in receiving power and measuring accuracy. Subjects to be discussed for HOPE applications are also identified.

1. MLS System Overview

1.1 System Configuration

The Microwave Landing System (MLS) is a navigation aid designed for the ALFLEX. It provides angular guidance information in the approaching and landing phase of the ALFLEX vehicle. As depicted in Fig. 1, the system consists of ground equipments and an on-board receiver. The on-board MLS receiver detects microwave signals transmitted from the ground equipments and measures angles of the ALFLEX vehicle during approach and landing relative to the ground elements.

The MLS ground equipment comprises azimuth guidance, elevation guidance and remote control elements. The azimuth guidance equipment located on the extended centerline off the end of the runway provides azimuth guidance information. The elevation guidance equipment located laterally off the runway 160m and 300m from threshold provides elevation guidance information. The remote control

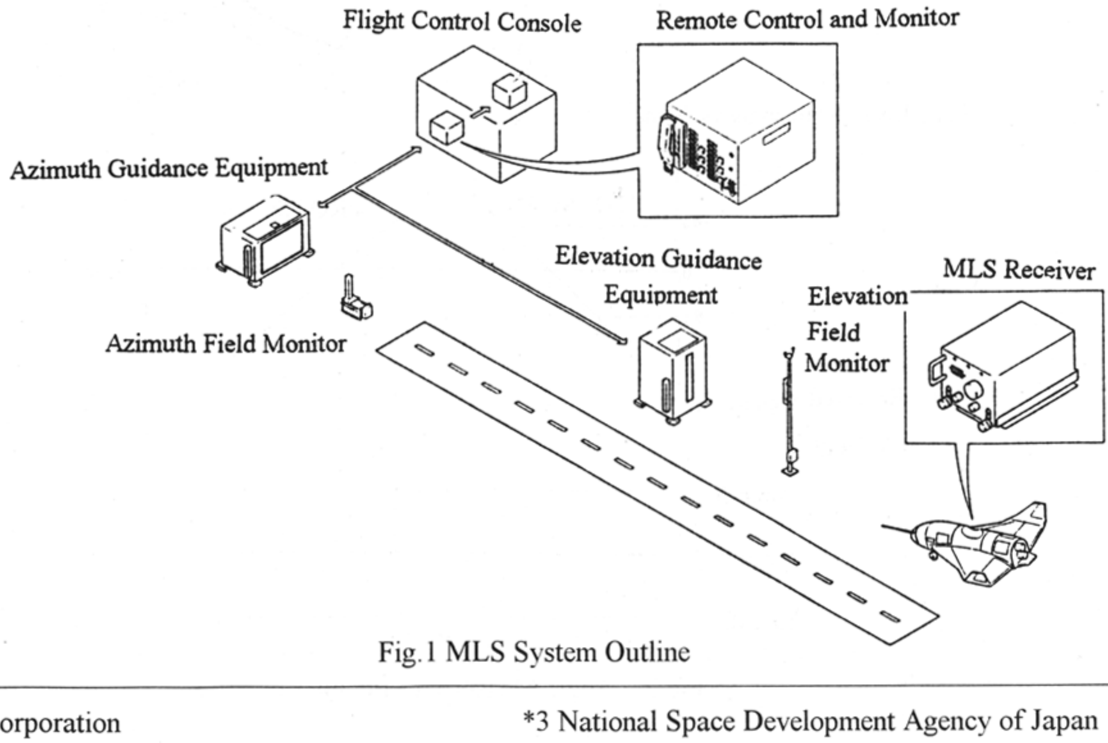

Fig. 1 MLS System Outline

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unit located in the flight control facility provides monitor and control of operation of the azimuth and elevation guidance equipments as well as providing operational status of the MLS system to the flight control console.

1.2 Basic Principles of Guidance Angle Measurement

The basic azimuth and elevation angle guidance signal generation is shown Fig. 2. The azimuth antenna generates a narrow vertical fan-shaped beam and scans it ("TO" and "FRO") about the runway centerline horizontally at a precise rate. As the "TO" beam sweeps past the vehicle, the signal is detected and a pulse is generated in the receiver. The beam returns as a "FRO" beam and the second sweep past the vehicle generates a "FRO" pulse. The time measured between the "TO" and "FRO" pulses is directly related to the azimuth angle with respect to runway centerline. The ALFLEX ① approaching on left side (viewing from the azimuth station) of the runway would generate "TO" / "FRO" pulses with much time separation compared to the ALFLEX ② and ③. The elevation antenna generates a narrow horizontal fan-shaped beam and scans it ("TO" and "FRO") up and down over the elevation coverage angle. The elevation angle measurement is performed in a similar manner as in azimuth.

1.3 MLS System Requirements

The system requirements for the ALFLEX are summarized in Table 1.

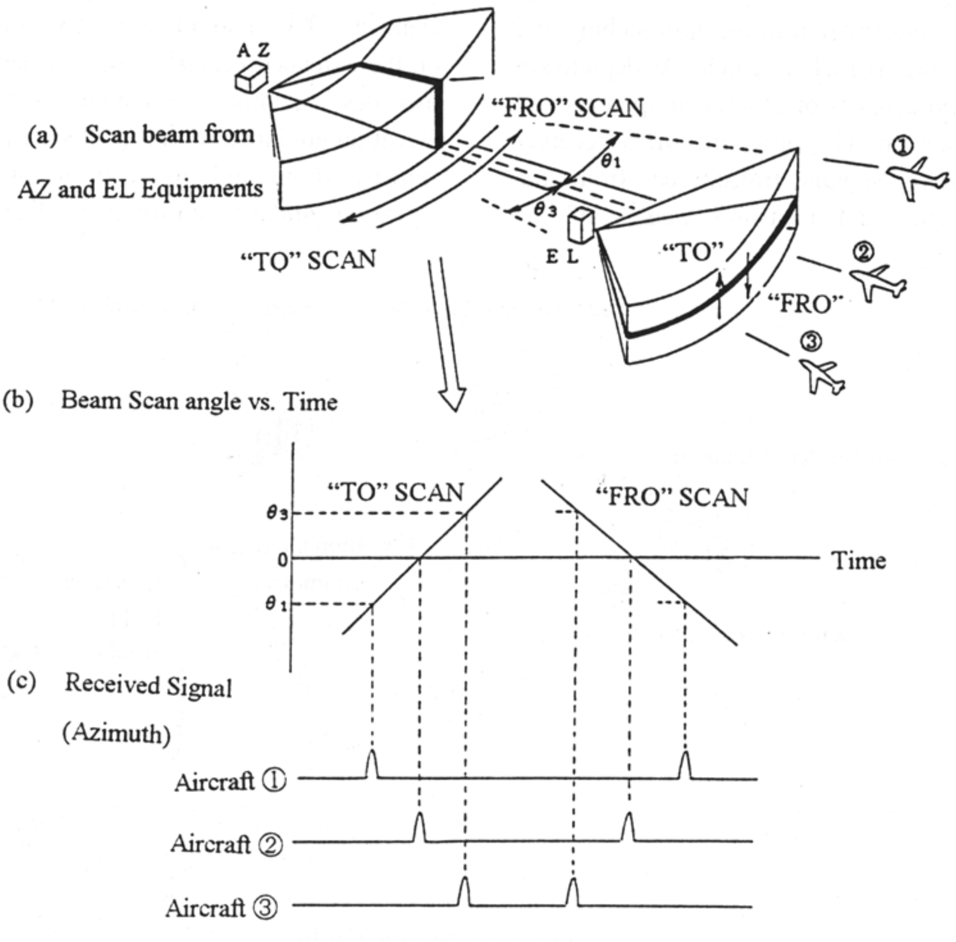

Fig.2 Angle Measuring Principles of MLS

Table 1 MLS System Requirements

	AZ	EL
Coverage	-40deg to +40deg	+0.9deg to +40deg
Transmitter Power	2W	2W
Error Budget at Threshold		
Bias	0.027deg	0.110deg
Noise(3sigma)	0.081deg	0.099deg
Error Budget at X=12km		
Bias	0.027deg	0.041deg
Noise(3sigma)	0.104deg	0.111deg

2. ALFLEX Flight Results and Evaluation

2.1 Summary

The typical performance of first free flight(#01) is shown in Fig. 3 through Fig. 11. Fig. 3 is telemetry data of the azimuth beam level at the on-board receiver in #01. The beam level is as strong as expected and has a good margin with respect to the minimum receiving level of the receiver. Fig. 4 is a simulation result for the same flight conditions. The simulation is considered well in accordance with the actual flight data when considering the limited availability of the simulation models. That is, some simulation parameters such as an on-board antenna pattern and cable loss which are derived from the scale model test data, and the specifications of the cable, respectively, instead of using actual data. Also a multipath effect is simulated only for ground reflection assuming the earth surface is simple plane. Concerning the elevation beam level, the similar comparison is to between the flight data(Fig. 5) and simulation(Fig.6).

Fig. 7 and 8 indicate the #01 telemetry profiles of MLS measured angles, azimuth and elevation, respectively. To evaluate the MLS angle measurement accuracy, the MLS angle telemetry data was compared with the reference which is derived from the laser tracking data. The difference between MLS telemetry and the reference is shown in Fig. 9 and 10 as MLS error. The MLS error for the 13 ALFLEX trials is summarized in Table 2. In Table 2 the MLS elevation error is evaluated at three flight stages (prior to separation, minus 2km,and minus 500m) separately where the MLS error profile indicates different profiles as illustrated in Fig. 10. The overall performance of angle measurement accuracy is satisfactory compared with the system requirements in Table 1. The data of all 13 trials are similar to the first trial and are satisfactory. Typical characteristics observed in the flight data are discussed below.

Table 2 MLS Error Summary (with Respect to Laser Tracker)

Flight No.	AZ average deg	AZ 2sigma deg	EL(prior to release) average deg	EL(prior to release) 2sigma deg	EL(-2km) average deg	EL(-2km) 2sigma deg	EL(-500m) average deg	EL(-500m) 2sigma deg
#01	0.012	0.013	0.017	0.018	-0.015	0.012	-0.045	0.059
#02	0.010	0.013	0.020	0.017	-0.008	0.012	-0.034	0.046
#03	0.002	0.016	0.013	0.016	-0.022	0.014	-0.079	0.071
#04	0.010	0.014	0.013	0.016	-0.016	0.016	-0.059	0.053
#05	0.006	0.014	0.019	0.016	-0.008	0.017	-0.059	0.076
#06	0.010	0.014	0.016	0.021	-0.018	0.015	-0.069	0.076
#07	0.012	0.014	0.022	0.017	-0.009	0.013	-0.046	0.076
#08	0.013	0.013	0.022	0.018	-0.008	0.013	-0.044	0.064
#09	0.005	0.019	0.016	0.014	-0.010	0.013	-0.052	0.064
#10	0.001	0.020	0.021	0.016	-0.010	0.014	-0.046	0.072
#11	0.009	0.013	0.017	0.017	-0.016	0.014	-0.069	0.069
#12	0.009	0.013	0.021	0.018	-0.012	0.014	-0.053	0.069
#13	0.011	0.014	0.025	0.021	-0.008	0.015	-0.030	0.065

2.2 Periodic Variation of Azimuth Error

Fig. 7 indicates periodic variation of azimuth angle telemetry. Similar variation was observed first in the hanging tests with larger magnitudes of variation. As discussed in Section 3.2, the variation is caused by multipath reflection from the foreground.

2.3 Trend of Elevation Error

Fig. 11 shows a profile of elevation angular velocity of the #01 derived from the laser tracking data. This angular velocity profile is similar to the profile of elevation error in Fig. 10. This implies that elevation error depends on the elevation angular velocity. However the error is within the system requirements.

2.4 Increase of Elevation Noise Near Runway End

In Fig. 10, the noise of the elevation error begins to increase approximately at minus 1000m from the runway threshold. The causes of the increasing noise are likely to be an antenna swapping and multipath effects. At this stage of the flight path, the antenna swapping and multipath effects can be easily induced compared to other flight stages due to a fast elevation angle change and a lobe of on-board antenna pattern. However the order of magnitude of the noise is comparable with the error budget in the system requirements and the system worked satisfactorily during the flight.

3. Special Subjects

Some interesting phenomena were observed in the preparation phase of the ALFLEX trials as well as the flight data shown above. Improvements for the future MLS system are discussed below.

3.1 Out of Beam Multipath

In the performance check, the unexpected MLS angle was measured in the azimuth telemetry. The observed angle matched with the direction of the reflection path from the flight control facility located off the runway. It was found that the reflection from the flight control facility of azimuth beam radiation was erroneously acquired by the receiver and induced the incorrect angle measurement. To avoid this multipath, the azimuth beam scanning range was reduced to the maximum of 10 degrees allowableafor the ALFLEX flight, considering its limited flight path though the scanning range had been set to 42 degrees initially. For future HOPE system it is needed to take anti-multipath measures in systematic approach such as installing directional on-board antennas and also implementing discrimination function of multipath signal in the receiver. The multipath discrimination function has not been installed in the ALFLEX receiver as the purpose of ALFLEX trials is to obtain the basic technical data.

3.2 In-beam Multipath

In the hanging flight test, azimuth angle telemetry indicated periodic variation with a magnitude of approximately one-tenth of a degree. The variation showed two significant characteristics;

1) The greater the azimuth and elevation angles, the larger the variation.
2) The closer the vehicle is to the ground station, the shorter the time period.

This implied that radiation reflected from the inclined fore-ground of the azimuth station deformed the envelope of the received beam pulse interfering the direct radiation from the station, and induced angle measurement error. This was corrected by leveling the fore-ground and finally the variation was reduced to the order of magnitude shown in Fig. 7.

3.3. Transmitter Power

As indicated in Table 1, the transmitter power of 2 watts assures the operation of ALFLEX of which coverage volume is limited compared to future HOPE. The future HOPE specifications require a larger coverage volume and also higher transmitter power to assure its operation.

4. Conclusion

The ALFLEX MLS system achieved satisfactory flight performance as described, and also clarified that for the development of HOPE the areas of multipath and transmitter power require further research. Systematic implementation of anti-multipath measures shall be considered including on-board antennas, and higher transmitter power would be required to achieve larger coverage volume for HOPE.

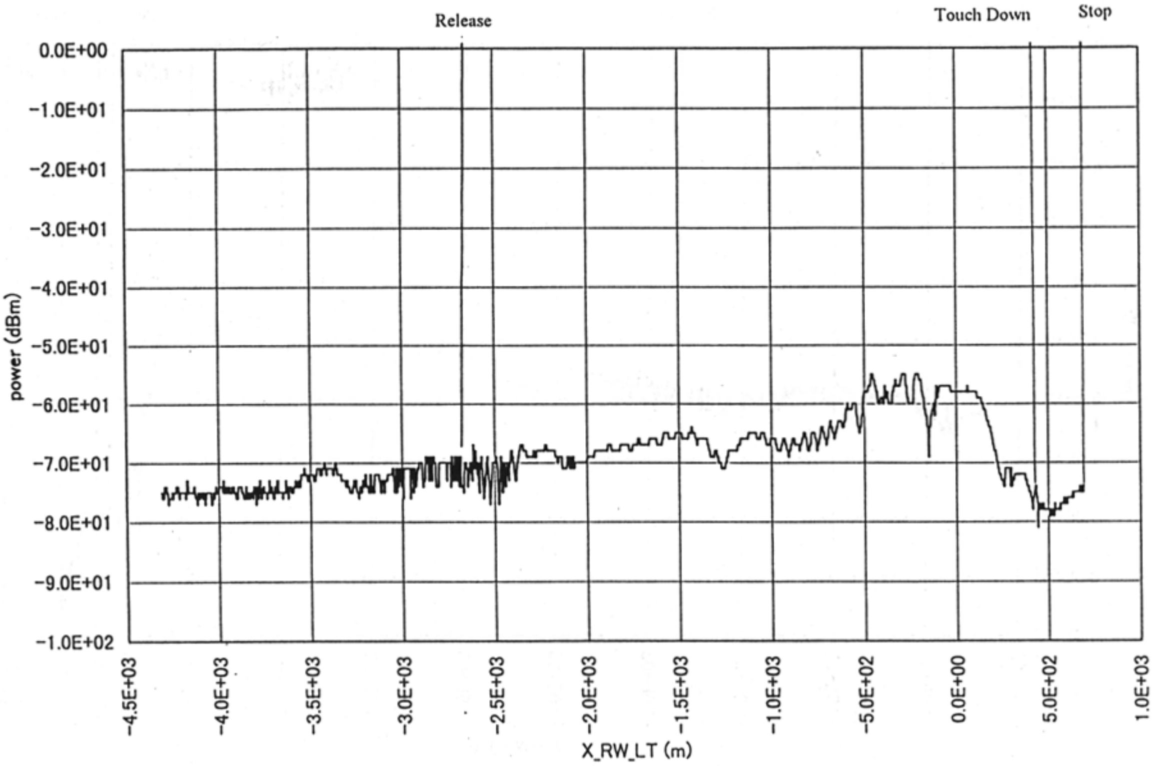

Fig.3 MLS AZ Beam Level (#01)

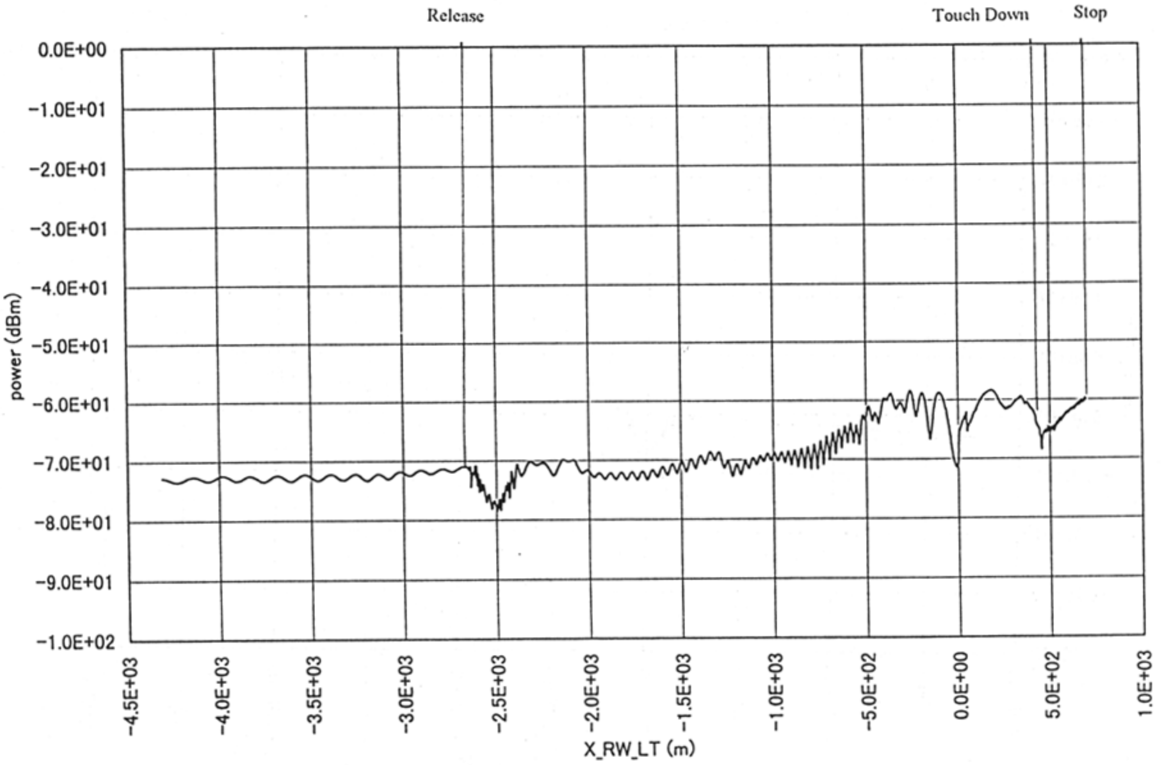

Fig.4 MLS AZ Beam Level (#01 Simulation)

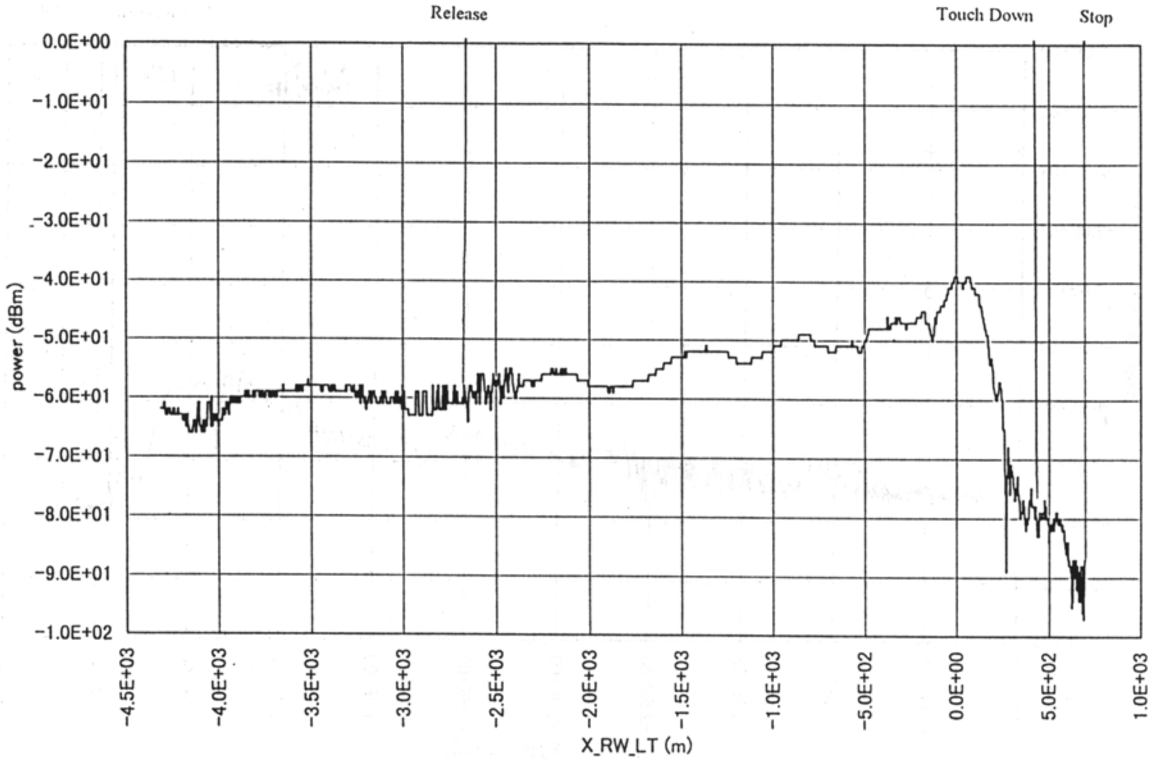

Fig.5 MLS EL Beam Level (#01)

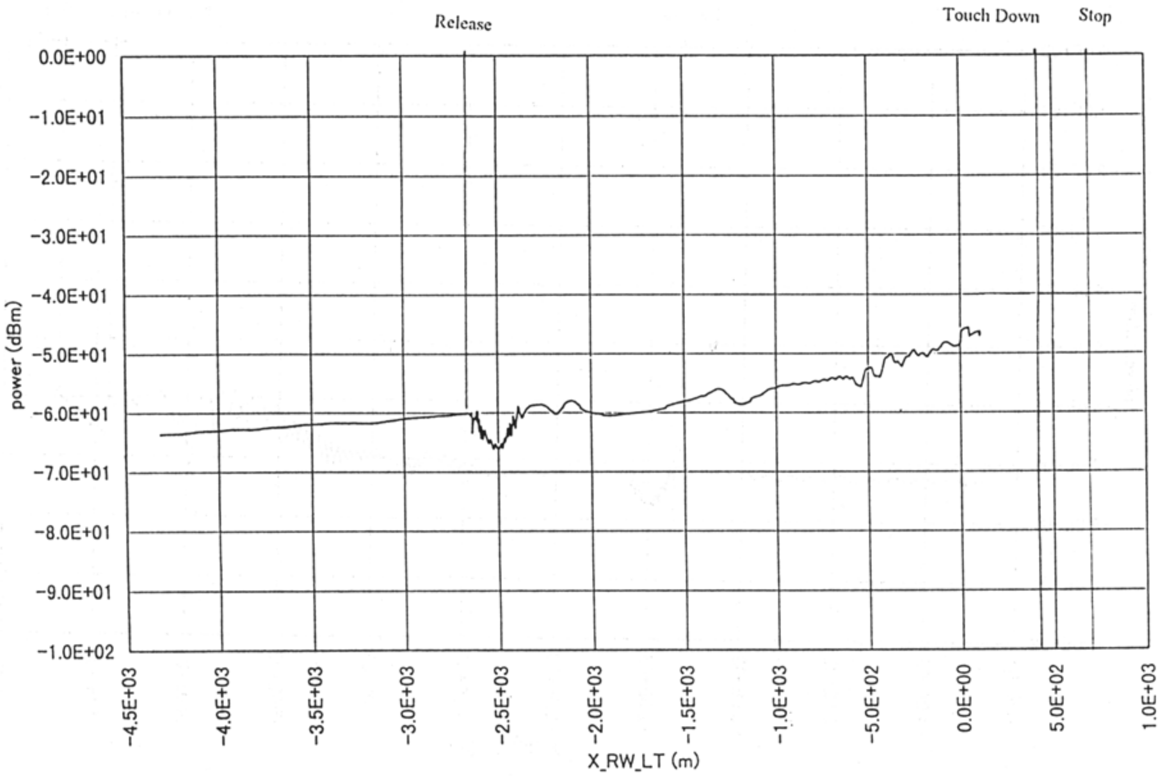

Fig.6 MLS EL Beam Level (#01 simulation)

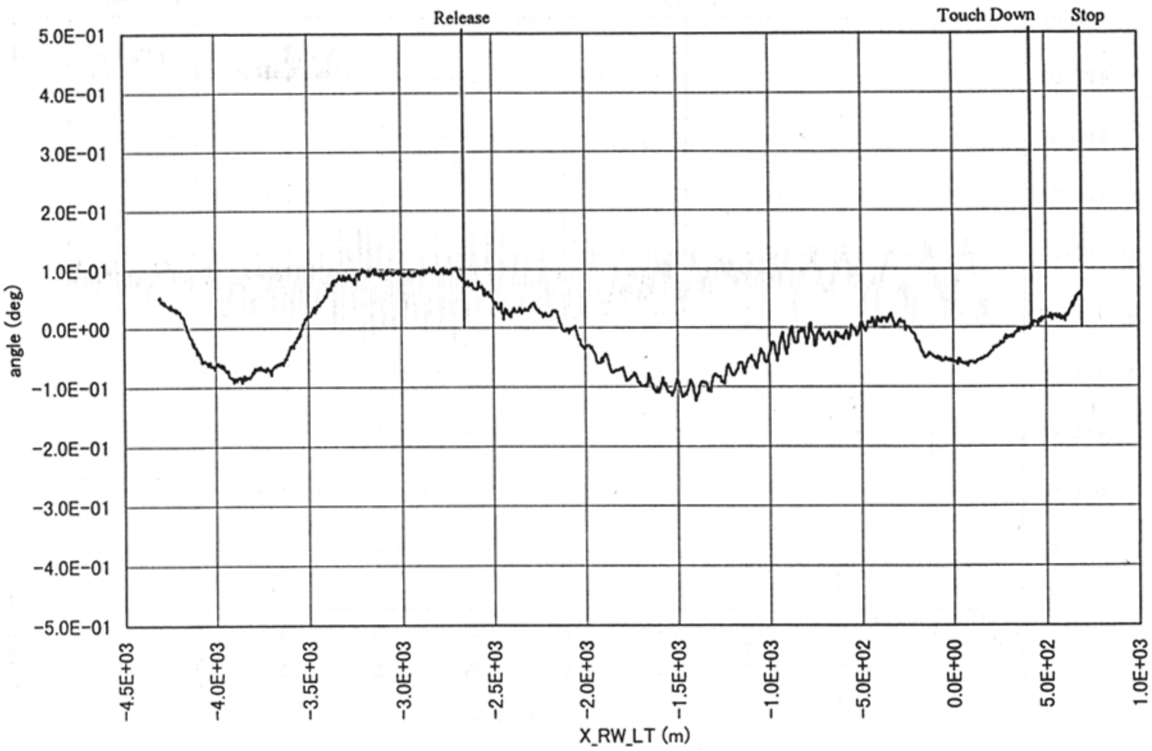

Fig.7 MLS AZ Angle (#01)

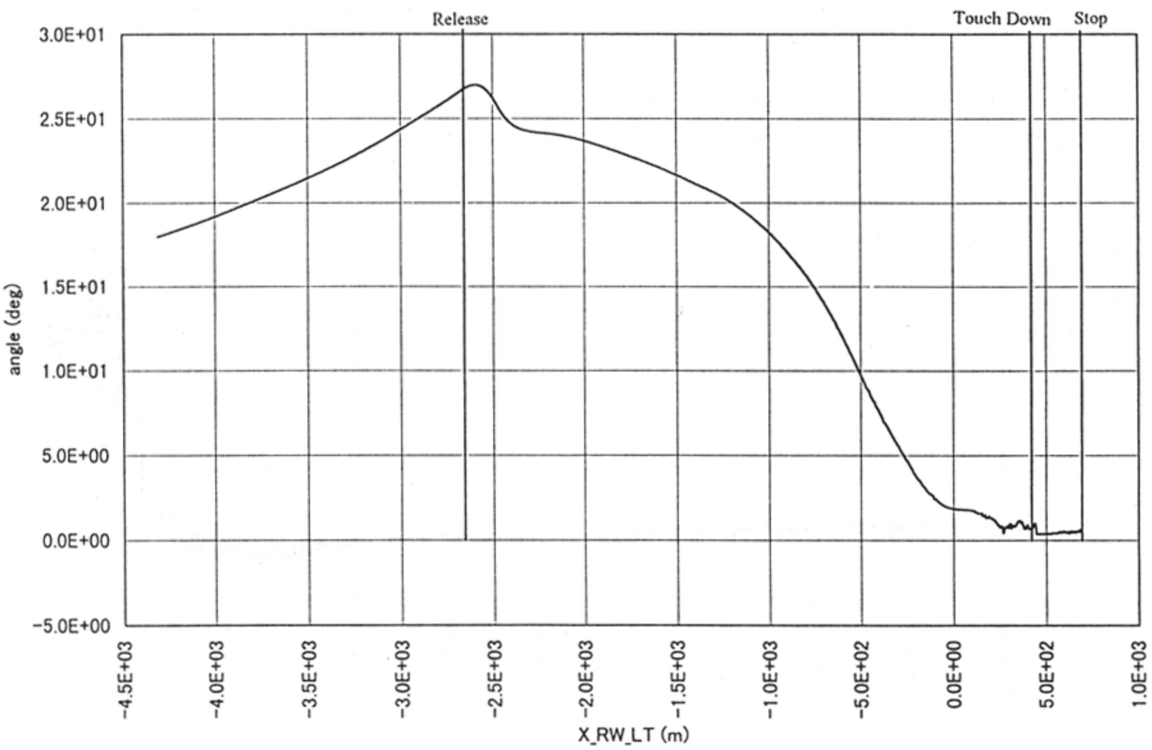

Fig.8 MLS EL Angle (#01)

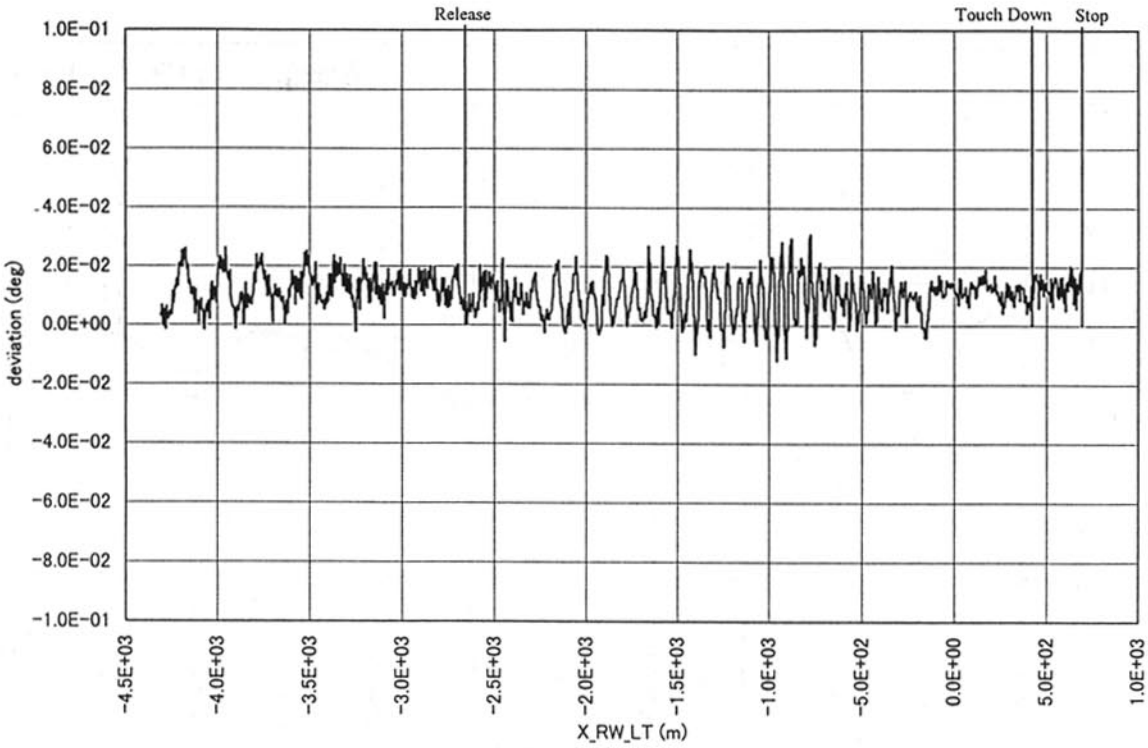

Fig.9 MLS AZ Error (#01)

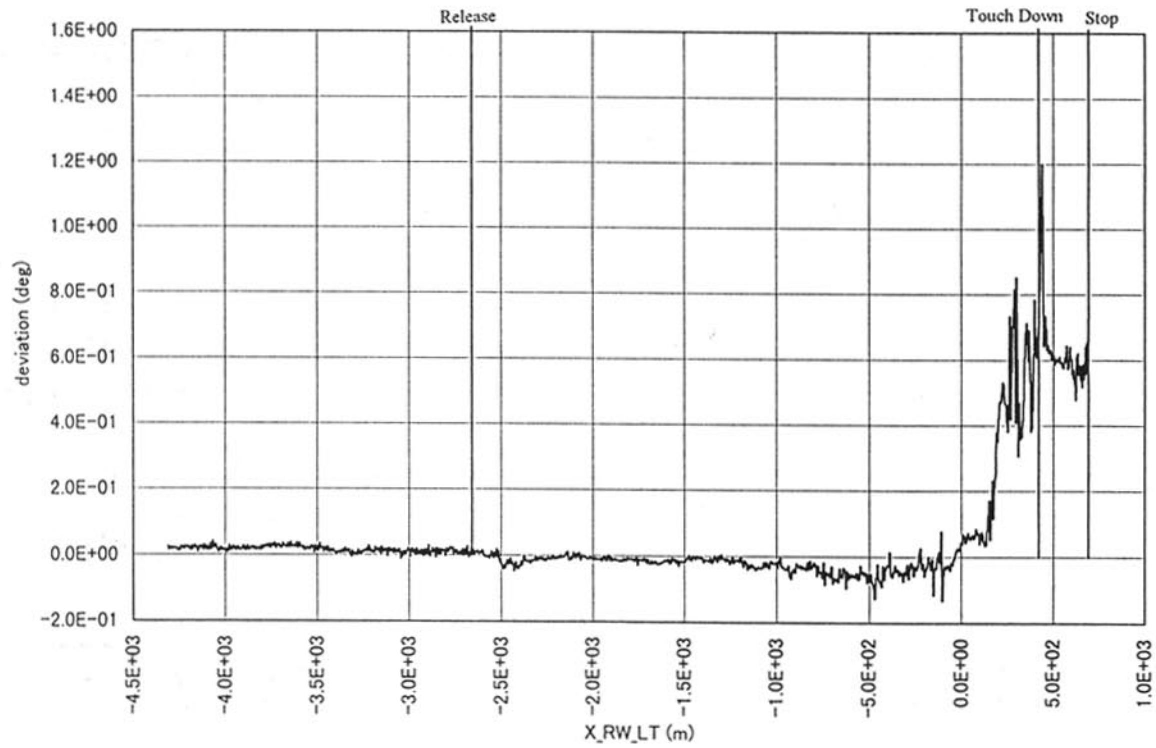

Fig.10 MLS EL Error (#01)

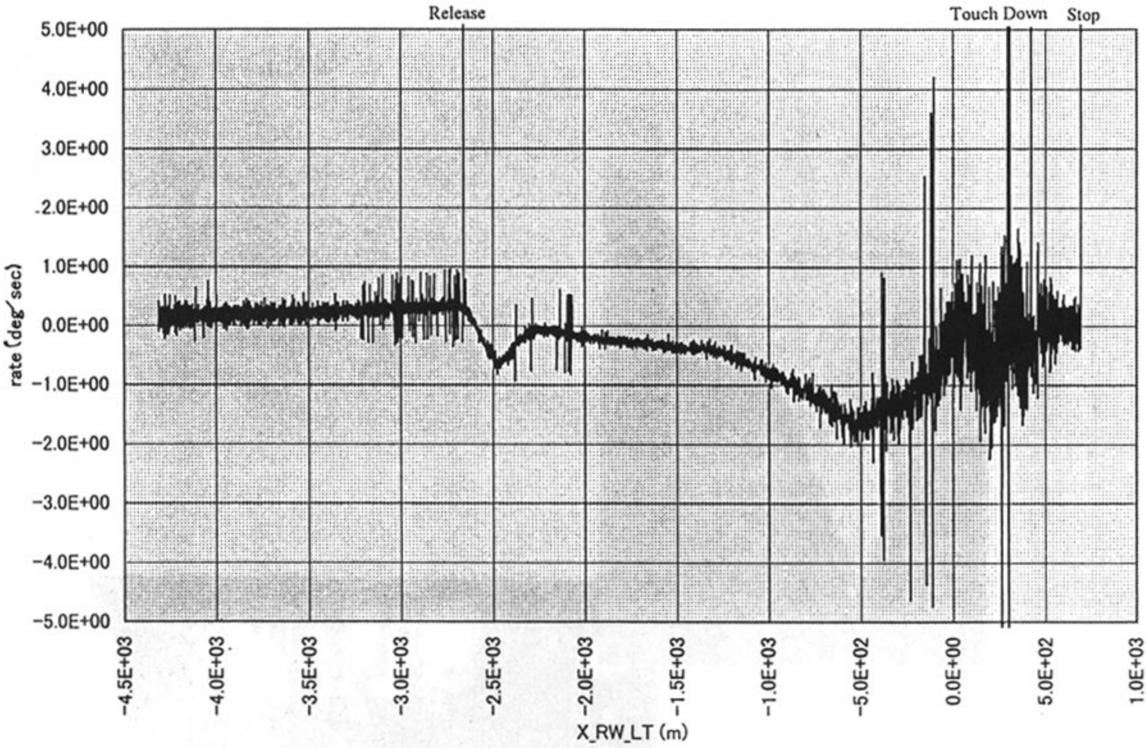

Fig.11 MLS Elevation Angular Velocity (#01)

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