Positioning Accuracy of the Tracking Radar for ALFLEX

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ABSTRACT

A tracking radar was used for real-time flight path monitoring of ALFLEX at Australia. Calibration data, compared with position data by a laser tracker, were obtained at the first hanging flight test, and the calibration data were installed in the tracking radar. After calibration, the positioning accuracy of tracking radar was evaluated in comparison with the laser tracker in hanging flight tests. The results confirmed that the accuracy was satisfactory for real-time monitoring. In addition, the accuracy was evaluated in free flight tests and the post correction data of the tracking radar were derived.

1. Introduction

Automatic Landing FLight EXperiment (ALFLEX) was carried out at the Woomera airport in Australia. In the experiment, an ALFLEX vehicle was lifted up by a helicopter, released from an altitude of about 1500 meters and landed on the runway automatically. To confirm that the ALFLEX vehicle does not deviate from the nominal flight path after releasing the vehicle from the helicopter, the flight path was observed on ground in real time. A tracking radar was used for acquisition of the position data for the real-time flight path monitor. The tracking radar is ground equipment capable of measuring the position of the target in real time by tracking the target automatically using 9.8 GHz micro-waves (X band). An external view of the entire tracking radar system is shown in Fig. 1.

The principle of tracking is explained as shown in Fig. 2. The interrogation wave with a beamwidth of 1.4 degrees is emitted from a cassegrainian type parabola antenna of the tracking radar on ground (referred to as the "ground radar" hereafter). The interrogation wave is received with a transponder on the ALFLEX vehicle and the response wave is transmitted to the ground radar about 30 μ seconds later.

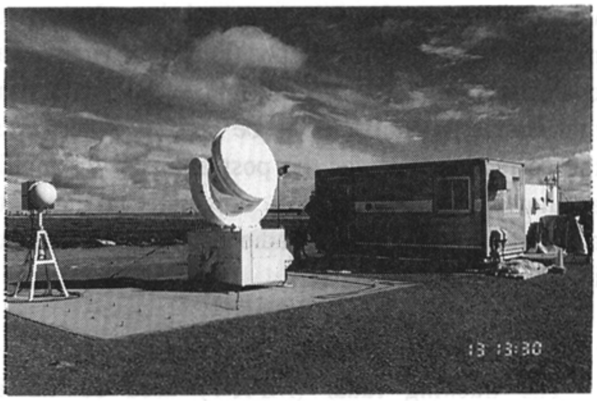

Fig. 1 Tracking Radar

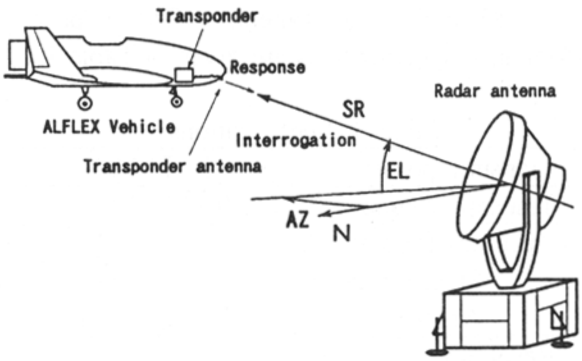

Fig. 2 Positioning using Tracking Radar

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The azimuth (AZ) and elevation (EL) of the target under the flight can be measured because the radar antenna aims automatically in the direction of the response wave. The slant range (SR) can be obtained at the time when the micro-wave shuttles between on the target and radar antenna and the delay time. In ALFLEX, this polar coordinate positioning data was converted into runway coordinates and it was provided for a flight path monitor.

The precision of the tracking radar was calibrated by comparison with the positioning data acquired by the laser tracker at the first hanging flight test (C001) in Australia, and the calibration value was input into the radar system as the bias correction value.

When subsequent hanging flight tests were examined, the accuracy of the positioning by the tracking radar was evaluated by comparison with the positioning data acquired by the laser tracker. It was confirmed that the positioning performance was satisfactory for use as a real-time flight path monitor. In addition, the positioning accuracy was evaluated in the free flight tests and the measurements confirmed to be precise. Afterwards, the correction data for the post analysis for highly accurate positioning was obtained taking into account the delay of the radio propagation velocity in the atmosphere.

2. Specifications of the tracking radar

The tracking radar (MPR-7) used so far in National Aerospace Laboratory was manufactured by Meisei Electric Corporation and improved for the ALFLEX experiment. The primary performance specifications are given in Table 1.

Table 1 Specifications

Transmit power	10 kW
Transmit frequency	9.825 GHz
Accuracy for stationary	
Slant Range	5 m
Angle	0.01 deg
Resolution	
Slant Range	1 m
Angle	0.005 deg

The conditions under which this accuracy can be achieved are as follows:

1) The target is stationary.
2) Receiving strength of the radio wave must be -86 dBm or more.
3) Signal-noise ratio must be 20 dB or more.
4) Elevation to the target must be 4 degrees or more.
5) There must be neither obstacle nor a radio frequency radiation deteriorating the radio environment in the vicinity.

The positioning accuracy of the flying object differs depending on the individual target and a clear specification does not exist though accuracy to the stationary object (Table 1). Therefore, the positioning accuracy of the tracking radar to the ALFLEX was evaluated by this experiment.

3. Calibration of tracking radar

When the tracking radar was set up, the level was taken by the accuracy at about 10 seconds with an electric level meter which was built into the radar antenna. The rotation axis of the antenna azimuth angle was aligned to be perpendicular in this way.

Taking a level was done at each experiment to correct for any change that may have occurred with the lapse of time of the inclination of the foundation in the experiment area, and the level accuracy of about 10 seconds was maintained.

Next, a transponder antenna was set up on the rooftop of a hangar as a fixed target for a simple angular calibration. Because the position of a fixed target had been measured beforehand, it was tracked automatically and the tracking radar was calibrated. The reliability of the calibration is not enough because the tracking accuracy is influenced easily by the multipath of the micro-wave in the target fixed to the ground, although a simple calibration which uses a fixed target is a simple method of correcting for this. Because the amount of the delay of the transponder directly influences the ranging about the slant range measurement, it is necessary to calibrate with the transponder of the ALFLEX vehicle.

When the C001 hanging flight test was

examined after simple calibration was finished, the ALFLEX positioning data by the laser tracker was regarded as the true value and the precision of the tracking radar was calibrated. The positioning accuracy of the laser tracker is thought to be adequate when based as follows according to the manufacturer's specifications:

Accuracy of angle measurement:

0.0057 deg (1 σ)

Accuracy of slant range measurement:

0.3 m (1 σ)

The flight pattern of the C001 hanging flight test by the tracking radar acquisition data is shown in Fig. 3. It is a complex pattern because this examination was not originally done only for calibration of the tracking radar, and a flight pattern which is not especially suitable for the calibration is adopted.

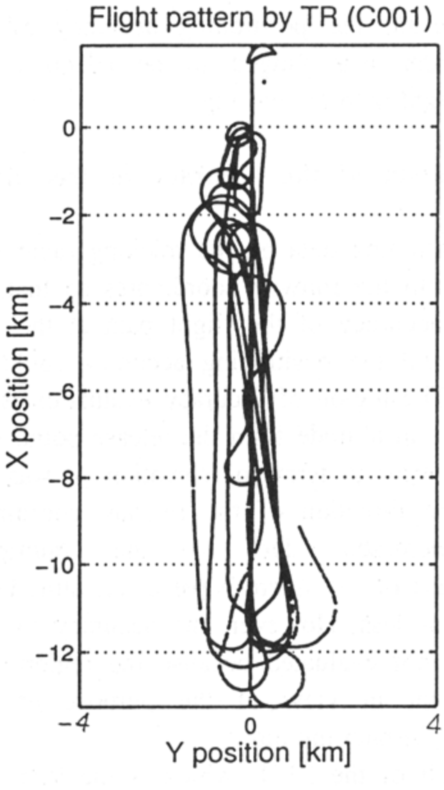

Fig. 3 Flight Pattern of the C001

The calibration data of the tracking radar acquired in the C001 hanging flight test are shown in Fig. 4(a), (b), and (c). Fig. 4(a) is the calibration data of the azimuth angle, Fig. 4(b) is the calibration data of the elevation angle and Fig. 4(c) is the calibration data of the slant range.

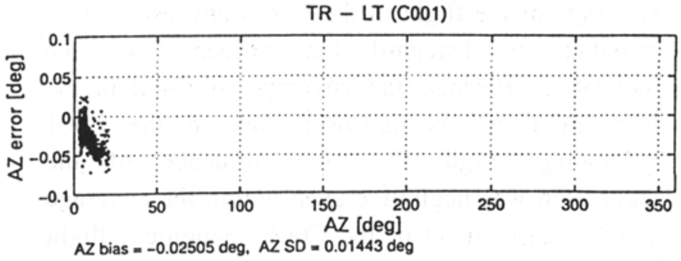

Fig. 4 (a) Calibration Data of AZ

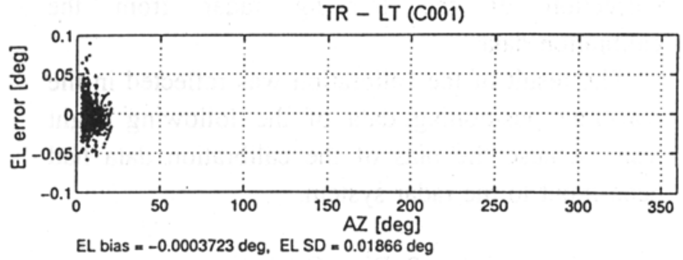

Fig. 4 (b) Calibration Data of EL

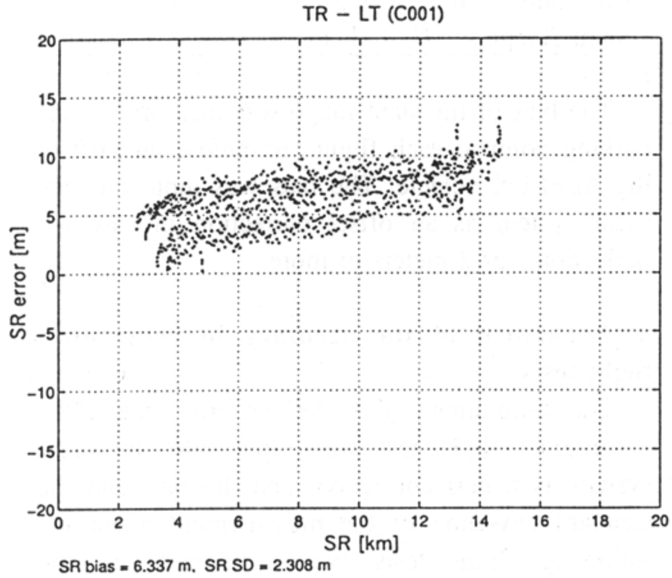

Fig. 4 (c) Calibration Data of SR

If the rotation axis of the antenna azimuth angle inclines to the Z-axis of the runway coordinates, the calibration data of the elevation angle is sure to become a sine curve. Because figure 4(b) shows that only a part of the azimuth angle of the tracking radar of the measurable 360 degrees is used in the calibration, the amount of the inclination can not be obtained in the calibration at this time. However, it was judged that the coverage of the flight in the free flight test made it possible to disregard the influence of the inclination. Because the coverage of flight in the free flight test is narrower than in the C001 hanging flight test, the influence of the inclination was negligible even within the coverage of the measurement of the C001 hanging flight test. The value of the bias correction shown in Table 2 was decided in consideration of the resolution which was able to be input as a correction of the tracking radar from the calibration data.

The result of the calibration was reflected in the real-time positioning data of the following flight tests because the bias of the calibration data had been input to the radar system.

Table 2 Bias Correction

	Bias error	Bias correction
Azimuth	-0.0251 deg	0.0275 deg
Elevation	-0.0004 deg	0
Slant Range	6.3 m	-7 m

The bias of the slant range was measured at the parking point at each flight test before take-off of the ALFLEX vehicle. The bias was input into the radar system as an offset correction in case the deflection was 3 meters or more.

4. Evaluation of the accuracy in constrained flight tests

The calibration value derived from the C001 hanging flight test was input into the radar system as a bias correction, and the bias and the standard deviation of the measurement about the following flight tests were evaluated by the comparison with positioning of the laser tracker. The bias deviation of the slant range which uses the ALFLEX vehicle before taking off was measured and corrected at each examination, as mentioned above. In constrained flight tests, the positioning accuracy was evaluated in the polar coordinates based on the radar antenna in order to examine the accuracy characteristic of the tracking radar first of all, and the positioning accuracy at the release point was converted into the runway coordinates next because the point where the distance of the radar antenna and the ALFLEX vehicle is the furthest is the release point in free flight tests.

The standard deviation added to the absolute value of the bias regarded as the positioning accuracy. The average of 10 hanging flight tests after calibration is shown in Table 3.

Table 3 Accuracy in Constrained Flight Test

Angle	0.023 deg
Slant Range	3.5 m
Accuracy at the release point	
Runway coordinates	X: 3.4 m
	Y: 1.7 m
	Z: 2.1 m

As a result, the positioning accuracy of the tracking radar was judged to be adequate for real-time flight path monitoring.

5. Evaluation of the accuracy in free flight tests

The positioning data by the tracking radar was converted into the runway coordinates so that the measuring accuracy of the flight path at the free flight test and the positioning accuracy could be evaluated. The region of accuracy evaluation is up to 30 meters in altitude from the release point. The positioning error in terms of elevation (it was the same as the direction of the runway coordinate Z-axis) increased due to the multipath characteristics of the micro-wave at an altitude of 30 meters or less. However, the accuracy in this region was not evaluated because the region was not important in view of the purpose of the real-time flight path monitor.

The result of the F101, which is the first free flight test, is shown in Fig. 5 as an example. In this figure, the data is displayed to the landing from the release. It is included the altitude region of under 30 meters.

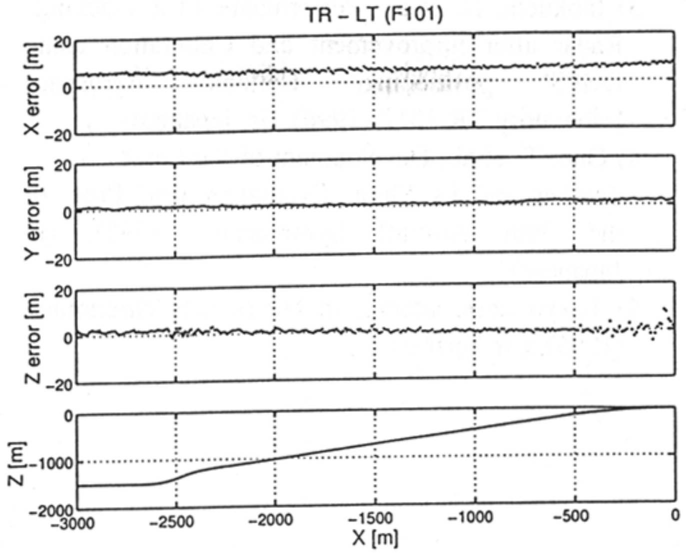

Fig. 5 Free Flight Test

Tracking fell into disorder because of the multipath of the micro-wave around the landing. The phenomenon is obvious in the error of the direction of the runway coordinate Z-axis. The deviation of the slant range bias could not be measured accurately in the F101 due to the influence of the multipath of the micro-wave. Because the ALFLEX vehicle was arranged backward from the ground radar before take-off, it was not possible to look straight at the antenna. Therefore, the error of the slant range increased and the error of the X-axis direction increased as a result. The standard deviation added to the absolute value of the bias was regarded as the positioning accuracy. The average of 13 free flight tests result is shown in Table 4.

Table 4 Accuracy in Free Flight Test

between the release point and altitude of 30 m	
Runway coordinates	X: 4.2 m
	Y: 1.6 m
	Z: 1.6 m

It was confirmed that the accuracy of the measurement was excellent in the free flight tests. Moreover, high reliability of tracking was proven as the tracking radar never missed the target in 13 free flight tests by automatic tracking.

6. Slant range correction by the post processing

The positioning data with the tracking radar was chiefly used in real time in the ALFLEX experiment. However, part of the data was used for the following data analysis because the positioning data of the tracking radar was useful as an external measuring device that is the independent of the ALFLEX vehicle. Therefore, to obtain more accurate positioning data, the post processing correction was examined.

In this tracking radar, the definition value of the velocity of light in a void space is used as the propagation velocity of the micro-wave when the slant range is calculated in real time. However, the propagation velocity of the micro-wave is delayed by the influence of atmosphere and the slant range is overestimated. The propagation velocity of the micro-wave in the standard atmosphere was estimated to use the positioning data for the post processing, and the compensation coefficient for the slant range to be led though the function to correct this error in real time was not provided in the radar system. The delay of the propagation velocity due to the atmosphere varied depending on the temperature, pressure and humidity. However, as the influence by these deflections compared the propagation velocity in the standard atmosphere is small, it was neglected.

The following value is defined as for velocity of light in a void space (C) and the propagation velocity of the electric wave is also the same in a void space.

$C = 299792.458$ km/s.

When relative permittivity of standard atmosphere is assumed to be ε , propagation velocity of the electric wave in a standard atmosphere (V) is obtained by the following equation.

$V = C / \sqrt{\varepsilon} = 299631.855$ km/s.

Slant range (SR) after the atmosphere correction by the delay of propagation velocity is obtained from the measured slant range (SRm) by the following equations.

$SR = (V/C) \times SRm$

$= 0.99946 \times SRm.$

Corrected slant range was calculated, and slant range error in the C001 hanging flight test is shown in Fig. 6. The value of the bias which depends on the range was reduced and the ranging accuracy was improved. The value of the average bias in all ranges of the flight was reduced to 1.8 meters from 6.3 meters.

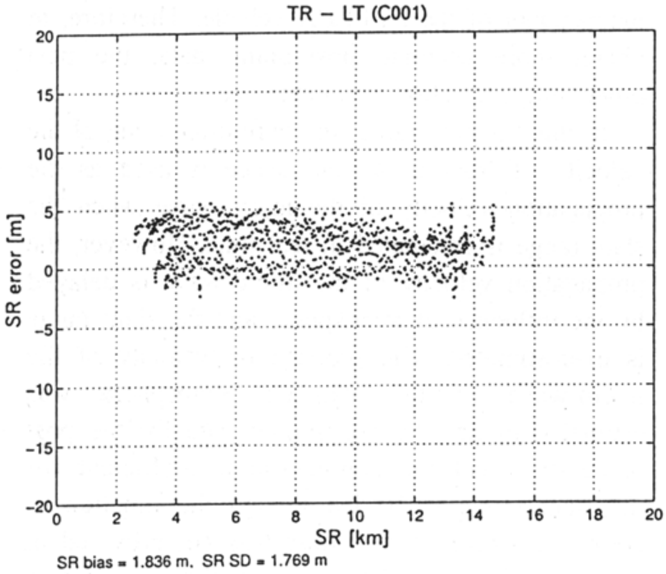

Fig. 6 Atmosphere Correction

7. Concluding remarks

1) Accuracy evaluation in hanging flight tests confirmed that the tracking radar has an enough performance as a real-time flight path monitor.

2) It was confirmed that safety monitoring had been carried out accurately in free flight tests.

3) Because the automatic tracking never failed in 13 free flight tests, high reliability of the tracking radar was proven.

4) In post flight correction, it was found that the range error could be reduced by using the propagation velocity of the electric wave in a standard atmosphere to calculate the slant range.

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