ALFLEX Airfield and Ground Equipment System

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ABSTRACT

Trials of the small-sized unmanned vehicle, ALFLEX (Automatic Landing FLight EXperiment) were conducted at the Woomera Airfield in South Australia. The Woomera Airfield was selected as the most suitable site among several proposed airfields and was equipped with the ground equipment for the ALFLEX trials. The ground equipment system played an important part in ALFLEX because most of the flight operation control and measurement had to be made on the ground.

This paper describes the following:

1) Outline of the ground equipment system and the telecommunication/measurement system.
2) Outline of the interface test among the ALFLEX vehicle and the ground equipment (e.g. flight control console, tracking radar, laser tracker).
3) The operation of the ground equipment system and its results.

1. Introduction

Investigation of the airfield for ALFLEX with regard to the airfield system requirements and site requirements was begun in October 1993. As the result, the Woomera Airfield in Australia was selected as the most suitable site and the Preliminary Design of the test site facilities for ALFLEX was begun in July 1994. After a preliminaly agreement concerning the experiment was reached between NASDA and the Australian Government, the preparation of test site facilities and surveying of the ground equipment reference points were conducted from November 1995 to February 1996. After that, the installation of the ground equipment and functional tests (i.e. Ground Equipment System Tests and Vehicle/Ground Equipment system Tests) were conducted. These test site facilities and the ground equipment were operated for the flight trials (hanging flight and automatic landing flight).

Experiment systems are divided broadly into two categories. One category includes the vehicle and onboard equipment system (e.g. IMU, FCC). The other is the ground equipment system (e.g. Ground Measuring System, Navigation Ground System and Flight Control System). Both categories have to work well together to carry out the experiment. If the ALFLEX vehicle components or onboard equipment do not work as expected, the vehicle can not glide or land. On the other hand if the ground equipment system and adequate flight control do not work, the flight data can not be obtained and more importantly, the flight experiment becomes out of control. Since the flight experiment of a small-sized unmanned vehicle such as ALFLEX is without pilots and instrument personnel, the flight control system and measuring system had to be placed on the ground. Therefore, the ground equipment system undertook an essential part of the ALFLEX operations.

This report indicates, at first, an outline of the preparation of the test site facilities, surveying, structure of the ground equipment and ground measuring system, and functional tests for ground equipment. Secondly, the operations of the ground equipment system during the trials are described with some examples.

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2. Preparation of the ALFLEX airfield

2.1 Design requirements and structure of the ALFLEX airfield

Based on the following design requirements for ALFLEX experiment site, the Woomera Airfield was selected as the most suitable place for ALFLEX.

(1) Range safety requirement

- Protection of personnel on the ground and in the air
- Protection of personnel and property on the ground

(2) Location

No houses in Experiment area

(3) Scale

Adequate scale on the view point of function, safety and economy

(4) Weather conditions

Calm weather to be able to perform the planned flight program

(5) Facilities

Adequate facilities for the experiment (including power, water, sewerage etc.)

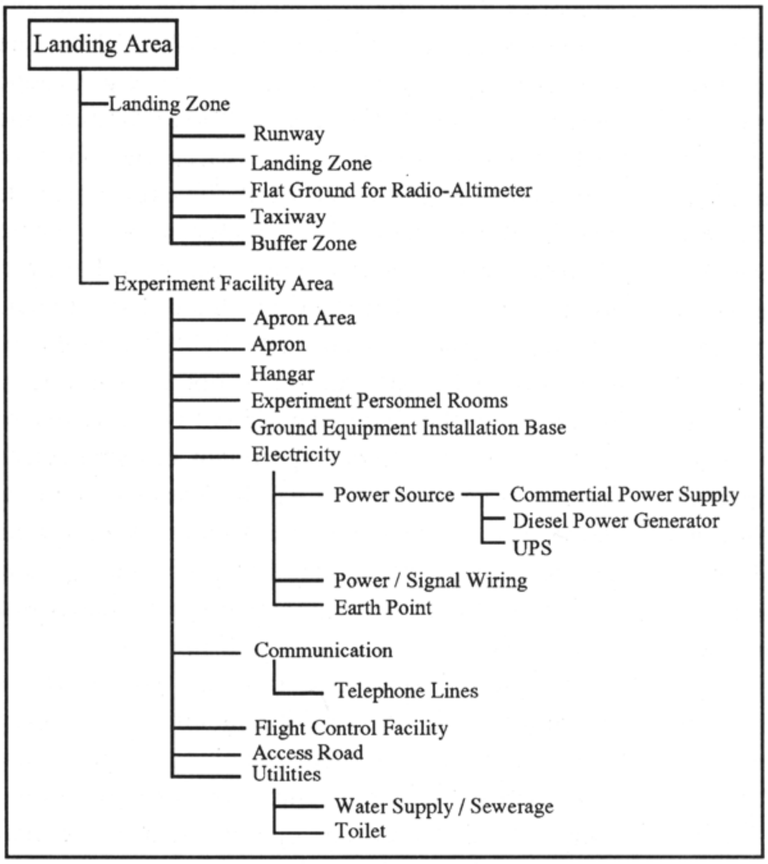


Fig. 1 Structural Block Diagram of ALFLEX Airfield

The experiment site is divided into two areas; one is the landing area which includes the landing zone and the experiment facility area, and the other is the experiment area which includes the designated zone and hazardous area. Figure 1 shows a structural block diagram of landing area.

2.2 Woomera Airfield

The Woomera Airfield is a part of Woomera Prohibited Area in South Australia, which is controlled by the Australian Government. There are facilities such as hangars and a control tower at the airfield. This airfield has two runways; the main runway is asphalt paved and sub-runway is gravel. The main runway was selected for ALFLEX. The main runway direction extends north and south; it is 2372m long and 45m wide. The specifications of this runway exceed those required for ALFLEX experiments; (length 1000 m, width 45 m).

2.3 Experiment Facilities

The experiment facilities were designed by Kawasaki Heavy Industry and it's sub-contractors (British Aerospace Australia, Works Australia etc.) on the basis of examination and surveying by NAL/NASDA and it's contractors. Construction of the experiment facilities was a cooperative effort between Japanese and Australian companies.

(1) Arrangement of the ground equipment

The ground equipment was arranged with regard to the layout of the Woomera Airfield, compatibility to the experiment system, and the limits of the airfield obstruction regulations. Investigations and land surveying by use of GPS receiver or theodolite were carried out several times to set up the arrangement. Figure 2 shows the arrangement of the ground equipment and experiment facilities.

(2) Ground equipment installation base

Installation bases for the ground equipment were constructed at the airfield. The characteristics of the ground around the airfield were taken into consideration when designing the foundation. Especially for

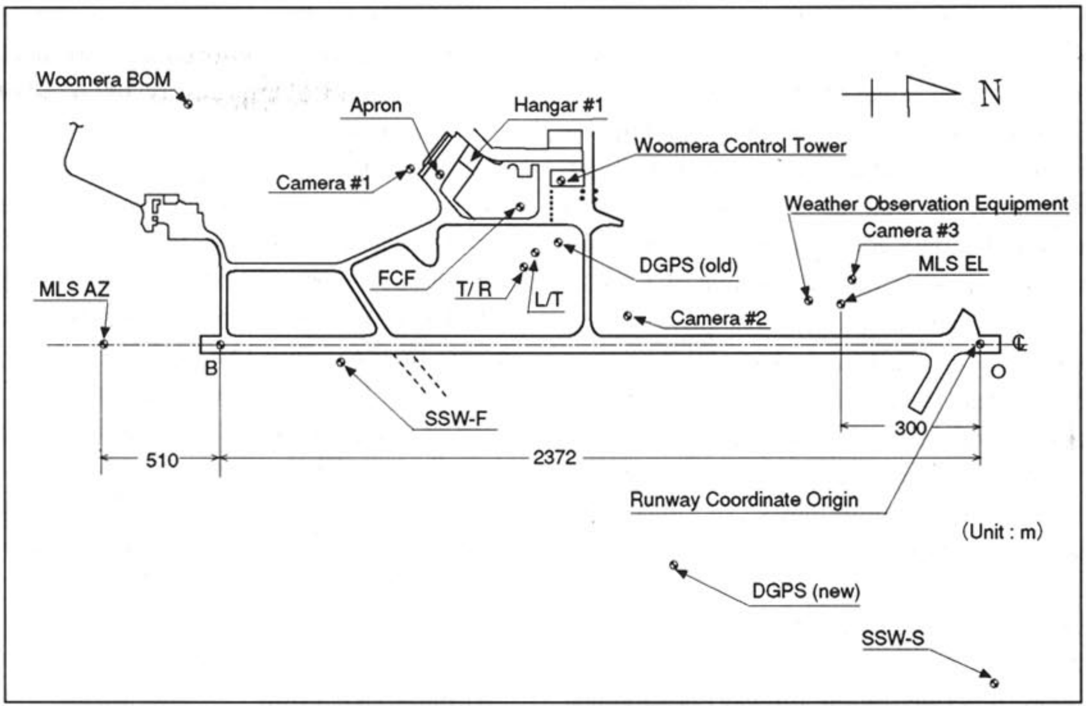


Fig.2 Woomera Airfield

MLS, Laser Tracker (L/T) and Tracking Radar (T/R), whose accuracy depend on the stiffness of the foundations, concrete piles were constructed on a layer of tightly compacted rock under the ground because the ground around the airfield was not firm.

(3) Electricity

Electricity consists of power source and power / signal wiring. Commercial power with 415VAC, 50Hz and 3-phase was supplied to Hangar #1 and to the Flight Control Facility (FCF). Power to the ground equipment around FCF (DGPS ground equipment, L/T, T/R and Monitoring TV camera #1/#2) were supplied via the distribution board beside the FCF transformed to 100V(1 ϕ), 200V(3 ϕ),and 240V(3 ϕ). Two generator sets were provided at the north and south ends of the runway. The MLS EL (Elevation Subsystem), Monitoring TV camera #3 and the Weather Observation Equipment were placed at the north end; the MLS AZ (Azimuth Subsystem) was placed at the south end. A small generator was prepared for DGPS ground equipment at the new location before the hanging flight experiment phase.

In Hangar #1, the distribution boards and transformers were prepared. Power for personal use was supplied to side rooms in Hangar #1. Outlet points for maintenance of the ALFLEX vehicle, Mother Helicopter and Hanging Equipment were provided at the maintenance area in Hangar #1. UPS (uninterruptable power supply) was prepared in FCF in order to maintain a power supply for a minimum of 2 minutes to the ground flight control system in case of power failure during automatic landing flight.

Power and signal cables were run under the ground according to Australian Standard.

(4) Hangar #1

Existing Hangar #1 was refurbished for ALFLEX. Hangar #1 was used for the following purpose.

- Accommodation of the two ALFLEX vehicles
- Accommodation of the Mother Helicopter
- Storage and maintenance of the Hanging Equipment
- Storage, maintenance and operation of ALFLEX Ground Equipment (measuring instruments, etc.)
- Office and workshop accommodation and facilities for ALFLEX personnel
- General working and storage areas
- External mounting of a small mirror for Laser Tracker calibration and a battery-powered transponder for Tracking Radar calibration

(5) Flight Control Facility (FCF)

The Flight Control Facility is used for the control and monitoring of all stage of the ALFLEX trials. FCF was constructed as a temporary building to accommodate the Japanese and Australian flight control personnel as well as a range of ground equipment. The building consists of four 12m×3m modules plus an entrance airlock module of 3.6m× 3m. The airlock entrance area was provided to minimize ingress of heat and dust. To prevent ingress of salty dust, double door with good seals to the entrance module and sealed windows were provided. Taking into account the health of personnel, air-conditioning units of sufficient capacity were provided.

2.4 Surveying of the airfield

As the ALFLEX vehicle is guided automatically along the slope described on the runway coordinates, the X-axis of the runway coordinates must coincide with the center line of the runway accurately. The origin of the runway coordinates was defined as the north end point of the runway. Each reference point of the ground equipment was surveyed by the DGPS method using two GPS receivers to minimize surveying error. This is because surveying errors at the reference point of MLS and DGPS ground equipment cause navigation errors during the ALFLEX trial, and errors at Laser Tracker cause errors in measuring the position of the ALFLEX vehicle by Laser Tracker. The results of surveying with GPS receivers are obtained on WGS84 coordinates. The runway coordinates are a little different from the WGS84 coordinates, but this difference was found to be negligible. The origin of the runway coordinates is

Lat. 31° 8' 6.43600"S
Long. 136° 48' 49.93342"E
Altitude 167.338m

on WGS84 coordinates.

Table 1 Results of Woomera Airfield Survey

Survey Point	X(m)	Y(m)	Z(m)
O:Runway Origin (R/W18)	0.0	0.0	0.0
B:Runway Threshold (R/W36)	2372.588	0.0	-2.917
MLS AZ Phase Center	2882.590	-0.004	-6.286
MLS EL Phase Center	299.982	159.990	-2.237
SSW-F	2199.999	-130.106	-4.017
SSW-S	-390.945	-3555.281	24.919
Tracking Radar Phase Center	1386.973	256.871	-4.684
Laser Tracker Center	1376.984	272.874	-4.264
DGPS(new) Receiving Antenna Phase Center	1078.0527	-1009.955	-5.450
DGPS(new) Transmission Antenna Phase Center	1073.667	-1000.796	-3.419

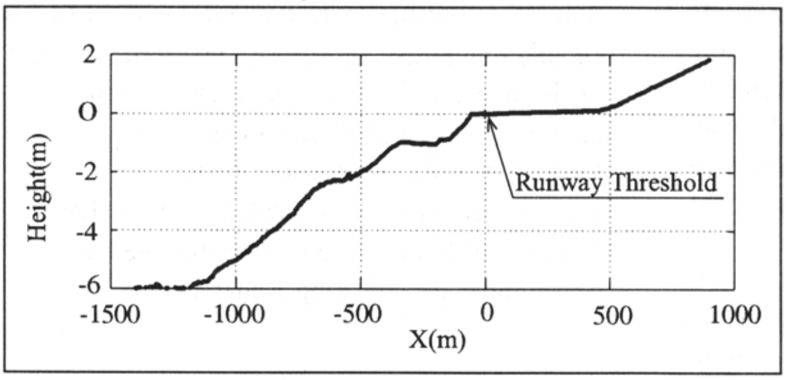


Fig. 3 Runway Level

Data from the Tidbinbilla IGS Observation Station near Canberra was used for obtaining an absolute position. Table 1 shows the results of surveying on the runway coordinates. The height of the north area along the center line of the runway was surveyed by a kinematic GPS method. These height data are used to correct the output data of onboard Radio Altimeter. Table 3 shows that the surface at X=-1500m is about 6m lower than the origin point and that the surface at X=900m is about 2m higher than the origin point. These results corresponds with the results surveyed by Australian side to within a few centimeter.

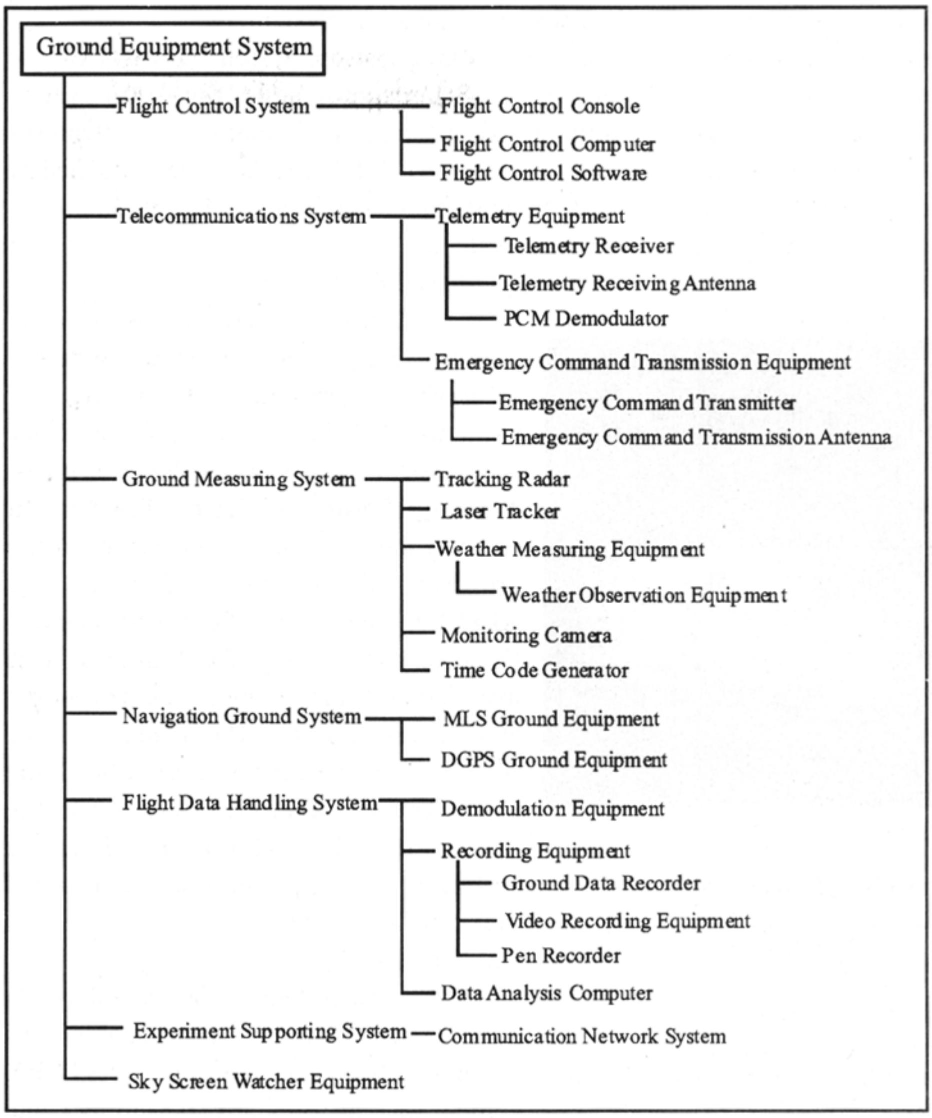


Fig. 4 Structural Block Diagram of Ground Equipment

3. Structural of ground equipment and telecommunication-measurment system

3.1 Ground Equipment System

The ground equipment system is divided into 6 sub-systems "Flight Control System", "Telecommunication System", "Ground Measuring System","Navigation Ground System", "Flight Data Handling System" and "Experiment Supporting System", and Sky Screen Watcher Equipment. Figure 4 shows a structural block diagram of the ground equipment system.

(1) Flight Control System

Flight control system consists of flight control console, flight control computer and flight control software. The functions include:

- Communication with the mother helicopter personnel (pilots and instrument personnel) and ground personnel
- Control and monitoring of instrumentation
- Display of video data from monitoring cameras
- Display of ALFLEX telemetry data
- Display of ALFLEX position (Telemetry, Tracking Radar and Laser Tracker)
- Safety monitoring by flight path monitoring and sky screen watcher equipment

The flight control console consists of 6 CRT displays and emergency command switches. The displays provide the following information.

- ALFLEX vehicle system status from telemetry data
- Instantaneous vehicle position (horizontal and vertical view) together with 'caution lines' and 'limit lines'
- Sequence of the flight trail
- ALFLEX vehicle attitude
- Status of the onboard equipment

Fig. 5 Flight Control Console

The emergency command switches comprise an arming command button, an execution command button and a reset button. The arming command is transmitted to the ALFLEX vehicle in case of transgression of a flight path caution line. The execution command is transmitted for terminating the flight in case of transgression of a flight path limit line. Figure 5 shows the flight control console installed in the Flight Control Facility.

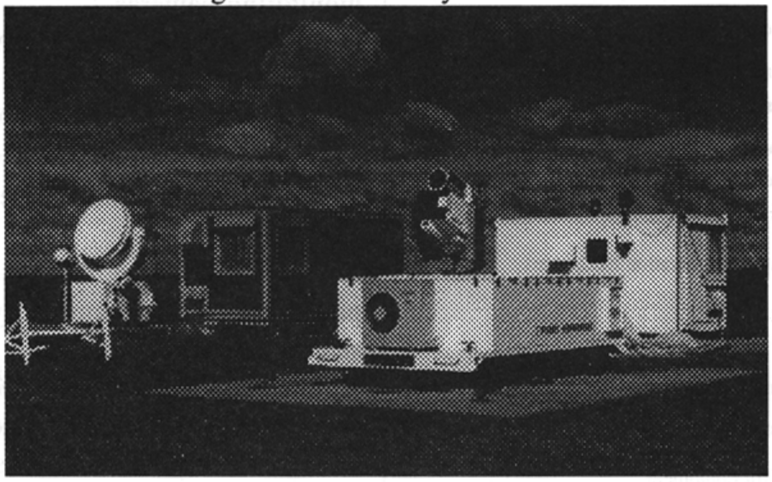


Fig. 6 Tracking Radar (Left) and Laser Tracker (Right)

Table 2 Specification of Tracking Radar

Items	Specifications
Static Accuracy	
Angle	0.59 mrad (0.0338 deg) (3σ)
Range	15 m (3σ)
Antenna Type	1.5 m Cassegrainian Antenna (Gain > 38dB)
Transmission Frequency	9825 MHz
Transmission Power	10 kW
Receiving Gain	-92 dBm
Onboard Transponder	
Transmission Frequency	9875 MHz
Transmission Power	1 kW

Table 3 Specification of Laser Tracker

Items	Specifications
Coverage Zone	
Azimuth	±175 deg
Elevation	-10～90 deg
Range	300 m～40 km (Laser Tracking, Fine Weather)
	50 m～10 km (TV Tracking, Fine Weather)
Positioning Accuracy	
Angle	0.3 mrad (0.0172 deg) (3σ)
Range	0.9 m (3σ) (Laser Tracking)
Tracking Performance	30 deg/sec, 30 deg/sec^2
Data Sampling	60 sample/sec
Type of Laser	Nd-YAG Pulse Laser

(2) Telecommunication System

The Telecommunication System consists of the Telemetry Equipment and the Emergency Command Transmission Equipment. Telemetry PCM data from ALFLEX vehicle is demodulated by the PCM demodulator and sent to Flight Data Handling System.

(3) Ground Measuring System

The Ground Measuring System consists of Tracking Radar, Laser Tracker, Weather Measuring Equipment, Monitoring TV Cameras (#1,#2,#3) and Time Code Generator. Figure 6 shows the exterior of Tracking Radar and Laser Tracker. In order to monitor the circumstances of the pre-flight check and landing of the ALFLEX vehicle in the Flight Control Facility, monitoring TV Cameras were installed at three points; near the north end of the runway, the center of the runway and the apron area. The Time Code Generator using GPS receiver tags the time code to the telemetry data from the ALFLEX vehicle, Laser Tracker data and Tracking Radar data.

(a) Tracking Radar

This Tracking Radar is a secondary X-band radar which is capable of automatically tracking the ALFLEX vehicle with an onboard transponder and measuring the flight location. Table 2 shows the specification of the Tracking Radar. The main role of the Tracking Radar is to monitor of the vehicle position to maintain flight safety. An antenna of the onboard transponder is installed on the nose of the ALFLEX vehicle so that the flight path of the vehicle can be monitored from the constrained flight before the release point to the landing. Also, the safety of radio wave exposure for the human body was investigated based on Japanese regulations and was confirmed to agree with Australian regulations.

(b) Laser Tracker

The Laser Tracker is used for the following purposes.

Table 4 Specification of MLS Ground Equipment

Items	Azimuth	Elevation
Transmission Frequency	5090.7 ± 0.01 MHz	5090.7 ± 0.01 MHz
Transmission Power	2 W	2 W
Beam Scan	Phased Array	Phased Array
Scanning Coverage Zone	±40 deg	0.9 ~ 40 deg
Antenna Beam Width	1.5 deg (-3 dB: Horizontal)	1.5 deg (-3 dB: Vertical)
System Error at the Threshold		
Bias	2.7×10^{-2} deg	1.1×10^{-1} deg
Noise (3σ)	8.1×10^{-2} deg	9.9×10^{-2} deg

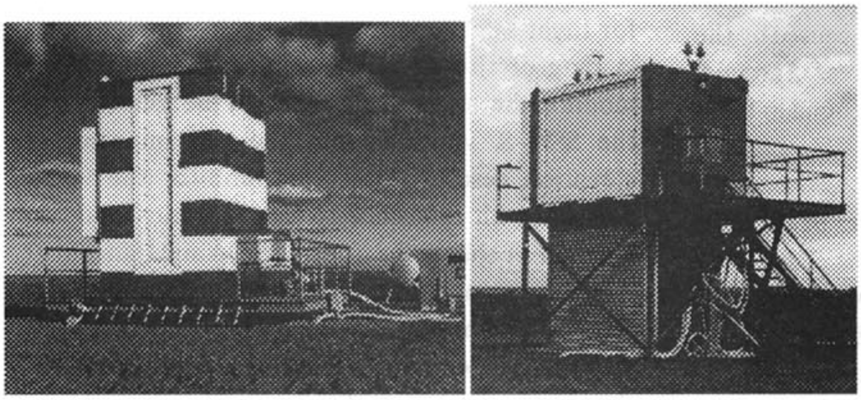


Fig. 7 MLS Elevation Subsystem (Left) and Azimuth Subsystem (Right)

Table 5 Specification of DGPS Ground Equipment

Items	Specifications
GPS Receiver	
Function	L1,C/A Code
Frequency	1575.42 MHz
Number of Channel	8 ch
Accuracy	Pseudorange : 7.5 m (1σ) Deltarange : 10.0 mm (1σ, 1 sec)
Output Period	1 sec
Pseudolite Transmitter	
Frequency	1624.61 MHz
Transmission Power	80 mW
Modulation and PRN Code	BPSK C/A Code, M-sequence Code

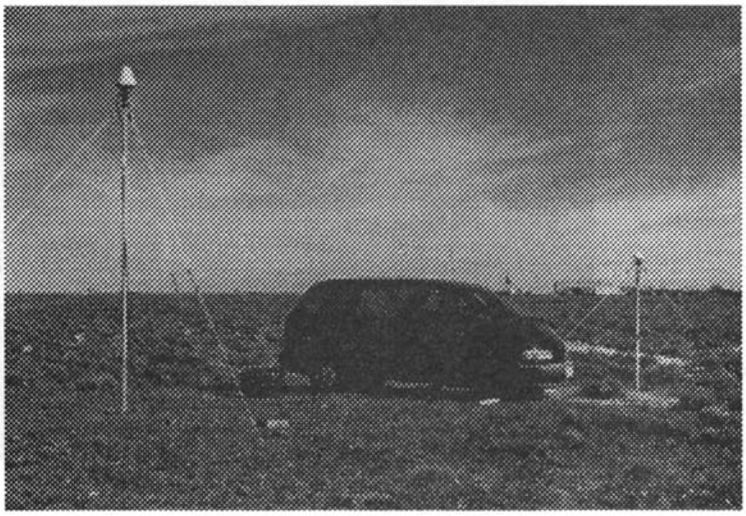


Fig. 8 DGPS Ground Equipment

- Monitoring the flight path of the ALFLEX vehicle
- Reference data of the navigation sensor data (e.g. Radio Altimeter, MLS, DGPS) and the results of the hybrid navigation (IMU-DGPS, IMU-MLS, IMU-RA)
- Reference data of flight data analysis

The laser reflector is installed on the nose of the ALFLEX vehicle. The Laser Tracker can not measure the vehicle position in case the reflector is invisible as below.

- The ALFLEX vehicle flies away from the Laser Tracker
- Clouds or the Pitot Boom installed the ALFLEX vehicle obstruct the view of the laser reflector

Table 3 shows the specifications of the Laser Tracker. Since laser is an Nd-YAG pulse laser classified as Class 4, the eye safety for airborne and ground personnel was examined on the basis of JIS C6802. As the result of the examination, the limits for the operation were set up. It was confirmed that the Australian regulations were also complied with.

(4) Navigation Ground System

The Navigation Ground System consists of the MLS Ground Equipment and the DGPS Ground Equipment.

(a) MLS Ground Equipment

The MLS Ground Equipment consists of the Azimuth Subsystem (AZ) installed at the south end of the runway, the Elevation Subsystem (EL) installed near the north end of the runway and the Remote Monitoring Equipment installed in the Flight Control Facility. The specification of the MLS Ground Equipment is provided in Table 4. Figure 7 shows the exterior of the MLS. The AZ and EL transmit the fan beam to scan the coverage zone.

On the ground roll test, multi-path noise appeared in the azimuth data of the onboard MLS receiver. The azimuth signal is used as the direction control signal of the vehicle during the ground run after landing. Therefore, abnormal behavior of the vehicle may be caused by multi-path noise. It was found out that the cause of the noise was the reflection of the fan beam on the ground facility. To prevent the multi-path noise, scanning coverage zone was changed to ±10 degrees from ±40 degrees. On the hanging flight test, periodic deviation in comparing with Laser Tracker data appeared in the azimuth data. It was also found that the deviation was the multi-path noise caused by the reflection of the fan beam on the depressed ground. To prevent the multi-path noise, the ground in front of the AZ was smoothed out.

(b) DGPS Ground Equipment

The DGPS Ground Equipment consists of the GPS Receiver, the Receiving Antenna, the Pseudolite Transmitter and the Transmitting Antenna. The specifications of the DGPS Ground Equipment are provided in Table 5, and the exterior of the equipment is shown in Figure 8. The GPS Receiver, the Pseudolite Transmitter and other instruments are installed in a van. On functional tests on the ground, the value of pseudolite bias could not be determined for multi-path noise by the ground facility. To prevent it, the DGPS Ground Equipment was moved to the new point (center place of the airfield) indicated in Figure 2.

(5) Flight Data Handling System

The Flight Data Handling System consists of the Demodulation Equipment, the Recording Equipment and the Data Analysis Computer. The Demodulation Equipment demodulates the telemetry data (PCM). The Recording Equipment record the flight data and the videos. The Data Analysis Computer supplies the time history of the flight path, attitude of the vehicle, the results of hybrid navigation compared with the Laser Tracker data, aerodynamics data and so on.

(6) Experiment Supporting System

The Experiment Supporting System consists of the Communication Network System. The Communication Network System comprises a UHF/VHF Crossband Repeater, VHF transceivers, airband transceivers, airband monitors and a Safety Control ALFLEX Telemetry System. The Safety Control ALFLEX Telemetry System is used for transmitting signals between the Flight Control Facility and the Sky Screen Watcher Equipment. This Communication Network System is used for communications between operators and safety personnel during ALFLEX flight trials.

(7) Sky Screen Watcher Equipment

The Sky Screen Watcher Equipment (SSW) comprises two sets (SSW-F, SSW-S) of calibrated wire sighting screen for visual monitoring of the azimuth and elevation track of the ALFLEX vehicle for flight safety purposes. The SSW-F, viewing the landing of the ALFLEX vehicle from the front, monitor the azimuth approach of the vehicle, while the SSW-S, viewing from the side, monitor the elevation descent. Observers monitor the vehicle position with reference to 'caution lines' and 'limit lines' on a calibrated wire sky screen and transmit the position signal of the vehicle to personnel in the Flight Control Facility using the Safety Control ALFLEX Telemetry System. If the vehicle crosses the limit line (condition Red), the observer transmits the Red signal to the Flight Control Facility and an emergency command should be transmitted to the vehicle immediately in order to spin the vehicle towards the ground by the operator. However, the F003 flight trial was aborted before release of the vehicle because the observer could not track the vehicle in the shade of cloud (i.e. SSW 'inactive' condition) even though the vehicle had no problem.

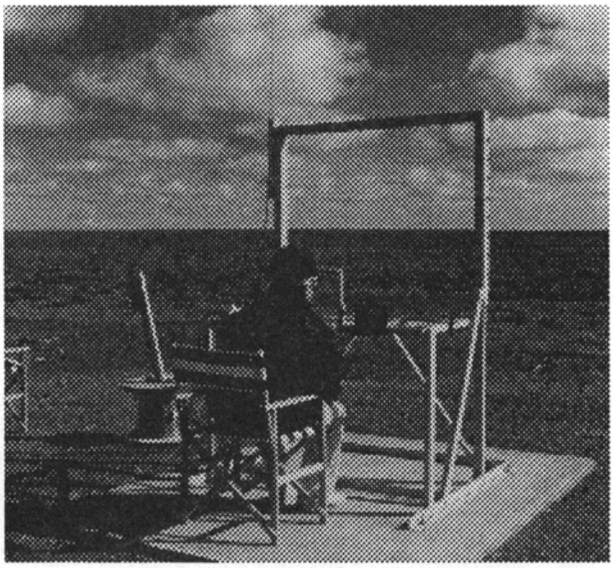


Fig. 9 Sky Screen Watcher Equipment

On the other hand, sufficient reliability data of the Tracking Radar were accumulated via hanging flight tests and automatic landing flight trials. So the vehicle release proceeded with SSW 'inactive' providing that one of the Tracking Radar , Laser Tracker and Telemetry data is 'active'. Figure 9 shows the exterior of the SSW.

3.2 Telecommunication and Measurement System

Block diagram of the Telecommunication and Measurement System is provided in Figure 10. Data from onboard sensors, which comprise IMU, GPS receiver, Radio Altimeter, Pressure sensor, Strain gauge etc., are output as 1553B signals, analog signals and discrete signals. These data are transmitted to the ground as telemetry data after being modulated by a PCM encoder.

At the same time, an onboard data recorder is mounted to record these data from release to land in order to secure data as preparing for transmission miss. Table 6 shows measuring items, Table 7 shows the specification of Telemetry Equipment. On the ground, the vehicle position data from Tracking Radar and Laser Tracker are transmitted to the Flight Control Computer and the Data Acquisition and Analysis Computer. Also, the GPS time code is transmitted to the Data Acquisition and Analysis Computer for synchronizing telemetry data, Tracking Radar data and Laser Tracker data. Wind direction / speed on the ground are observed with the Weather Observation Equipment installed beside the runway. The upper wind profile is obtained by analyzing the sonde data observed by BOM before and after flight trials.

4. Interface tests on the ground

Interface tests as follows were conducted to confirm the normal operation of the ground equipment system before flight trials phase.

- Ground equipment system tests
- Vehicle/Ground equipment system tests

4.1 Ground equipment system tests

These tests were conducted to confirm the interface of each ground equipment (1) and items of tests (2) as follows:

(1) Equipment

(a) Flight Control System

(b) Weather Observation Equipment

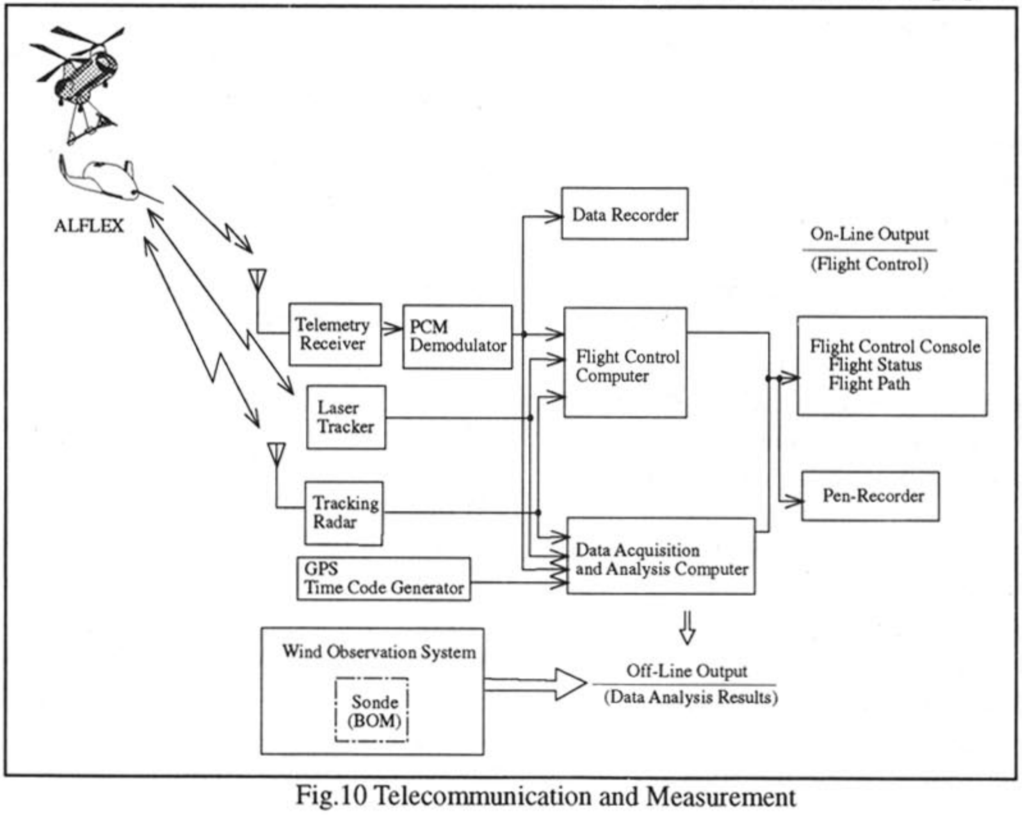


Fig.10 Telecommunication and Measurement

Table 6 Measuring Items

Item Name	No.of Item	Data Source	Note
Hybrid Navigation Results	6	FCC	X,Y,Z,Vx,Vy,Vz
Actuator Control Signal / Monitor	14	Actuators	Control Signal:7 Monitor:7
Navigation Sensor Data	160	IMU,MLSR,DGPSR, RA,ADS	Sensor Output, Calculated Data etc.
Guidance Command Monitor	6	FCC	Az, α , β , ϕ ,r SpeedBrake Angle
Pressure/Strain Sensor Data	44	Pressure sensor/ Strain gauge	Pressure:30 Strain:14
Sequence Relay Monitor	16	PSDB etc.	
Technical Data	8	Gimbal,Sling Load Cell Wheel etc.	
House Keeping Monitor	33	Battery, Brake System, Actuator, Onboard Components	Status, AGC, Voltage, Temperature etc.

Table 7 Specification of Telemetry Equipment

Items	Specifications
Telemetry Transmission	
Frequency	296.2 MHz
Transmission Power	4 W
Modulation	PCM - PM Bi ϕ -L
PCM Encoder	
Bit Rate	81.92 Kbps
Frame	8 bit/word
Input Signal	Analog 56 ch
	12 ch
	Digital 11 ch
	Discrete 11 ch

(c) Monitoring TV Cameras
(d) Data Recorder
(e) Data Acquisition and Analysis Computer
(f) Tracking Radar
(g) Laser Tracker
(h) MLS Ground Equipment

(2) Test items
(a) Telecommunication test of pseudo-signal or simulation data
(b) Transmission test of real data
(c) Picture test of TV cameras Tracking Radar camera and Laser Tracker camera
(d) Laser Tracker slaving test with Tracking Radar data
(e) Tracking Radar slaving test with telemetry data using pseudo data
(f) Tracking Radar Antenna operation test with simulation data
(g) Tracking Radar and Laser Tracker system confirmation test
(h) MLS remote equipment confirmation test
(i) Data acquisition confirmation

4.2 Vehicle and Ground equipment system tests

Contents of the interface tests are as follows.

(1) Confirmation of telemetry receiving condition, emergency command receiving condition and DGPS receiving for the vehicle at the apron area reference point. DGPS navigation test on that position.

(2) MLS azimuth data accuracy confirmation test using the vehicle

(3) Navigation functional test

Comparing test of onboard results of IMU-DGPS hybrid navigation, DGPS navigation and MLS navigation at the runway origin point.

(4) MLS/Tracking Radar/Laser Tracker functional test standing vehicle on the runway

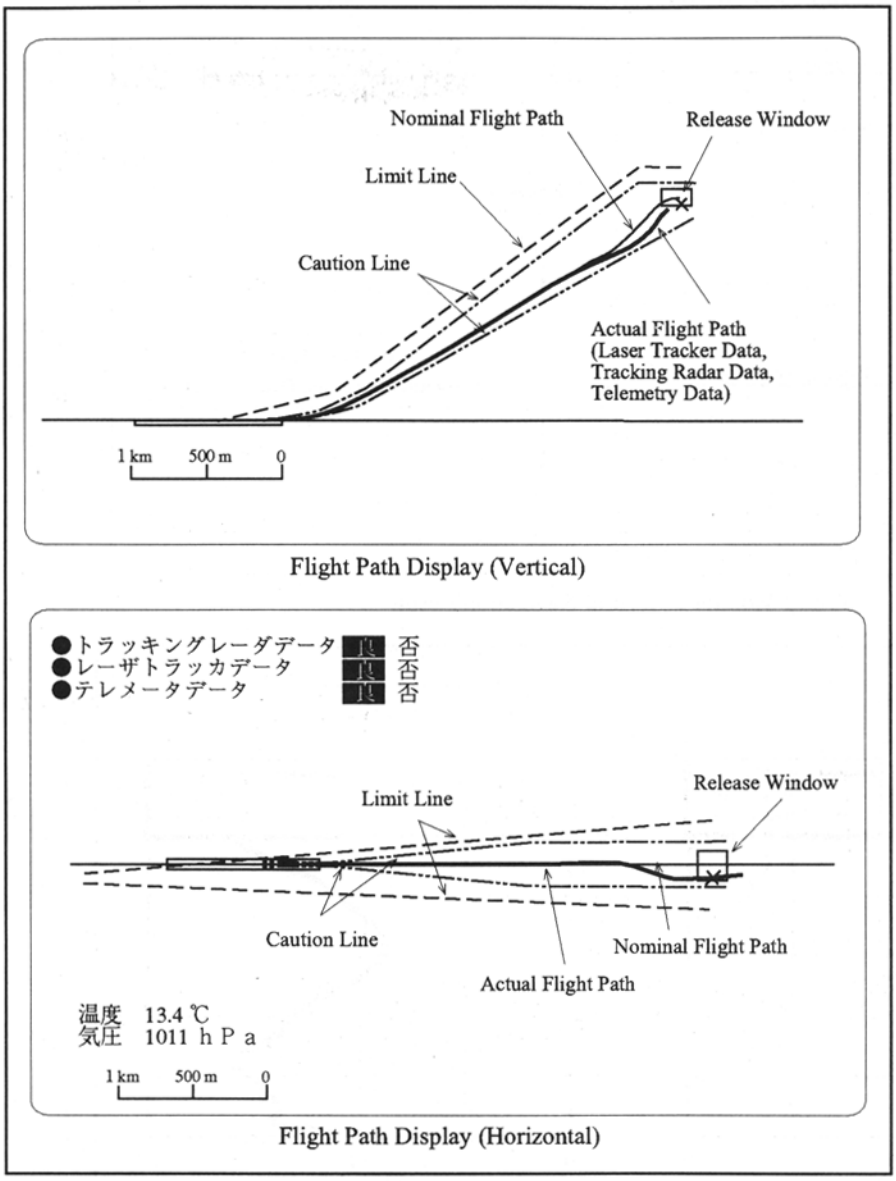
5. Operation of the Ground Equipment System

After completion of the functional tests and interface tests of the ground equipment on ground, hanging flight tests were started. Two types of operation of the ground equipment are required; one is a 'real-time operation' such as the flight control on the flight experiment, and the other is an 'off-line operation' such as the analysis of the sonde data and flight data before/after the flight experiment using the Data Analysis Computer and personal computers.

5.1 Real-Time Operation (Ground Flight Control)

(1) Monitoring of the flight path

Monitoring the flight path of the vehicle is one of the most important items on the ground flight control. Flight path monitoring operators monitor the flight path monitoring CRT, on which the position of the vehicle (Tracking Radar data, Laser Tracker data and Telemetry data) is indicated, whether the vehicle fly along the nominal flight path or not. Figure 11 shows flight path displays;



Flight Path Display (Vertical)

Flight Path Display (Horizontal)

Fig.11 Flight Path Monitoring CRT

this is an example of the F009 trail 'off-set release'. The upper display shows a vertical view and the lower displays shows a horizontal view. Actual flight paths from Tracking Radar data, Laser Tracker data and Telemetry data are indicated by bold lines. The correspondence of these three data sets means that there is no inconsistency of the results when measuring with different equipment. In the horizontal view, Japanese '良/否' means the "status "of each of equipment and 良 means "good condition". Then, if one of the three status is good condition and the flight path is shown on the display, it is possible to confirm whether the vehicle is flying within the caution/limit lines or not.

(2) Monitoring of the Pen-Recorder

Some of the measuring items of the vehicle are put out on the pen-recorders to monitor the status of the vehicle throughout the flight experiment.

Operators have to make some important judgments during the flight such as:

(a) As a condition to the constrained configuration, the operator must judge the vehicle attitude by monitoring the pen recorder time history.

(b) Before the vehicle can be released from the Mother Helicopter, the operator have to confirm that the results of the hybrid navigation have converged. Its condition is defined as deviation from the Laser Tracker data within ±20 m on each axis. Figure 12 shows the pen recorder output of the deviation. This is an example of the F101 first trail. The deviations of each axis are very small before release. This means that the onboard hybrid navigation result and Laser Tracker result are in good agreement. Therefore, the vehicle could be released from the mother helicopter.

5.2 Off-Line Operation (Data analysis Output)

(1) Analysis Output of Sonde Data

Before the flight test, OMEGA sonde was released from the Bureau of Meteorology of the Woomera Airfield (ref. Fig. 2 BOM point) and was sounded by Australian BOM. Calculation of the direction and velocity of the upper wind using the sonde data and analysis of the ratio of the design wind condition were conducted. The result was used to judge 'Trail Go' or 'Trail No-Go'. Figure 13 shows an example of

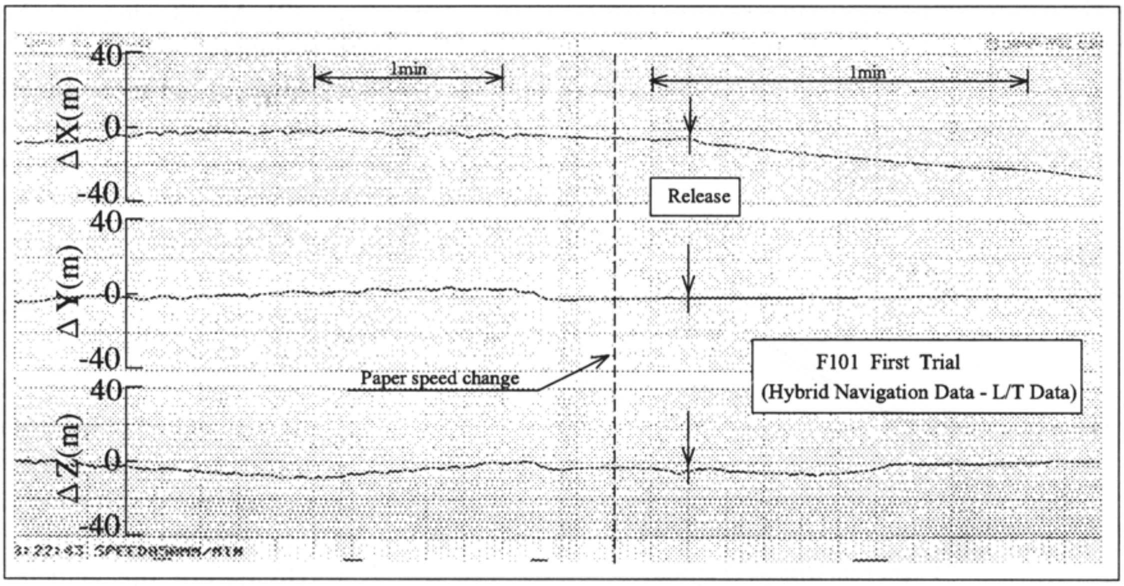


Fig.12 Monitor of Hybrid Navigation Result

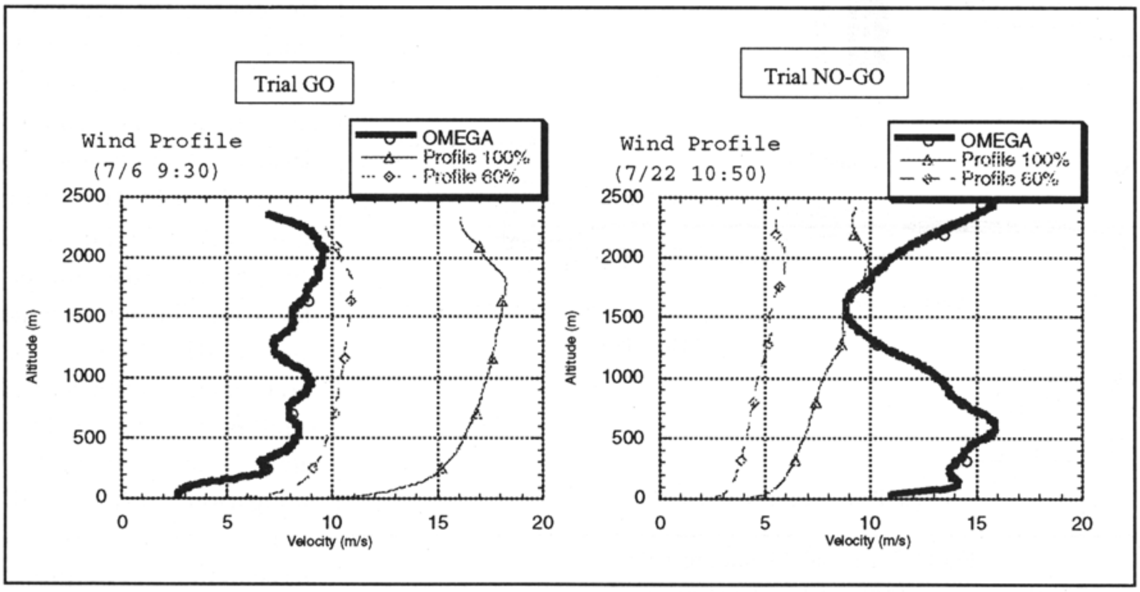


Fig.13 Decision of Trial Go/No-Go by Upper Wind

the analysis output. The ordinate is altitude, and the abscissa is the wind velocity. In this figure, the design wind velocity at an altitude is indicated as a value in the wind direction at the altitude because the design wind velocity varies with direction. The design wind velocity at 20 ft altitude is less than 9.3 m/s (head-wind), less than 3.7 m/s (tail-wind), and less than 5.5 m/s (cross-wind). The first trial was scheduled within 60% of the design wind velocity. The graph on left shows the analysis result at the first trial and 'Trail Go'. The graph on right shows the example of 'Trail No-Go'.

(2) Analysis Output of Flight Trajectory

After the trial, the Post-flight briefing was conducted to examine the affair of the trial based on some quick reports such as figures of flight trajectory and figures of the vehicle attitude information. Figure 14 shows an example of the result of the flight at first trial (F101). Also, the enlarged figure before and after touch down is shown. The flight trajectory was corrected to the value on the center of gravity of the vehicle and the figure was shown to compare with Laser Tracker result as the reference data and the onboard hybrid navigation result. Nominal flight trajectory

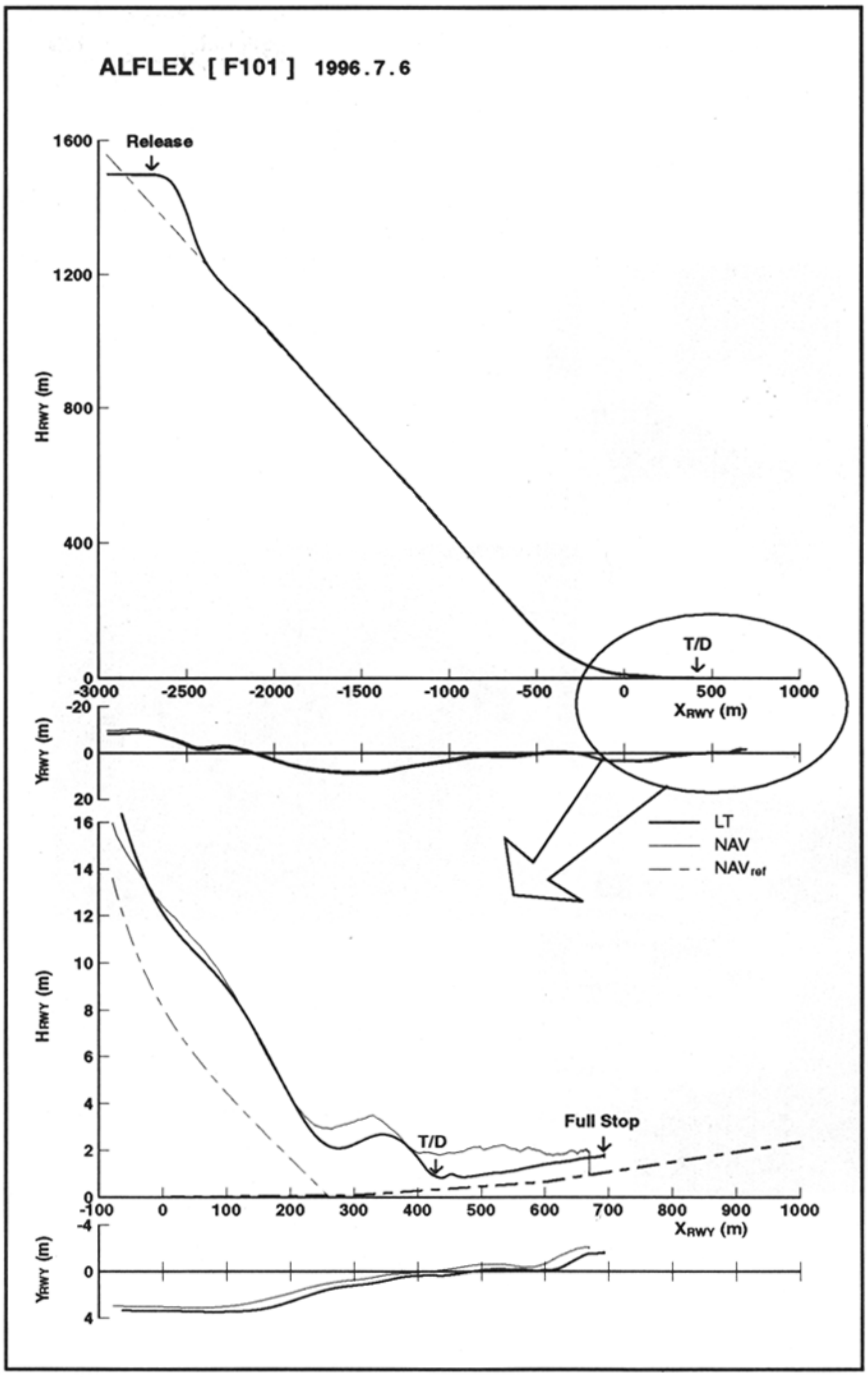


Fig.14 Result of Flight Trajectory

(NAVref) is indicated as a reference. On the enlarged figure, the bold broken and dotted line indicates the level of the runway. The movement of flare and ground roll of the vehicle is recognized clearly.

6. Conclusions

The ALFLEX airfield and the ground equipment system were introduced. From this description, it is clear that the ground equipment system played an important part in the ALFLEX trials. This report will be used as a basic material for the next unmanned automatic landing vehicle test.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