Planning, Operation and Results of the ALFLEX Flight Trials

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ABSTRACT

The first ALFLEX landing trial was conducted on July 6, 1996 with success and 13 landing trials in total were completed by August 15. As the ALFLEX has employed unique and unprecedented features and its trials were conducted in a foreign country, one of the most crucial themes of the program was to establish the methodology for such an experiment. In this paper, activities toward and during the flight test such as setting the experiment conditions, planning, preparation, the procedure on the trial day, the method of the trials, communications links, as well as operation of the Vertol helicopter and the chase helicopter are summarized. Also, the outcome of the flight trials is explained. Conclusions of the ALFLEX flight trials are given with regard to the goals of the program as: (1) the flight data confirmed performance of the control, guidance and navigation system, and thereby established that the automatic landing technology used for this type of unmanned vehicle is appropriate; (2) data of the low speed flying characteristics of the vehicle having a shape of the HOPE were collected; and (3) flight test methodology incorporating a scaled model vehicle by utilizing a stepping-up procedure including hanging flights and mathematical models to the full extent has been demonstrated.

1. Introduction

The ALFLEX has been under development since 1993 aiming at establishing a technology base for the HOPE automatic landing system design.

The landing trials were the final stage of the ALFLEX program and were to evaluate its automatic landing performance in actual flight environment. Various function tests have been carried out both in Japan and in Australia prior to the final flight trials. This paper deals with the final flight trials of the ALFLEX program conducted in Australia, and summarizes their planning, operations and results.

2. Outline of the Flight Experiments

2.1 Feature of the Experiments in Australia

Flight test planning commenced in December 1994 when Woomera Airfield was nominated as a candidate flight test field, and its eligibility has been investigated since then along with the Risk Analysis of the trials at Woomera. Preparations of the detailed flight test plan started in March 1994, and the plan was revised according to progress of survey of the airfield, development of the vehicle and ground facilities, function tests as well as hanging flight tests conducted in the Nagoya area of Japan. The final flight test plan was compiled

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in March 1996, where it was designed to conduct 10 flights for hanging flight tests and 13 flights for automatic landing trials in 3 months. According to the plan, the number of hanging flight tests was minimized by making full use of the results obtained in domestic hanging flight tests. Test items of the hanging flight test in Australia focused on functions that were not confirmed in Japan, such as those of devices that were modified after the domestic tests and on familiarization of trial operations. Among the automatic landing flight trials, the first three trials were planned to evaluate the fundamental performance of the vehicle. Conditions such as relaxation of the wind restrictions were to be reviewed based on the results of three initial trials.

The features of the experiment conducted at the Woomera Airfield in Australia are briefly described here. Geographically, there are no mountains or seas near Woomera. This leads to consistent wind effects and stabilized air flow, and yielded more stabilized flight data compared with domestic data.

Even though there was little chance of rain in the Woomera area, there was considerable precipitation during the flight test period very unusually. After the rain fall, access roads to test sites became muddy and caused difficulty in transportation as well as troubles with scattered mud in and around the test sites. When the dirt dried up, it was blown up by automotive movements. In order to prevent machines from being damaged by dirt, operational measures such as avoiding car movement when the ALFLEX was in the apron area were required. Low temperature and high humidity especially with southerly winds often brought dew in the early morning, occasional mist after dawn and low clouds before

Table 1 Trial Conditions

Period	Item	Condition
Carry Out	Temperature Humidity Wind	more than 0℃ less than 95% no flying grit
Vehicle Operation	Time	not to operate DGPS at 5:30∼9:00 am (Woomera time)on Sunday avoid GPS orbit data renewal time zone
Vehicle Power on	Humidity	less than 85%
Take Off	Before Take Off Check Weather Area Laser Tracker (sunlight) Sky Screen Watchers GPS Regular Flight High priority flight	Completed satisfied including the upper air cleared by SOLO shutter is not closed not against the sunlight satellites arrangement is proper no interference no interference (ex. flying doctor, US Air Force)
Pull Down Vehicle	Vehicle	stabilized
Release	Flight Course Release Window Navigation (MLS/IMU) Surface Wind SSW Area Time	Stabilized within the window converged within the limit ready clear have to land within 90 minutes after IMU alignment

noon. Each of them caused delay or cancellation of the flight test. This trend became greater after raining, and, along with necessity of removing water on the apron area, formed climatic obstacles to the flight tests.

Priority of runway usage for the ALFLEX trials were set lower than that of regular commercial airplanes. However, as the frequency of landings to the airfield was much lower than at Japanese airports, and as organizations in Australia were so supportive of the ALFLEX program, runway usage did not present a problem. The flight tests were conducted under the following general conditions.

2.2 Trial Conditions

Specific trial conditions necessary to proceed with the tests, including those of the preparation phase, are summarized in Table 1. It is noted that preparations had to be suspended occasionally due to unsatisfactory conditions, especially due to humidity. Also, it is noteworthy that the necessity to make the vehicle land within 90 minutes after completion of the IMU alignment allowed one retrial of vehicle release operation.

2.3 Planning and Preparation

The general stepping up flow of the activities from arrival in Australia to completion of the automatic landing trials is shown in Fig. 1. As indicated in the figure, after rebuilding the vehicle and installment of the ground facilities and subsequent tests of each sub-system, system interface tests were conducted prior to the automatic landing trials.

3. Procedure and Operation

3.1 Procedure

Figure 2 depicts a task flow of a flight trial. As shown in the flow, the date and the contents of the trial were determined and its procedure was confirmed by all the staff well before the day, and a go/no-go decision was made based on the

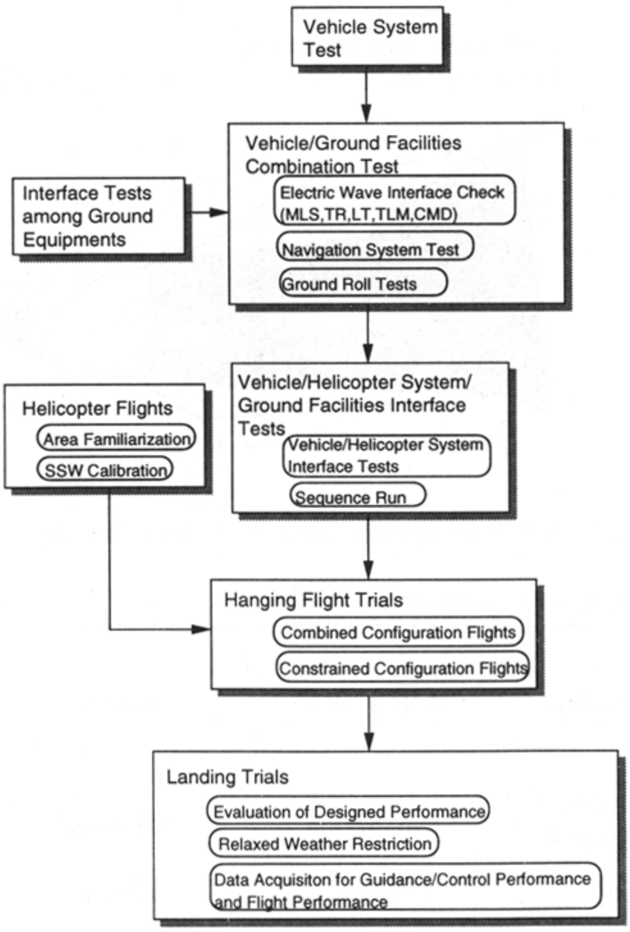

Fig. 1 Stepping up Flow

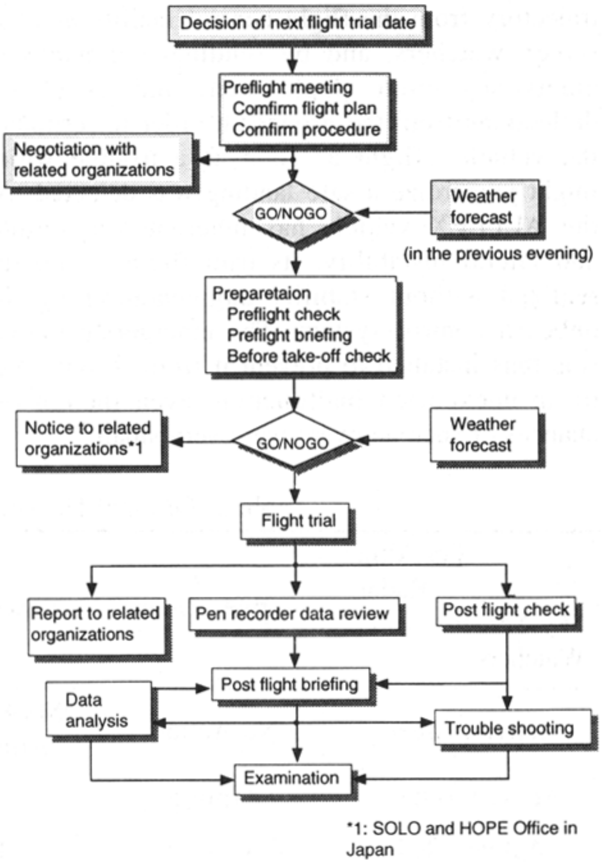

Fig. 2 Task Flow

weather forecast from the previous day. On the day of the trial, the go decision was reconfirmed, taking the progress of the preparations, the most recent weather forecast and the system conditions into account.

After the trial, a quick review report and the first-stage flight data analysis report were issued the same day. Necessary analysis or review of detected malfunctions were conducted upon receiving the reports so that the next trial could be properly arranged.

Close contact with Australian participants was realized by Liaison Meetings where flight test plans were introduced and information on general issues were exchanged, and by Trial Planning Meetings and Trial Outcome Meetings before and after each flight trial, respectively.

3.2 Safety Considerations

The overriding principle of the ALFLEX flight safety was to maintain the safety of the people on the ground by monitoring the vehicle's flight trajectory from the flight control facility and sky screen watchers, and by sending commands of emergency chute deployment and of elevon deflections from the ground in order to terminate the vehicle's flight as soon as a trouble which might jeopardize a safe landing was detected. As the ALFLEX vehicle has inherent longitudinal and lateral instability, its trim flight cannot be realized without stability augmentation by the onboard control system. The emergency system was thus installed to prevent it from straying due to an unexpected malfunction, even though the chances of such an event were very small.

The Designated Zone (DZ) was specified to clear the area for potential falling of the vehicle. The Hazardous Area (HA) was defined in the first place as the area in which the vehicle has the chance of falling, and then the DZ was defined so as to include this HA (Fig. 3). The decision matrix for command execution is summarized in Table 2. After the first automatic landing trial was successfully completed, we confirm the link margin of the tracking radar. Sufficient link margin of the tracking radar meant that it was highly reliable and this enabled us to modify the decision matrix as given in Table 3 so that the workload of the sky screen watchers could be reduced.

In summary, combination of flight trajectory monitoring in the flight control facility and monitoring by the sky screen watchers proved to be sufficient for safe conduct of all the automatic landing trials.

3.3 Checks and Setting up

Flight trial preparations were scheduled to start

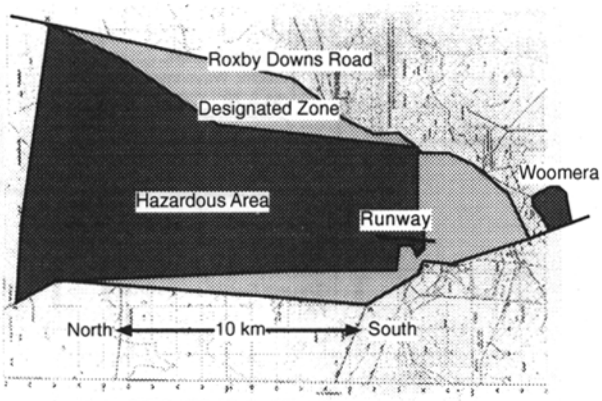

Fig. 3 Designated Zone and Hazardous Area

Table 2: Original Decision Matrix for Command Execution

Tracking Radar / Sky Screen Watchers	Active : Green	Active : Yellow	Active : Red	Inactive
Active : Green	No Action	No Action (SSW-S) Arming (SSW-F)	No Action	No Action
Active : Yellow	Arming	Arming	Arming	Arming
Active : Red	Execution	Execution	Execution	Execution
Inactive	No Action	Arming	Execution	Execution

Table 3: Revised Decision Matrix for Command Execution

Tracking Radar / Sky Screen Watchers	Active : Green	Active : Yellow	Active : Red	Inactive
Active : Green	No Action	Arming	Execution	No Action
Active : Yellow	No Action	Arming	Execution	Arming
Active : Red	Arming	Arming	Execution	Execution
Inactive	No Action	Arming	Execution	Execution

Fig. 4 Preparation on the Apron

as early as possible because the weather conditions, especially the wind condition, were generally favorable early in the morning. To realize this, some of pre-flight check items were scheduled to be completed on the previous day.

In the morning of the trial day, the remaining pre-flight checks of the ALFLEX vehicle, the Vertol helicopter and the hanging equipment were conducted in the hangar, where a better environment for the inspections was maintained. The installation of the hanging equipment on the vehicle (Fig. 4) and the subsequent checks were conducted in the apron area.

3.4 Flight Procedure

Planned flight trajectories of the vehicle are shown in Fig. 5. The Vertol helicopter together with the ALFLEX vehicle climbed up to 1500 m (5000 ft) AGL before completing the first round flight, and the crew reported the weather conditions. Then, before reaching Point C in the figure, the decision to lower the vehicle to proceed to the constrained flight configuration was made after confirming the health of the system conditions. The constrained flight configuration must be established before making the final turn. During the approach on the final course to the release point, final confirmation of the navigation and control system functions was made, and the releasing task started after passing Point E. The final count down started at 500 m before the release point, and the separation switch was engaged in response to the release command from the flight control facility to initiate the vehicle's automatic flight. Immediately after the release, the Vertol helicopter made a left and descending turn to return to the apron with the remaining hanging equipment.

When a chase helicopter accompanied, it took off before the completion of the preflight check of the ALFLEX vehicle (Fig. 6) and hovered on the runway to wait for the vehicle's take-off in order to minimize interference. The chase helicopter kept its position left and behind the ALFLEX vehicle until it was released. After the release, the chase helicopter followed the ALFLEX vehicle from its rear left side with a shallower path to maximize the recording period of the vehicle behavior.

It should be emphasized that operations of the Vertol helicopter for use of this kind of experiment heavily depended on the pilot's skill, and especially during lifting up and down the vehicle and putting down the hanging equipment after the release required close cooperation between the ground operators and the helicopter

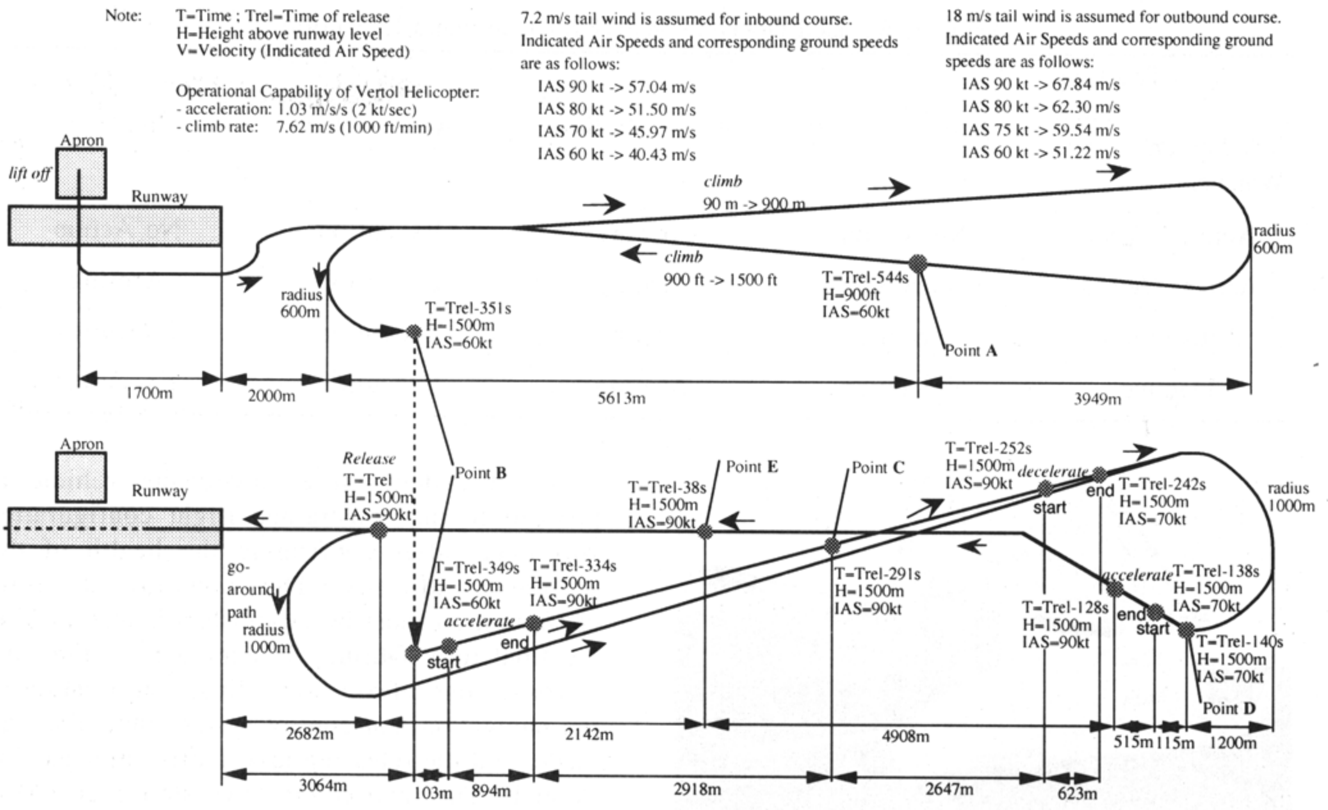

Fig. 5 Detailed Flight Procedure

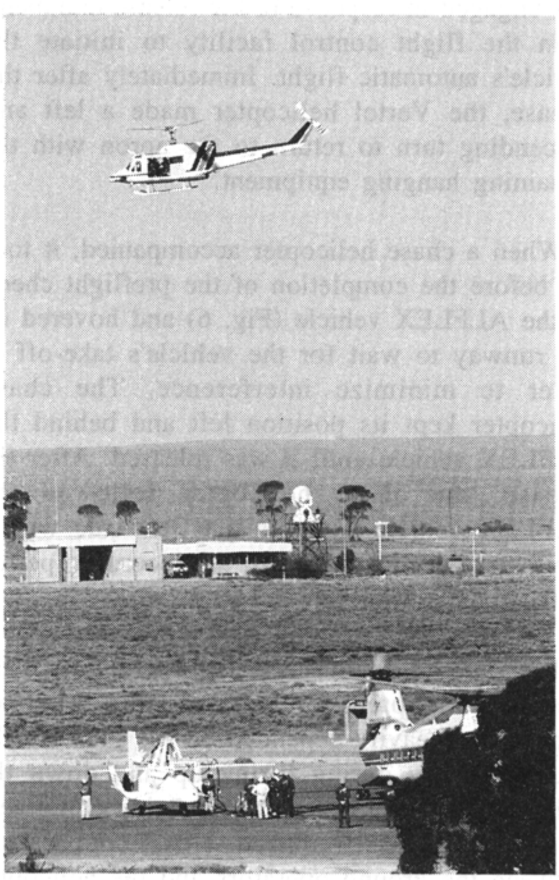
Fig. 6 Chase Helicopter

crew and a high degree of concentration on the part of the pilot. Moreover, the course setting of the Vertol helicopter during the final approach to the release point was manually controlled only by monitoring a small pilot guidance indicator installed on the flight instrument panel of the helicopter. The fact that the accuracy of this guidance by manual control was fully sufficient for the experiment is clearly indicated in the plots of the release points (Fig. 8).

4. Results of the Flight Experiments

4.1 Hanging Flight Tests

Prior to the hanging flight tests, a series of ground tests such as ground roll tests, interface tests of ground equipment, a vehicle/ground facilities combination test and vehicle/helicopter system/ground facilities interface tests were completed, which were also utilized to modify the operational procedures. One flight in combined flight configuration and five flights in constrained flight configuration were initially planned for the hanging flight phase. However, as additional flight tests were required, nine hanging flight tests were realized in the end. The objectives of the hanging flight tests are summarized as follows:

(1) Function check after the shipping and assembly: Function check of the helicopter system, the vehicle communication/measurement system, the emergency system, the vehicle navigation/guidance/control system and ground facilities (i.e., flight monitoring system, laser tracker and tracking radar), electromagnetic compatibility, training for Vertol helicopter flight, helicopter system operation, communications and operations of ground facilities were included in this test series.

(2) Performance check tests/Calibration tests: Function and performance check of MLS, tracking radar and laser tracker, calibration of hybrid navigation and air data system, speed brake check and control and aerodynamic performance check were conducted.

(3) Operating procedure confirmation and training for the landing trial were also conducted.

(4) Check of functions not confirmed in Japan: Final check of MLS and improved navigation /guidance/control system [i.e., DGPS, ADS, FCC (RA) and control system software]

(5) Function and performance check for the systems modified during the hanging flight tests

Table 4 outlines the hanging flight tests conducted during the hanging flight phase. The outcome of the each hanging flight ·and helicopter flight are summarized in order of time as follows:

(a) Hanging flight test in the combined flight configuration (C001) As this was the first hanging flight test in Australia, the functions of each equipment (such as MLS, DGPS, radio altimeter, laser tracker, tracking radar, control system, emergency system, communication/measurement system) and performance of the main instruments were checked in the combined flight configuration. The MLS was evaluated in flight for the first time. Results of this test indicate that the MLS, DGPS, laser tracker, tracking radar, communication/measurement system, emergency system and guidance, navigation and control system all functioned properly.

(b) Helicopter flight (H001) In order to check the airspace boundary, the release point and the limit lines of the ALFLEX vehicle trajectory on the FPM-H monitor, the Vertol helicopter flew across the boundaries. It was revealed from this test that the data displayed on the FPM-H monitor agreed with the SSW-F reports. It became necessary to adjust the screen for SSW-S.

(c) Constrained flight test (C002) This constrained flight showed that the function and performance of the control system were as

Table 4 Sumary of Hanging Flight Phase

Trial Number	Trial Objectives	Comments	Date	Time
C001	Function check of MLS, SSW, telemetry system and ground facilities and calibration of TR, LT, DGPS	Combined configuration flight	21 May	11:29-13:03
C002	Function check of GNC system and helicopter on-board system	Constrained configuration flight with Chase Helicopter	24 May	11:28-12:52
C003	Flight trial procedure training	Constrained configuration flight	28 May	11:52-13:28
C004	Sensor calibration and performance check of speed brake	Constrained configuration flight	31 May	10:53-12:09
C005	Flight trial procedure training	Constrained configuration flight	5 June	11:23-12:37
C006	MLS and aerodynamic performance check and SSW calibration	Constrained configuration flight	11 June	11:02-12:40
C007	DGPS & ADS performance check	Constrained configuration flight	20 June	11:37-12:32
C008	Training of flight trial	Training of every system	25 June	10:27-11:53

designed. Navigation data such as MLS and DGPS were also collected. A chase helicopter was employed to this flight for the purpose of monitoring and recording by using photo and video cameras. It was confirmed from the chase helicopter that modification of the separation equipment could adequately suppress its flutter which had been found in the preliminary hanging flight tests in Japan.

(d) Constrained flight test (C003) The operation procedures of both onboard operators and ground monitors toward the vehicle release were checked in the real flight environment. Furthermore, an approach simulating an automatic landing was conducted in this flight to confirm the guidance performance.

(e) Helicopter flight (H002) SSW-S calibration was conducted again to confirm the result of adjustment applied after the H001 helicopter flight. The data analysis showed that the information from SSW-S was reliable as a flight path monitor for the landing trial.

(f) Constrained flight test (C004) Data was obtained to confirm the performance of the air data system and the speed brake. In the latter half of this test, the helicopter and the vehicle approached the runway twice to determine the signal quality of the onboard MLS receiver. It was confirmed that the measurement of the angle of attack, side slip angle, pressure altitude and air speed and function and performance of the speed brakes were all as expected.

(g) Constrained flight test (C005) The remaining items requiring further confirmation were tested in conjunction with flight procedure training.

(h) Constrained flight test (C006) The purposes of this test were to obtain longitudinal stability data, to confirm RF link of MLS near the release point and to calibrate SSW-F. Longitudinal data were obtained up to 12 degrees of the angle of attack, which indicated sufficient stability. Also it was confirmed that both Az and EL of MLS had satisfactory performance around the release point. Furthermore, the caution line for SSW-F was readjusted based on the data obtained in this test.

(i) Constrained flight test (C007) This was the last hanging flight test before stepping up to the flight trial phase. As all the systems were confirmed by this test, it was decided to proceed to the flight trial phase.

4.2 Flight Trials

In total 16 flights were conducted during the flight trial phase including hanging flight tests for automatic landing simulation and the training for the flight trial operations, and 13 landing trials were completed as planned (Table 5). The progress is summarized below.

(1) Hanging flight test for flight trial procedure rehearsal (C008)

Various operations and checks such as system checks on the ground, hanging flight and countdown were necessary to conduct the landing trial. These procedures were confirmed during the hanging flight phase. A final rehearsal was conducted in this flight. Although the main purpose of this test was rehearsal of the trial, performance data of the radio altimeter around the runway end and the laser tracker data were also collected.

This test confirmed that the operators were accustomed to the procedure, that SSW-F judgment regarding the caution lines was reliable and that the laser tracker could track the vehicle properly.

(2) Three flight trials were scheduled for the nominal landing. As we could confirm the basic performance by the first two flight trials (F101 and F002), it was decided to relax the trial conditions from the third trial (F103), in which the vehicle was released at an offset point in the 60% restriction of the designed wind condition.

(a) F001: The first landing trial was attempted, but the release of the vehicle was aborted because of unexpected fluctuations of the radio altimeter data on the final approach course although it happened out of the altitude range.

(b) F101: This was the retry of the first landing trial aborted in the previous flight. Firstly, the radio altimeter performance was checked at the altitude range of its usage, then the helicopter climbed up with the vehicle and released it at the intended release point. The full stop point was 1 m left from the center of the runway because of the imbalance of braking power, but the full stop point was well within the fluctuations expected in the design. The performance of the vehicle was confirmed to be satisfactory as expected in this trial. It was decided to change the radio altimeter

Table 5 Summary of Flight Trial Phase

Trial Number	Trial Objectives	Comments	Date	Time
(F001)	Evaluation of designed performance was attempted Data acquisition for the Radio Altimeter	Landing trial was attempted but aborted Constrained configuration flight with Chase Helicopter	30 June	10:39-11:50
F101	Evaluation of designed performance	wind restriction 60% with Chase Helicopter	6 July	10:42-11:24
C009	RA check	Constrained configuration flight	10 July	14:01-14:47
F002	Evaluation of designed performance	wind restriction 60% with Chase Helicopter	14 July	10:54-11:27
(F003)	Data acquisition under relaxed weather restriction was attempted	wind restriction 80% Landing trial was attempted but aborted Constrained configuration flight	21 July	12:16-12:59
F103	Data acquisition for guidance/control performance	Release from offset point 80 m to the left wind restriction 60%	24 July	15:51-16:17
F004	Data acquisition for flight performance	Elevator input	27 July	13:50-14:22
F005	Data acquisition for flight performance	Rudder input	28 July	13:20-13:52
F006	Data acquisition for flight performance	Elevator input	30 July	11:46-12:15
F007	Data acquisition for flight performance	Aileron input	5 August	11:35-12:06
F008	Data acquisition for flight performance and guidance/control performance	Rudder input Release from offset point 100 m aft (to the north)	7 August	11:02-11:32
F009	Data acquisition for guidance/control performance	Release from offset point 100 m to the left and 50 m below	8 August	10:57-11:25
F010	Data acquisition for guidance/control performance	Release from offset point 200 m to the left	9 August	10:50-11:19
F011	Data acquisition for flight performance and guidance/control performance	Aileron input Release from offset point 100 m aft (to the north)	10 August	10:50-11:19
F012	Data acquisition for flight performance and guidance/control performance	Elevator input Release from offset point 50 m above	14 August	10:34-11:03
F013	Data acquisition for flight performance	Elevator input Release from offset point 100 m aft (to the north)	15 August	11:01-11:30

with that of the No. 2 vehicle because the fluctuations were also observed in the bias of its data.

(c) C009 (constrained flight test): This was a supplementary hanging flight test to check the installed radio altimeter. The test results indicated normal functions of the new radio altimeter.

(d) F002: This was a landing trial to evaluate the designed performance as well, and was a repetition of F101 with the following differences:

1) The radio altimeter had been replaced,
2) Brake pressure had been reduced from 3700 KPa to 2900 KPa because of the imbalance of the braking power, and
3) The ASOP was modified to assign the highest priority to the tracking radar in place of the sky screen watchers with the approval of the Australian side (Table 3).

Following the normal flight procedure, the vehicle was released at the nominal release point and landed automatically. The result was almost the same as F101 and was as expected, and yielded the basic performance of the ALFLEX.

(e) F003: An automatic landing trial was attempted, but it was aborted by the go-around direction from the FCF just before the release because clouds obstructed SSW-S's view. The helicopter and the vehicle returned to the normal course in the constrained flight configuration in an attempt to retry and approached the release point, but the trial was again aborted by the go-around direction from FCF because both the laser tracker and sky screen watchers were functioning intermittently.

(f) F103: Guidance and control performance data were acquired by releasing the vehicle at an offset point 67.1 m east of the nominal point. The guidance system activated at 7 seconds from the release, and the vehicle aligned to the nominal course at about 20 seconds after the release toward the center of MLS Az. The vehicle flared, touched down and completed its flight as in previous flights.

(3) From the 4th flight (F004), the wind restrictions were relaxed to 100% of the designed wind for the side wind and 150% for the tail wind. Originally it was planned to conduct data acquisition by adding command to the control surfaces and offset release in separate flights. However, the numerical simulation indicated the possibility of realizing the two items in one flight without interference. Thus, these two were combined in flights in the latter half of the flight trial phase (F008, F011, F012, F013). In addition, the trials could be made more frequently after such revisions of the trial conditions as rearrangement of the pre-flight checks to enable a flight trial every day and as an extension of the time zone for the landing trial. As a result of these efforts, the following flight trials were realized smoothly.

(a) F004: The elevator joggling command was applied during the equilibrium gliding phase to collect flight performance data. The amplitude of the command was 1.5 degrees.

(b) F005: As in the previous flight, the rudder joggling command was applied during the equilibrium gliding phase to collect flight performance data. The amplitude of the command was 3 degrees.

(c) F006: A flight to obtain flight performance data by applying the elevator joggling command during the equilibrium gliding phase was repeated in this trial.

(d) F007: Flight performance data was acquired by applying the joggling command to the ailerons during the equilibrium gliding phase. The input amplitude was 1 degree.

(e) F008: The vehicle was released at an offset point 100 m aft to obtain guidance/control performance data and the rudder joggling command (3 degrees) was applied to acquire flight performance data. This was the second trial to input the rudder command.

(f) F009: Even though clouds were developing in the area, the vehicle was released at an offset point 100 m to the left and 50 m below the nominal release point as scheduled.

(g) F010: The vehicle was released at an offset point 200 m to the left of the nominal release point as planned. As the release point of this trial was outside of the original caution line, the caution line had to be shifted to the limit line at X < - 1500 m in order to extend the normal flight area. Since SSW-F reported that this release point was observed outside the limit line during the hanging flight for checking, and required readjustment of SSW-F's line of sight. It was found from the examination after the trail that insufficient accuracy of the sky screen watchers caused this discrepancy.

(h) F011: This was the 4th day of daily flights. Offset release at 100 m aft and aileron joggling (1 degree) were conducted for the second time.

(i) F012: Offset release at 50 m above and elevator joggling (2 degrees) were conducted as planned.

(j) F013: This was the final of all the planned flight trials. Offset release at 100 m aft and elevator joggling (2 degrees) were conducted for the 4th time.

During the flight trial phase, there were no major problems which might have caused a large schedule delay. The greatest problem in the flight trial phase seemed to be finding a time zone when all the conditions listed below were satisfied.

(a) Carrying out the vehicle: The condition of the temperature to allow carrying out the vehicle was satisfied generally only after about 8:30 a.m., but the vehicle could not take off before 11:00 a.m. when carrying out was after 8:30 a.m.

(b) Clouds: A southerly wind meant a head wind for the approaching ALFLEX vehicle and was suitable for the trial. However, its temperature is generally low with humidity. When a southerly wind blows, clouds developed at low altitude (about 500 ~ 2000 m) due to convection of the atmosphere after sunrise. These clouds started developing at about 11:00 a.m. and usually the sky cover became over 4/8 in about 1 hour. On the other hand, ground wind speed generally increased due to an upper air flow and the wind conditions became less satisfactory in the afternoon.

(c) Sky screen watchers: Sky screen watchers could not operate when the sun positioned behind the vehicle because they watched the vehicle with their own eyes. It was hard for SSW-F to monitor the vehicle around noon (11:30 am ~ 12:30 pm) as they had to watch the vehicle while facing north from the south side of the runway. On the other hand, SSW-S could not watch the vehicle in the evening (after about 4:00 pm) as they faced to the west from the east side of the runway. Therefore, the vehicle had to take off earlier than 3:30 p.m. Furthermore, the vehicle was sometimes not visible due to clouds, and the trial had to be cancelled as in F003.

(d) Sunset: Outdoor tasks such as rolling back the vehicle to the hangar could not be conducted after sunset. Also the Vertol helicopter was permitted to fly only in the visual meteorological conditions. This required the Vertol to take off more than about 1 hour before sunset. Sunset around June 20th was about 5:30 p.m.

Difficulty in finding a time zone satisfying all of these conditions triggered efforts to extend the time zone possible to conduct the flight trial such as:

(a) The humidity condition allowing carrying out of the vehicle was revised up to 95%.

(b) By introducing a sun visor and a sun shade for the SSW operators, SSW-F became possible to monitor all the time. Moreover, the decision matrix for emergency command execution in the ASOP was revised to assign highest priority to the tracking radar, which made it possible to conduct a flight trial even when sky screen watchers were inactive.

Humidity and clouds which restricted landing trials depended on the movements of high pressure air which came over the area almost every week. However, as the fundamental performance of the vehicle became evident owing to the results of F101 and F002 in the earlier stage, we could relax the wind conditions. This relaxation increased the possibility of flight trials and contributed to efficient conduct of the trials. In addition, as both data collection of the flight performance (control surface joggling) and the guidance/control performance (offset release) could be done in a single flight, the outcome was better than the earlier stage.

Concerning the flight safety, the vehicle's flight path has been successfully monitored by using the information from sky screen watchers, tracking radar and other monitors in the ground flight control console. Based on the reliability of the tracking radar data obtained in early flight trials, the operational procedure was modified to decrease the load of sky screen watchers.

5. Summary of the Results

The total number of the flight trials is given in Table 6. With reference to the goals of the ALFLEX, and from the view point of its contribution to the HOPE development, the flight test results were as follows:

(1) Demonstration of the automatic landing technology

The performance of the navigation/guidance

Table 6 The Number of Flight Trials in Australia

Type of Trials	Number
Hanging Flight Tests	9
Helicopter Flights	2
Landing Trials	13
Cancelled Landing Trials	2
Total	26

/control system developed for the ALFLEX vehicle demonstrated to be in accordance with the designed performance, and this enabled to repeat automatic approach to the runway, flare/landing, landing roll and stopping. As indicated in Figs. 7 and 8, we obtained flight data for various wind conditions and releasing points which have been parameters of the landing experiment. The touch down points shown in Fig. 9 indicate that the present navigation/guidance/control system attained better performance than designed. Excellent performance of navigation can be observed in the accuracy data near the release point (Fig. 10): Errors between position data of the navigation output and of the laser tracker were about 5 m which is much smaller than the required performance of 25 m. The performance is also observed in the fact that the wind restrictions could be relaxed to 150% of the originally designed values. These results imply that the present design method can be a candidate for the automatic landing system for HOPE.

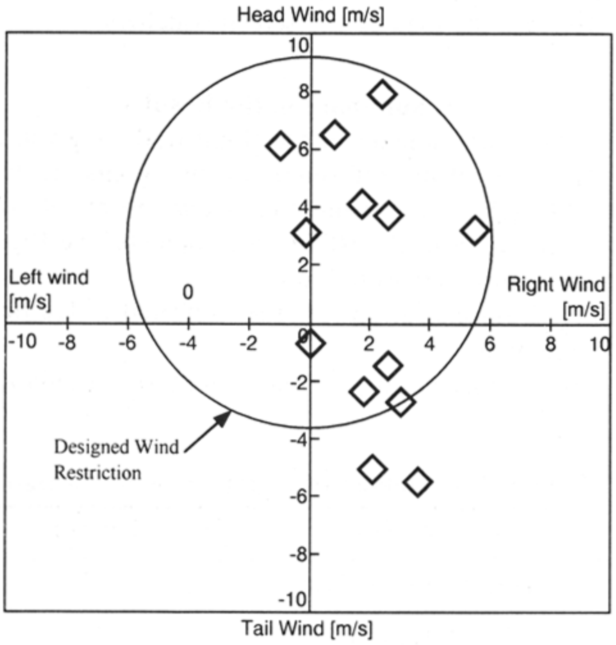

Fig. Surface Wind at Landing Trials

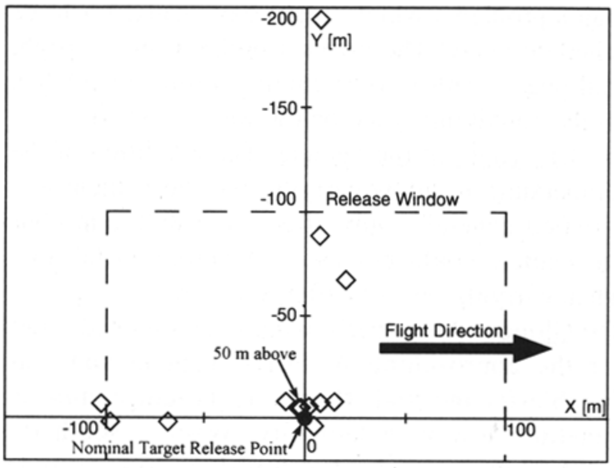

Fig. 8 Release Points

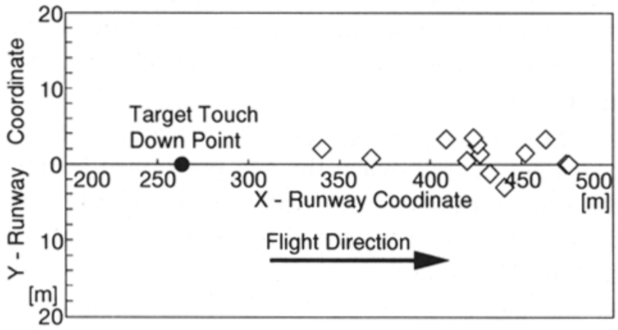

Fig. 9 Touch Down Points

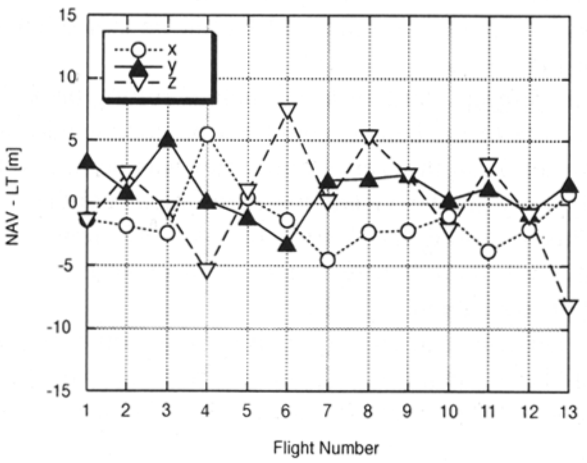

Fig. 10 IMU-DGPS Navigation Error
(The average of last 30 seconds before release)

(2) An example of the low-speed flight characteristics of a vehicle having the HOPE aerodynamic configuration

Consistent flight characteristics can be observed in Fig. 11, which indicates that flare landings can be made from a steep approach path. The flight characteristics are analyzed in detail to evaluate the navigation/guidance/control system and to estimate aerodynamics including ground effects. The data will be utilized as the low-speed aerodynamic database of a HOPE shape vehicle and as the database of the control system.

(3) Evaluation of the flight experiment methodology for HOPE using a scale model

A scaled flight experiment using a small size model of HOPE was conducted and the design methodology of the automatic landing system was confirmed. The experiment was planned and conducted so as to incorporate a stepping up policy including the hanging flight tests by utilizing the mathematical models of the system dynamics. The stepping up method brought sure and efficient conduct of the experiment by full utilization of the previous test results. Also, by utilizing the advantages of repeatability of helicopter flights, we could smoothly conduct the hanging flight tests and the automatic landing trials step by step.

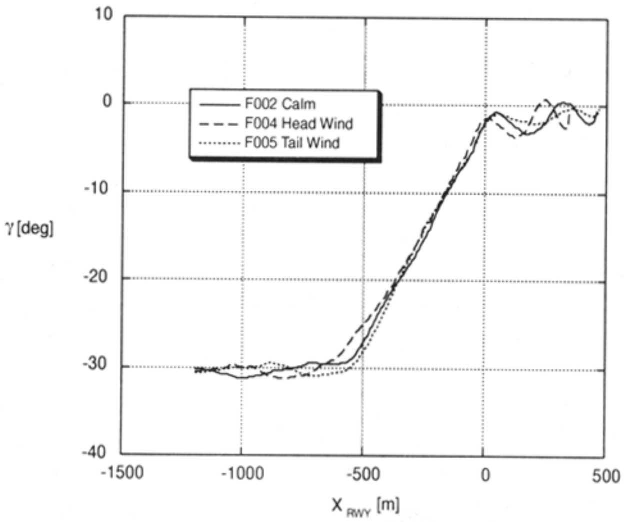

Fig. 11 Flight Path Angle

It should be also highlighted that computer simulations were fully applied. A newly developed device generally has characteristics not yet fully revealed, and this makes it difficult to predict its performance beforehand. Thus, the most efficient method to minimize steps and repetitions of the test should be simulation by using mathematical models, such as vehicle characteristics, aerodynamics, control characteristics and all possible models. In the ALFLEX program, 6-degree-of-freedom models for two typical conditions, the hanging flight configuration and the automatic landing flight condition, were constructed and were used for stepping up decisions, prediction of influence of errors or other factors of performance variations and for analysis of detailed performance by comparing actual responses with those of the model. Such analysis contributed to safe and sure planning of the flight trials. The appropriateness and accuracy of these models were evaluated step by step by comparing with the test results conducted so far also step by step. In addition, quick data reduction and quick analysis of the test results contributed to efficient conduct of the experiment. The analysis results were issued on the same day by making use of the hardware and the software brought into Australia.

In summary, the ALFLEX flight trials were repeated by combining the stepping up method using a helicopter and the performance prediction using the mathematical models. The present method could be used in similar programs of future space development activities.

6. Concluding Remarks

The ALFLEX has been completed as planned and is considered to have achieved its goals. It is obvious that these goals would not have been attained without various support from a lot of people. Especially, consistent and warm support from the Australian people greatly contributed to the smooth conduct of the experiment. Authors would like to express their thanks particularly to Mr. van Homelen (Area Administrator Woomera), Mr. G. Stanton (Safety and Operation Liaison Officer) and Dr. I. Tuohy (British Aerospace Australia) and many DSCW staffs, who gave supportive activities of the ALFLEX at Woomera.