Wind Tunnel Tests for ALFLEX

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ABSTRACT

For the development of the ALFLEX vehicle, it was necessary to estimate its aerodynamic characteristics before as accurately as possible, since they were essential for the design of the control system loaded onboard. To meet this requirement, six wind tunnel tests were conducted using several models of different sizes. In addition, two wind tunnel tests were conducted in the final stage of development to confirm the performance of subsystems or to check the result of the improvement of a subsystem. In this paper, these eight wind tunnel tests made at three organizations employing four wind tunnels are introduced along with the aerodynamic characteristics of the ALFLEX vehicle estimated in those tests.

1. Introduction

Since the ALFLEX vehicle has no intrinsic stability in itself, artificial control is indispensable for stable flight. The control system is, therefore, the most important system of the vehicle. Against this background, it was necessary to estimate the aerodynamic characteristics of the vehicle and the hanging equipment as accurately as possible, for the design of the control system. To fulfill this requirement, a total of six wind tunnel tests with scale models of different size were performed for collection and verification of the aerodynamic data. There were two additional wind tunnel tests, which were conducted to confirm the performance of subsystems, and to find the reason and countermeasure of a trouble found in the domestic constrained flight test. The outline of the wind tunnel tests along with the aerodynamic characteristics estimated by them are introduced below.

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2. Wind Tunnel Tests

For the development of aircraft, the aerodynamic characteristics are determined in wind tunnel tests before any actual flight tests are carried out. In the development of the ALFLEX vehicle also, many wind tunnel tests were conducted during its development (Table 1). Some of the findings, such as the primary low-speed wind tunnel test[1)] or the wind tunnel test for basic aerodynamic data acquisition (Fig. 1), were typical of conventional aircraft, but others were unique and noteworthy because they were designed specially for the ALFLEX project and included some new concepts. The latter includes the secondary low-speed wind tunnel test[2)], in which a robot manufactured for industrial use was utilized as a model support tool (Fig. 2), and the wind tunnel test for aerodynamic characteristics verification, in which operation of the parachute or dynamic stability of the vehicle were examined using a scale model. Making use of the ability of the robot model support system to change the position and attitude of the model easily, both static and dynamic ground effects were realized efficiently. Another example of the wind tunnel test which reflected the uniqueness of the flight test

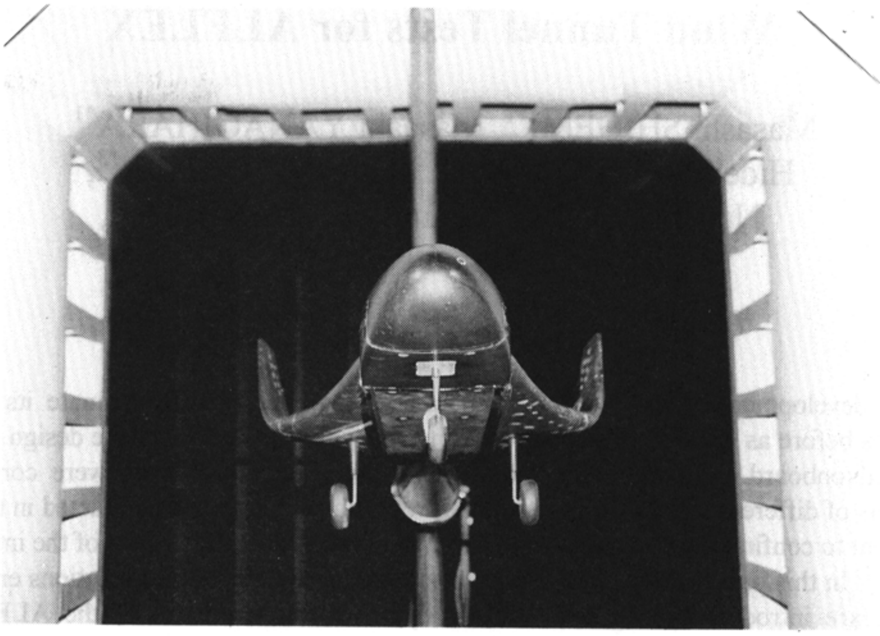

Fig. 1 Wind tunnel test for basic aerodynamic data acquisition

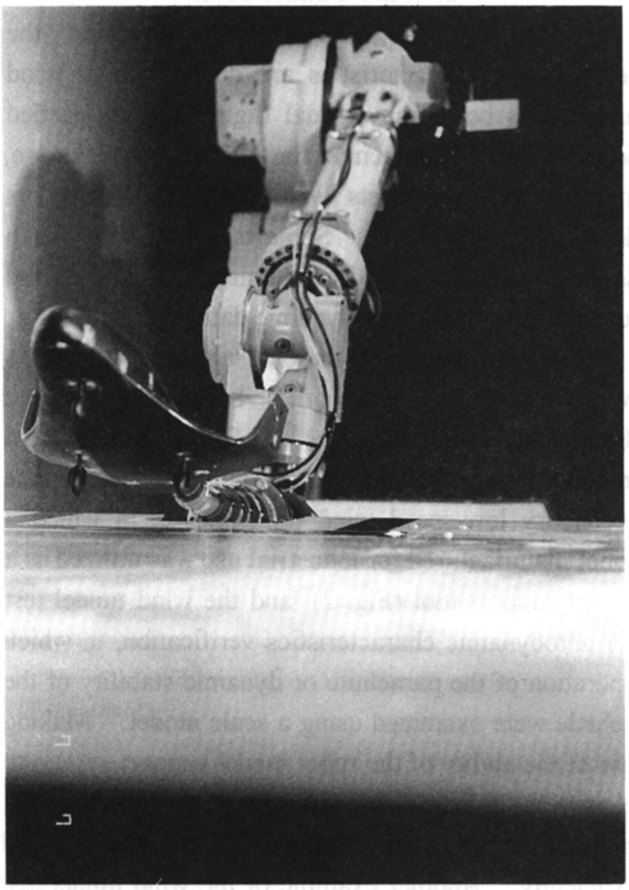

Fig. 2 Ground effect test with robot model support system

method of the ALFLEX vehicle was the wind tunnel test for verification of hanging characteristics[3]. In this test, a model, which was constructed similarly to the actual vehicle in both statically and dynamically, was hung in the test section of the wind tunnel (Fig. 3), simulating the state of the ALFLEX vehicle hung from the hanging equipment. The dynamic stability test for the hanging equipment and the vehicle were carried out, and then the performance of the control law was examined by making the vehicle model maintain balance under the domination of the control law. These wind tunnel tests were designed for use in ALFLEX, but the new engineering methods included in them are expected to be applied widely to other wind tunnel tests in the future.

Besides these wind tunnel tests for estimation of the aerodynamic characteristics of the vehicle and hanging equipment, there was another category of tests, which was found to be needed during the development of subsystems; they were the wind tunnel test for verification of air data system (ADS) performance, which became necessary after the ADS was developed, and the wind tunnel test to investigate cable flutter of the mother helicopter system. The phenomenon of cable flutter was first observed during the domestic hanging flight test.

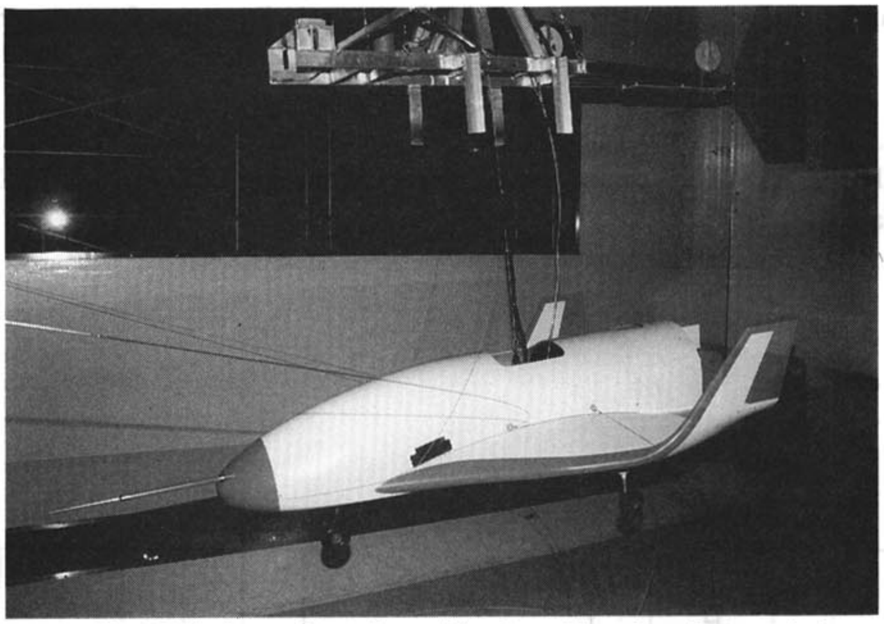

Fig. 3 Wind tunnel test for verification of hanging characteristics

3. Estimated Aerodynamic Characteristics of the ALFLEX Vehicle

The ALFLEX vehicle had a pair of elevons, a pair of rudders, and a pair of speed-brakes as control surfaces. Although much data regarding the aerodynamic characteristics of the vehicle and the hanging equipment was obtained in the wind tunnel tests cited above, only the most important data is shown below. They include the basic characteristics in longitudinal and lateral directions, effectiveness of control surfaces, and the ground effect characteristics.

(1) Basic longitudinal characteristics

The lift, drag and pitching moment characteristics of the vehicle in the basic configuration are shown in Figs. 4, 5 and 6, respectively. Fig. 6 shows that the vehicle has its intrinsic stability in the longitudinal direction ($Cm_{\alpha} < 0$) only in the restricted angle of attack region..

(2) Basic lateral and directional characteristics

The side force, yawing moment and rolling moment characteristics of the vehicle in basic configuration are shown in Figs. 7, 8, and 9, respectively. As Fig. 8 shows, the ALFLEX vehicle has no intrinsic directional stability ($Cn_{\beta} > 0$) in itself.

(3) Effectiveness of control surfaces

Since the ALFLEX vehicle could not fly stably without being controlled, it was necessary for the FCC (Flight Control Computer) to operate the control surfaces during its flight. The effectiveness of the elevator, rudder and aileron are shown if Figs. 10, 11 and 12, respectively. It was confirmed that the vehicle could be well trimmed with operation of these control surfaces.

(4) Ground effect characteristics

The static ground effect characteristics obtained in the secondary low-speed wind tunnel test are shown in Fig. 13. In the figure, h is defined as the distance between the ground and the (estimated) position of the aerodynamic centre of the model.

4. Concluding Remarks

The eight wind tunnel tests conducted in the development of the ALFLEX vehicle were introduced. It is apparent that these wind tunnel tests, some of which were carefully planned and others which were done to answer questions that unexpectedly came up, contributed greatly to the success of the automatic landing flight experiment. The outcome of the wind tunnel tests, which were conducted with new engineering in equipment, models, and model support system, are expected to influence wind tunnel techniques of the future.

References

1) Shigemi, M. et al.: "Low Speed Wind Tunnel Test for 8.9% Model of HOPE ALFLEX Vehicle", NAL TR-1215, 1993 (in Japanese).

2) Shigemi, M. et al.: "Experimental Investigation of Static and Dynamic Ground Effect on HOPE ALFLEX Vehicle", NAL TR-1236, 1994 (in Japanese).

3) Yanagihara, M. et al.: "Suspending Wind-Tunnel Test for the ALFLEX vehicle", NAL TR-1306, 1996 (in Japanese).

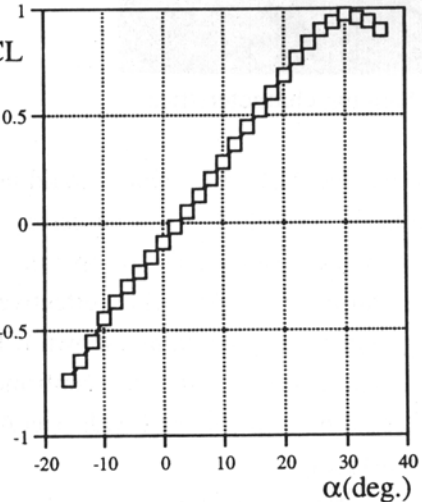

Fig. 4 Lift Coefficient

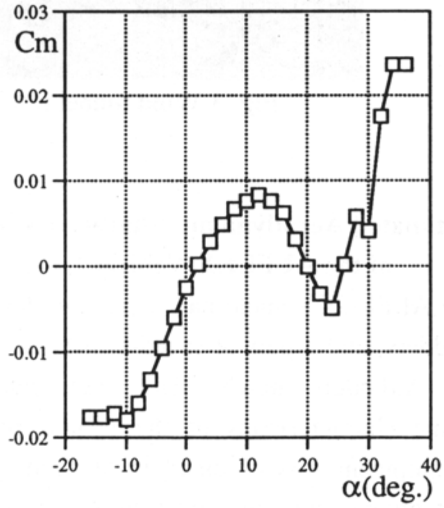

Fig. 6 Pitching Moment Coefficient

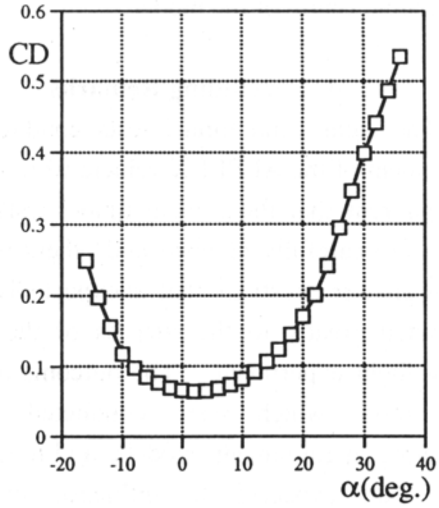

Fig. 5 Drag Coefficient

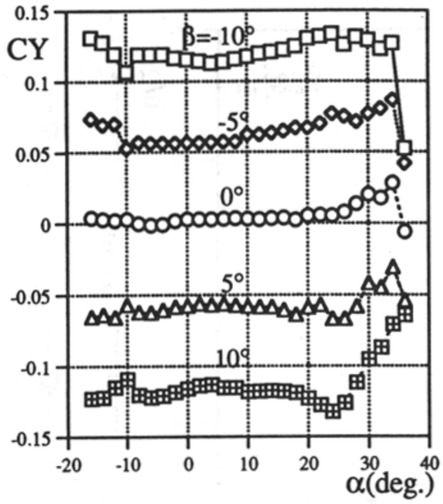

Fig. 7 Side Force Coefficient

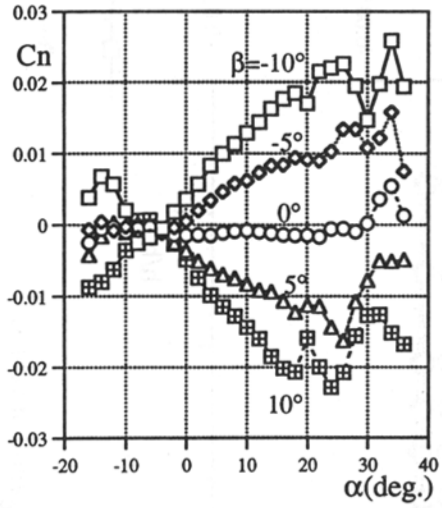

Fig. 8 Yawing Moment Coefficient

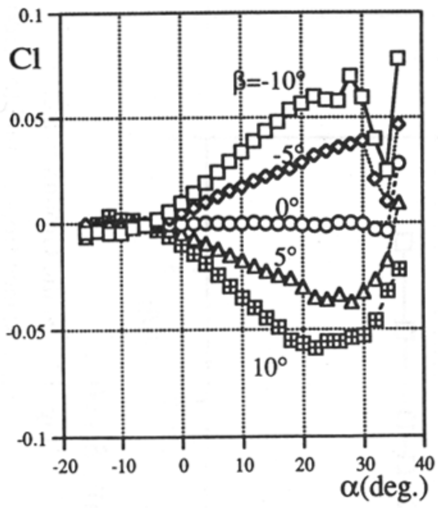

Fig. 9 Rolling Moment Coefficient

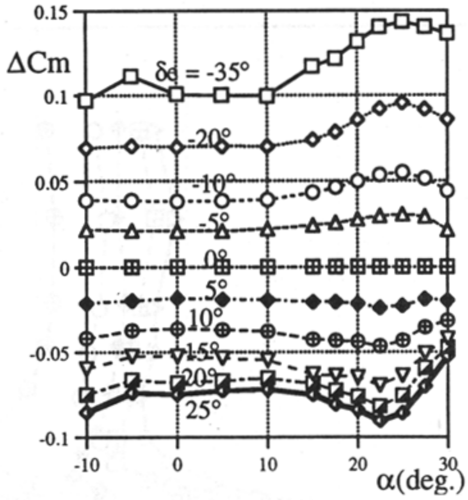

Fig. 10 Elevator Effectiveness

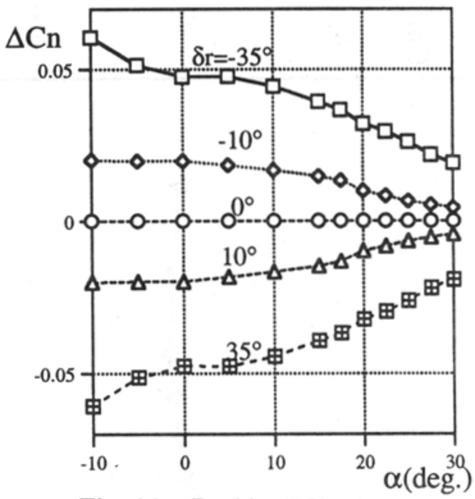

Fig. 11 Rudder Effectiveness

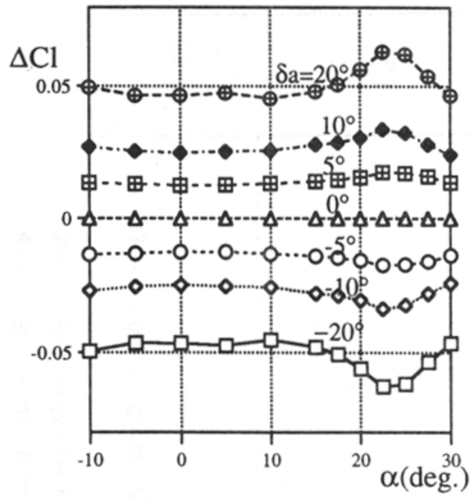

Fig. 12 Aileron Effectiveness

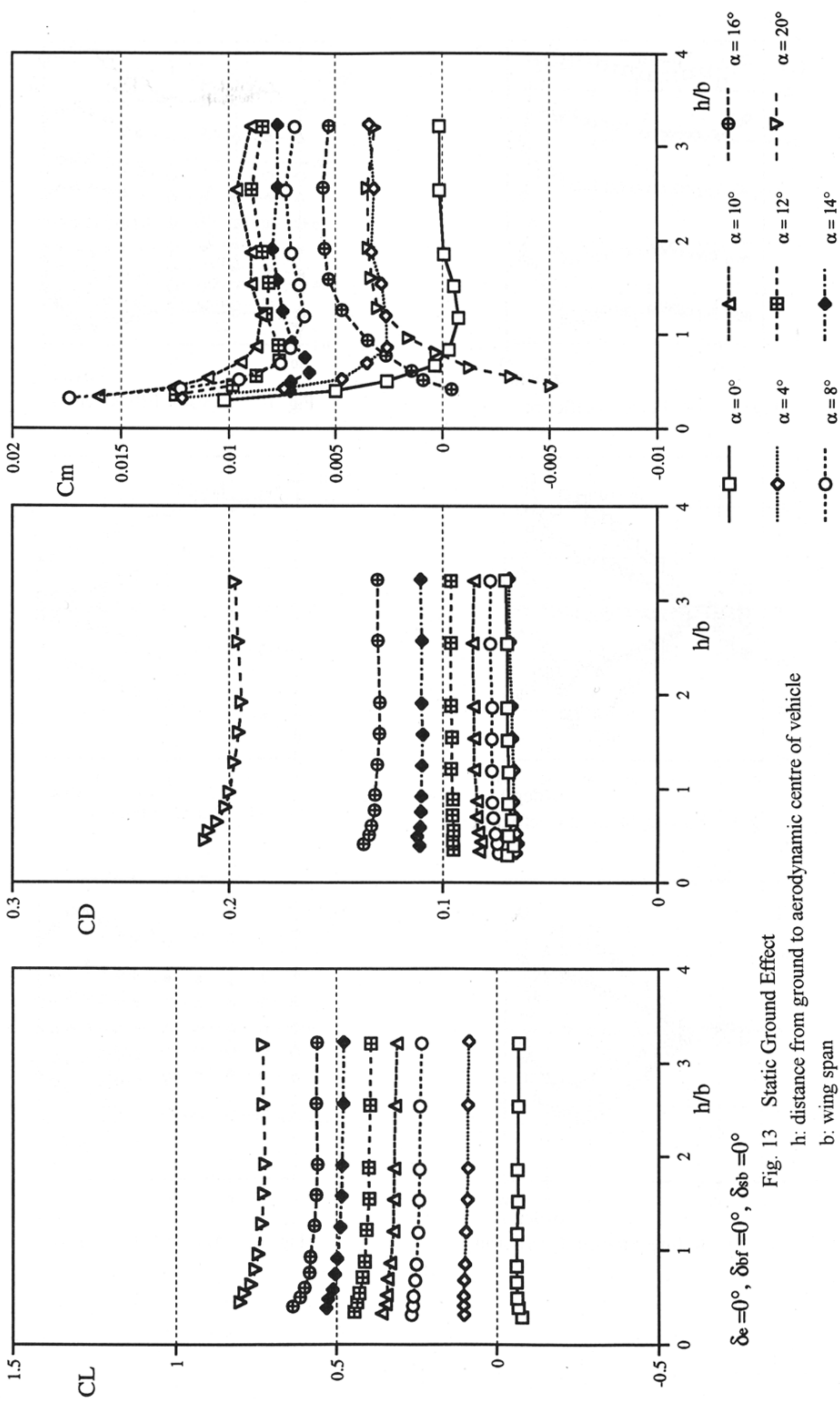

Fig. 13 Static Ground Effect
h: distance from ground to aerodynamic centre of vehicle
b: wing span

TEST NAME	FACILITY USED	TEST PERIOD	MODEL SCALE	PURPOSE	TEST ITEMS	FEEDBACK
1. Primary low-speed wind tunnel test	NAL gust wind tunnel	Mar. 1993- Apr. 1993	8.9%	> To acquire basic aerodynamic data for design.	> Clarification about the effect of makeshift sting system on the air flow field > Basic aerodynamic characteristics test (fundamental characteristics / control surface effectiveness) > Measurement of hinge moment > Measurement of pressure distribution > Observation of flow field (transition / separation of boundary layer)	preliminary/ first aerodynamic model
2. Secondary low-speed wind tunnel test	NAL gust wind tunnel	Jun. 1993- Jul. 1993	8.9%	> To measure ground effect using robot type model support system.	> Acquisition of basic aerodynamic characteristics by robot model support system > Static ground effect test > Dynamic ground effect test	supplement to third aerodynamic model
3. Wind tunnel test for basic aerodynamic data acquisition	FHI low-speed wind tunnel	Aug. 1993	14.9%	> To acquire aerodynamic data using model with improved shape, which was determined in the preliminary design.	> Verification test after modification of body/wing shape > Verification of effect of landing gear fairing > Measurement of hinge moment to complete Test 1 data with new speed brake forms added and with range of Reynolds number extended	second aerodynamic model
4. Wind tunnel test for aerodynamic characterist-ics verification	FHI low-speed wind tunnel	Dec. 1993- Feb. 1994	14.9% & 10.8%	> To verify the aerodynamic characteristics of the vehicle with the final configuration. > To acquire ground effect to complement Test 2. > To acquire aerodynamic characteristics of hanging equipment. > To verify operational characteristics of parachute. > To acquire data on dynamic stability to determine dynamic stability coefficient.	> Verification test for the final configuration > Aerodynamic Characteristics test of hanging equipment > Aerodynamic characteristics test of vehicle /hanging equipment I/F > Measurement of pitot tube position error > Verification of effect of wake on the parachute deployment > Ground effect test > Dynamic stability test	third aerodynamic model

Table 1. Wind tunnel tests

TEST NAME	FACILITY USED	TEST PERIOD	MODEL SCALE	PURPOSE	TEST ITEMS	FEEDBACK
5. Wind tunnel test for verification of hanging characteristics	NAL large size low-speed wind tunnel;	Jun. 1994-Jul. 1994, Sep. 1994-Nov. 1994	40%	> To verify aerodynamic characteristics of the vehicle, hanging equipment and their combination and to test their stability during hanging.	[static test] > Verification of static aerodynamic data for the vehicle, hanging equipment and their combination > Evaluation of pitot tube position error > Comparison of results using two different model support systems [dynamic test] > Hanging equipment test > Vehicle/hanging equipment integration test > Five degrees of freedom constrained test	supplement to third aerodynamic model
6. Wind tunnel test for dynamic stability in hanging	FHI low-speed wind tunnel	Nov. 1994-Mar. 1995	10.8%	> To measure dynamic stability coefficients of hanging equipment and vehicle/hanging equipment combination to complete Test 4.	> Dynamic stability test for measuring; -Cl and Cn at ϕ oscillation -Cm at θ oscillation -Cl & Cn at ψ oscillation	third aerodynamic model
7. Wind tunnel test for verification of air data system(ADS) performance	MHI low-speed wind tunnel	May 1995	actual ADS	> To verify accuracy and employable limit of ADS.	> Confirmation of flow condition > Static test > Angle sweep test	
8. Wind tunnel test to investigate cable flutter of mother helicopter system	NAL large size low-speed wind tunnel	Feb. 1996	100% (actual parts and model of actual size)	> To clarify the oscillation phenomenon of release equipment, which was proven to exist in the domestic constrained flight experiments, and to verify the effectiveness of countermeasures against it.	> Reappearance test for oscillation > Verification of the effectiveness of countermeasures employed > Specification of the best countermeasure and verification of its robustness	

Table 1. Wind tunnel tests (Continued)