A Study on the Dynamic Characteristics of Airship Through the Flight Test

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Abstract

Nowadays, many kinds of research for airship have being studied with increase of interests in airship. But these make little progress even now. In flight test, the data acquisition from the actual flight test has lots of difficulties because the airship dynamic response is slow and sensitive to external environment. In this paper, through the actual flight test, appropriateness of the mathematical dynamic model was presented by showing the test results in various conditions. The turning, the acceleration, and the deceleration motions were tested and analyzed.

Key Word : Airship, Flight test, Turning, Acceleration, Deceleration

Introduction

For a long time, the research for airship made little progress. With the commercial success of Zeppelin NT, the Germany Company, now development is leaping. For more, the research for a stratospheric communication airship has being studied in Korea, Japan, and other countries.

In this paper, based on the results of the research in mid-size rigid airship for observation[1-3], the prototype was designed, manufactured, tested and then analyzed from the flight test data. To get the data, all equipments were mounted on the gondola: an anemometer, a weathercock, a clinometer, a GPS, one set of RF modem, and etc.

The tests were divided two parts; the ground test and the flight test. In the ground test, data signal compensation test with the transmitter/receiver and error correction test were accomplished in and out of laboratory. In flight test, the attitudes, position, velocities were measured at given control inputs. In this paper, three flight test results were presented along with the flight modes: turning, acceleration, and deceleration. Because the wind gust remarkably affected the motion of airship during the flight test, the effects by gust was also analyzed.

Dynamic Modeling of Unmanned Airship

The dynamic model used for comparison was simplified by following assumptions; it is a symmetric and non-rigid type airship and can be neglected the aeroelatic effects[3]. The origin is set on the buoyancy center because the aerodynamic coefficients were measured at the buoyancy center. The center of gravity is located at the symmetric plane. Finally, the airship envelope is a rigid body. The following Fig. 1 shows the model for simulation and coordinate systems[4-6].

In Fig. 1, the origin is located at the center of buoyancy, so the buoyancy makes no moments. The center of mass lies at a distance apart as a_x and a_z along the x- and z- axis, respectively.

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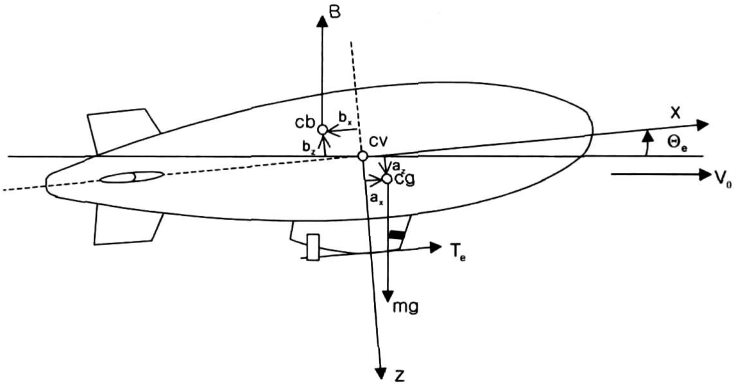

Fig. 1. Dynamic model of airship

The engine is located at gondola and it was mounted with angle Θ_e. The dynamic equations of motion were modeled as followings:

$$m_x \dot{U} + (ma_z - \bar{X}_{\dot{q}})\dot{q} + m_z qW - m_y rV - ma_x(q^2 + r^2) + ma_z pr = X_{ext} \tag{1}$$

$$m_y \dot{V} + (ma_z - \bar{Y}_{\dot{p}})\dot{p} + (ma_x - doyY_{\dot{r}})\dot{r} + m_x rU - m_z pW + ma_x pq + ma_z qr = Y_{ext} \tag{2}$$

$$m_z \dot{W} - (ma_x - \bar{Z}_{\dot{q}})\dot{q} + m_y pV - m_x qU + m_x pr - ma_z(p^2 + r^2) = Z_{ext} \tag{3}$$

$$J_x \dot{p} - (J_y - J_z)qr - J_{xz}(\dot{r} + pq) - (ma_z + \bar{L}_{\dot{V}})\dot{V} - ma_z(rU - pW) = L_{ext} \tag{4}$$

$$\begin{aligned} J_y \dot{q} + (J_x - J_z)pr - J_{xz}(r^2 - p^2) &+ (ma_z + \bar{M}_{\dot{U}})\dot{U} - (ma_z + \bar{M}_{\dot{W}})\dot{W} \\ &- ma_x(pV - qU) + ma_z(qW - rV) = M_{ext} \end{aligned} \tag{5}$$

$$J_z \dot{r} - (J_x - J_y)pq - J_{xz}(\dot{p} - pq) + (ma_x - \bar{N}_{\dot{V}})\dot{V} + ma_x(rU - pW) = N_{ext} \tag{6}$$

Flight Test Results and Analysis

Test Equipments and Monitoring Environment

Fig. 2 shows the designed airship for flight test and Fig. 3 is the sketch of gondola drawn by CATIA. Fig. 4 represents the picture of gondola which an anemometer, a weathercock, and other sensors and transmitter were mounted. The airship has two engines with the same power on both sides of gondola. The tilting angle of engine was controlled simultaneously. In the fore part, each sensor and transmitter were mounted. For the reduction of vibration caused by engines, the damping system was devised. The position of gondola could be adjustable for weight balance.

The length is 11m, maximum diameter is 2.8m and its volume is about 43m^3 of the test airship. The masses of each parts and sensors are presented at Table 1. Payload of this airship was planned about 10kg and it finally didn't exceed the limitation. The valid control range is over 200m.

Center of mass of this airship is located 4.9m from the head and 0.6m below from the centerline. The location of center of mass and moments of inertia was calculated by CATIA. The engine mounted at gondola was located at (-0.1m, 0.6m, 0.9m) from the center of mass.

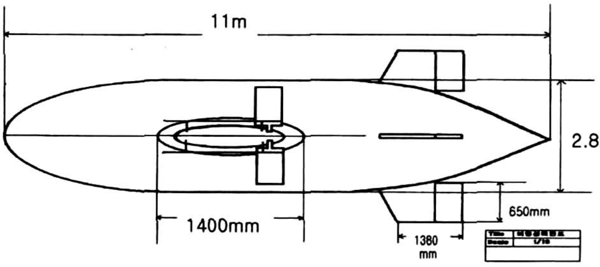

Fig. 2. Designed airship

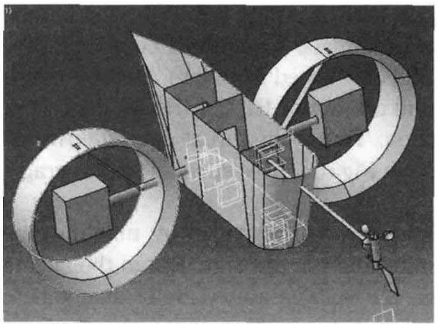

Fig. 3. Design of gondola by CATIA

Fig. 4. Gondola picture and sensors

Table 1. Parameter of test airship

Length		11 m	Height		2.8 m
Volume		43.72 m^3	Moment of inertia	I_{xz}	151.56 kg · m^3
Weight	Envelope	20 kg		I_{xz}	248.35 kg · m^3
	Fins	4.5 kg		I_{xz}	201.44 kg · m^3
	Gondola	20 kg		I_{xz}	0.867 kg · m^3
	Engine	4.2 kg (2.1 kg EA.)			
Payload(max)		10 kg	Valid control range(max)		2000 m
Weights of sensors					
Clinometer		0.31 kg	GPS		0.22 kg
Anemometer		0.737 kg	Data Acquisition board		0.33 kg

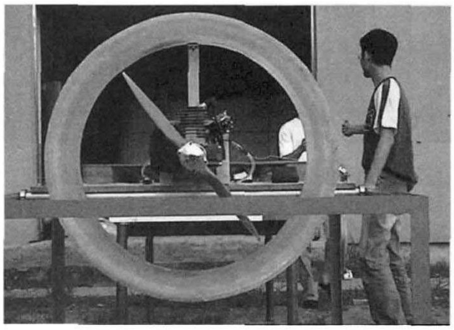

Fig. 5. Thrust test picture

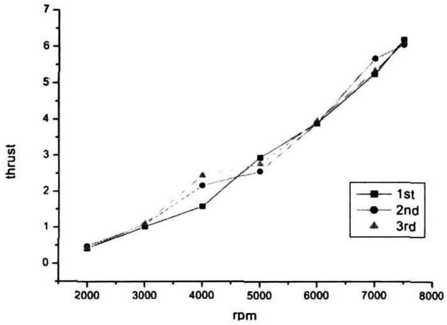

Fig. 6. Engine thrust test results

Table 2. Pulse width of receiver

Signal	Displacement	Pulse width
Rudder	-30~30°	1152-1908
Elevator	-30~40°	1056-1820
Throttle	40~7600rpm	1284-1832
Tilting	0~90°	1280-1624

The engine is G450PU 45cc 2 cycle gasoline engine with maximum 3.2 PS at maximum rpm (10,000 rpm), GPS RMS resolution is 10m. The anemometer made by DAVIS company was used: its direction can be measured from 0° to 360°(16 phase) and also speed from 0 to 78m/s. Its resolution is 0.1m/s and 1°, respectively. A TCM2-50 Clinometer and one set of RF 2.4GHz Modem were used. RS232C interface board was designed for data transmission. To get the thrust data, following thrust test(Fig. 5) was accomplished and got the thrust curve like Fig. 6. After several test, average value was adopted.

To calibrated the anemometer, exact reference indicator that provided by manufacturer was used. After measuring the exact north direction by indicator, the electric signal from the anemometer was adjusted. To calibrate the speed of the anemometer, the voltage amplitude of anemometer was used fitting the speed value equal to that of the indicator. By repeating these simultaneous test, anemometer was corrected. Test altitude was about 10m from the ground. At that altitude the wind condition is very unstable and variable, so the airship velocity was corrected by using two anemometers. To measure the modified airship velocity and direction, two anemometers were used for flight test; one was mounted in front of the gondola, and the other was located in the air, 2m from the ground. At that time, one assumption was taken that the wind condition at 10m from the ground was the same as that of the ground.

By measuring the pulse width of receiver channel for the control inputs(rudder angle, elevator angle, throttle, tilting angle), the relations between the pulse width and the real control input were summarized as Table 2.

To observe the real-time test data and to know the trajectory of the airship, a ground monitoring environment program was composed and applied to the observation as Fig. 7 and Fig. 8. This monitoring program can show the heading angle, pitch angle, roll angle as well as the current speed, direction

Fig. 7. Monitoring environment

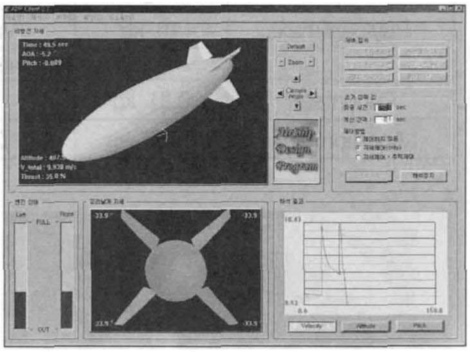

Fig. 8. Client server program

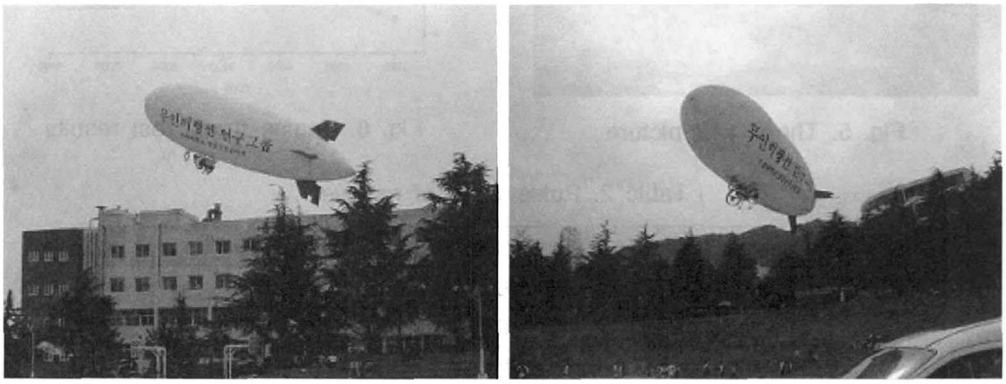

Fig. 9. Test flight picture

and trajectory of the airship in real-time.

Using the above equipment and monitoring environment program, flight test was peformed and the results were analyzed. The Fig. 9 shows the pictures of flight tests.

Results and analysis

Flight tests were carried out in different flight mode; turning, acceleration and deceleration. During the flight test, airship speed was 10m/s, while the average wind speed was 1.2m/s and the direction was north-north-east. For analysis of the airship data, the wind velocity was considered to modify the airship velocity and the uncertainty of velocity data was included in this test data.

Two cases of turning test was carried out; (1) fixed control angles and (2) free control angles. Fig. 10 shows the position trajectory of turning from the GPS signal and Fig. 11 are the roll angle and pitch angle at turning. Known from the Fig. 11, roll angle was changed from -6° to 2° while the pitch angles were varied from zero to 20°. It is known that the former case has less variation in attitude than the latter.

Table 3 expresses turning performances of two cases. The turning radii are 52.5m and 63.4m, respectively. At each cases, the time spent for turning is 25sec and 30sec.

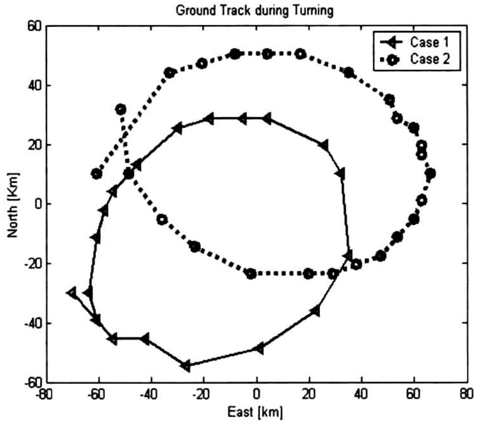

Fig. 10. Trajectory during turning

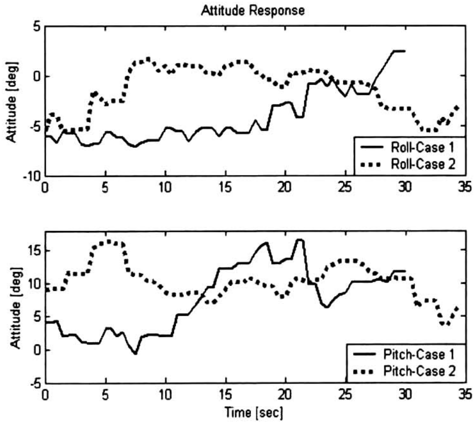

Fig. 11. Roll angle and pitch angle

Table 3. Turning performance

Case	Maximum Turning Radius	Turning Time
1	52.5 m	25 sec
2	63.4 m	30 sec

To confirm the stability of airship in a case of engine failure, deceleration test was carried out. The results are showed from Fig. 12 to Fig. 15.

In deceleration cases, the thrust was fixed from maximum to zero. Fig. 12 and Fig.14 represent the velocities and attitudes: pitch angle and roll angle. Fig. 13 and Fig. 15 show the control inputs: thrust, tilting angle, rudder angle and elevator angle. In spite of zero thrust, the velocity of airship was slowly and steadily changed, the attitudes were converged to zeros. During the test the changes of pitch angles were slight while the roll changes and rudder deflections were enormous. From this facts, the side wind affected the yaw angle, so finally changed the roll angle of the airship.

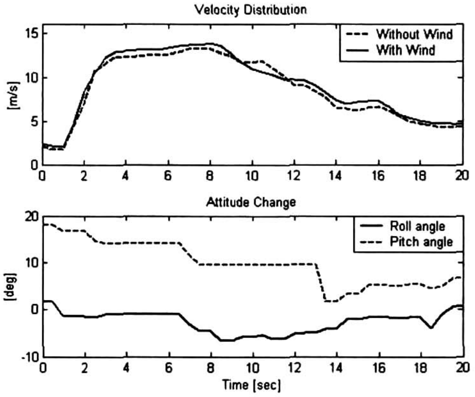

Fig. 12. Velocities and attitude angles at deceleration (Case 1)

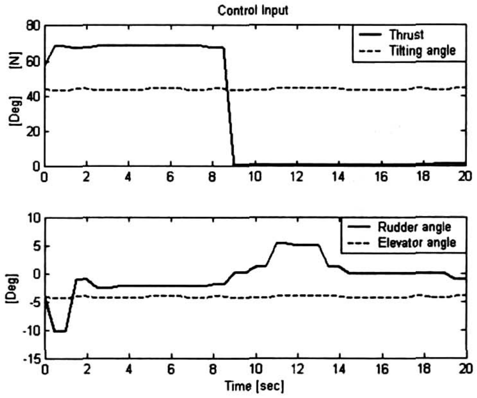

Fig. 13. Control Inputs at deceleration (Case 1)

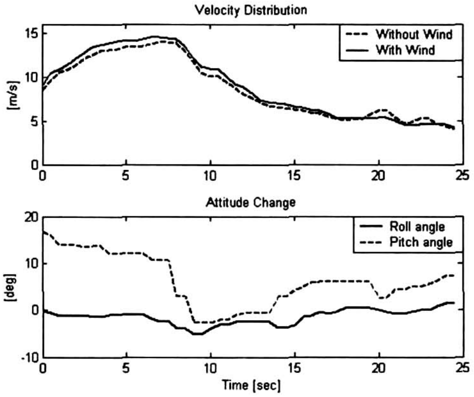

Fig. 14. Velocities and attitude angles at deceleration (Case 2)

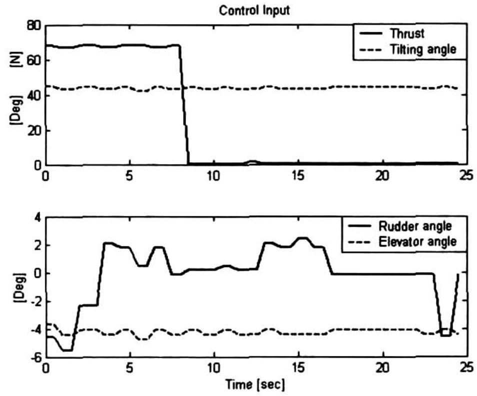

Fig. 15. Control Inputs at deceleration (Case 2)

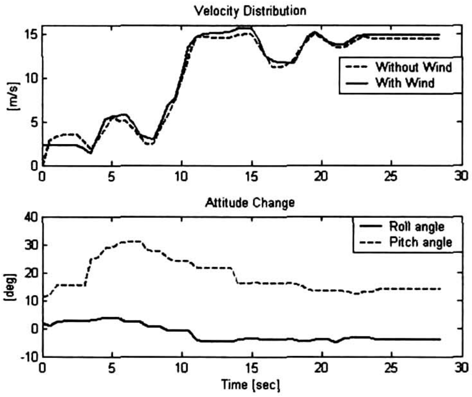

Fig. 16. Velocities and attitude angles at acceleration (Case 1)

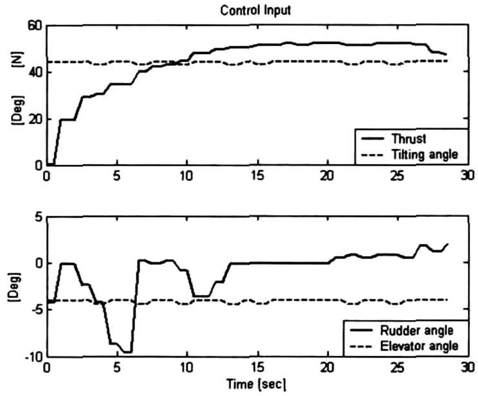

Fig. 17. Control Inputs at acceleration (Case 1)

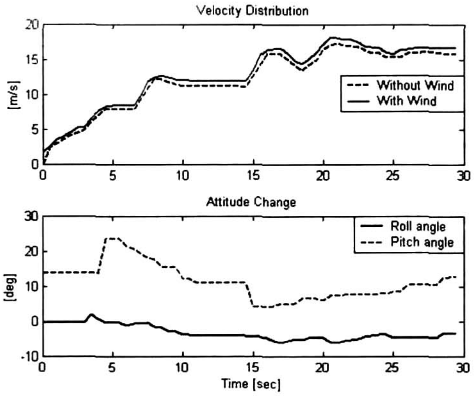

Fig. 18. Velocities and attitude angles at acceleration (Case 2)

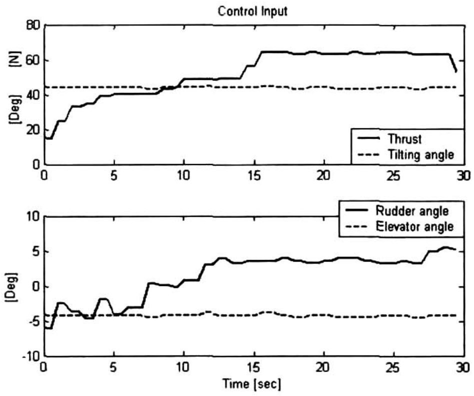

Fig. 19. Control Inputs at acceleration (Case 2)

Table 4. Acceleration and deceleration performance

Flight type	Case	Maximum	Minimum
Acceleration	1	5.62 ㎨	2.63 ㎨
	2	4.75 ㎨	1.55 ㎨
Deceleration	1	3.3 ㎨	2.45 ㎨
	2	2.9 ㎨	2.54 ㎨

To know the acceleration performance, the acceleration test was accomplished. Fig. 16 and Fig. 18 show the velocities and attitudes of the airship. In Fig. 17 and Fig. 19 represent the control inputs; Thrust, tilting angle, rudder angle, and elevator angle. Table 4 shows the acceleration and deceleration performance.

In the acceleration case, engine tilting angle was fixed and the thrust was gradually increased up to maximum value. In Fig. 16, between 5 sec and 10 sec, an unexpected decrease of velocity was occurred by wind effects and this velocity decrease caused the reduction of airship speed. So it is known that there was an adverse wind effects. In Fig. 17., the rudder deflected greatly about 5 sec, this also altered the velocity. During acceleration, the airship was pitched up and didn't revered to the zero value. This could be observed in Fig. 17 and Fig. 19. The elevator angles were fixed at -4.3°.

In Table 4, the maximum acceleration was about 5.62㎨ and the minimum acceleration was about 1.55㎨. For deceleration, the change was smoother than acceleration. It was decreased up to 3.3㎨.

Conclusions

In this paper, through the flight test, airship performance was analyzed for turning, deceleration, and acceleration mode. At each mode, the velocities and attitudes were strongly affected by wind gust and they were controlled by the rudder. The airship could be turned with small turning radius and within reasonable time flight. During the deceleration, airship was stable enough for zero thrust and the acceleration had also reasonable performance.

The radius of turning was 52.5m and 63.4m, respectively. These are small enough for 11m airship. The acceleration for two case, each was 5.62㎨ and 4.75㎨. These are fast enough for accelerating. For the deceleration, the case of engine turn-off, the velocity changed smoothly and the attitudes were converged to zero.

For the next, for the verification of the airship model appropriateness, parameter identification and eigenvalue analysis will be studied.

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