Unsteady Aerodynamic characteristics of Wings in Ground Effect

T. Matsuzaki* , S. Yoshioka**, T. Kato**, and Y. Kohama**

* Dept. of Mech. Eng., Tohoku University ,
** Institute of Fluid Science, Tohoku University

ABSTRACT

In spite of the great deal of effort has been made on researching the ground effect in the steady condition, little attention has been given to the ground effect in the unsteady condition. This paper is, therefore, intended as an investigation of the force generated and the flow around the wing when it undergoes unsteady movement at constant speed near the ground. And then it was proven that unsteady aerodynamic characteristics exist in the ground effect when moving in the direction of the height. The cause of these unsteady phenomena was the influence of the induced velocity. The induced velocity is derived from the starting vortex keeping on generating because the circulation around the wing continuously carried on changing when moving heightwise near the ground.

Key Words: ground effect, wing, vortex, unsteady flow

1. Introduction

The transportation system using ground effect is expected to become one of high speed and efficient transportation systems[1, 2]. Kohama proposed a new transportation system using ground effect, which is called the "Aero-Train"[3]. Our research team has developed Aero-Train (Fig.1) and it has wings and flies near the ground inside a guide way using ground effect.

Aero-Train has been developed through wind tunnel testing and numerical simulation just like other aircraft. Wind tunnel testing and numerical simulation have often been applied to in the steady condition. But actual aircraft (including Aero-Train) are flying while undergoing unsteady movement like pitching, rolling, yawing, and heaving, etc.

Aircraft are developed based on the result of wind tunnel testing and numerical simulation, mainly in the steady condition. The aerodynamic force in the unsteady condition is usually calculated in the steady condition in each state, by assuming the unsteady forces to be quasi-steady.

However, ground effect is a phenomenon with unique characteristics even in the steady condition. The authors suggest that there is a phenomenon that has not been clarified in the ground effect in the unsteady condition.

Therefore, this research aims at the clarification of the force generated and the flow around the wing when it undergoes unsteady movement near the ground. This is carried out paying special attention to the phenomenon when the wing moves in the height direction, so the ground effect is a phenomenon that strongly depends on the height from the ground.

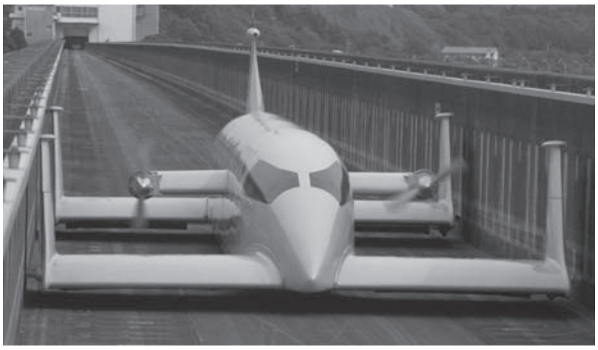

Fig. 1 Aero-Train test model.

2. Experiments

2.1. Experimental setup

At first, the aerodynamic characteristics with ground effect in the steady condition were measured in detail. And then, this data was used to identify the characteristics of the ground effect in the unsteady condition. Considering these results, the characteristics with ground effect were investigated in the unsteady condition about heaving motion.

Fig.2 shows the experimental setup. The wing model and the wing support parts fixed to the loadcells. The loadcells were moved up or down with electric sliders at constant speed. Aerodynamic forces were measured with the three momentum loadcells.

The measurement of the height from the ground was cross-checked by using a laser displacement sensor and the positional confirmation function of motor controller. The fixed ground plate was used to imitate the ground.

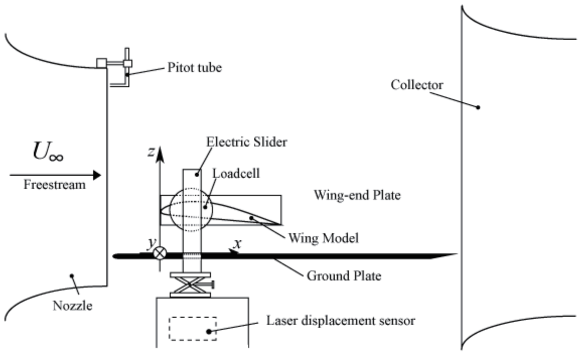

Fig. 2 Experimental setup

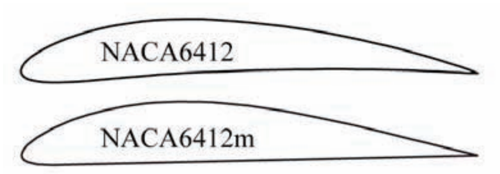

Fig. 3 Airfoils

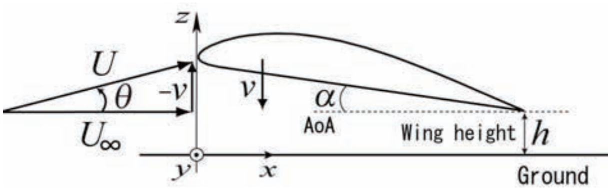

Fig. 4 Parameters and axis coordinates

Table 1 Parameters

Re	2.0×10^5
h/c	0.01 ~ 1.0
α	1.0 ~ 5.0 [deg]
θ	0.1 ~ 1.0 [deg]

2.2. Wing model

NACA6412-modified (NACA6412m) is used for the airfoil in this research. NACA6412m is improved to better shape based on NACA6412 in order to effectively use the ground effect wing. It has a flat bottom surface to suppress sucking at the lower surface, and the camber line is curved upwards at trailing edge area to decrease separation at the area.

The geometry of the wing model is recorded Fig. 3. The chord length *c* is 0.2 m. The span width *b* is 0.4 m. Aspect ratio AR is 2.0.

2.3 Parameters

The Parameters are Reynolds number *Re,* height over chord length *h/c*, the angle of attack , and the amount of change of the effective angle of attack . The parameters and axis coordinates indicated in Fig.4. Reynolds number was based on the chord length and the freestream velocity. The parameters are shown in Table 1.

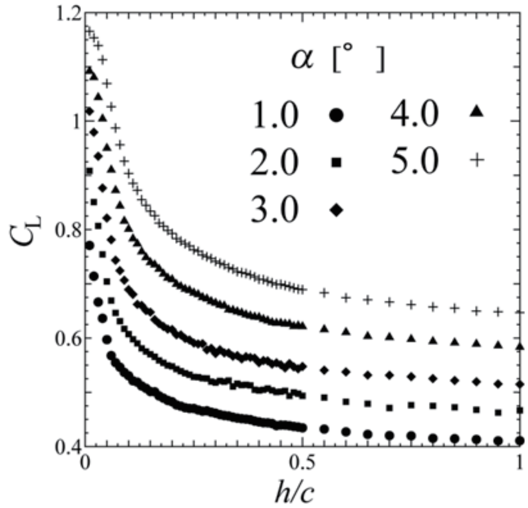

Fig.5 Lift coefficient as a function of *h/c* in steady condition

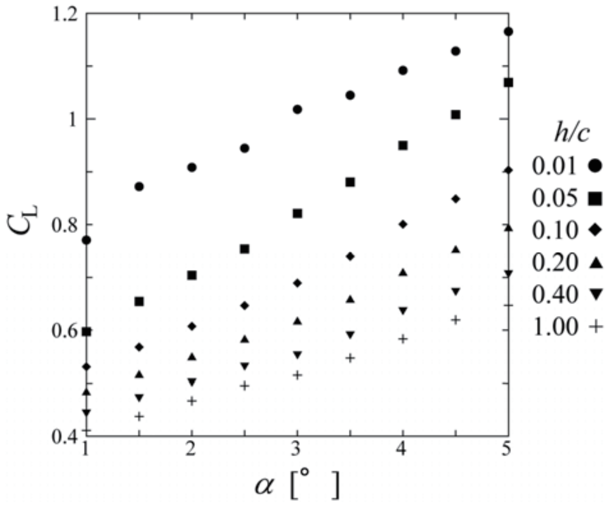

Fig.6 Lift coefficient as a function of α in steady condition

3. Results and discussions

3.1.Results in steady condition

First, experiments were carried out in steady condition, and the base line result was obtained. Fig. 5 shows lift coefficient C_L vs. h/c and Fig. 6 shows C_L vs. α.

Fig. 5 shows that C_L nonlinearly increased as *h/c* became small. The inclination of the curve tended to become steep as *h/c* became small. This characteristic was seen in the ground effect.

Fig. 6 shows that C_L increased as the angle of attack became large.

Considering these results, the aerodynamic force in the unsteady condition is calculated in the steady condition in each state, by assuming the unsteady forces to be quasi-steady.

3.2.Results in unsteady condition

Actual value measured in the unsteady condition was compared with these identification values. The results where the effective angle of attack α_e were equated are shown. α_e is the sum of α and θ. θ is the amount of the changing of the effective angle of attack. θ is defined by freestream velocity U_∞ and the heaving speed v (Fig.4).

In this time, the one effective angle of attack α_e was used as an object of comparison. All of their α_e is 4 degrees. One is where α is 3 degrees and θ is +1 degrees. Another is where α is 4 degrees and θ is 0 degrees (no move). The other is where α is 5 degrees and θ is -1 degrees.

Fig. 7 (a) shows that the drag coefficient C_D changed when the wing moved up or down. When the wing moved down, the value measured was lower than the value identified. The value measured was, on the other hand, higher than the value identified when the wing moved up. This is because the axis of the lift and drag was inclined by the change in effective angle of attack (Fig.8). Fig. 7 (b) shows the results, taking the change in the inclination of the axis into consideration. These values identified and the actual values measured were nearly equal if this was taken into consideration. The inclination of the axis is taken into consideration for identifying at all the following.

Fig. 9 shows that the lift coefficient C_L changed when the wing moved up or down. When the wing moved down, the value measured was lower than the value identified. On the other hand, the value measured was higher than the value identified when the wing moved up.

Fig. 10 shows that lift coefficient C_L changed if the amount of effective angle of attack changed. It shows that the larger the change in effective angle of attack is, the more the gap grew.

The reason why there is the difference between the value identified and the value actual measured is the changing of the induced velocity around the wing. For example, it treats when wing moving down.. Lift force increases as the ground approaches. Another way of saying, the circulation around the wing increases as the ground approaches. In fact, the circulation around the wing kept changing when the wing moved down (Fig.11).

The circulation around the wing kept changing and the starting vortex kept being generated at the same time while the wing moved down in the direction of height. As a result, the starting vortex inclined the effective angle of attack. For example, the starting vortex was generated and the downwash was strengthened when the wing moved down. The downwash worked to decreasing the effective angle of attack, so the lift coefficient came down. In consequence, the difference between the value identified and the value actual measured is occurred.

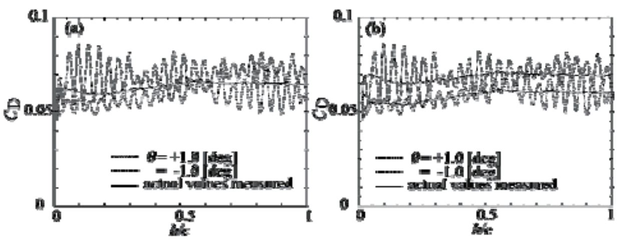

Fig. 7 The drag coefficient as a function of *h/c* in unsteady condition

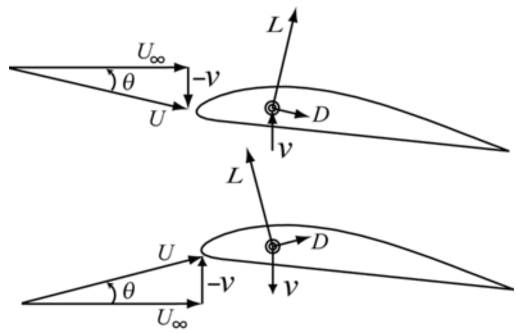

Fig. 8 The inclination of the axis

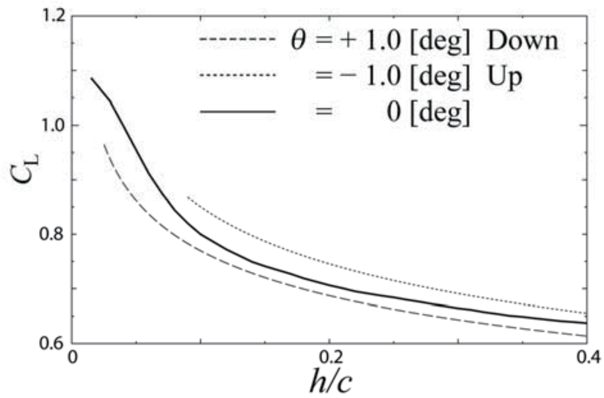

Fig. 9 The lift coefficient as a function of *h/c* in unsteady condition

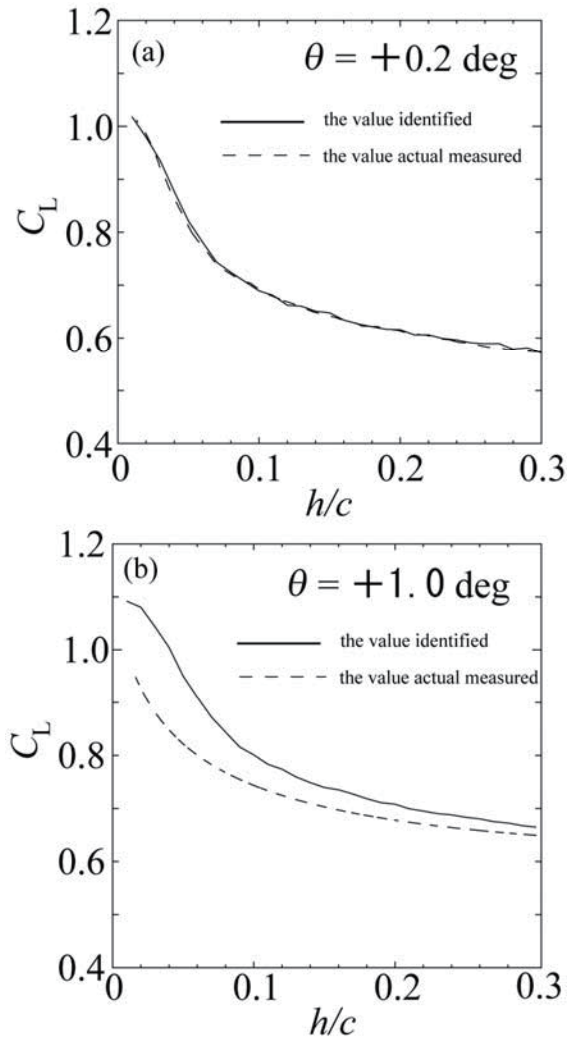

Fig. 10 The difference of the amount of effective angle of attack changed

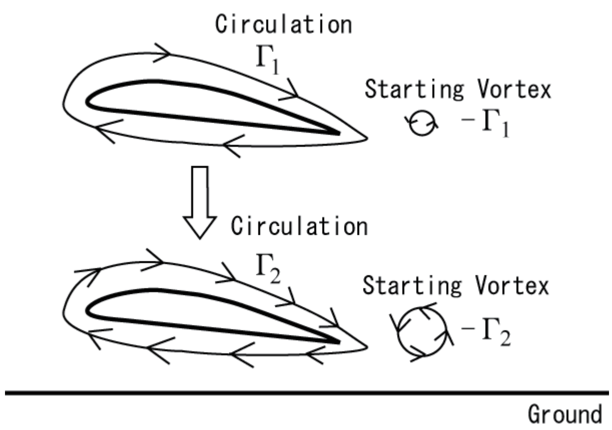

Fig. 11 The reason why the difference was occurred

4. Conclusion

This study demonstrates that it paid attention to clarify the unsteady characteristics of wings in the ground effect for the improvement of the flight performance of the WIG crafts.

Unsteady characteristics couldn't be estimated from the steady characteristics in the ground effect when moving in the direction of the height.

The unsteady characteristics are caused by the changing of induced velocity around the wing. This phenomenon is peculiar to the ground effect.

The nearer the distance between the wing and the ground is, the more remarkable the unsteady characteristics becomes.

Moreover, these unsteady characteristics are decided depending on the direction of the movement and the speed of the movement.

It will be possible to contribute to the stability improvement of the WIG vehicles if the control law is constructed taking this unsteady characteristic into consideration when the WIG vehicles are put to practical use in the future.

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