Experiments at the Sunrise-Beach Research Facility of the Aerodynamic Characteristics on Ground Effects of Aerofoils with a secondary aerofoil

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ABSTRACT

Investigation of a new high-speed zero-emission transportation "Aerotrain" is proceeded mainly in Tohoku University and Miyazaki University. Since the aerotrain utilizes the ground effect, researches of the aerofoil section which can harnesses the ground effect effectively are important. The aerotrain moves along U-shaped guide way which has a ground and side walls, so it has many viscous interference elements. We analyze the flow through a primary and secondary aerofoils, to prevent the boundary layer separation for the improvement of the aerodynamic characteristics at low speed and near the ground. A small secondary aerofoil is equipped above the trailing edge to increase lift at takeoff and landing. We find out the most suitable location of secondary aerofoil by the boundary layer approximation analysis, and experiment using towing wind tunnel at the Sunrise-Beach Research Facility in Miyazaki.

Key Words: Ground Effect, Secondary Aerofoil, Towing Wind Tunnel, Boundary Layer Approximation

1. Introduction

Recently, global warming caused mainly by greenhouse gas emissions, such as carbon dioxide, has became a more serious problem. The level of greenhouse gas emissions in transportation division is not small, therefore it is necessary to improve the energy efficiency to reduce the emissions of these gases and the utilization of natural energy for a power source.

On the basis of this background, an investigation on a new type of high-speed zero-emission mass transportation, the "Aerotrain" has been carried out mainly in Tohoku University and University of Miyazaki. The aerotrain with several short aerofoils is an aerodynamically levitated vehicle, which harnesses the energy of the sun and the wind around the guide way. The aerotrain runs at high energy efficiency, using the ground effect, which occurs when an aerofoil moves near the ground. Because the aerotrain utilizes the ground effect, researche on the aerofoil section, which can harness the ground effect effectively, is important. The aerotrain cruises along U-shaped guide way, which has a ground and side walls, so it has many viscous interference elements. In an analysis of ground effects on the aerodynamic characteristics of aerofoils, the boundary layers on the aerofoil surface must be considered.

We analyze the flow through primary and secondary aerofoils, to prevent the boundary layer separation for the improvement of the aerodynamic characteristics at low speed and near the ground. A small secondary aerofoil is equipped above the trailing edge to increase lift at takeoff and landing. We find out the most suitable location of secondary aerofoil by the boundary layer approximation analysis, and experiment using towing wind tunnel. We verify the effect of secondary aerofoil by experiment, and verify the accuracy of the analysis by comparing with experimental results, and try to find the most suitable aerofoil section for Aerotrain

2. Analysis and Experimental Procedure

The ground effect on the aerodynamic characteristics of the aerofoils was znalyzed using the following procedure. First, the vortex method is used to calculate the velocity distribution on the outside of the boundary layer. Next, the boundary layer approximation is used to calculate the boundary layer thickness. Then, the displacement thickness of the boundary layer is added to the aerofoil thickness. Finally, the vortex method in used to calculate the velocity distribution on the modified aerofoil profile. This procedure id repeated. When the solution converges, we estimate the aerodynamic characteristics of aerofoils. The computational geometry and parameters are shown in Fig.1.

The measurement of pressure distribution on aerofoil surfaces was carried using a towing wind tunnel. The equipment has 500m long test section, 1000m long accelerating and 500m long decelerating section. The experiment was done only in the wind tunnel with the 500m full length. The cross section of the wind tunnel is shown in Fig.2. Aerofoil characteristics were measured by towing a test aerofoil in 50km/h with the car which is shown in Fig.3. An acrylic fiber board with 1.55m length, 0.9m height, 6mm thickness is equipped by the aerofoil tips to secure a two dimensional of the flow. The chord length and the width of the primary aerofoil is 1000mm and 1820 mm the secondary aerofoil is 300mm and 1810mm. The primary aerofoil has 37 pressure measurement holes with 1.2mm caliber along the direction of the moving at the centre of the aerofoil width, and the secondary aerofoil has 24 holes with 1.0mm. Both aerofoils adjust an angle of attack with the lever at the fixation axis of the aerofoils, and adjust the altitude with the elevator at the fixation axis. The test aerofoil section is NACA4412 for both aerofoils. The pressure on aerofoil surfaces is measured using the digital sensor array (scanivalve DSA3217). As the experimental parameter of the primary and secondary aerofoils, an angle of attack α and α_s, an altitude of the trailing edge h and h_s, was varied.

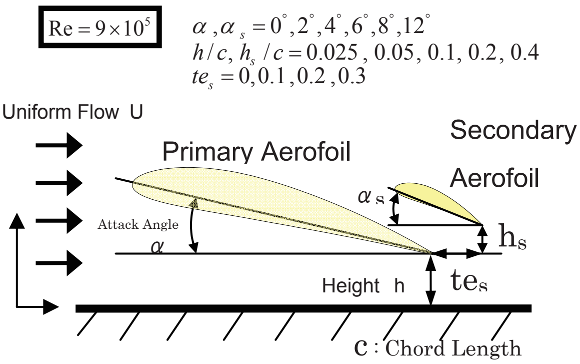

Fig.1 Computational geometry and parameters

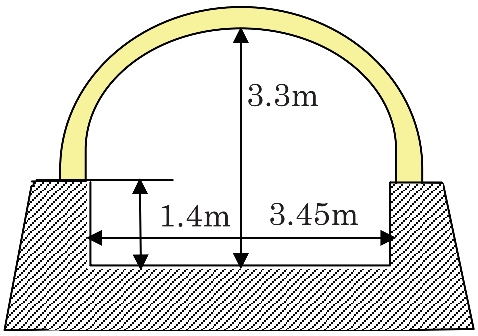

Fig.2 Cross section of wind tunnel

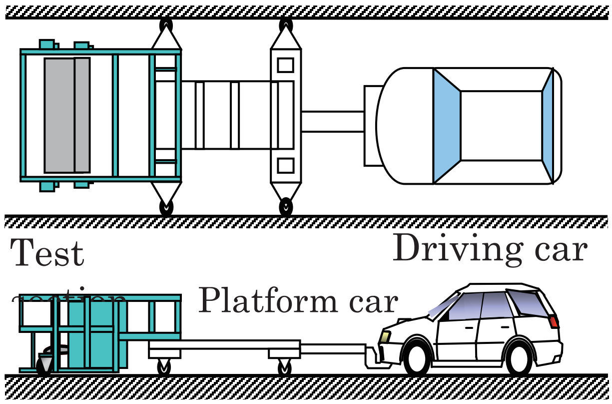

Fig.3 Experimental Device

3. Results and Discussion

The example of the computed pressure distribution on aerofoil is shown in Fig.4. The pressure coefficient for the primary aetofoil surface and on the secondary aerofoil are shown this figure. The pressure of the secondary aerofoil decreases suddenly, near the leading edge of lower surface. And, the pressure on the primary aerofoil is dipped near the leading edge of the secondary aerofoil. The reason for this, the flow through between primary and secondary aerofoils was accelerated like a venturi tube.

The relation between total lift coefficient and height of secondary aerofoil h_s is shown in Fig.5. Total lift coefficient is defined the sum of cl for primary and secondary aerofoils. In this figure, horizontal lines indicate for the case without secondary aerofoil, curved line with secondary aerofoil. Lift coefficient is improved above each horizontal line. That is, the improved range is larger than about 0.15 of h_s in this computational parameter.

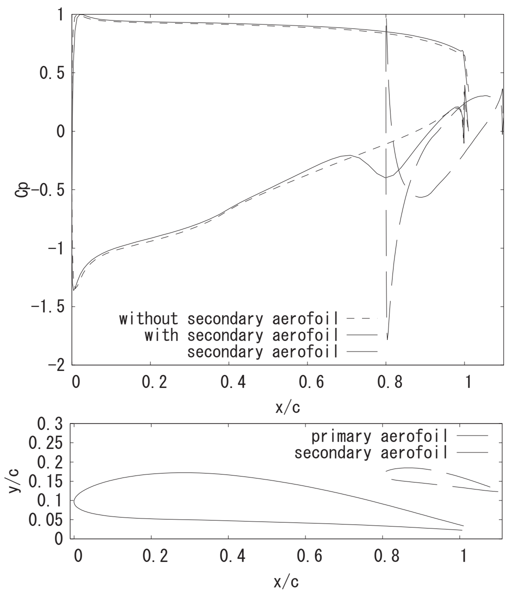

Fig.4 Pressure distributions of aerofoils

The relation between separation point and height of secondary aerofoil is shown in Fig.6. The vertical lines indicate for the case without secondary aerofoil. Separation point is improved on the right side of vertical lines. That is, the improved range is 0.07 to 0.25 of h_s. The effect of attack angle on secondary aerofoil is shown in Fig.7.

The angle of attack on primary aerofoil is 4 degrees and 8 degrees. Just like previous Fig.4, lift coefficient is improved above horizontal lines. That is, in the case of alpha 4degree, lift coefficient is improved at almost range of secondary alpha α_s. However, in the case of alpha 8 degree, the improvement is not found below 8 degrees of α_s

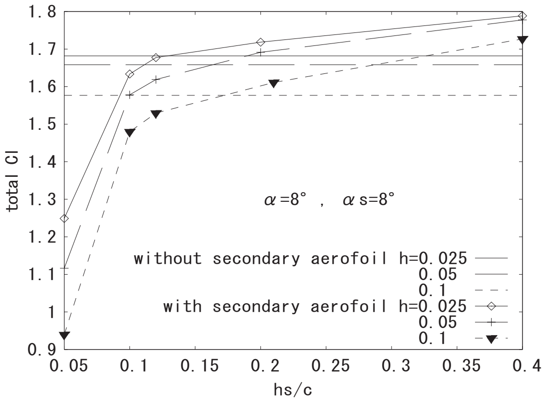

Fig.5 Total lift coefficient

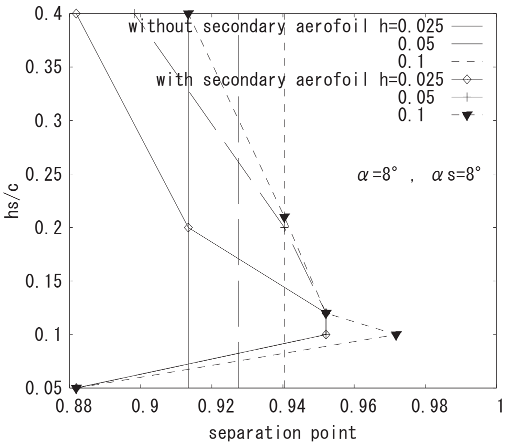

Fig.6 Separation point (primary aerofoil)

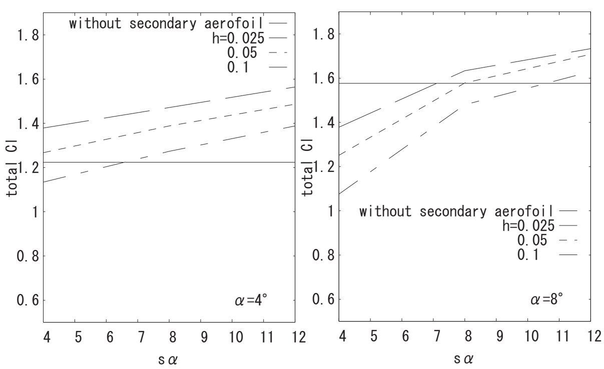

Fig.7 Total lift coefficient (h=0.1)

The example of the experimental pressure coefficients on aerofoil using the towing wind tunnel is shown in Fig.8. The computational results and experimental results, on the whole, indicate the same tendency. The example of the pressure distribution on primary and secondary aerofoils by attack angle of secondary aerofoil is shown in Fig.9 and Fig.10. This tendency became stronger, when the attack angle of secondary aerofoil αs to smaller.

Comparison between the lift coefficient of primary aerofoil and the lift coefficient of single aerofoil is shown in Fig.11. In the case of hs less than 0.2, the lift coefficient of the primary aerofoil is improved than case of the single aerofoil. The lift coefficient is improved at lower hs and αs. On the other hand, the lift coefficient of primary and secondary aerofoil is shown in Fig.12. Oppositely, the total lift coefficient of primary aerofoil and secondary aerofoil is improved at higher hs and αs.

4. Summary

We tried to improve ground effects on aerodynamics of aerofoils using secondary aerofoil. We examined the effect of the secondary aerofoil by analysis using vortex method with boundary layer approximation and experiment using towing wind tunnel at the Sunrise-Beach Research Facility in Miyazaki. We examined the improve range for an arrangement of the secondary aerofoil.

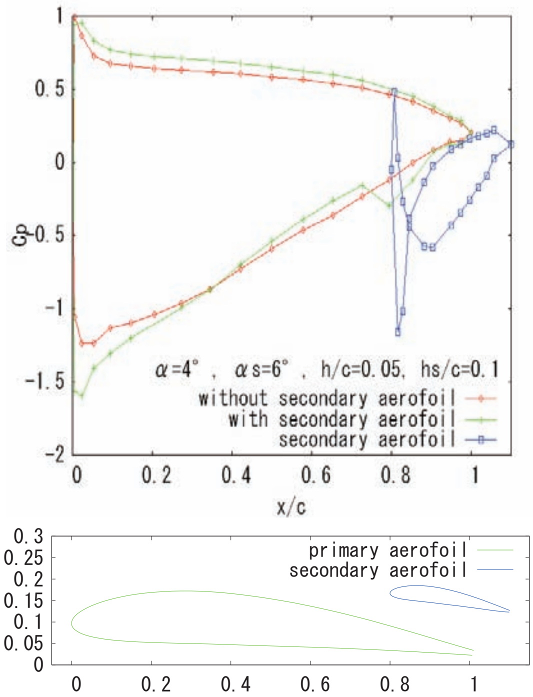

Fig.8 Pressure distribution of aerofoils

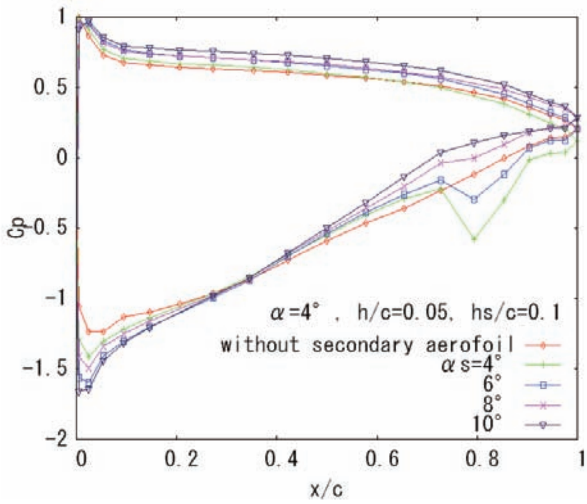

Fig.9 Pressure distribution of primary aerofoil

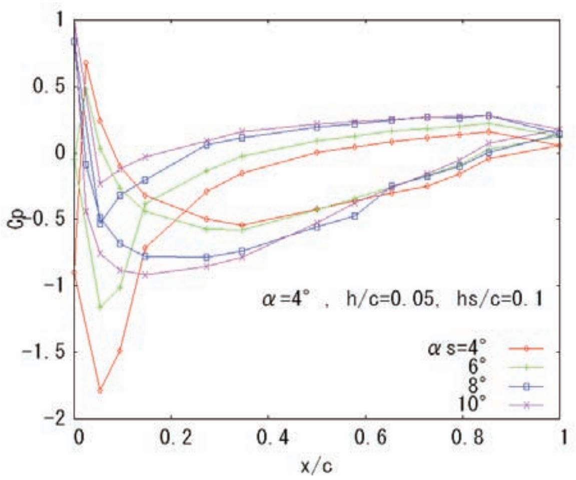

Fig.10 Pressure distribution of secondary aerofoil

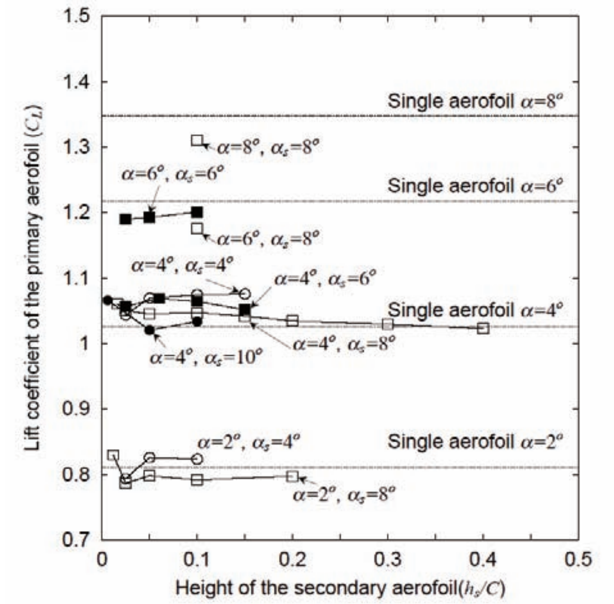

Fig.11 Lift coefficient of primary aerofoil (t_{es}/c=0.2)

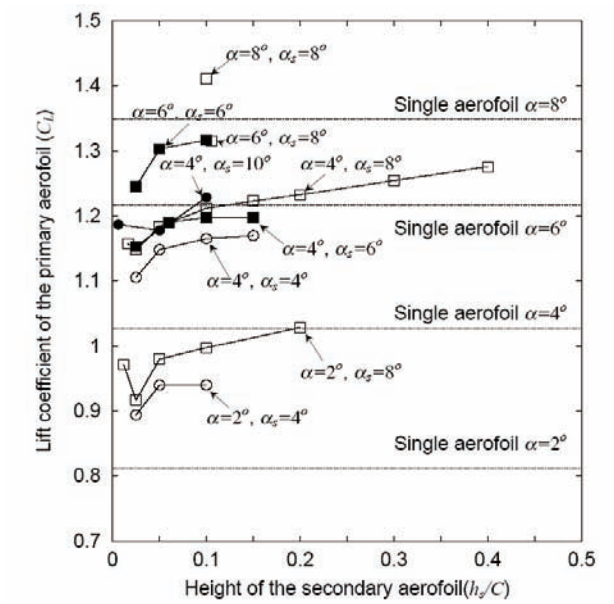

Fig.11 Lift coefficient of primary and secondary aerofoil (t_{es}/c=0.2)

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