

Aerodynamic characteristics and flow field of delta wings with the canard

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Abstract. Now, many kinds of explorations for outer planets have been proposed around the world. Among them Mars attracts much attention for future exploration. Orbiters and landers have been used for Mars exploration. Recently as a new exploration method, the usage of an airplane has been seriously considered and there are some development projects for Mars airplane. However, the airplane flying on the Earth atmosphere cannot fly on the Mars atmosphere, because atmospheric conditions are much different each other. Therefore, we focused on the usage of the airplane with unfolding wings for Mars exploration. These unfolding wings are designed as delta wings. However, delta wings do not have enough aerodynamics characteristics in a low speed region. In this study, to improve the aerodynamic characteristics of delta wings, we have proposed the usage of canard wings. The purpose of this study is to examine the effectiveness of canard wings to improve aerodynamic characteristics in a low speed region. CFD analysis is performed using four wing models with different canard shapes. The result shows that the usage of canards is effective to improve aerodynamic characteristics of delta wings in a low speed region. In addition, increasing lift coefficient is possible by changing the shape of canards.

1 Introduction

Now, many kinds of explorations for outer planets have been proposed around the world. Among them Mars attracts much attention for future exploration. ^{[1], [2]} Orbiters and landers have been used for Mars exploration. Although landers can obtain high resolution data, it cannot explore over a wide range. On the other hand, orbiters can explore over a wide range, but the resolution of the observed data is low. Recently as a new exploration method, there are some development projects for Mars airplane. ^[3] However, atmospheric conditions are much different between Mars and Earth. The flying conditions are low Reynolds number and high Mach number due to the decrease of atmospheric density and sound velocity. Additionally, the airplane must correspond to flight from low speed to high speed. Because, when it flies immediately after the discharge from a capsule, the flight condition is high speed, and as it approaches Mars, the flight condition is low speed. Therefore, it is necessary that new airplane which can fly on the Mars is developed.

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We focused on the airplane with unfolding wings by gliding for Mars exploration. Figure 1 shows a flight profile of the airplane with unfolding wings. The shape at a supersonic speed is streamlined-lifting-body which reduces the projected area. It is suitable for flight at a high speed. The lifting-body with unfolding wings that is expected to improve aerodynamic characteristics is used from transonic speed region to low speed region. These unfolding wings are designed as delta wings which are suitable for flight at a high speed. When the projected area expands, it is expected to improve lift coefficient and expand exploration range. Aerodynamic characteristics of delta wings were investigated from high subsonic to supersonic speed, and it has been clarified that the unfolding wings can improve aerodynamic characteristics.^[4] However, delta wings do not have enough aerodynamic characteristics in a low speed region.

In this study, to improve the aerodynamic characteristics of delta wings, we have proposed the usage of canard wings. The purpose of this study is to examine the effectiveness of canard wings to improve aerodynamic characteristics in a low speed region by the computational fluid dynamics (CFD).



Fig. 1. Outline of the flight profile of the airplane with unfolding wings.

2 Analysis Overview

2.1 Condition

This Analysis use a calculator of usual personal computer level. Table 1 shows the specification of hardware and software. The simulation was conducted using OpenFOAM.

Table 1. The specification of hardware and software.

Hardware	
CPU	Intel Xeon E5-2640 (Core10, 2.30GHz)
Software	
CFD	OpenFOAM-4.0
Mesher	blockMesh snappyHexMesh
Postprocessor	paraView

2.2 Models

Figure 2 shows four wing models with different canard shapes. In Fig.2 (a), base (body) is an isosceles triangle with the vertical angle of 30 degrees. In Fig.2 (b), delta45 is composed of the body and an unfolding wing, and the wing is designed as delta wing with the sweep-back angle of 45 degrees. In Fig.2 (c), canard1 is composed of the body, unfolding wing and canard wing. The canard wing with the sweep-back angle of 45 degrees is positioned forward of the unfolding wing, and its wing area is 1/3 of the unfolding wings. In Fig.2 (d), canard2 is the same shape as canard1. Its wing area is 1/4 of the unfolding wing. All of these four models are flat plate with the total length of 300mm and the thickness of 2mm.

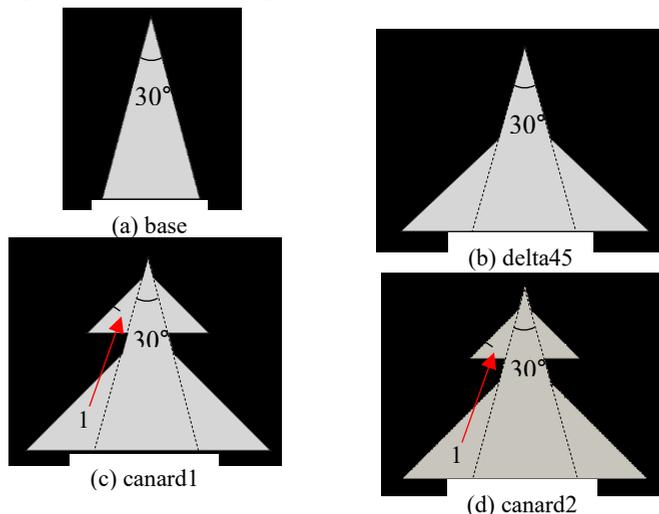


Fig. 2. Four wing models with different canard shapes.

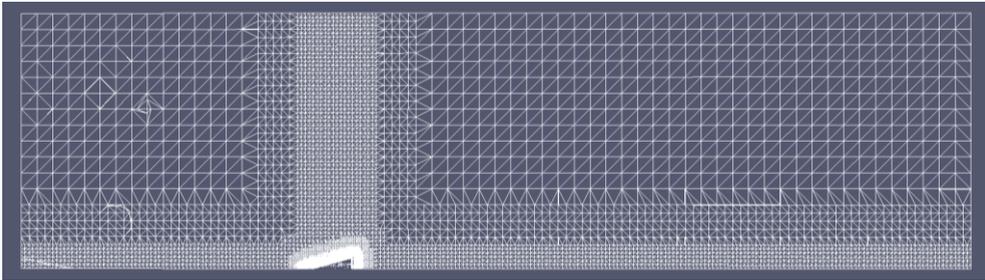
2.3 Flow Field

The analysis fluid was air at standard atmosphere (1013hPa, 15°C), density $\rho = 1.225\text{kg/m}^3$ and kinematic viscosity $\nu = 1.47 \times 10^{-5}\text{m}^2/\text{s}$, and the airflow speeds were 15m/s, 20m/s, 25m/s and 30m/s. CFD analysis was conducted as the angle of attack of from 0 degree to 30 degrees in 3 degree intervals. Mach number is ranging from 0.044 to 0.088, satisfying a condition of incompressible fluid ($M_\infty < 0.14$). Therefore, flow field is incompressible fluid. The total length of models and the airflow speed gave the Reynolds numbers of $3.0 \times 10^5 \sim 6.2 \times 10^5$. The flow field was assumed to be turbulent flow, because it cannot be judged as laminar flow or turbulent flow by the Reynolds number.

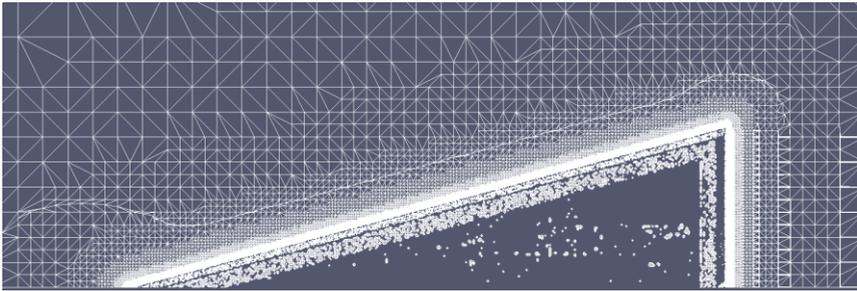
Numerical simulation of airflow around the four types of models was carried out in three dimensional steady states condition. The solver was simpleFoam which was standard solver in OpenFOAM based on SIMPLE method, because the airflow field was incompressible turbulent flow. The equation of the motion was the Reynolds averaged Navier-Stokes (RANS) in which the $k-\omega$ SST (Shear-Stress Transport) model was adopted as a turbulent model.

2.4 Numerical grid

Numerical grids are created by blockMesh and snappyHexMesh which are standard Meshers in OpenFOAM. Figure 3 shows numerical grids for the base. The number of cells of the case is about 2 million cells. Previously, CFD analysis was carried out using the case of 3.5 million cells, and it was confirmed that the suggested grid has no grid dependency on calculated results. The numerical grids are decided with the consideration of the calculation cost. The size of the case is set as 20 times the total length of models in X-axis direction (the direction of the total length of models), 20 times the wing span in Y-axis direction (the direction of the wing span), and 100 times the wing thickness in Z-axis direction (the direction of the wing thickness). Owing to the symmetry of the suggested delta wing because of no-roll and no-yaw angles, a half span model of the wing was analysed. As the boundary condition of the case, all the boundary surfaces of the front, rear, left, right and up of the space of Fig.3 (a) were freestream (the distant boundary), and the boundary surfaces of the down of the space of Fig.3 (a) was symmetryPlane (symmetry boundary).



(a) the whole of numerical grids



(b) the enlarged figure around the wing.

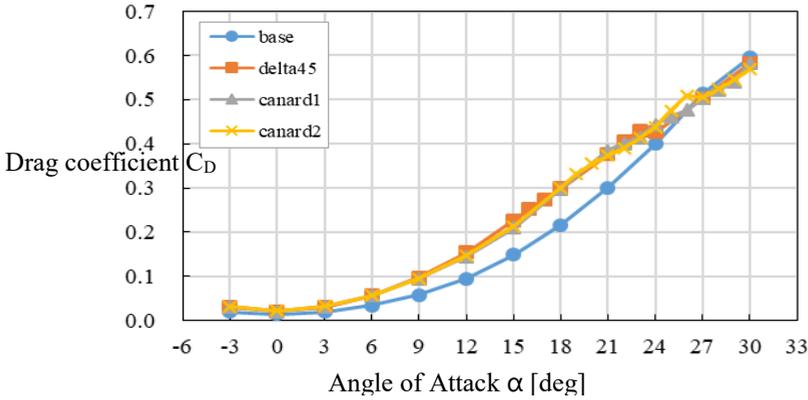
Fig. 3. Numerical grids for the base

3 Results and Discussion

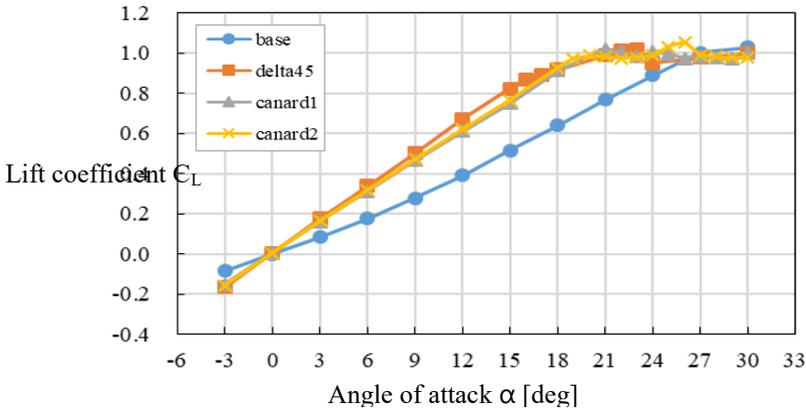
3.1 Aerodynamic characteristics by CFD analysis

Aerodynamic characteristics of the suggested four types of models with flow velocity of 15m/s are shown in Fig.4. Aerodynamic characteristics of the base are lower than those of other models. It is found that aerodynamic characteristics are improved by the unfolding wings. The lift coefficients C_L compared between the suggested delta45 and canard1 or canard2 with flow velocity of 15m/s are shown in Fig.5. The lift slope of the delta45 become gentle from the angle of attack of 16 degrees, and a stall occurs at angle of attack of 23 degrees. The lift coefficient of the canard1 rises until the angle of attack of 21 degrees and stagnates after that. On the other hand, although the lift coefficient of the canard2 stagnates

from the angle of attack of 20 degrees that is lower than canard1, it rises again and stalls at the angle of attack of 26 degrees. Although the maximum lift coefficient is almost the same between the delta45 and canard1 as seen in Fig.5 (a), the maximum lift coefficient of the canard2 is larger than that of delta45. It is found that attaching the canard wings could delay the angle of attack where stall occurs. Figure 6 shows the lift coefficient compared between canard1 and canard2. The canard2 gave the best result of aerodynamic characteristics in comparison with two types of the delta wings with canard. It is found that the smaller wing area of the canard wings increases lift coefficient.



(a) Drag coefficient C_D



(b) Lift coefficient C_L

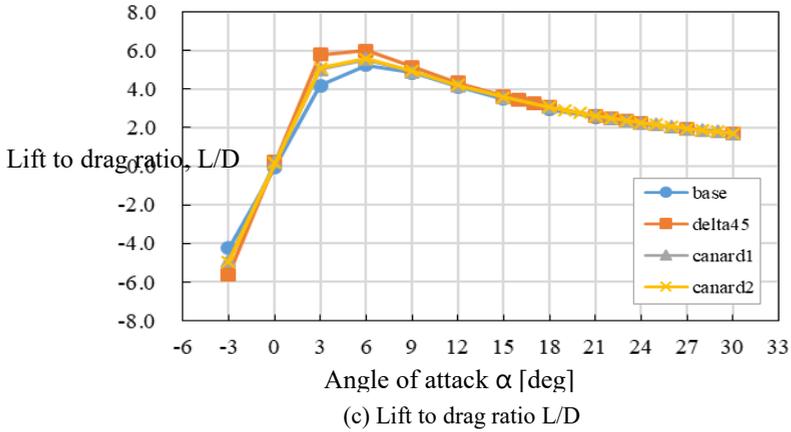
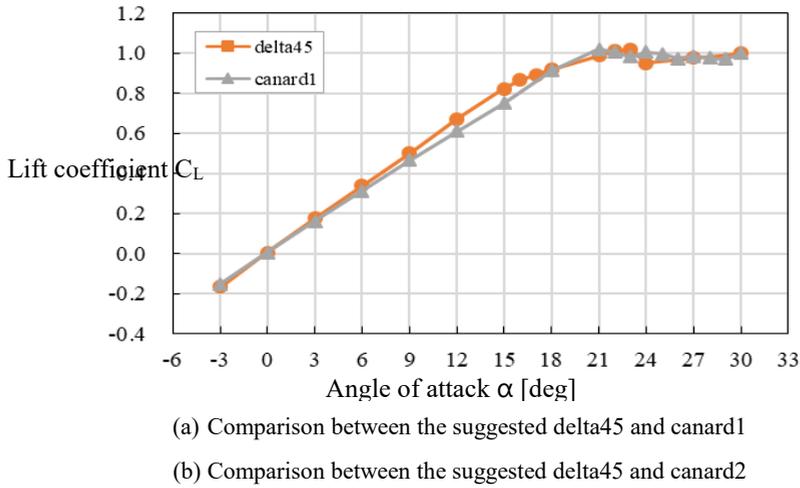


Fig. 4. Aerodynamic characteristics of the suggested four types of models with flow velocity of 15m/s.



(b) Comparison between the suggested delta45 and canard2

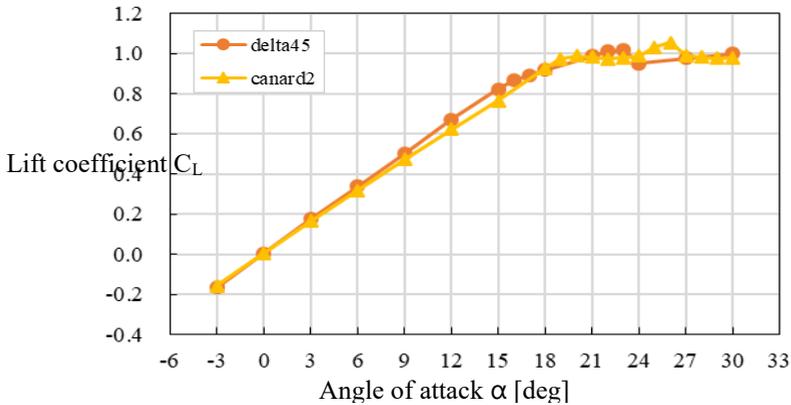


Fig. 5. The lift coefficient C_L compared between delta45 and canard1 or canard2 with flow velocity of 15m/s

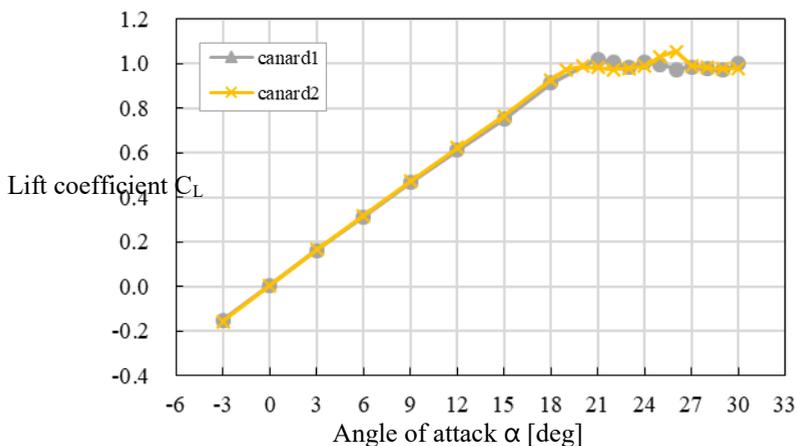


Fig. 6. the lift coefficient compared between canard1 and canard2.

3.2 Flow field

Figure 7 shows the pressure distribution of the delta45 at angles of attack of 23, 24 and 25 degrees. The pressure at $\alpha=24$ degrees is higher than that at $\alpha=23$ degrees in the rear region of the wings. It is considered that vortex breakdown occurs, causing a stall. On the other hands, it is found that leading edge separation vortex grow. That is the reason why lift coefficient increases again after the stall. Figure 8 shows the pressure distribution of the canard1 and canard2 at the angles of attack of 25, 26 and 27 degrees. The low-pressure area of the canard1 is decreasing with increasing of the angle of attack. The low-pressure area of the canard2 expands on the canard wing at the angle of attack of 26 degrees comparison with that of 25 degrees. Figure 9 shows the cross section of the pressure distribution of one fifth root chord point, $x/c=0.2$, and three fifth root chord point, $x/c=0.6$, at the angles of attack of 26 and 27 degrees of the canard2. It is found that vortex breakdown occurs on the canard and unfolding wing as the angle of attack increases. Figure 10 shows the cross section of the pressure distribution of three fifth root chord point, $x/c=0.6$, at the angle of attack of 18 degrees for the canard1 and canard2. The vortex from the tip of the canard2 exists inside of the main wings, and the pressure is lower in comparison with the canard1. The quantity of the vortex from the tip of the canard2, that reached the main wings without conjunction with the vortex of the canard wing, was larger than that of the canard1, because the canard wing area of the canard2 is smaller than that of canard1.

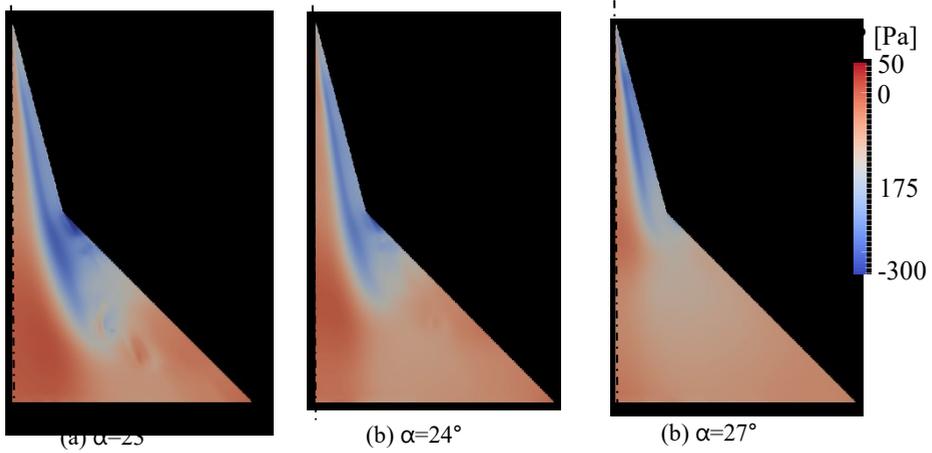


Fig. 7. the pressure distribution of the suggested delta45

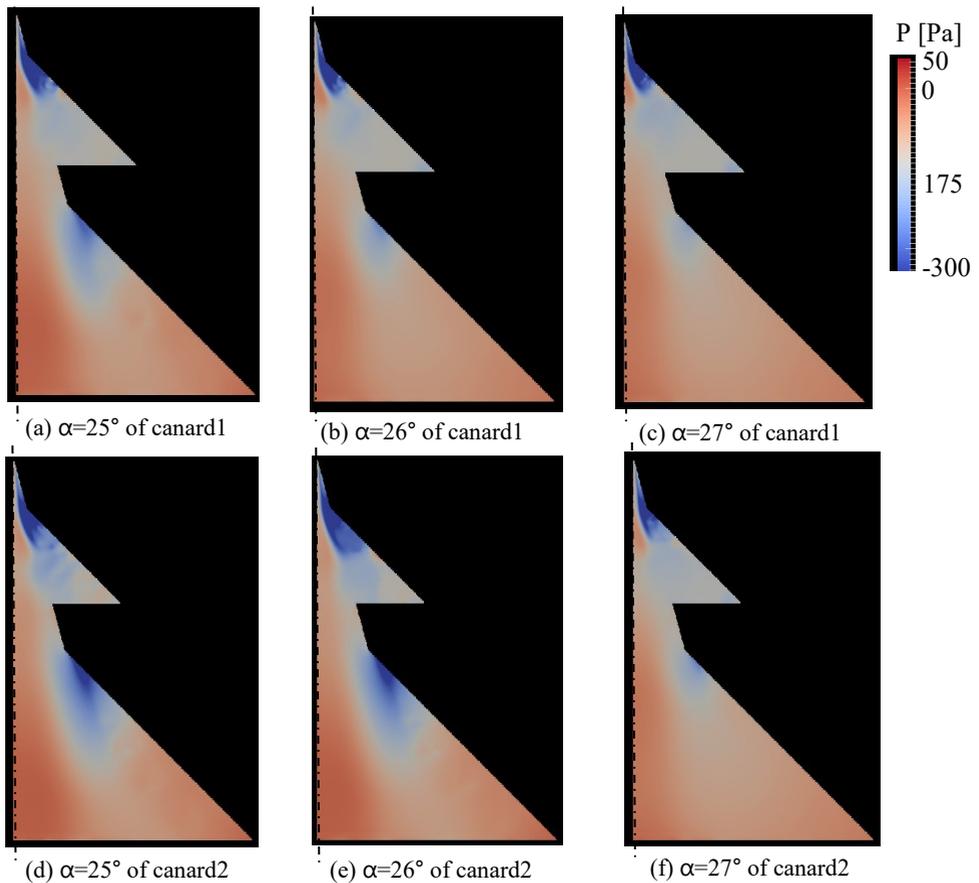


Fig. 8. the pressure distribution of the suggested canard1 and canard2

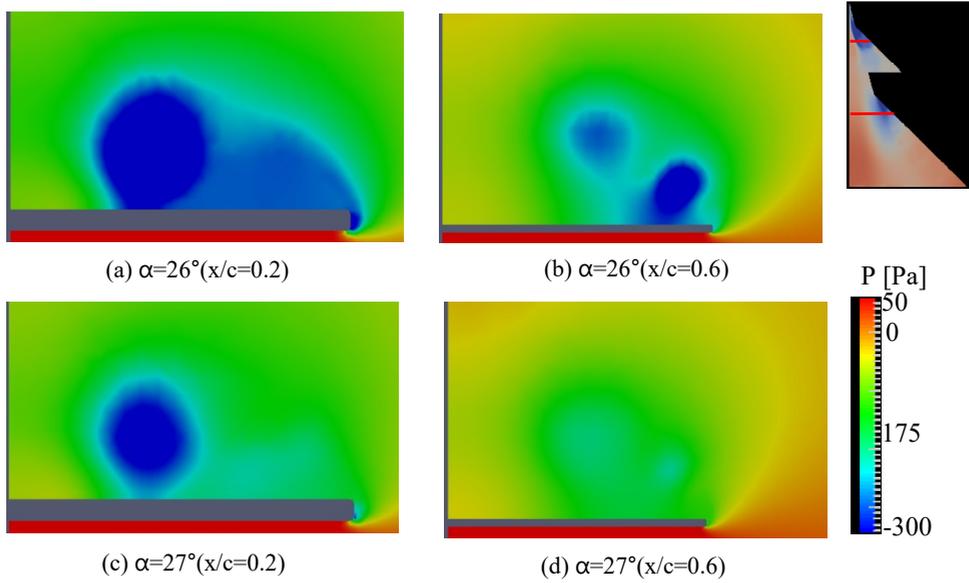


Fig. 9. the cross section of the pressure distribution of the canard2

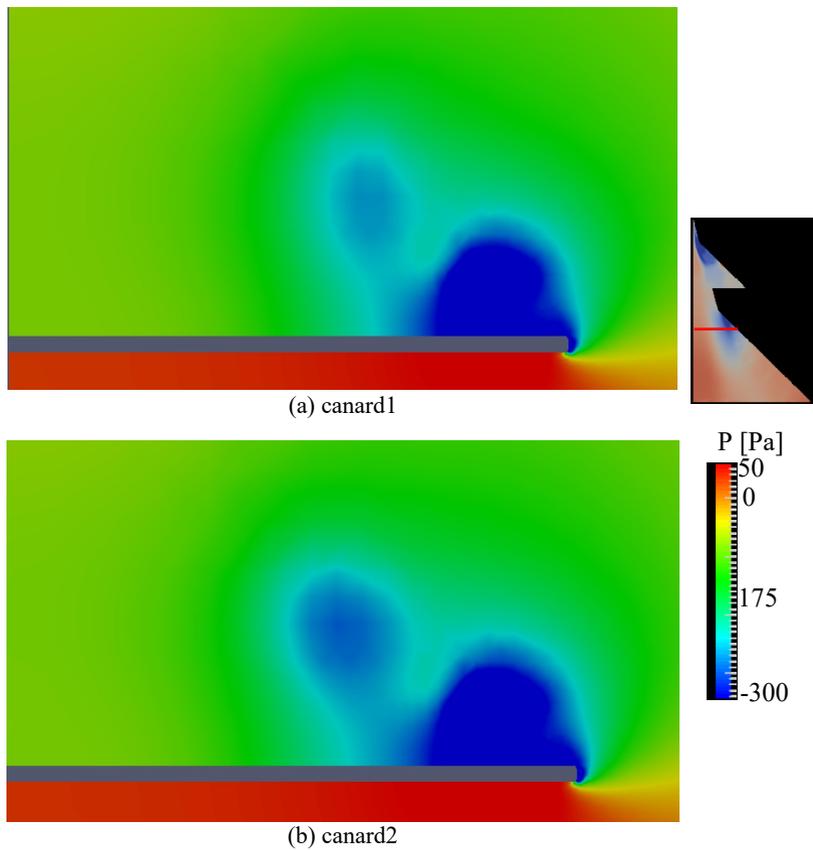


Fig. 10. the cross section of the pressure distribution at the attack of angle of 18 degrees ($x/c=0.6$)

4 Conclusions

In this study, to improve the aerodynamic characteristics of delta wings in a low speed region, we have proposed the usage of canard wings. The purpose of this study is to examine the effectiveness of canard wings to improve aerodynamic characteristics in a low speed region. CFD analysis are performed using four wing models with different canard shapes. The result shows that the usage of canards is effective to improve aerodynamic characteristics of delta wings in a low speed region. Lift coefficient of the canard2 is highest in all of four types of models. In addition, increasing lift coefficient is possible by changing the shape of canards.

References

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