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NUMERICAL SIMULATION OF THE LOW SPEED AERODYNAMIC CHARACTERISTICS OF A SET OF CLOSE-COUPLED CANARD CONFIGURATIONS

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Abstract: In the article, a numerical simulation method simulating the leading edge shedding vortex in potential flow is utilized. Numerical simulation is conducted on an incompressible flow and at a large angle of attack as the flow passes a set of close-coupled canard configurations. Analysis shows that at a large angle of attack, with certain main wing and canard parameter selection and position configuration, the lift in the case of the canard configuration is higher than that of a single main wing; the main reason is because the canard can delay the breakdown of the main wing shedding vortex. The other factors that increase the main wing lift are negative pressure produced at the main wing surface by the canard shedding vortex, and the variation of the main flow field caused by the flow of the canard shedding vortex.

Keywords: numrical simulation, canard configuration, leading edge shedding vortex, and low speed aerodynamics.

I. Introduction

The close-coupled canard configuration is one of the configurations that are of interest to aircraft designers. In recent years, many researchers intensively investigated this aspect. In the situation of the shedding vortex and interaction between the surfaces of these two wings, the flow situation is quite complicated: therefore, most efforts are concentrated mainly on experimentation and research.

Not long ago, Z. Rusak et al. [1] applied a nonlinear vortex lattice method (NLVLM) to conduct numerical simulation on a 45° delta wing canard configuration; they obtained results consistent with those of experimentation. However, this computation example was carried out in a situation of mainly downward perturbation at the main wing due to the canard.

As indicated by the work of J. Er-Er et al. [2,3], for a particular main wing and canard configuration, the presence of the canard has the function of increasing main wing lift. In the present article, a numerical simulation of the leading edge shedding vortex in the potential flow [4] is utilized to conduct aerodynamic numerical simulation on a set of close-coupled canard configuration; results were obtained that are in agreement with those of experimentation.

At present, there are several methods for simulating the leading edge shedding vortex flow based on potential flow equations. From the theoretical view, these methods are incapable of handling the breakdown phenomena; therefore, there are certain limitations on applying the range of the aspect ratio of the wing and the angle of attack of the incoming flow. W. H. Wentz [5] conducted an overall experimental investigation on the shedding vortex of a small-aspect-ratio wing. As indicated in the results, the breakdown points of the shedding vortex are shifted to above the wing surface when the incoming flow angle of attack is larger than 10° for the case of a 60° delta wing. Therefore, for the numerical method beginning from the potential flow equation in simulating the shedding vortex in processing wings with a larger aspect ratio, there are certain limitations on the angle of attack range. However, the situation changes for the close-coupled canard configuration. As indicated in the experiments, by properly selecting the main wing and canard parameters in a situation of a certain main wing and canard configuration, the breakdown with the angle of attack for the main wing shedding vortex is delayed owing to the presence of the canard. Refer to Fig. 1. One possible reason is the effect of the downward disturbance at the main wing on the canard such that the relative air flow angle of attack of the wing is significantly reduced, thus delaying the breakdown of the main wing shedding vortex. In this situation, a numerical method for simulating the leading edge shedding vortex beginning from the potential flow equation can be used in numerical simulation of canard configuration.

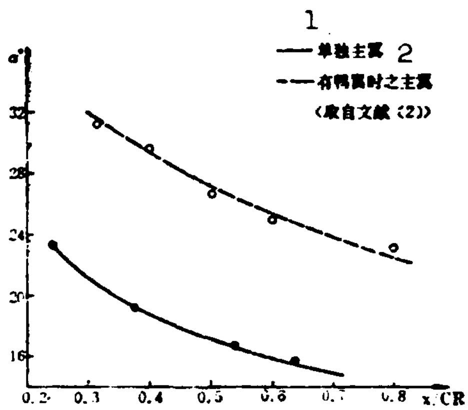


Fig. 1. Comparison of shedding vortex breakdown points of the main wing in the presence and in the absence of canard
KEY: 1 - With main wing only 2 - Main wing and canard (from Ref. [2])

II. Numerical Simulation of Leading Edge Shedding Vortex

In the situation of no breakdown of the shedding vortex and neglecting secondary separation from the wing surface caused by the leading edge shedding vortex, the flow is inviscid for the parts other than the internal core of the shedding vortex. In incompressible flow, the Laplace equation can be used to describe the situation.

$$\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}=0$$

The boundary conditions that the flow must satisfy are as follows:

at a point infinitely removed

$$\nabla\phi=0$$

on the wing surface

$$\frac{\partial\phi}{\partial n}+\bar{V}_{\infty}\cdot\bar{n}=0$$

on the trailing vortex surface of the wing

$$\frac{\partial\phi}{\partial n_{w}}+\bar{V}_{\infty}\cdot\bar{n}=0$$

In this article, this boundary equation is satisfied by using a simple treatment method along the free flow direction of the trailing vortex surface.

On the vortex surface of the shedding surface,

$$\Delta C_{p_{w}}=0$$

In the article, another expression $\bar{V} \times \bar{T} = 0$ is used since the vortex surface is not under force.

At the trailing edge of the wing and the edge producing the shedding vortex, the Kutta condition is satisfied. By applying the horseshoe vortex lattice mesh method, the equation can be satisfied. Moreover, with iterative substitution, the above-mentioned boundary conditions are satisfied. In detail, the process was described in [4].

III. Aerodynamic Numerical Simulation of Canard Configuration

J. Er-Er published a set of experimental results of canard configurations. In the experiment, the layout was adopted in which canards with two sets of area (delta wing with a 75° sweptback angle and a 56° sharp-cut delta wing), as well as a 60° delta wing and a main wing were used. In the layout, the wide canard (56° sharp-cut dclta wing) has different positions (Figs. 2-4) of two relative longitudinal distances to the main wing at the front and rear.

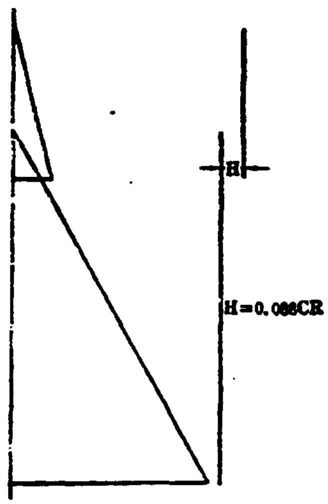


Fig. 2. Narrow canard and main wing configuration

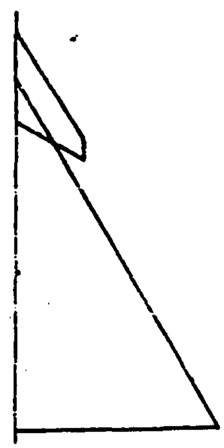


Fig. 3. Wide canard and main wing configuration (rear position)

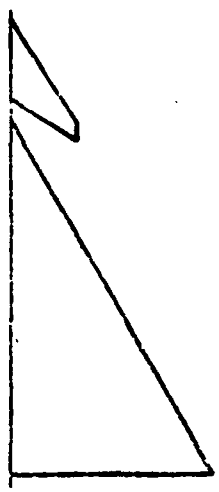


Fig. 4. Wide canard and main wing configuration (front position)

In calculating the narrow canard configuration, the computation mode is selected in which the shedding vortex is produced on the surfaces of the two wings with mutual perturbation. Figs. 5 and 6 show a comparison between the epxerimental data on the one hand, and the calculated lift as well as the dip and elevation moment of force, on the other. Fig. 7 shows a comparison between the experimentation on the one hand, and the special positions that the canard shedding vortex passes through the main wing. Because of the interaction between two sets of vortex systems, it is very apparent for the trend that the canard shedding vortex is close to the main wing surface.

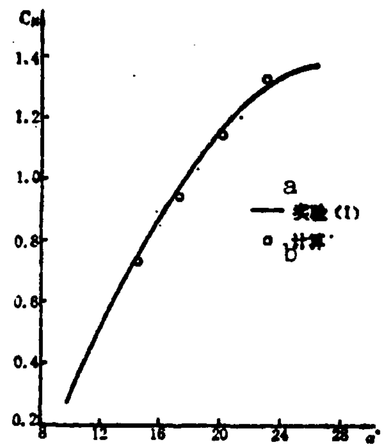


Fig. 5. Normal-direction force of narrow canard and main wing configuration
KEY: a - Experimentation b - Computation

In the calculation of the wide canard configuration, the computation mode of producing the shedding vortex is still adopted for the main wing; however, the computation of the canard adopts the attached flow. The computation mode, just as for the narrow canard, is still adopted for the special position that the canard tip vortex passes through the main wing and its effect on the main wing shedding vortex. As indicated by the calculation results, the wing tip of the wide canard has not been attracted to be close to the main wing surface.

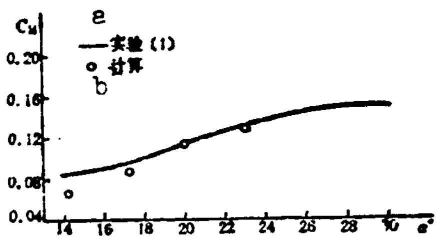


Fig. 6. Longitudinal-direction moment of force in the case of narrow canard and main wing configuration
KEY: a - Experimentation
b - Computation

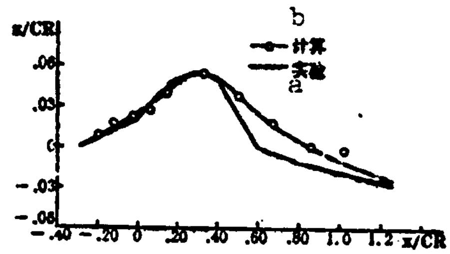


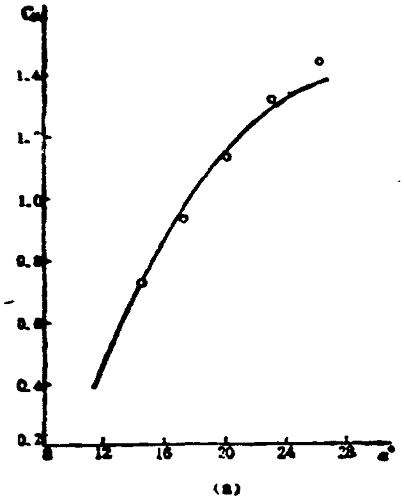
Fig. 7. Locus (alpha=0.4rad) for the case of narrow canard shedding vortex
KEY: a - Experimentation
b - Computation

Fig. 8 shows the comparison of the calculated lift and the experimental results for two longitudinal-direction positions of the wide canard at the front and rear positions. The reason for having a greater lift for the canard in the longitudinal-direction position close to the front can be explained by the fact that the main wing is under a smaller downward disturbance in this configuration situation.

Fig. 9 shows a comparison between the calculated data of the wide canard configurations and the properties of the longitudinal-direction moment of force in the experimentation. Obviously, since the force arm is greater, there is a larger uplifting moment for the case of front canard configuration.

IV. Discussion

In the numerical method of simulating the leading edge shedding vortex of potential flow used in the article, numerical simulation of the aerodynamic properties for a set of canard configurations is carried out. There is good agreement between the calculation results and the experimental data.



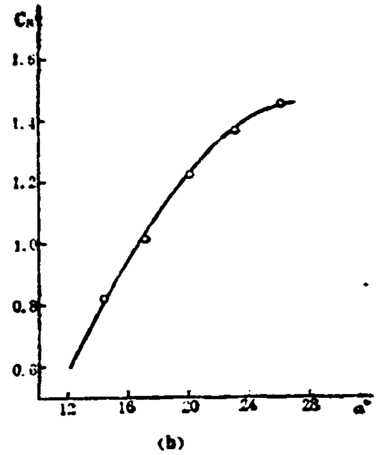
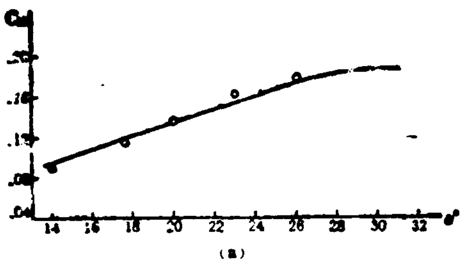


Fig. 8. Normal-direction force of wide canard and main wing configuration (rear position)

Fig. 8. Normal-direction force of wide canard and main wing configuration (front position)



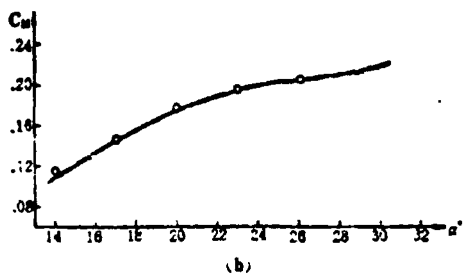


Fig. 9. Moment properties of wide canard and main wing configuration (rear position)

Fig. 9. Moment properties of wide canard and main wing configuration (front position)

With an appropriate main wing and canard configuration, the breakdown of the main wing shedding vortex can be delayed. In this situation, the numerical calculation can be used to simulate and analyze the flow of the canard configuration and the aerodynamic properties.

At a large angle of attack for the close-coupled canard configuration of a suitable layout, the main reason why the main wing loading is increased than of the main wing only is because of the canard effect. The delay in the breakdown of the main wing shedding vortex exists. The negative pressure produced on the main wing surface by the canard shedding vortex and the variation in circulation distribution on the main wing surface also increase the main wing loading.

For the case of a close-coupled canard configuration producing the leading edge shedding vortex of the main wing, the canard effect on the breakdown of the main wing shedding vortex is a problem that should be stressed when evaluating configuration research. However, after determining the state of shedding vortex breakdown of the main wing surface, the numerical calculation method of the leading edge shedding vortex of the potential flow can be an effective simulation tool in analyzing the flow situation and aerodynamic properties of the canard configuration.

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