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by

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EFFECT OF CANARD WING POSITIONS ON AERODYNAMIC CHARACTERISTICS OF SWEPT-FORWARD WING

Zhang Binqian of Northwest Industrial University, and B. Laschka of Munich Industrial University

Abst.act

Based on force measurements, oil flow observations, and eddy measurements in low air-speed wind tunnels, the paper studies the mechanism underlying the effect of canard wing positions on the aerodynamic characteristics of swept-forward canard wing configurations. As shown in studies, canard wing positions play the most significant role with respect to aerodynamic characteristics. Improvements in characteristics through a large incident angle in the swept-forward canard wing configuration depends on the relative position and the mutual control of the eddy at the leading edge of main wing. Based on the experimental results of an assembly with swept-forward and swept-back canard wing as well as the main wing, the paper presents the two-dimensional shapes of the canard and main wings, as well as their relative positions when adopting canard configuration. In addition, the authors express some of their views on the configuration of dual swept forward wings.

Key terms: swept-forward wing, canard wing, position, aerodynamic characteristics, separation, and eddy.

I. Introduction

Studies on swept-forward wings have been underway for a good number of years. The investigations were hampered due to the problem of aerodynamic elasticity divergence. With the requirements that newer-generation aircraft should have supersonic persistent maneuverability, and low airspeed maneuverability past stalling airspeed, research on swept-forward wing configurations has had a renaissance. When the distribution of circulation amount for the swept-forward wing approaches elliptical in shape, induced drag is much reduced. In transonic flight, the swept-forward configuration can increase the excitation wave swept angle at the wing's trailing edge, thus increasing the divergence M number of drag. The property of a large incident angle at low airspeed is far ahead of the swept-back wing feature. Thus, this swept-forward configuration can better aid in our comprehension of maneuverability at high and low airspeeds. For the above-mentioned reasons, in the United States a vast research and development project on certification of the advanced technique of the swept-forward wing in the X-29 has taken giant strides. We have reason to believe that the configuration scheme of the swept-forward wing will receive very strong emphasis.

The most serious problem of swept-forward wing is that stall occurs too early at the wing root; this phenomenon hinders adequate exploitation of the large-incident-angle feature. So it is very important to clarify the mechanism of divergence at the wing root, and to seek an avenue toward solving this problem. Adoption of the canard pattern configuration is a very promising route of utilizing the flow state at the root of the swept-forward wing for improving the interference with the detached eddy of the canard wing.

Based on these considerations, on the research foundation [1,2] of a single swept-forward wing and wing--fuselage assembly that has been underway, the paper reports on low airspeed experimental studies on the flow mechanism and aerodynamic characteristics of the swept-forward wing canard pattern configuration.

II. Experimental Equipment and Models

Experiments were conducted in two open-ended low airspeed wind tunnels, one with a diameter of 1.3 meters and the other with a diameter of 1.5 meters. The airspeeds were 40 and 35 meters per second, respectively. Corresponding to the main wing, the R_e of the mean aerodynamic chord is, respectively, 6.2×10^5 and 5.4×10^5.

Fig. 1 shows the experimental model. The aircraft wing in the model is a simple swept-forward wing. The swept angle at the leading and trailing edges is, respectively, -40^o and -52^o; the aspect ratio λ=3.81; and the tip-to-root ratio ξ=0.4. There are swept-back and swept-forward canard wings. The swept angle at the leading and trailing edges (for the swept-back canard wing) is, respectively, 49^o and 24_o; the aspect ratio λ_e=3.08; and the tip-to-root ratio ξ_c=0.3. The swept-forward canard wing is just the reverse of swept-back canard wing. Along the direction of air flow, both the aircraft wing and canard wing adopt the NACA 64 A 010 wing section: the fuselage is an elliptical cylinder; the slenderness ratio is 0.1. With a conical nose with 5^o droop, and a contractible empennage, there is a crew compartment in the fuselage. The canard wing can be varied in nine longitudinal direction positions, and three up-or-down positions; in other words, experiments on the canard wing can be conducted in an assembly of 27 positions.

III. Aerodynamic Characteristics

After the canard configuration was adopted for the swept-forward wing, the aerodynamic characteristics in the longitudinal direction were significantly improved within the range of the incident angles under study. In the following, the effects of aerodynamic characteristics with the placing of canard wing, and its positions are discussed.

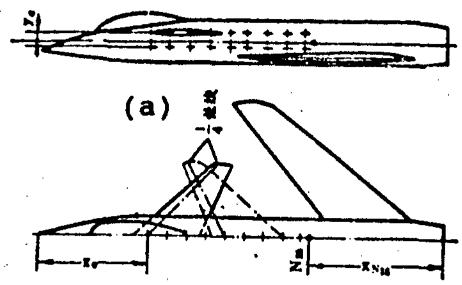

Fig. 1. Model Used in Experiments
KEY: (a) Chord line

1. Effect of swept-back canard wing in longitudinal-direction positions

The effect on aerodynamic characteristics is significant from changing the longitudinal-direction positions (along the fuselage symmetrical axis) of the canard wing. Fig. 2 shows a set of typical results on the effects of aerodynamic characteristics due to the longitudinal-direction positions without changing the up-or-down positions of the canard wing. In the figure, (O- and U- are the up-and-down positions of the canard wing; F+R shows the situation without the presence of canard wing.) the effect on the lift and drag properties is very slight when there is a change in the longitudinal-direction positions of the canard wing at intermediate and small incident angles (a is less than 10°). Later, with further rearward positions of the canard wing (in other words, the canard wing position is closer to the main wing), the aerodynamic advantages are higher. This conclusion is consistent with the optimal conclusion of the close-distance coupling pattern for the swept-back canard wing configuration. As revealed in air flow observations, downstream along the canard wing the air flow is more intense than at the main wing as the canard wing position is moved increasingly rearward at intermediate and small incident angles. At the same time, this downstream area also speeds up the air flow at the root of the main wing, thus moderating the air flow divergence at the wing root while the upstream action is intensified by the main wing to the canard wing. The result of the mutual compensation of these two interferences leads to an effect in which the lift and drag properties are insensitive with respect to change in the longitudinal-direction positions. With increasing incident angle, the leading-edge eddy of main wing and canard wing are formed successively; thus, the effect on the leading-edge eddy that is traceable to the canard wing is very small when there is a change in the longitudinal-direction position. By moving the canard wing position further rearward, the pushing function of the detached eddy of the canard wing is intensified to the leading-edge eddy of the main wing; thus, the detached eddy deviates outwardly and its control zone becomes smaller (Fig. 3). On the other hand, induced by the lateral stream of the detached eddy of the canard wing, the leading-edge eddy of the main wing is intensified, thus carrying away the separating air flow as accumulated at the root of the main wing. Then, the root of the main wing becomes cleared of air flow (Fig. 4), thus advancing the lift and drag properties at the rear position for the canard wing. The change of the dip-and-elevating force moment also helps to ensure the existence of this phenomenon. Besides the reduction of the upward force moment by moving the canard wing rearward, the improvement in the air flow at the root of the main wing also provides certain increment on the downward force moment. From Fig. 2a, it is apparent that the dip-and-elevating force moment does not move in a level direction. It is worthwhile to point out that moving rearward for the longitudinal position of the canard wing has its boundary such that the canard wing does not overshadow the main wing;

otherwise, the aerodynamic advantage will be reduced. With different up-or-down positions, the effect achieved by changing the longitudinal-direction positions also differs.

2. Effect of up-or-down position of swept-back canard wing

Fig. 2 also reveals the effect on aerodynamic characteristics by a change in the canard wing up-or-down positions. In this case, the longitudinal position of the canard

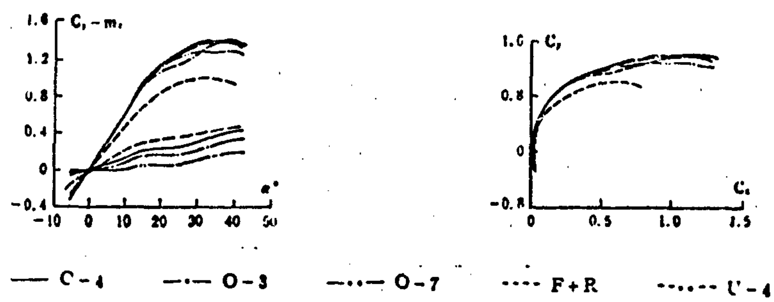

Fig. 2. Effect on Aerodynamic Characteristics due to Longitudinal-direction Positions

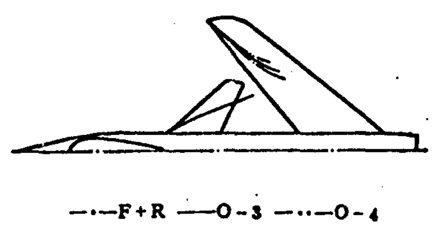

Fig. 3. Effect on Eddy Position at Main Wing due to Detached Eddy of Canard Wing

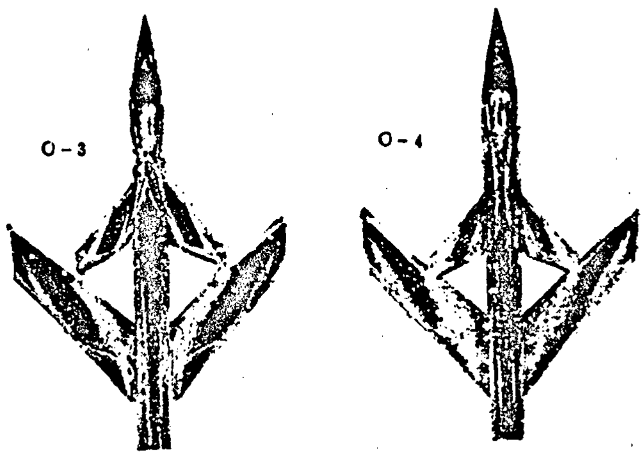

Fig. 4. Flow Spectrum (a=15°) for Effect of Longitudinal-Direction Positions

wing remains unchanged. The effect on the up-or-down position also occurs mainly within the range of incident angles for the case when a is greater than 10°; the aerodynamic characteristics of the canard wing assembly in the upper position is apparently better than that in the lower position. This range for variation of incident angle is also in the stage from the inception to the breakup of the leading edge eddy of the main wing and canard wing. Therefore, the difference between the aerodynamic characteristics of the canard wing assembly in the upper-or-low position is mainly due to the effect of the eddy. As shown in the flow state, in the lower position the leading-edge eddy of the canard wing is apparently weaker than the leading-edge eddy for canard wing in the upper position; moreover, eddy breakup is also advanced (Fig. 5). This phenomenon not only indicates that the eddy lift provided by the leading-edge (of the canard wing) eddy is reduced, but also the effect on the main wing is decreased. In other words, the induced lateral stream washing of the main wing leading-edge eddy is reduced by the detached eddy of the canard wing in the lower position, while the pressing outward becomes intensified. Thus, the control zone of the main wing eddy becomes smaller. Since the distance between the main wing and the canard wing is closer, the wake of canard wing eddy that earlier broke up sweeps to the leading edge of the main wing, thus intensifying the separation at the leading edge of main wing. Downstream washing is intensified on the main wing by the lower-position canard wing. Hence, moving the canard wing position downward leads to greater acceleration of the air flow at the root of the main wing; the stream washing function becomes more intensified; and the root of the main wing is more cleared of air flow. In spite of the foregoing, however, the aerodynamic characteristics of the lower position canard wing assembly deteriorate even further as the combined results of the foregoing factors.

As revealed by the above-mentioned analysis, the appropriate relative positions of canard wing and main wing can generate advantageous interference to improve the aerodynamic characteristics. As discovered in research, it is most advantageous for the canard wing to be in the upper, rear position. Compared with the wing--fuselage assembly, the inclination $C;$ of the lift line is 27 percent higher; the maximum lift-to-drag ratio is increased by 20 percent. With the intermediate incident angle, the lift coefficient is increased by 12 to 17 percent after subtracting the contribution made by the canard wing area; the critical incident angle is increased by 5 to 7°, while the curve in the vicinity of maximum lift coefficient changes moderately. This point is very important to newer-generation fighter planes as their super-maneuverability is a must [3,4].

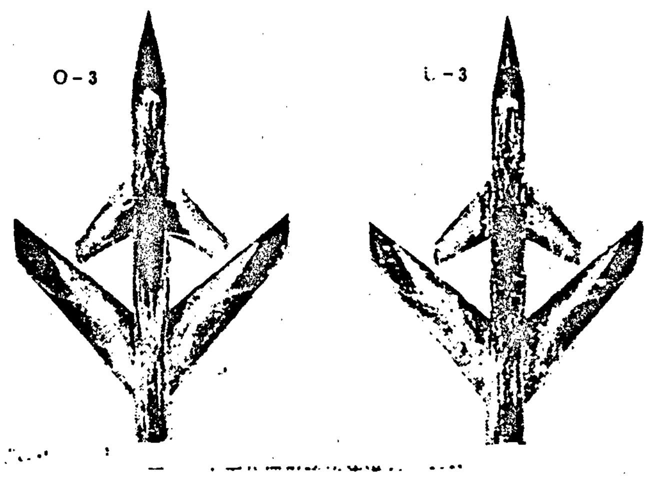

Fig. 5. Flow Spectrum ($a=25^{\circ}$)
for Effect due to Up-or-Down Position

3. Effect of longitudinal-direction position for swept-forward canard wing

There are features to be noted for changes in the longitudinal-direction position of the swept-forward canard wing: not like the swept-back canard wing, the more rearward the canard wing position, the more pronounced is the improvement in aerodynamic characteristics. However, there is a disadvantageous medium position: the aerodynamic characteristics are the best for the canard wing being at a position that is relatively forward; next in order is a position that is relatively rearward (Fig. 6). This result seems self-contradictory; however, observation and measurement results of the flow explain most of this contradiction (Fig. 7). As adopted in this experimentation, the swept angle at the leading edge of the swept-forward canard wing is relatively small (-24°); therefore the leading-edge eddy thus generated is not intensified with relatively early occurrence of eddy breaking up (a is greater than 18°). Thus, not only is the eddy lift that is realized small, but also the flow divergence at the canard wing root is intensified, thereby degrading the air flow caused by the canard wing. Now the effect on the main wing that is due to the canard wing detached eddy is very small; the interference between main wing and canard wing is mainly exhibited in the downstream washing effect on the main wing due to the canard wing, and the clearing function on the root of the main wing. Hence, the more to the rear that the canard wing is placed, the more intensified is the downstream wash; thus, the aerodynamic characteristics are relatively deteriorated. In reality, however, the aerodynamic characteristics with the rearward position canard wing assembly (U-9) are improved to a relatively greater extent. This phenomenon stems from the intensifying upstream washing function of canard wing by the main wing due to improvements in air flow at the root of the main wing.

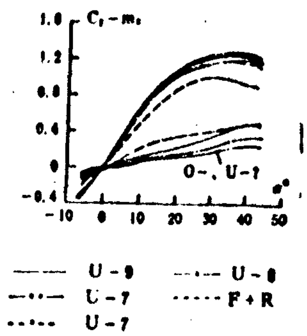

Fig. 6. Effect on Aerodynamic Features By Swept-forward Canard Wing Assembly in Longitudinal-Direction Positions

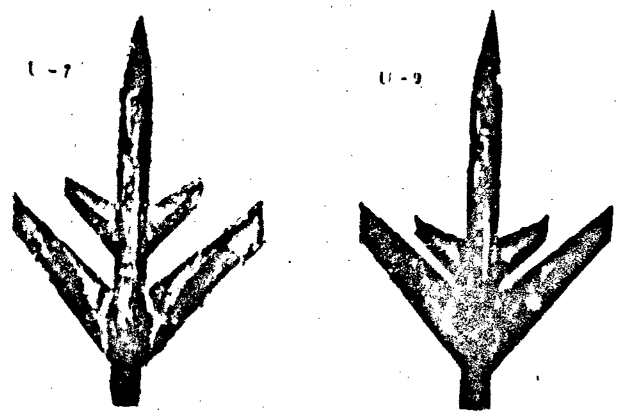

Fig. 7. Flow Spectrum ($a=18^{O}$) of Swept-forward Canard Wing Assembly

4. Effect on swept-forward canard wing at up-or-down positions

The effect on the aerodynamic characteristics due to changes in the upper or lower positions of the swept-forward canard wing again appears to be just the reverse of the swept-back canard wing assembly. Within the range of variation in incident angles studied, the lift and drag properties for the lower position canard wing assembly are better than those at the upper positions. However, the force moment properties are fundamentally consistent (Fig. 6). The unique properties of the swept-forward wing of spanwise flow pointing toward the inner side of wing enable the interference effect to concentrate mainly on the inner side of the main wing, whatever the canard wing detached eddy, or the canard wing downstream washing. This spot, the inner side of main wing, is just within the root divergence zone, with the most deteriorated flow state of the main wing. Hence, the clearing function caused by the lower position canard wing is undoubtedly more intensive than that of the upper position canard wing. In addition, the upstream washing function on the canard wing traceable to the main wing is also more intensive, and the contribution of the two leads to the result that the lift-drag properties of the lower position assembly is better than that of the upper position assembly. The fundamentally consistent force moment property is the result of two reverse-direction increments of force moment brought forth by the two above-mentioned interferences.

IV. Conclusions

1. Improvements in the aerodynamic characteristics of large incident angle for the swept-forward wing configuration is determined by the relative position of the leading edge eddies of the main wing and canard wing, as well as their mutual control, which is, in other words, their mutual interference.

2. A relatively large swept-back angle and a particular swept-forward angle at the trailing edge should be adopted for the canard wing in the canard configuration of the swept-forward wing. According to the positions of the divergence zone at the root of the main wing, the appropriate aspect ratio of canard wing is determined. It is best to take the upper, rear position for the canard wing relative to the main wing; this is the close distance coupling canard configuration. The boundary in moving

the position of canard wing position rearward should be that the main wing is not overshadowed.

3. An appropriate swept-back shape should be adopted for the root of the main wing in order to establish that the local swept-back flow field eliminates the fuselage effect. In addition, the separation zone at the root portion should be reduced in order to control the expected position so that the detached eddy of the canard wing carries away the detached eddy [5-8].

4. The lower position is better for the assembly of swept-forward canard wing and main wing. By consideration of the maneuvering problem, the forward position of the longitudinal direction is appropriate. If the effect of obtaining the mutual attraction with the same-direction rotating eddies for the eddies of the main wing and the canard wing in the dual swept-forward wing configuration [9], the swept-forward angle of canard wing should be larger than that of the main wing. It seems that the dual swept-forward wing canard configuration is inappropriate to be adopted for the swept-forward wing; though this can solve the problem of separating flow at the main wing root, yet flow separation will be caused at the canard wing root.

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