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Engineering Notes

Aerodynamic Characteristics of High-Lift Devices with Downward Deflection of Spoiler

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I. Introduction

THE aerodynamic characteristics of high-lift systems are very important for the performance of takeoff and landing of aircraft. Successful improvement of the aerodynamic characteristics of high-lift devices has a strong impact on the operating cost and environments around airports, such as increase of payload, reduction of weight, fuel consumption, and aerodynamic noise emission [1]. For example, an increase in maximum lift coefficient of 1.0% translates into an increase in payload of 22 passengers or 4400 lb for a fixed approach speed on landing. An increase of 1.0% in takeoff lift-to-drag ratio L/D for a typical long-range twin-engine subsonic transport can result in a payload increase of 2800 lb or a 150 nm in range. An increase of 0.1 in lift coefficient in the range of linear region of lift coefficient can reduce by a 1.0 deg angle of attack of landing, resulting in the decrease of weight of the undercarriage and making the empty weight of the aircraft decrease by 1400 lb [2,3].

Generally, through the optimization design of configuration of high-lift devices, the performance can be improved. In this Note, we proposed an approach that can improve the performance of landing through the method of downward deflection of the spoiler.

Previous research on spoilers mainly focused on the analysis of steady or unsteady aerodynamic characteristics of the spoiler as aerodynamic brakes or lift dumpers and the use of spoilers as effective control devices during flight when combined with the movement of ailerons. Recent progress in active control technology suggests that spoilers have the potential to control unsteady aerodynamic loads such as flutter and buffet suppression or gust load alleviation [4–6].

In this Note, using the computational fluid dynamics (CFD) approach, we analyze the capability of downward deflection of a conventional spoiler as a device of increasing lift in landing. A conventional spoiler can be found on many modern transport aircraft. The wing's shroud in this case is deflected upward, leaving a wide opening between the rear end of the wing and the flap. This opening can be aerodynamically characterized as a vent (Fig. 1) [4]. Through the analysis of downward deflection of a conventional spoiler, we verified the feasibility that the downward deflection spoiler can increase the lift coefficient Cl and maximum lift coefficient $Cl\max$ and can be used to improve the performance of landing.

This Note is organized as follows: The numerical algorithm to compute flowfield of high-lift devices is described in Sec. II. In Sec. III, capability of the present numerical method to calculate the lift coefficient accurately is validated. The aerodynamic characteristics of different deflection of the spoiler under the conditions of two dimensions (2-D) and three dimensions (3-D) are analyzed in Sec. IV. In the final section, we draw some conclusions about aerodynamic characteristics of downward deflection of the spoiler.

II. Numerical Algorithm

In the context of CFD, there are four approaches that are used to compute flowfield. These are integral boundary-layer (IBL) methods, Reynolds-averaged Navier–Stokes equations (RANS), large eddy simulation, and direct numerical simulation.

Most of computational methods that have been used to compute high-lift flowfield since the late 1980s are IBL methods and RANS methods [7]. Other CFD methods and some new methods will be used in the design of high-lift devices with the development of computational methods and computing power in the future [8–10]. The RANS methods can analyze the complex flow better than the IBL method. Therefore, we used the RANS method of commercial CFD software FLUENT in this Note.

Based on the RANS equations, there are density-based and pressure-based solvers in FLUENT [11]. Generally, the pressure-based solver was developed for low-speed incompressible flows, and the density-based approach was mainly used for high-speed compressible flows.

Although high-lift systems usually operate at low Mach numbers ($Ma \approx 0.25$), their performance can be affected by compressibility effects [12]. Therefore, we used the density-based solver with coupled-implicit formulation in FLUENT.

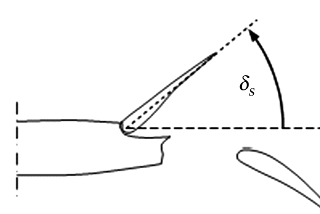

Fig. 1 Conventional spoiler configuration.

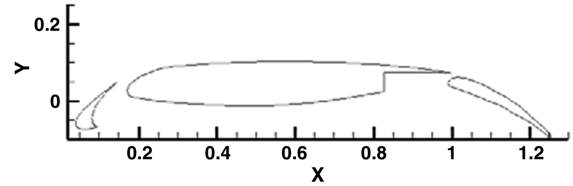

Fig. 2 MD 30P-30N configuration.

Table 1 Slat and flap setting of MD 30P-30N

	Overlap	Gap
Slat	$-0.025c$	$0.0295c$
Flap	$0.0025c$	$0.0127c$

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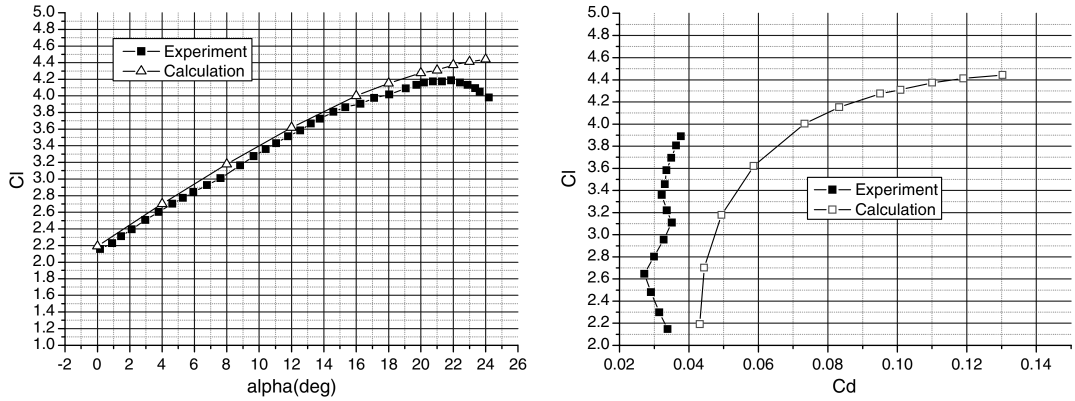

a) b)

Fig. 3 Comparisons between experimented and calculated lift and drag coefficients for MD 30P-30N.

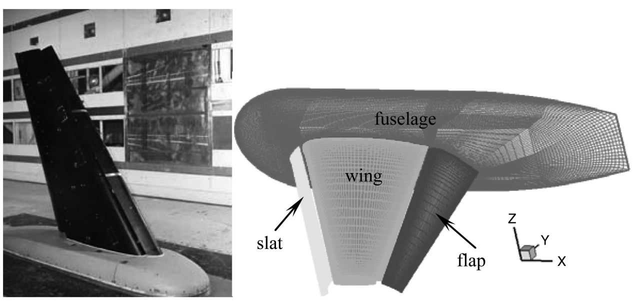

Fig. 4 NASA trap wing high-lift geometry and surface mesh.

With regard to the RANS formulation, turbulence models are needed to determine additional unknown variables. The Spalart–Allmaras one-equation model [13,14] in use nowadays has a significant impact on RANS codes in the aerospace industry. Therefore, the Spalart–Allmaras turbulence model was used in this Note.

The grid of the flowfield will influence the calculated values of lift and drag coefficients. Accurate representation of the flow in the near-wall region determines successful predictions of wall-bounded turbulent flows. Numerous experiments have shown that the parameter of wall $Y+$ should not larger than 1.0. Therefore, in this Note the wall $Y+$ values of the grids used in the following calculation are not larger than 1.0.

III. Validation of the Numerical Algorithm

To verify the validation of numerical algorithm, we calculated the aerodynamic characteristics of a 2-D MD 30P-30N three-element configuration and a 3-D NASA trap wing and compared the results with experiments.

A. Two-Dimensional MD 30P-30N Three-Element Configuration

The wind-tunnel measurements of a three-element airfoil configuration tested at the NASA Langley Research Center low-turbulence pressure tunnel [15,16], denoted as MD 30P-30N, shown in Fig. 2, was used as the test case. The deflections of slat and the flap of 30P-30N are set at -30 and 30 deg, respectively. The gaps and overlaps of slat and flap are shown in Table 1. The configuration was tested at a Mach number of about $Ma = 0.2$ with two Reynolds numbers: $Re = 5.0 \times 10^6$ and 9.0×10^6. In this Note, we use the experimental results of $Re = 5.0 \times 10^6$ as the verified condition.

From the comparison of results of experimented and calculated lift coefficients shown in Fig. 3a, we can draw the conclusion that the lift coefficient can be obtained accurately in the linear region of lift coefficient. The error will increase in the region of stall angle.

The drag characteristics were considered, and the results are presented in Fig. 3b. The calculated drag coefficients of MD 30P-30N are higher than those of the experiment. Drag calculations by RANS methods are usually very sensitive to the proximity of the outer boundary to the airfoil and to the outer boundary conditions, particularly at large lifts. The outer boundary can influence the force vector angle, and a small angle change can lead to very large drag changes [17].

B. Three-Dimensional NASA Trap Wing

In the wind-tunnel tests, the NASA trap wing models have a variety of slat and flap settings. In this Note, a setting for landing is used, shown in Fig. 4. The slat and flap deflections are 30 and 25 deg, respectively. The mean aerodynamic chord of the model, c, is 39.6 in., the model semispan is 85.1 in., and the reference area is 22.028 ft^2. The slat gap and slat height are $0.015c$. The flap gap and flap overlap are $0.015c$ and $0.005c$, respectively. The configuration was tested at a Mach number of about $Ma = 0.2$ with Reynolds number $Re = 4.3 \times 10^6$ based on the mean aerodynamic chord. Fully turbulent flows are assumed in the computations.

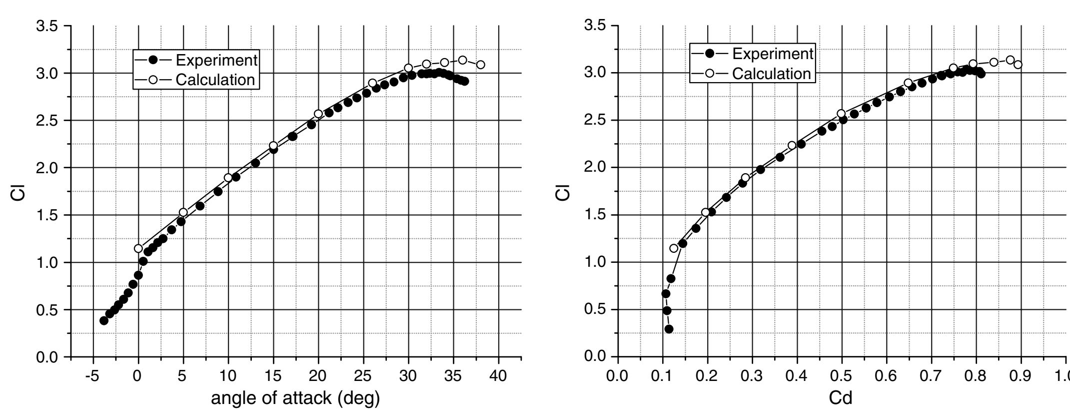

Fig. 5 Comparisons between experimented and calculated lift and drag coefficients for the NASA trap wing.

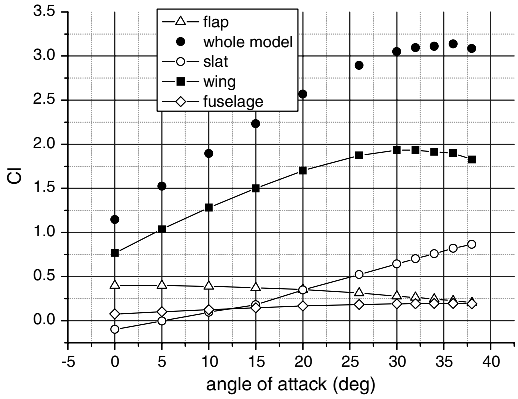

Fig. 6 Lift coefficients of wing, slat, flap, fuselage, and whole model.

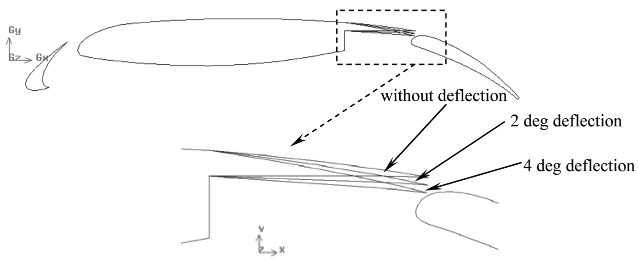

Fig. 7 Deflection of the spoiler only.

The results shown in Figs. 5 and 6 indicate that the numerical algorithm can accurately calculate the lift and drag of high-lift devices. The error will increase in the large angle of attack; however, the trend is the same as the experimental results.

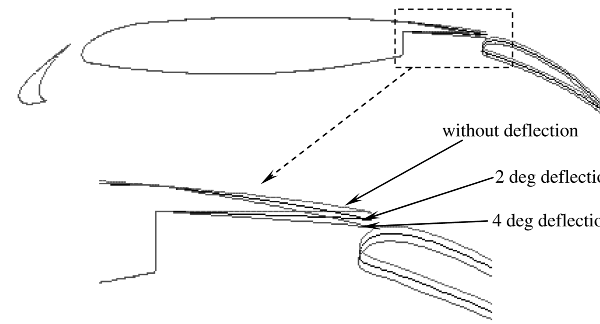

Fig. 9 Deflection of the spoiler under the conditions of keeping the invariable parameters of gap and overlap of flap.

IV. Aerodynamic Characteristics of Downward Deflection of Spoiler

A. Two-Dimensional Aerodynamic Characteristics of Downward Deflection of Spoiler

In this section, we used the MD 30P-30N configuration as the original configuration to analyze the influence of downward deflection of the spoiler on the aerodynamic characteristics. First, we calculated the lift, drag, and lift-to-drag ratio of deflection of only the spoiler, shown in Fig. 7. Then the lift, drag, and lift-to-drag ratio of deflection of the spoiler were calculated and analyzed under the conditions of keeping the invariable parameters of gap and overlap of flap.

From the results shown in Fig. 8, we can predict that the lift coefficient will decrease with the increase of deflection angle. The aerodynamic characteristics will change worse with the increase of angle of deflection under the condition of only deflection of the spoiler.

The calculated results of lift coefficient, drag coefficient, and lift-to-drag ratio under the conditions of different deflections of the spoiler with the invariable parameters of gap and overlap of the flap shown in Fig. 9 are presented in Fig. 10. We can predict that the

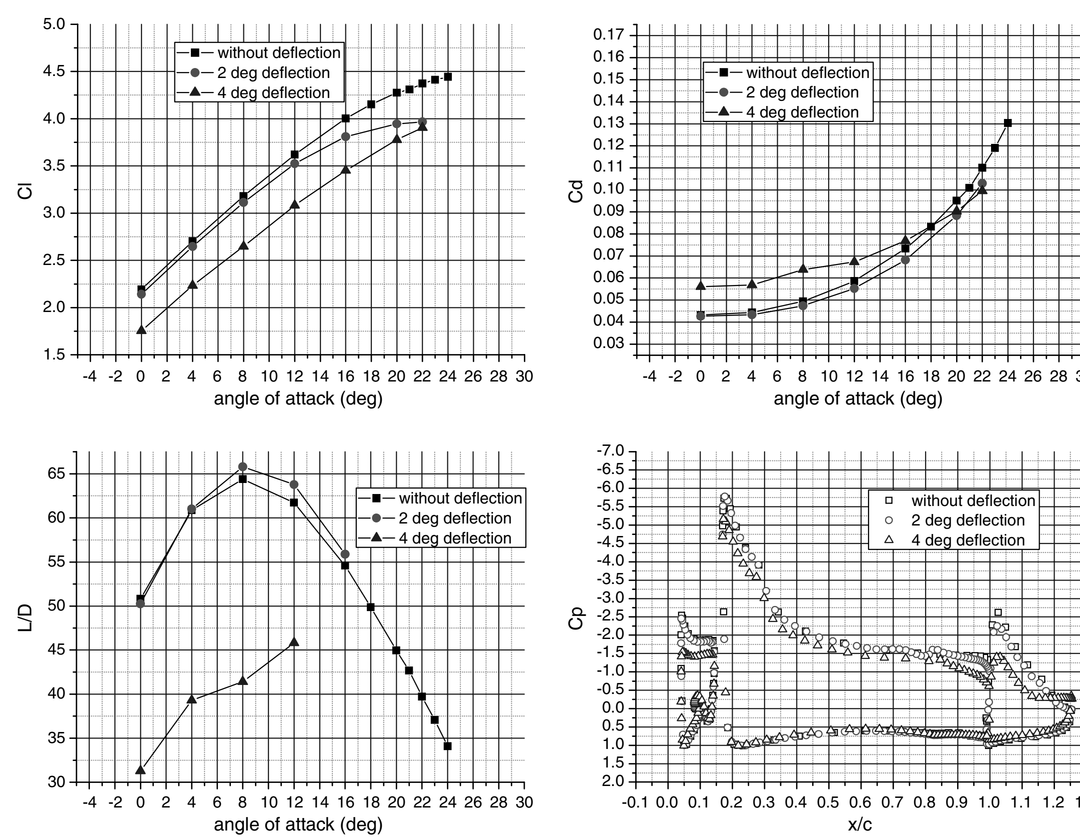

Fig. 8 Lift coefficient, drag coefficient, lift-to-drag ratio, and pressure coefficient under the conditions of different angles of deflection of the spoiler only.

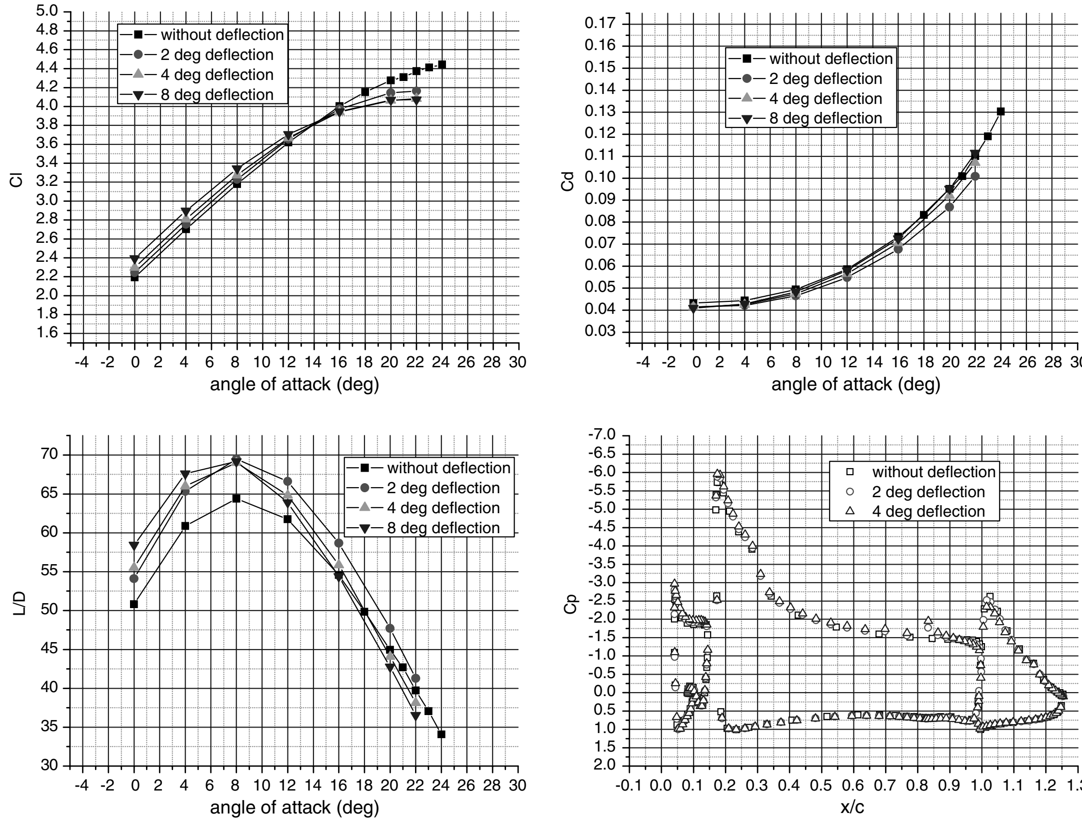

Fig. 10 Lift coefficient, drag coefficient, lift-to-drag ratio, and pressure coefficient under the conditions of different angles of deflection of the spoiler.

aerodynamic characteristics will improve with the increase of angle of deflection of the spoiler.

B. Three-Dimensional Aerodynamic Characteristics of Downward Deflection of Spoiler

In Sec. IV.A, we can see that the downward deflection of the spoiler with the invariable parameter of the flap will increase the lift coefficient and lift-to-drag ratio; thus, the performance will be improved. For verifying the feasibility of this approach, we calculated and analyzed the aerodynamic characteristics under the real three-dimensional condition.

In this section, we used a certain whole-aircraft configuration with high lift and spoiler as the original configure to analyze the influence of downward deflection of the spoiler on the aerodynamic

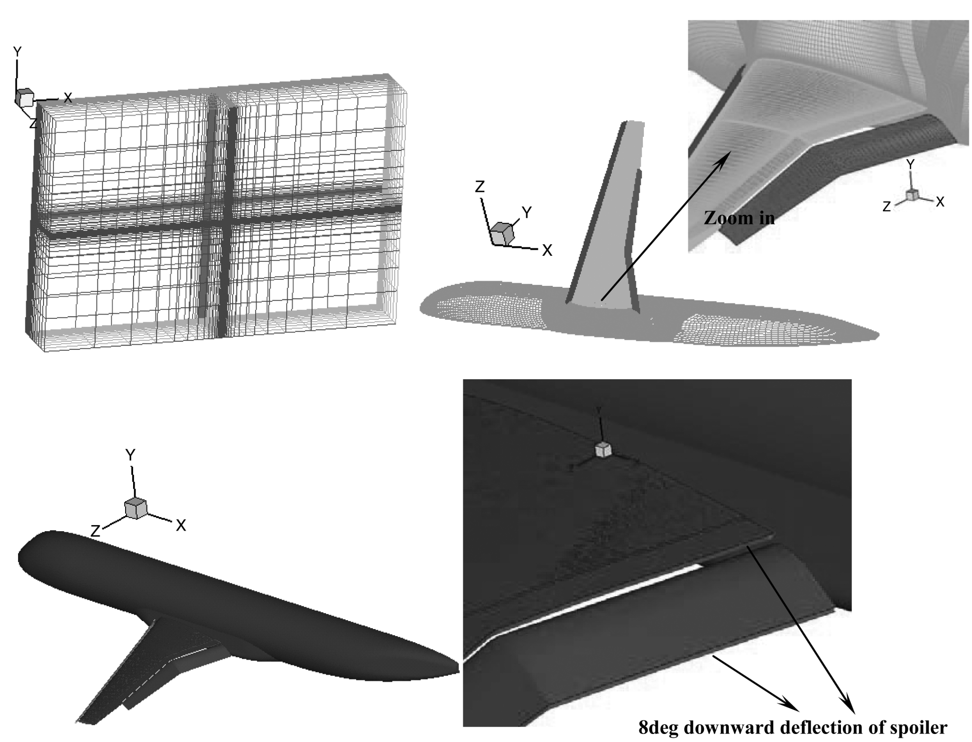

Fig. 11 Whole-aircraft model with high lift and spoiler.

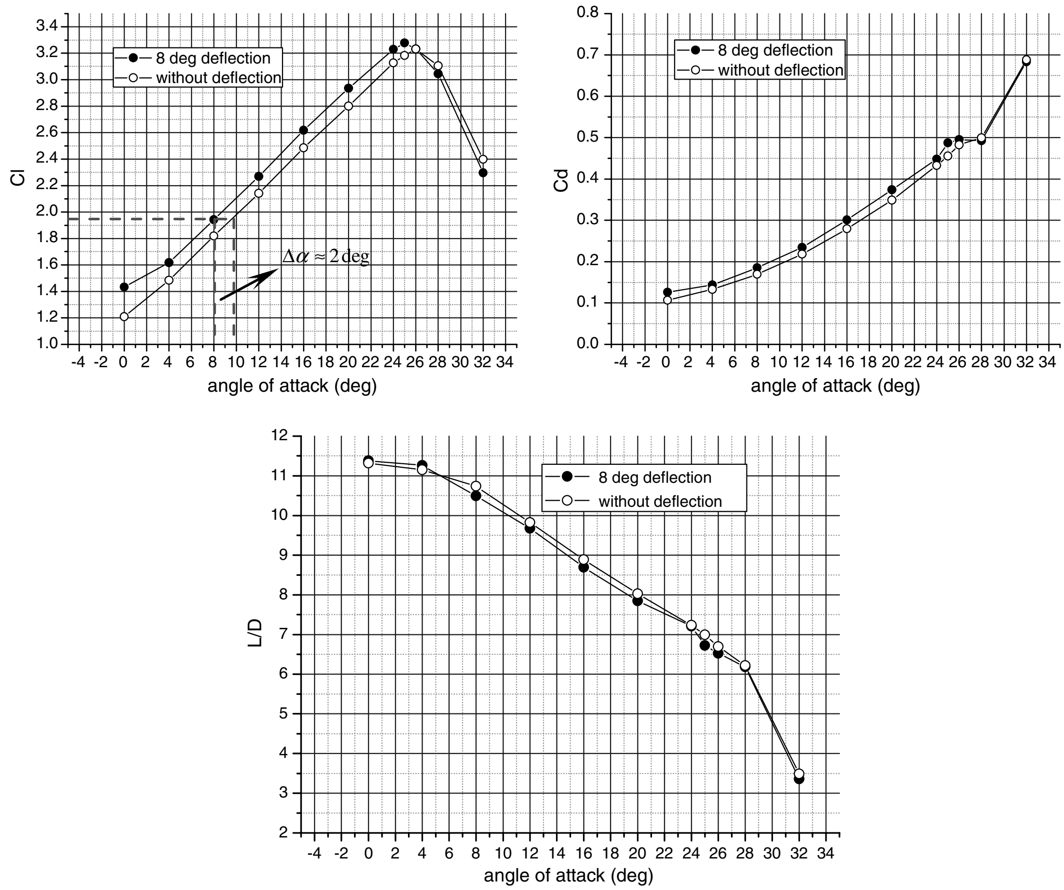

Fig. 12 Lift coefficient, drag coefficient, and lift-to-drag ratio of 3-D whole-aircraft model with deflection of the spoiler under the conditions of keeping the invariable parameters of gap and overlap of flap.

characteristics. The angle of deflection of the spoiler is 8 deg. The original and spoiler 8 deg configurations are shown in Fig. 11.

The calculated results of lift coefficient, drag coefficient, and lift-to-drag ratio of the 3-D whole-aircraft model with high-lift devices and spoiler under the conditions of different deflections of the spoiler, keeping the invariable parameters of gap and overlap of the flap, are presented in Fig. 12. We can predict that the aerodynamic characteristics will improve with the downward deflection of the spoiler.

The lift coefficient in the linear region can increase about 0.1 and the maximum lift coefficient can increase about 0.05–0.1 (1–3% of maximum lift coefficient of the original configuration) with the 8 deg downward deflected spoiler under the conditions of keeping the gap and overlap parameters of the flap unchanged.

V. Conclusions

The aerodynamic characteristics of high-lift devices with downward deflection of the spoiler were analyzed using the CFD method in this Note. We can draw the following conclusions:

1) If the spoiler deflects only downward, the aerodynamic performance will become worse than the original configuration.

2) The aerodynamic performance will be improved if the spoiler deploys downward under the conditions of making the gap and overlap parameters of the flap the same as the original configuration.

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