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Vortex Flaps Canard Configuration for Improved Maneuverability

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Introduction

MODERN design of air-to-air missiles is directly connected to flying at high angles of attack. The needs of maneuverability, as well as improved tracking features, dictate the basic design goals. However, the region of high angles of attack presents many difficulties for canard configurations. The use of such configurations has three main advantages.

1) The forward location of the control surfaces enables close and easy connection between the tracking and control systems, as well as the installation of the control servomotors at a convenient location.

2) The long distance between the control surface and the c.g. enables the production of large moments by small control forces.

3) The forces on the control surfaces are in the same direction as the intended maneuver, which gives a better dynamic response than tail control.

With all of these merits in mind, it is evident that a canard-controlled configuration having the ability to perform at high angles of attack would be desirable; however, experience shows that a loss of controllability occurs in this region.[1] This loss of controllability is attributed to the flow separation over the canard surface.[2] At high deflection angles combined with high angles of attack, it is impossible to maintain a monotonically growing lift force.[3] Another aspect of this problem is connected with the control method that is based on hinge moment control as opposed to direct force control. This method calls for monotonic behavior of the hinge moment. The breakdown of the vortex, in addition to the change in the lift force slope, also causes a forward motion of the c.p., which results in pitch-up of the control surface.[4]

To overcome this situation, a solution is sought that will enable a control surface to achieve high angles of attack, maintaining a monotonically growing lift force, and, preferably, hinge moment. Such a solution was suggested by Katz et al.[4] Their solution was based on a split canard configuration, where part of the canard was free to move around a hinge, and contributed lift only at high combined angles. The results showed improvement in the high-angle-of-attack range, but a low efficient configuration at the low-angle-of-attack range.

The new approach presented in this Note is based on the use of vortex flaps. The vortex flaps technique is common in airplane configurations that have delta wings. The vortex flaps effect is to redirect the leading-edge suction. The leading-edge suction reduces the drag when the flow is attached to the wing; however, delta wings flying at moderate and high angles of attack have a separated flow that generates the leading-edge vortex. This vortex enhances the suction above the wing upper surface, generating an additional lift, referred to as the nonlinear lift. The drag, however, grows as well. Polhamus leading-edge suction analogy[5] supplies a tool to calculate this additional lift, as well as an explanation of how the repositioning of the suction peak above the wing enhances the lift and drag. By implementing the vortex flap, the effective angle of attack on the leading edge is reduced, and the positioning of the leading-edge vortex and the direction of the suction force can be controlled. Rao,[6] as well as other researchers, have shown that an optimization of the lift-to-drag ratio can be obtained, and the airplane performance can be improved. The lift-to-drag ratio has little importance for canard performance, and the difference in the geometry of a typical canard configuration compared to the geometry of a wing in airplane configuration results in no benefits to the lift-to-drag ratio when vortex flaps are attached to thick delta wings.[7] However, Ref. 7 shows that vortex flaps can produce a considerable delay in the stall angle, which is a favorable characteristic sought for canard configurations. The feasibility of this idea was tested experimentally in the current investigation.

Test Model and Apparatus

Tests were conducted in the 0.6 × 0.8 m transonic wind tunnel in the Wind Tunnel Laboratory in the Aerodynamic

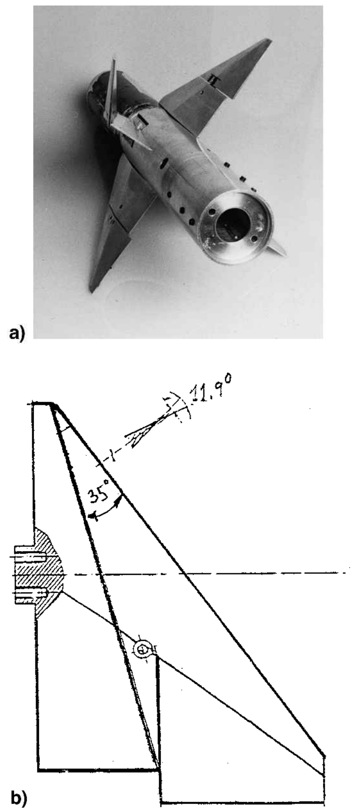

Fig. 1 a) Vortex flap model and b) canard and vortex flap.

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Research Center of the Technion—Israel Institute of Technology. The model used is shown in Fig. 1a. It has a cylindrical body with a hemispherical nose. Four canards are attached to the body. Either one canard or two facing canards can be attached to a six-component sting balance that is housed inside the body, and becomes metric. The measured aerodynamic data are that of the canard only. Each canard may be positioned in any of five deflection angles (−20, −10, 0, 10, and 20 deg). The canard design is shown in Fig. 1b, it consists of two parts. The inner part (Fig. 1a) is connected to the body via an adapter that defines the canard deflection angle, while the outer part (Fig. 1b), the vortex flap, is connected to the inner part via a secondary adapter. The vortex flap deflection relative to the canard can be changed by using various adapters of 0, 15, 30, 45, and 60 deg. In every run, both the canard deflection angle and the vortex flap angles are set, and the model is continuously pitched from −10 to 50 deg.

Tests Results and Discussion

Experiments were conducted with the canard at three deflection angles and the vortex flap at five positions. The results of the aerodynamic normal force and pitching moment acting on the canard are presented as follows: The normal force coefficient variation with the angle of attack is presented in Figs. 2a–2c for the canard deflections angles of 0, 10, and 20 deg, respectively. The variation of the corresponding pitching moment coefficient, calculated about the canards hinge (45% of the canard chord), with the angle of attack, is shown in Fig. 3. The canard with no flap deflection stalls at 20 deg at zero canard deflection, and it stalls at about 14- and 8-deg angle of attack when deflected at 10 and 20 deg, respectively. The effect of the vortex flap is to decrease the lift slope and delay the stall. This effect grows with the magnitude of the flap deflection. For flaps at 45 and 60 deg, the stall is delayed to 30–40 deg at zero canard deflection, and to 25–28 and 13–

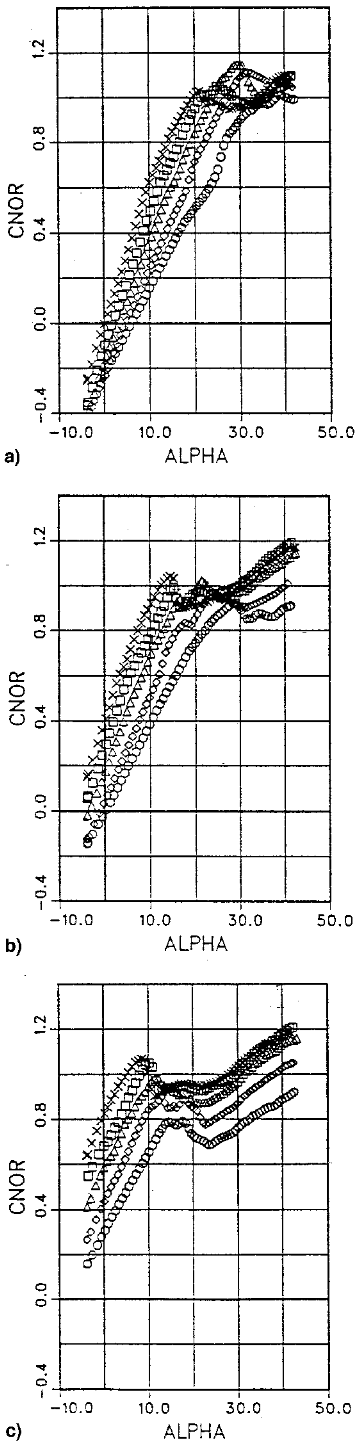

Fig. 2 Normal force coefficient variation with angle of attack. Canard deflection a) 0, b) 10, and c) 20 deg. Flap deflections: ×, 0; □, −15; △, −30; ◇, −45; and ○, −60.

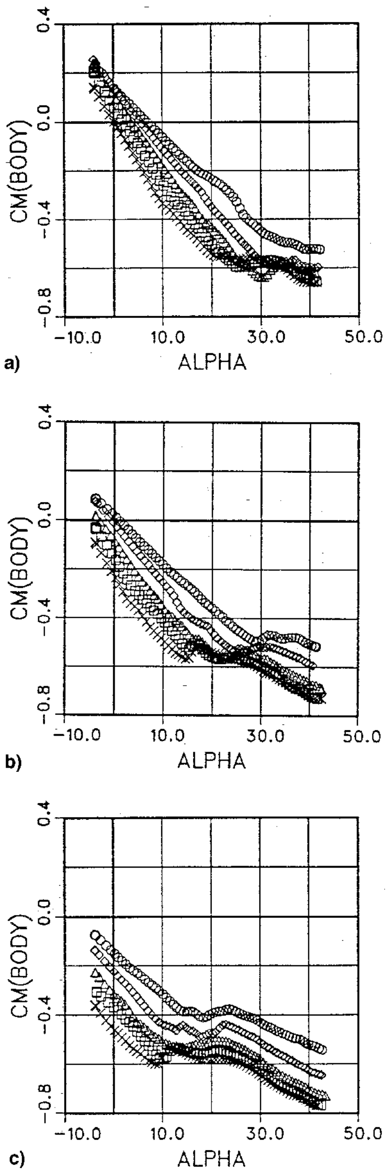

Fig. 3 Pitching moment variation with angle. a) Canard deflection a) 0, b) 10, and c) 20 deg. Flap deflections: ×, 0; □, −15; △, −30; ◇, −45; and ○, −60.

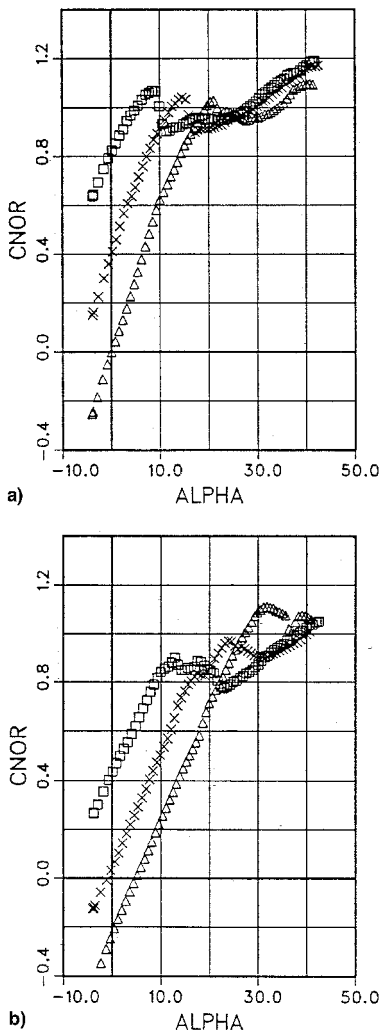

Fig. 4 Normal force coefficient variation with angle of attack. a) Vortex flap at 0-deg deflection and b) vortex flap at −45-deg deflection. Canard deflections: △, 0; ×, 10; and □, 20.

15 deg at canard deflections of 10 and 20 deg, respectively. The pitching moment coefficient curves show similar results, they maintain their monotonic trend to higher angles of attack with larger flap deflections. The effect of the vortex flap on the pitching moment coefficient slope is negligible. The maximum lift before stall increases with the vortex flaps deflection and no canard deflection, it is almost constant for 10-deg canard deflection, and it decreases with all flap deflections at 20-deg canard deflection. The improvement in the maneuverability can be seen when comparing the measure of separation between the lift curves of the canard with 0- and 45-deg flap deflection, at various canard deflections as shown in Fig. 4. This distance is the additional lift obtainable at each position with the increase of the canard deflection. With no flaps the canard lift cannot be increased beyond 17 deg, with the vortex flaps the limit is 26 deg; thus, the maneuverability of the configuration is extended to a much larger range. The control system should introduce the flap deflection as a function of the angle of attack and the canard deflection angle as well as the desired maneuver. With this approach, the basic canard configuration would be utilized at low combined angles of attack, and configurations with deflected flap at high angles of attack.

Conclusions

A large increase of the angle-of-attack range in which the canard lift characteristic remains monotonic has been obtained by using vortex flaps. This addition was obtained without any effort to optimize either the canard planform or the vortex flap size. The pitching or hinge moment characteristic has also been improved.

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