A Split-Canard Configuration for Improved Control at High Angles of Attack

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The ever-growing demands for improving the performance of air-to-air missiles call for exploring the region of high angle of attack. In this range, the common canard-controlled missile configuration tends to lose its maneuverability. This effect is attributed to the failure to maintain a monotonically growing lift force on the control surface when positioned at high combined angles. A dual-surface canard configuration is intended to overcome this problem by extending the range of angles for which the lift force on the control surfaces grows monotonically. Initial experiments prove the potential of this solution and lead to further development possibilities.

Nomenclature

C_H = hinge moment coefficient
C_m = pitching moment coefficient
C_z = lift force coefficient
α = angle of attack
δ = control-deflection angle
δ_T = tip-deflection angle
ϕ = roll angle

Subscripts

w = wing
w_T = wing tip

Introduction

MODERN design of air-to-air missiles is directly connected to flying at high angles of attack (alpha). The needs of maneuverability, as well as improved tracking features, dictate this as a basic design goal. However, the region of high alpha presents many difficulties for canard configurations. The use of such configurations is advantageous in three main aspects.

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

2) The long distance between the control surfaces and the center of gravity 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 these merits in mind, it is evident that a canard-controlled configuration having the ability to perform at high angle of attack would be very desirable. However, experience shows that a loss of controllability occurs in this region. This fact becomes obvious when observing the pitching-moment variation with angle of attack for various deflection angles of the canard surface, shown in Fig. 1. These results were obtained by Reinelle and Mifsud.[1] For this configuration there exists a maximum trim angle of about 11 deg. Higher deflection angle of the control-surface cannot exceed this limit. The loss of the controllability is attributed to the development of the flow over the canard surface. At high-deflection angles combined with high angles of attack, it is impossible to maintain a monotonically growing lift force, as is reported by Levin.[2] At these high combined angles, a vortex breakdown occurs above the control surface, as discussed by Lamborne and Bryer,[3] and causes a loss in its effectiveness. A typical lift-force variation with angle of attack is shown in Fig. 2 for various deflection angles, and easy correlation is drawn between these results and those of Fig. 1. 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 a monotonic behavior of the

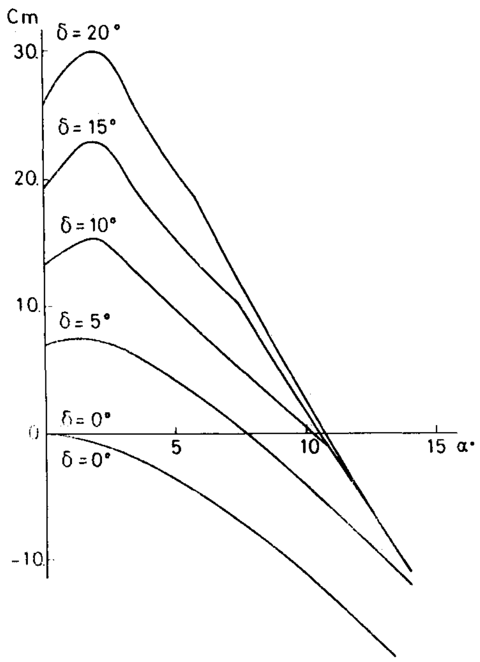

Fig. 1 Pitching moment coefficient variation with angle of attack.

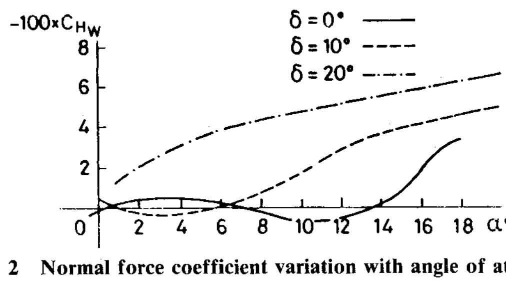

Fig. 2 Normal force coefficient variation with angle of attack.

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hinge moment. The breakdown of the vortex, in addition to changing the wing-lift force slope, also cause a forward movement of the center of pressure, which results in a "pitch up" of the control surface, as shown in Fig. 3. Because of this behavior, the control function ceases to be single-valued at a certain angle of attack.

To overcome this situation, a solution is sought that will enable a control surface to achieve high angles of attack keeping a monotonically growing lift force and, preferably, hinge moment. A possible solution is the split canard. The idea is based on a canard composed of two surfaces, an inner one and an outer one, as shown in Fig. 4. One of the surfaces is connected to the controls and carries the loads at low-deflection angles. The other surface is free to rotate around its shaft within a limited range. This free surface is designed to be aerodynamically stable so it will always seek a zero effective angle of attack. At low and moderate deflection angles the free surface contributes no lift. At high combined angles when the controlled surface starts to lose its lift force, the movement of the free surface is blocked by a mechanical constraint, and it starts contributing lift. The combined effect is a monotonically growing lift force on the whole configuration for a higher range of combined angles of attack. Initial tests were carried out in the Wind Tunnel Laboratory of the Technion to prove the feasibility of this idea. A configuration was chosen based on a common canard setup, without trying at this stage to achieve an optimal design. In this paper, the results of these experiments are presented and discussed, and early conclusions are drawn.

Test Apparatus and Model Description

To achieve a comprehensive parametric-testing capability, a model was design which could facilitate a wide variety of canard configurations and allow for many parametric changes and measurements.

The model consists of a cylindrical body with a hemispherical nose. Both nose shape and length can be varied for further investigation of the nose influence. Four canards are attached to the body. Either one canard or two facing canards can be attached to a six-component sting balance and become metric. The canards may be installed in either a plus or an x-configuration. Each canard may be positioned in any of five deflection angles (−20, −10, 0, 10 and 20 deg).

Each canard surface consists of two parts as shown in Fig. 4. The inner part is connected by an adaptor to the main frame, while the outer part is connected to the inner part through a shaft which enables five rotational locations of 0, 10, 20, 30 and 40 deg. The outer surface deflection is positive for nose downward position. On one of the canards this shaft was replaced by a miniature five-component balance that enable separate measurements of the forces and moments acting on the outer surface itself.

The canard configuration chosen for the initial testing sequence is of a regular shape. There was no effort to try to optimize the planform at this early stage.

Two sting balances are being used in the experiments. A standard 16-mm six-component sting balance and a specially designed miniature five-component balance. The six-component balance measured the forces and moments acting on the assembled canard configuration, and the five-component balance was used to measure the loads on the outer part of the canard alone.

The experiments were conducted in the transonic wind tunnel at Mach number 0.4. In each experiment the angle of attack varied in the range of −5 to 55 deg. The deflection angle was kept constant during each experiment.

Experiments and Results

In a dual-surface canard, several control ideas could be explored. Either of the surfaces could be "free," or each could be controlled separately. The free surface could be limited by an angular deflection or by a rotational spring. At this stage the only mode investigated was that of a "free" outer surface, with a limit on its angle of deflection. During the experiments, the outer surface was held firmly at deflection angles of 0, 10, 20, 30 and 40 deg. The hinge moment measurement defines whether the outer surface is free or force contributing.

Figure 5 shows the canard lift-force variation with angle of attack for different tip deflections and with the overall control deflection angle as a parameter. Points A and B describe the intersection of the curves for different canard control deflec-

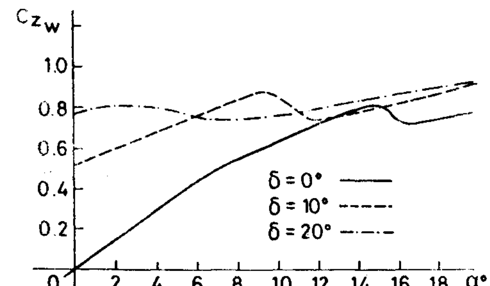

Fig. 3 Hinge moment coefficient variation with angle of attack.

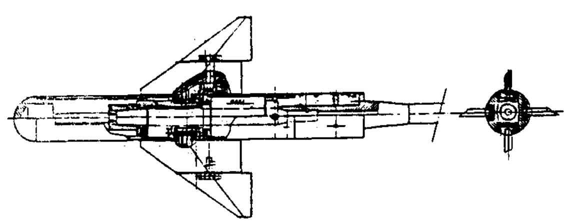

Fig. 4 Split-canard configuration.

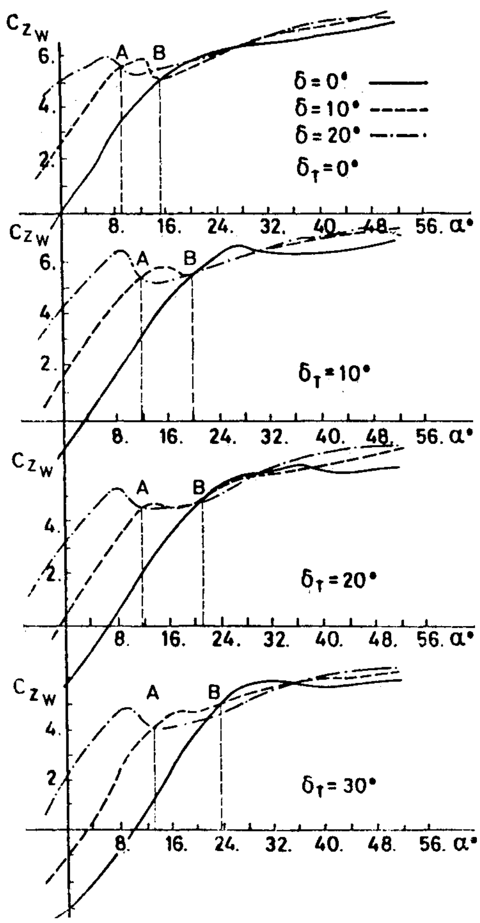

Fig. 5 Normal force of the canard, variation with angle of attack for different control (δ) and tip (δ_T) deflections.

tions. These intersections represent points where the controls lose their effectiveness, since increasing the control angle leads to a decrease in the resulting force. It is evident that these points move towards higher angles of attack with increasing tip deflections. Moreover, the curves tend to keep their monotonic behavior over a longer range. Similar results were obtained for the x-configuration as shown in Fig. 6, although the movement of points A and B is not pronounced.

In Fig. 7 the lift and the hinge moment of the tip surface variations with angle of attack are shown, for a zero-control deflection. Two interesting conclusions can be drawn from these curves. First, for the configuration chosen, all three deflections give a maximum in the lift curve at about 28 deg. Second, the hinge moment and the lift force were zero at angles much lower than expected, i.e. at 5.5, 11 and 17 deg for actual deflection angles of 10, 20 and 30 deg, respectively. This is evidently the result of the upwash induced by the lift-producing inner part on the outer surface. This upwash prevents the tip from producing the full effect it was designed for.

To obtain the behavior of the canard assembly with a free outer surface limited to 30 deg deflection, several experimental results were combined. An experiment was first run with the inner part alone, and then experiments were carried out with the outer surface deflected at 0, 10, 20 and 30 deg and with control angle of 0, 10 and 20 deg. From the hinge moments of the outer surface the locations of the limiting angles, where the outer surface starts contributing lift, were calculated. The results for control angles of 0, 10 and 20 deg are shown in Figs. 8-10, respectively. Cross-plotting these results gives the "free" tip lift-force variation with angle of attack for dif-

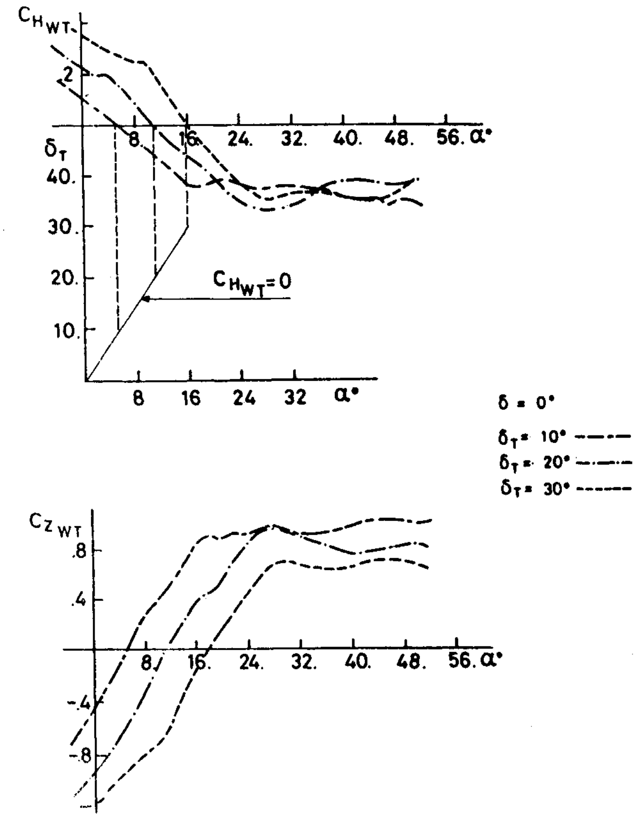

Fig. 7 Wing-tip lift and hinge-moment coefficients variation with angle of attack.

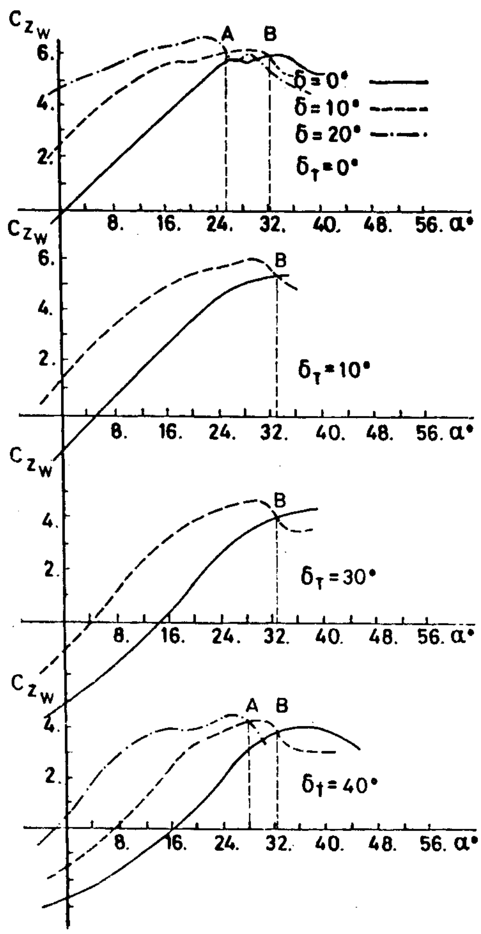

Fig. 6 Lift force of the canard variation with angles of attack for different control (δ) and tip (δ_T) deflections at roll angle $\phi = 45$.

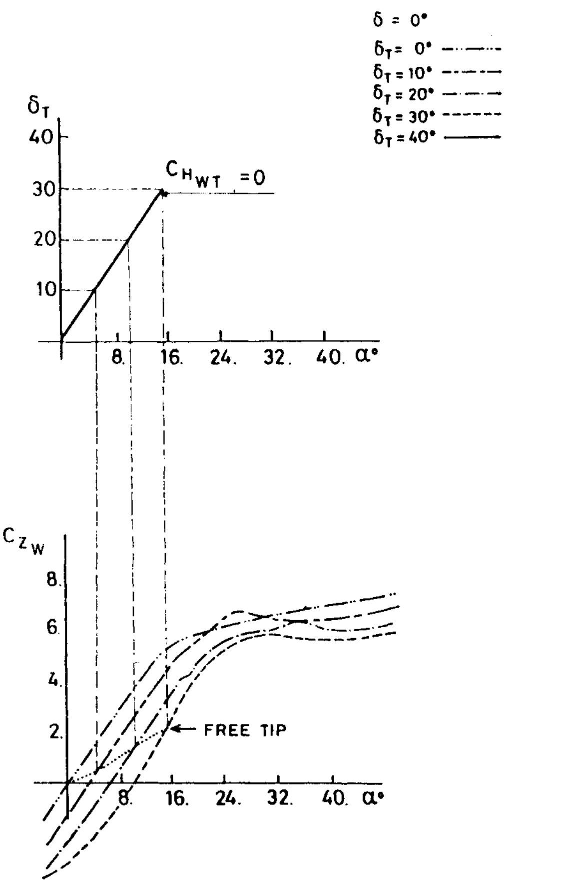

Fig. 8 Normal force coefficient variation with angle of attack, with various tip deflections.

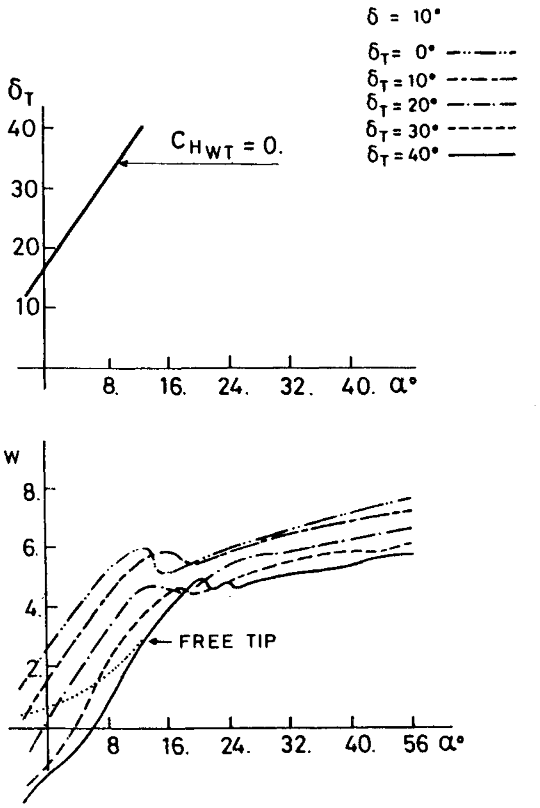

Fig. 9 Normal force coefficient variation with angle of attack, with various tip deflections and $\delta = 10$ deg.

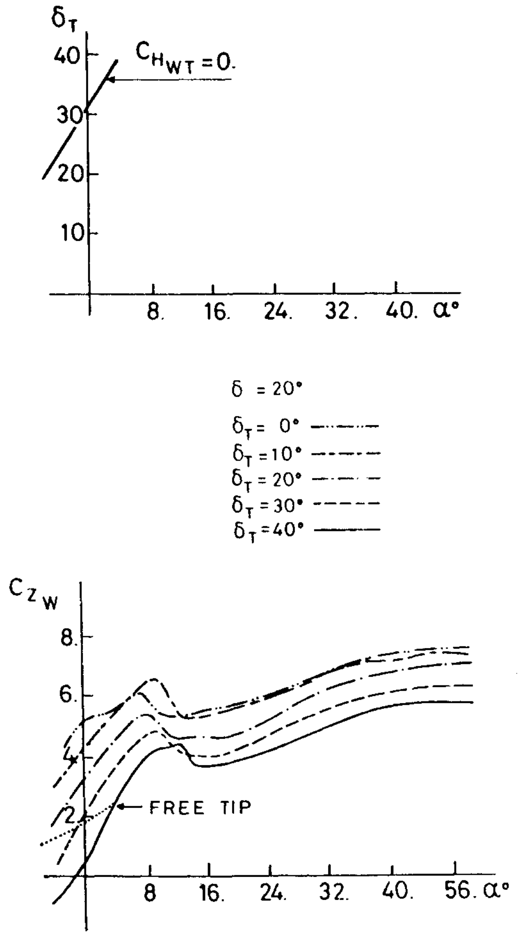

Fig. 10 Normal force coefficient variation with angle of attack, with various tip deflections and $\delta = 20$ deg.

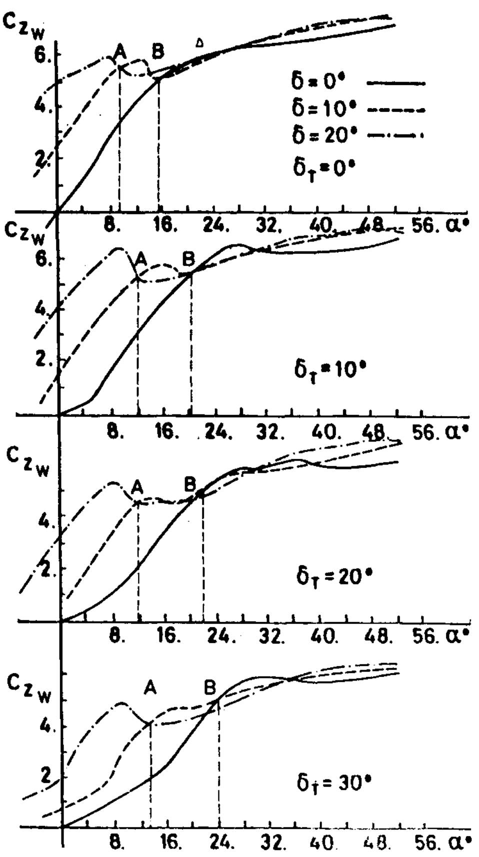

Fig. 11 Normal force coefficient variation with angle of attack, simulating free tip with various tip angle limitations.

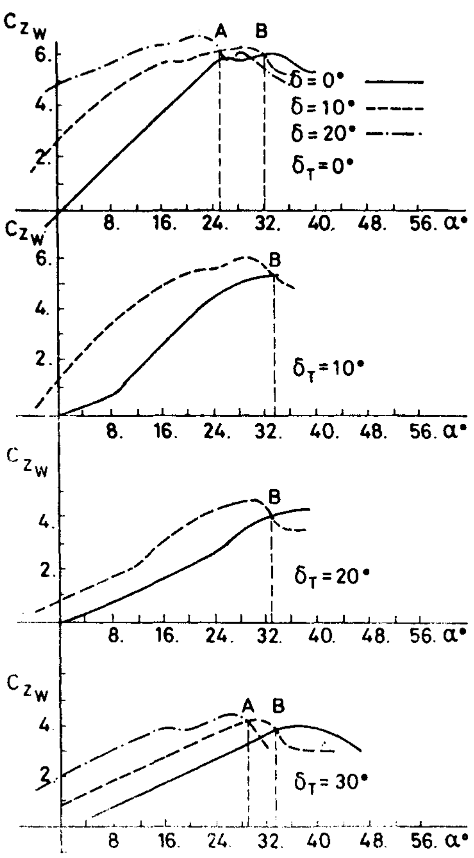

Fig. 12 Normal force coefficient variation with angle of attack, simulating free tip with various tip angle limitations at roll angle $\phi = 45$.

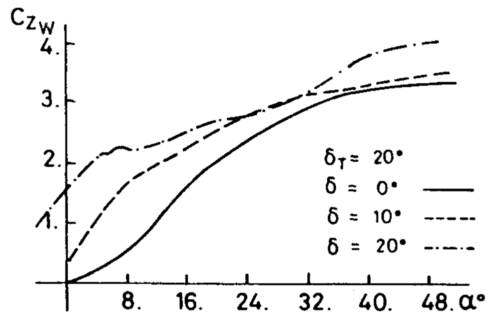

Fig. 13 Normal force variation with angle of attack for modified split-canard configuration.

ferent rotational limitation in Fig. 11. The same procedure was carried out for an x-configuragtion, and the results are shown in Fig. 12.

Discussion and Conclusion

The results obtained in these experiments show the potential of the split-canard configuration for controlling maneuvers at high angles of attack. The data for the plus-position shows a meaningful extension of the usable angle of attack, from 16 to 24 deg for a 10-deg control deflection, and the curves became smoother. The improvement for an x-configuration is not so pronounced. It is evident that the upwash induced by the inner part does not allow the "free" part to maintain its low angle of attack. This leads to the conclusion that further studies should be made, with an effort to decrease or eliminate the interference between the two surfaces. This could be done by several methods, such as different planforms, different longitudinal location, or different area ratio between the two surfaces. An experiment carried out according to these conclusions involved using end plates between the inner and outer parts of the canard, and has rendered the results shown in Fig. 13. In this figure, it is clear that the distinction between the curves has been extended to much higher angles of attack.

These results, combined with the fact that the configuration chosen was not optimal in any way, prove the potential of the idea and the need to further explore the possibilities of the split-canard configuration.

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