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WIND TUNNEL MEASUREMENTS OF LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS OF PRIMARY AND SECONDARY WING CONFIGURATIONS

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Abstract

Low speed wind tunnel measurements of the variations in pitching moment coefficient with angle of attack are described for primary and secondary wing configurations, wing-canard combinations. Experimental results are shown for various vertical and horizontal distances between the surfaces, canard incidence angles and canard flap angles. These experimental results show that the stability is nonlinear with both angle of attack and incidence angle and as a consequence the pitching moment coefficient at zero lift is an important parameter affecting the stability at trim conditions. At high angles of attack, above canard stall, the change in pitching moment coefficients with canard incidence angle and flap angle is reduced and for some configurations the change is reversed. Results also show that wind tunnel tests, at the appropriate Reynolds Number, are needed to determine longitudinal stability and control characteristics of wing-canard combinations.

Introduction

In recent years, the concept of using the canard surface as a secondary wing that provides a large percentage of the total lift, in addition to longitudinal control, has generated new interest in canard airplane configurations. Although flights of aircraft using this type of configuration appear to be successful, adequate experimental flight and wind tunnel data are not available to evaluate the aerodynamics of this type of airplane configuration and theoretical techniques are questionable when evaluating the mutual interference effects between the main wing and the secondary wing surfaces.

Wind tunnel tests, using a basic, straight rectangular wing and canard planform were conducted at NASA Ames Research Center by Terrell Feistel and Victor Corsiglia.(1) Results of these tests show that the canard configuration has the potential for offering improved performance over current day type airplane configurations. Additional tests using the same model were conducted in the Texas A&M 7'x10' Low Speed Wind Tunnel. The overall purpose of these tests was to obtain results for additional configurations and to provide a data base to show general aerodynamic characteristics of various wing-canard combinations. Tests were conducted for various canard aspect ratios, camber and ratio of canard area to wing area. In addition to obtaining performance characteristics of various canard configurations, significant longitudinal stability and control information was obtained. The purpose of this paper is to present the longitudinal stability and control characteristics of some of the configurations tested. Variations in pitching moment coefficient and canard lift coefficient with angle of attack are presented in this paper. Results obtained to show performance characteristics, lift and drag, are available and will be published at a later date.

Nomenclature

AR	aspect ratio
b	span
c	chord
C_L	lift coefficient = $L/q\,S_w$
C_m	pitching moment coefficient = M/qSwCw
Cm_o	pitching moment coefficient at zero lift
L	lift
M	pitching moment
q	dynamic pressure
S	surface area
X np	neutral point location measured forward of main wing quarter chord
X ca	center of area measured forward of main wing quarter chord
Z_c	vertical distance between surfaces in main wing chord lengths measured from the plane of the main wing, positive up
α	angle of attack, degs.
i	incidence angle, degs.
δ_F	forward surface flap deflection angle, degs.

Subscripts

c	forward surface, canard
w	aft surface, main wing

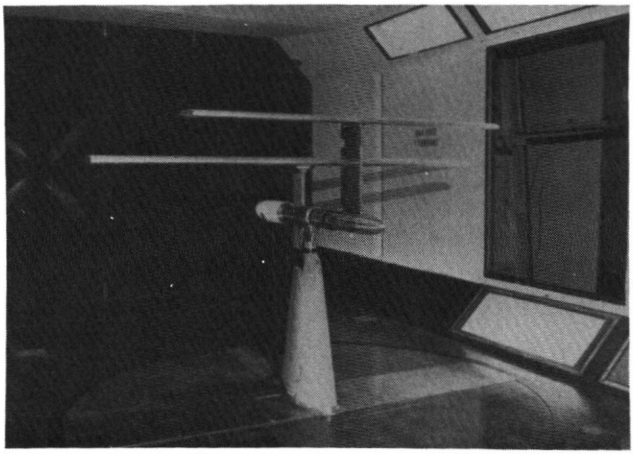
Model and Test Description

Figure 1 shows the model installed in the wind tunnel. Tests were conducted for two secondary wing positions forward of the main wing, 3.0 chord lengths (long body) and 1.63 chord lengths (short body). For each body length the vertical position of the secondary wing was varied from 0.5 chord lengths below the main wing to 0.5 chord lengths above the main wing. For each canard position the canard incidence angle was varied from -2° to +6° and the canard flap angle was varied from 0° to 30°. Results are presented in this paper for the configurations listed in Table 1.

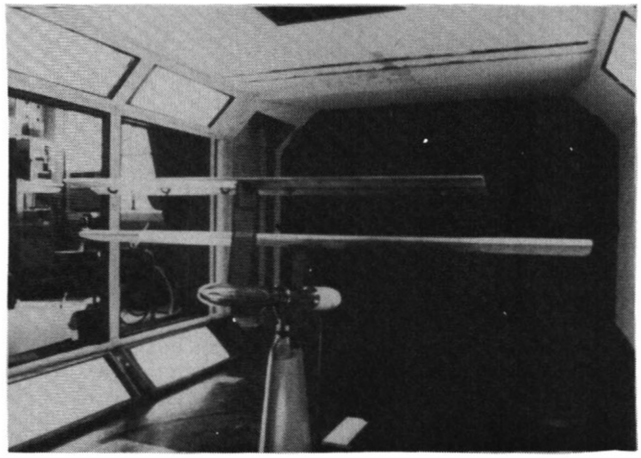
The maximum Reynold number for the test was 1.845×10^6. All results were reduced to coefficients based on the main wing chord and area.

The moment reference center was taken as a point in the plane of the main wing, independent of canard vertical position.

Tests of a model image support system were conducted. This image system included the fuselage and wing support mounts as shown in Figure 1. Therefore, the results presented reflect the aerodynamic characteristics of the two wings and the interference effects of the total support system, including the fuselage, has been removed.



(a) C_1W configuration, no flap



(b) C_3W configuration, with flap deflected

Fig. 1 Model in 7 x 10 Foot Wind Tunnel

Characteristics	Geometry		
	Main Wing W	Canard C_1	Canard C_3
Aspect Ratio, AR	6	6	8.9
Area, S	6 ft^2	3.00 ft^2	3.52 ft^2
Span, b	6 ft	4.243 ft	5.6 ft
Chord, c	1 ft	.707 ft	.628 ft
Taper, twist, dihedral	None	None	None
Section	GA(W)-2	GA(W)-2	GA(W)-2
Flap % of chord (full span)			25%

Note: Planform was rectangular for all surfaces.

Test Conditions

Wind Tunnel Dynamic Pressure Reynolds Number	20 to 100 psf
(based on ref. chord)	$.825 \times 10^6$ to 1.845×10^6
Angle of Attack Range	-6° to +24°

Configurations Tested

Wing	Canard	Gap	Stagger	Flap Angle	Canard Incidence
W_1	C_1	+0.5c,0,-0.5c	3.0 c	-	-2°,0,2°,4°,6°
W_1	C_1	+0.5c,0,-0.5c	1.63 c	-	-2°,0°,2°,4°,6°
-	C_1	-	-	-	0°
W_1	C_3	+0.5c,0,-0.5c	3.0 c	0°,10°,20°,30°	0°,2°,4°
W_1	C_3	+0.5c,0,-0.5c	1.63 c	0,10°,20°,30°	-2°,0°,2°,4°
-	C_3	-	-	0,10°,20°,30°	0°
W_2	C_3	+0.5c,0,-0.5c	1.63 c	0°,20°	0°,2°

TABLE 1 -- MODEL CHARACTERISTICS AND TEST CONDITIONS

Results

Figures 2 and 3 show typical variation in pitching moment coefficient with angle of attack for various canard incidence angles for the co-planar long and short body configurations. The reference center for the pitching moments were chosen to be the point of neutral stability at a canard deflection angle of +2° in the range of lift coefficient from 0 to approximately 0.4. In this range of lift coefficient, the pitching moment variation with lift coefficient is relatively linear. However, for lift coefficients above 0.4 the variation is nonlinear and it would be difficult to establish a reference neutral point. The neutral point location, x/c np, is measured forward of the main wing quarter chord. As noted in Figures 2 and 3, neutral point location is further forward than the center of area, x/c ca, of the two wing surfaces.

The results in Figures 2 and 3 show two areas of interest that are not generally associated with conventional tail-type airplane designs. These areas include the variation of neutral point location, or stability, for various canard incidence angles and the reversal of the change in pitching moment with canard incidence angle at or above the canard stall angle of attack.

At small angles of attack, 0° to 4°, the slope of the pitching moment coefficient curve decreases with increasing canard incidence angle. As shown in Figures 2 and 3, the stability increases with increasing canard incidence angle and amounts to as much as a ten percent change in vehicle stiffness for a change in instance angle from 2° to 6°. At higher angles of attack from 4° to 10°, the decrease in slope with increasing incidence angle is larger.

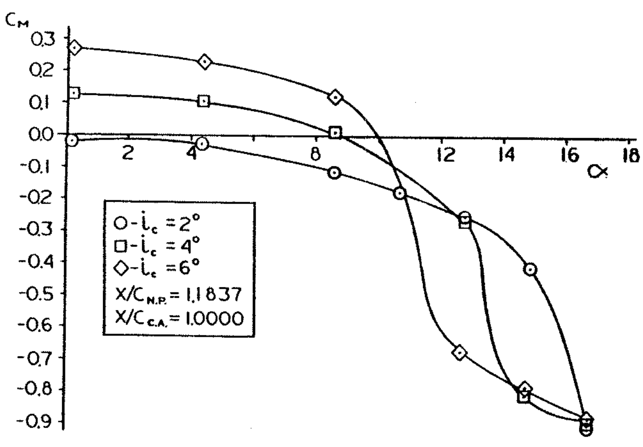


Fig. 2 Pitching Moment Coefficient Variation with Angle of Attack, Co-Planar, Long Body Configuration

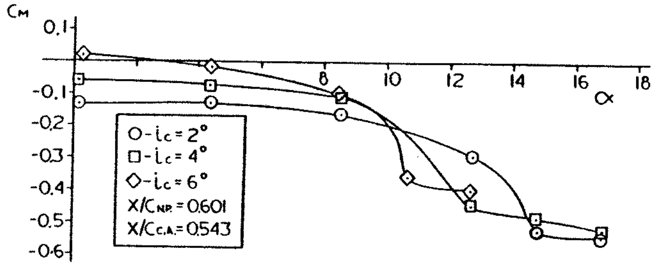


Fig. 3 Pitching Moment Coefficient Variation with Angle of Attack, Co-Planar, Short Body Configuration

It should be noted that for changes in center of gravity location, the curves in Figures 2 and 3 would rotate about the zero lift point, Cm_o. However, the pitching moment coefficients presented are for the wing-canard combination only and does not include the pitching moment for a complete aircraft configuration. For a complete airplane configuration, the canard incidence angle required for trim would be dependent upon both the center of gravity location and the pitching moment coefficient at zero lift. Considering that the stability is nonlinear with both angle of attack and canard incidence angle, the stability of a given aircraft configuration, at trim, could vary considerably with vehicle configuration changes. Therefore, the pitching moment, Cm_o, at zero lift is an important parameter and trimming a given configuration by varying the canard instance angle could result in relatively large changes in vehicle stability.

At higher angles of attack above 10°, the pitching moment curves for the larger canard incidence angles cross the curves for the smaller incidence angles. This cross over is obviously due to canard stall. At small angles of attack increasing canard incidence angle results in an increase in positive pitching moment. At angles of attack near 12°, increasing canard incidence angle results in a decrease in pitching moment. This characteristic could present a potential design difficulty when the canard incidence angle is used for longitudinal trim or control.

Figures 4 and 5 show a comparison of pitching moment variation with angle of attack for the short and long body configurations for the co-planar and canard above the wing configurations. In general, the curves are similar, and as would be expected, increasing the distance between the main wing and canard results in an increase in stability, in percent of chord, at the higher angles of attack.

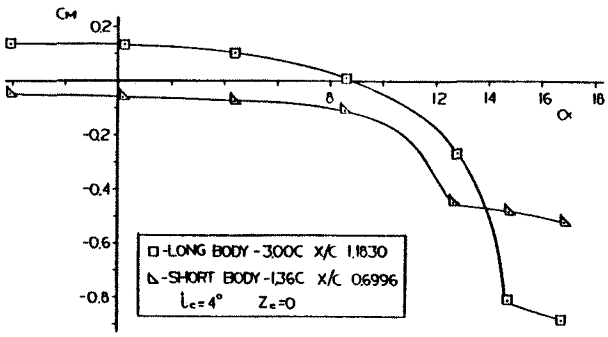


Fig. 4 Comparison of Pitching Moment Coefficient for Two Horizontal Distances Between Surfaces, Co-Planar Configuration

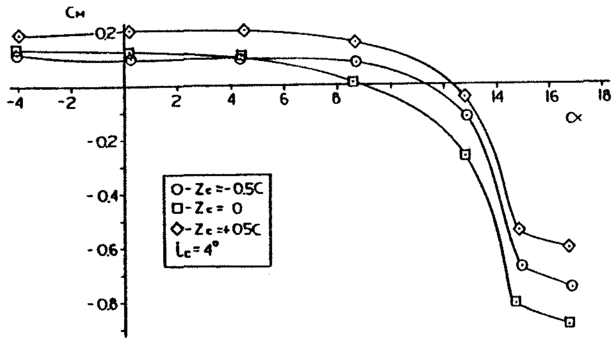


Fig. 6 Comparison of Pitching Moment Coefficient for Three Vertical Distances Between Surfaces, Long Body Configuration

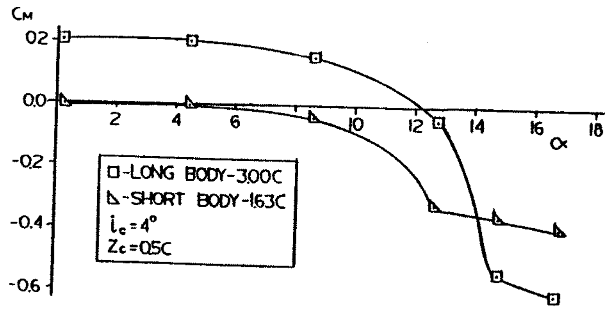


Fig. 5 Comparison of Pitching Moment Coefficient for Two Horizontal Distances Between Surfaces, Canard Above Main Wing

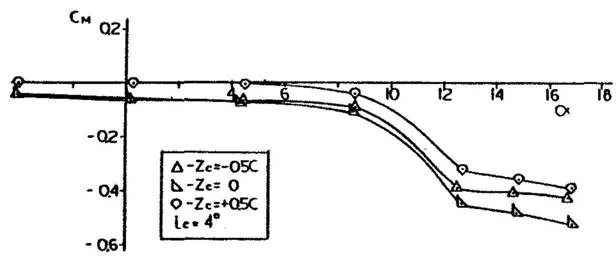


Fig. 7 Comparison of Pitching Moment Coefficient for Three Vertical Distances Between Surfaces, Short Body Configuration

Figures 6 and 7 show the effect of canard vertical position relative to the main wing, half chord length below the wing, co-planar and half chord length above the wing. The major change is the shift in pitching moment coefficient at zero lift. The pitching moment coefficient at zero lift is approximately the same for the co-planar and canard below the wing configurations. Moving the canard above the main wing results in an increase in the positive pitching moment. In general, the slope of the curves, for different canard positions, are similar throughout the angle of attack range.

It should be noted that the results obtained for these tests were for changing the canard incidence angle and are reflective of design problems that could be encountered when using a variable incidence canard for airplane trim. Varying the canard camber could alleviate some of the problems. Tests were conducted using a trailing edge flap surface to vary the canard camber. Figures 8 and 9 show the variation of pitching moment coefficient with angle of attack for canard flap angle changes from 0° to 30° for the long and short body configurations, respectively. It should be noted that for this planform configuration, the canard aspect ratio and the canard surface areas was higher resulting in moving the neutral point forward from that of the configuration shown in Figures 2 and 3.

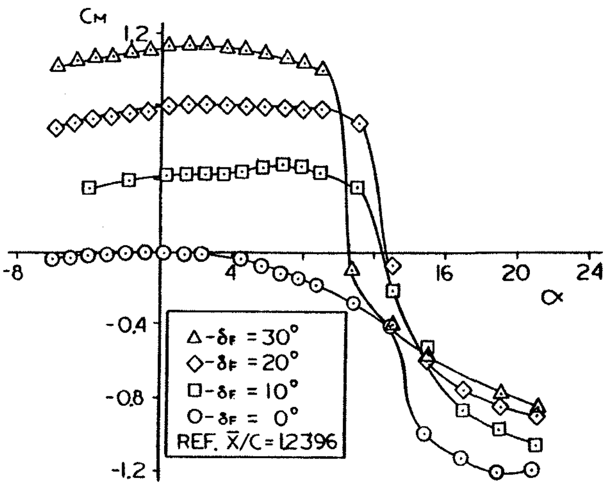


Fig. 8 Effect of Canard Flap Deflection on Pitching Moment Coefficient, Long Body Configuration

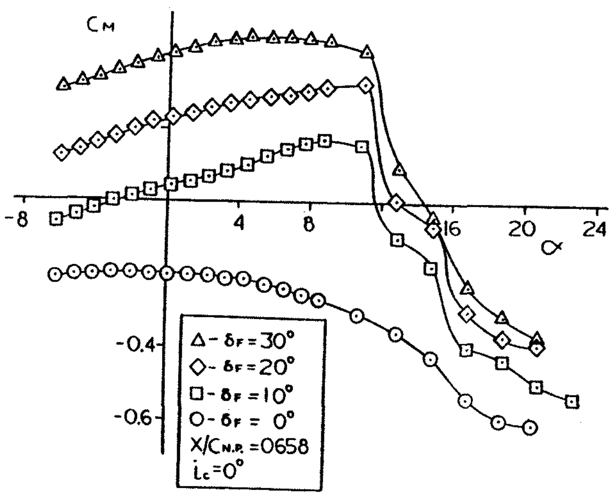


Fig. 9 Effect of Canard Flap Deflection on Pitching Moment Coefficient, Short Body Configuration

Probably the most noticeable change in the pitching moment characteristic with flap deflection angle is the destabilizing effect at low angles of attack. This change resulted from an increase in the lift curve slope of the canard surface with flap deflection. Figure 10 shows the variation of lift coefficient with angle of attack for the canard alone. The increase in lift curve slope resulted from an increase in canard area with flap deflection angle. The flap was hinged such that an increase in flap angle resulted in an increase in canard area for ten degrees flap deflection angle and remain relatively constant for further increases in flap deflection angle up to 30°. Thus, the resulting destabilizing effect shown in Figures 8 and 9 are explainable. However, this characteristic could easily be overlooked in designing of canard configurations.

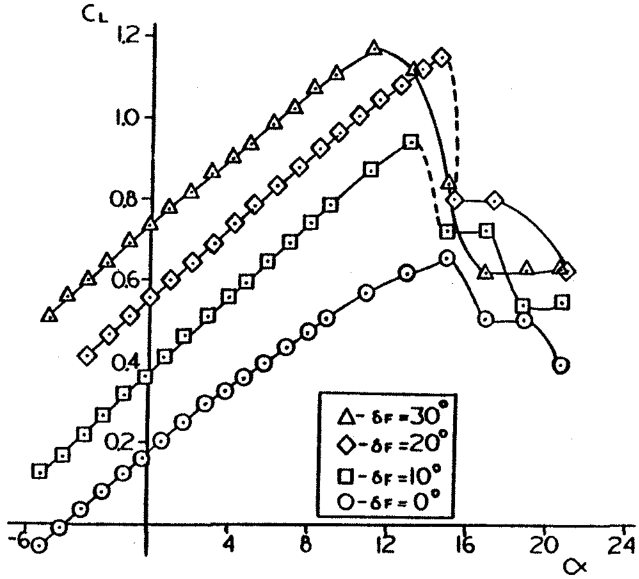


Fig. 10 Lift Coefficient Variation with Angle of Attack, Canard Alone

Figures 8 and 9 show that large changes in Cm_0 can be obtained by camber, or deflecting a flap surface, more effectively than by changing canard incidence angle. However, the pitching moment curves for the long body configuration still has a cross over at the higher angles of attack, above 12°. This type of an effect could result in a control effectiveness reversal at high angles of attack. Although the curves for the short body configuration did not show a cross over, the change in pitching moment with flap deflection angle was greatly reduced at the higher angles of attack.

It should be noted that the cross overs in pitching moment curves occur at angles of attack above the canard stall angle and the results presented in Figures 2, 3, 8 and 9 are probably not representative of all canard configurations. Obviously, the cross over characteristic would be dependent upon the stall characteristics of the canard, which would depend upon airfoil shape and camber, flap hinge line configuration and gap size, and Reynolds number.

In addition to the co-planar configuration, tests were also conducted for the canard above and below the main wing. In general, the trends were the same as the co-planar case presented in Figures 8 and 9.

Concluding Remarks

In summary, the results presented in this paper represent only a small percentage of the data currently available from wind tunnel tests at Texas A&M University; however, most of these tests were only recently completed and the analysis of the results are not complete. The preliminary results and analysis as presented in this paper do indicate that nonlinear effects, viscous flow effects, play an important role in determining the longitudinal stability and control of canard configurations and it would be extremely difficult to generalize for all canard configurations. The most important factor affecting the longitudinal stability and control is the flow separation and stall of a canard which cannot be predicted using current analytical and theoretical techniques.

The results to date indicate that each configuration would have to be considered on its own merit and wind tunnel tests, at the appropriate Reynolds number, are needed to determine stability and control characteristics.

References

1. T.W. Feistel, V.R. Corsiglia, and D.B. Levin, "Wind Tunnel Measurements of Wing-Canard Interference and a Comparison with Various Theories," SAE Technical Paper 810575, April 1981.