AN EXPERIMENTAL STUDY OF A THREE LIFTING SURFACE CONFIGURATION

ICAS-86-1.9.4

C. Ostowari* and D. Naik#
Texas A&M University
College Station, Texas

Abstract

The aerodynamic ramifications of utilizing three lifting surfaces as oppposed to the conventional or canard lifting configurations have been studied on a theoretical basis by previous researchers. This paper presents an experimental investigation of various configuration modifications for an unyawed typical business jet at a Reynolds number of 1.3 million. The three surface has better lift and high-lift drag characteristics than either the canard or tail-aft configurations, but the cruise drag is more. The induced drag at cruise is highest for the canard and lowest for the tail-aft configuration. The pitching moment characteristics are somewhat between those of the canard and tail-aft configurations. A decrease in gap adversely affects the pitching moment characteristics. A smaller stagger leads to better aerodynamic and stability characteristics. A decrease in span of the forward wing gives better cruise drag and longitudinal stability characteristics, but has adverse effects on high-lift drag. A variation in the incidence angles of either or both the forward and aft wings changes the zero-lift moments of the configuration, while marginally affecting overall lift and drag. At cruise, the lift to drag ratio is highest for the conventional and lowest for the three surface. For high lift conditions, the order is reversed.

Nomenclature

a.c.	aerodynamic center
AR	aspect ratio, b^2/S
b	lifting surface span
c	lifting surface mean aerodynamic chord
C_D	drag coefficient, drag/qS_1
C_L	lift coefficient, lift/qS_1
C_m	pitching moment coefficient w.r.t. 0.25 c_1 moment/qS_1c_1
C_{mg}	pitching moment coefficient w.r.t. given cg location, moment/qS_1c_1
g	gap (vertical distance between the a.c. of wings)
L	fuselage length
q	freestream dynamic pressure
RN	Reynolds number w.r.t. c_1
S	lifting surface planform area
s	stagger (horizontal distance between the a.c. of wings)
α	angle of attack
δ	incidence angle
Δ	difference

Subscripts

o	zero lift condition
1	main wing
2	aft wing
3	forward wing

I. Introduction

The theories and modifications to the theories of Prandtl and Munk have been used by a number of researchers[1,2,3,4,5] to explore the minimum induced drag of multiplanes (aircraft with multiple wings). These studies have yielded comparative predictions of the induced drag and static longitudinal stability of conventional aircraft, canard and three surface configurations. The effect of variations in gap and stagger are also an integral portion of these studies.

Kendall[6,7,8] has summarized these analytical results, theorizing that minimum induced drag should be attainable at any cg location so long as equal and opposite vertical loads are applied by the *forward* and *aft lifting (or trimming)* surfaces. Furthermore, these minimum induced drag loads should be achievable at any useable cg location, within the practical limits set by the size and shape of the lifting surfaces.

An important and pragmatic concern about these theoretical studies is that idealizing assumptions have been made, usually closely allied to Prandtl's and Munk's assumption of an elliptical spanwise lift distribution. Both Butler[3] and Kroo[4] have suggested that for non-elliptical lift distributions with pure canards, the effects are significantly different from idealised theory. Butler predicts that the three surface induced drag at both typical cruise and high lift conditions is lower than the induced drag of either a conventional aircraft or a canard-wing type.

A recent analytical study, by Selberg and Rokhsaz[9], of the aerodynamic tradeoff between the three configurations, shows that the three-surface is superior to the canard only at lower stabilator aspect ratios and that the overall induced drag penalty is not sufficiently different to be of primary concern in the configuration selection process.

The conventional airplane configuration has been the subject of numerous experimental investigations. Wind-tunnel measurements of wing-canard interference[10] have shown potential advantages, in terms of aerodynamic efficiency, high-lift capability and stall characteristics, for the lower subsonic speed range. Other experimental studies[11] have shown the importance

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* Assistant Professor, Member AIAA
\# Graduate Research Assistant
Aerospace Engineering Department

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of proper canard airfoil selection, to longitudinal stability of canard-wing configurations. These studies have also pointed out the need for basic experimental data on a typical three lifting surface configuration.

This paper presents aerodynamic force and moment measurements from a series of wind tunnel experiments using a practical airplane configuration to ascertain how non-elliptical lift distributions affect the lift, drag and static longtidunal stability for a three surface configuration. The configuration selected for the research was similar to a current tail-aft business jet aircraft that is modified by the addition of a forward wing and fuselage extension for stagger.

Comparisons are made between the ConVentional tail-Aft configuration (CVA), the Canard-Wing Configuration (CWC), and the Three Lifting surface Configuration (TLC). The effect of variation in tail and forward wing (f.w.) incidence angles, and the effects of stagger and gap, are also studied.

II. Procedure

The wind tunnel testing was carried out, on a 0.15 scale model of a typical business jet, at the Texas A&M University 2.13 m x 3.05 m low speed wind tunnel. The tunnel and its six component, pyramidal, virtual centre, external balance is described in Reference 12. The model has a removable fuselage extension to allow for two different stagger values. Two forward wing variations were considered. The first wing had the same span as the horizontal tail while the second forward wing was 75% of the horizontal tail. The locations of the f.w. and the fuselage plug are shown in Figure 1.

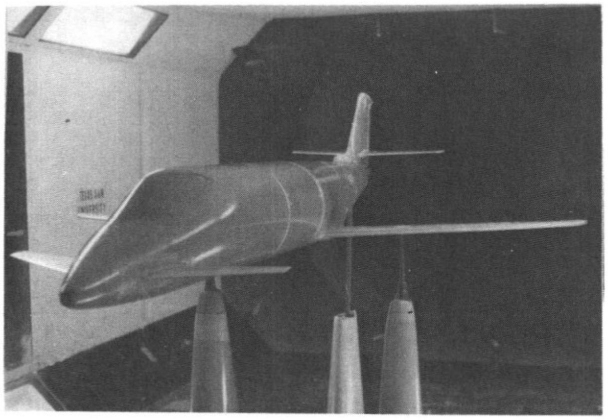


Figure 1 - Three Lifting Surface Model in the 2.13 m x 3.05 m Wind Tunnel.

Provisions were made to allow for forward wing and horizontal tail incidence variation. The effect of gap variation was studied by placing the horizontal tail at two different locations on the vertical tail. The various model congifurations are shown schematically in Figure 2 and also are tabulated (Table I).

Table I - Model Configurations

Configuration	Variables
Wing + fuselage	2 fuselage sizes
Wing + fuselage + horizontal tail	2 fuselage sizes 2 tail positions 3 tail incidence angles
Wing + fuselage + forward wing	2 fuselage sizes 2 forward wing sizes 3 f.w. incidence angles
Wing + fuselage + forward wing + horizontal tail	2 fuselage sizes 2 forward wing sizes 2 tail positions 3 f.w. incidence angles 3 tail incidence angles

Of the 98 possible configurations, 66 were studied and selected results are presented here. Pertinent model dimensions are given in Table II.

Table II - Pertinent model dimensions

b_1	2.00 m
b_2	0.336 b_1
b_3	large = 0.336 b_1 small = 0.257 b_1
c_1	0.3048 m
c_2	0.574 c_1
c_3	large = 0.465 c_1 small = 0.338 c_1
S_1	0.5529 m^2
S_2	0.204 S_1
S_3	large = 0.154 S_1 small = 0.090 S_1
AR_1	7.2
AR_2	4
AR_3	large = 5.3 small = 5.3
$g_{1,2}$	1.64 c_1 and 0.8 c_1
$s_{1,3}$	4.69 c_1 and 3.46 c_1
L	extended = 9.50 c_1, original = 8.27c_1

All force and moment measurements were made, on an unyawed model, at a dynamic pressure of 2.16 kPa (45 psf) which corresponds to a Reynolds Number, with respect to a mean aerodynamic chord of 0.3048 m (1 ft), of 1.3×10^6. The angle of attack range studied was -8° to 20° in increments of 2°. All data were corrected for tunnel-wall effects (wake blockage, solid blockage, buoyancy drag, etc.) using the standard procedure given in Reference 13. Although dimensional quantities are given here in SI units, measurements were made in U.S. Customary Units.

During testing, the force and moment data had originally been referred to the quarter-chord location of the mean aerodynamic chord of the model main wing. The pitching moment data was reduced in two separate formats in order to more clearly present the comparisons between the static longitudinal characteristics of the various configurations.

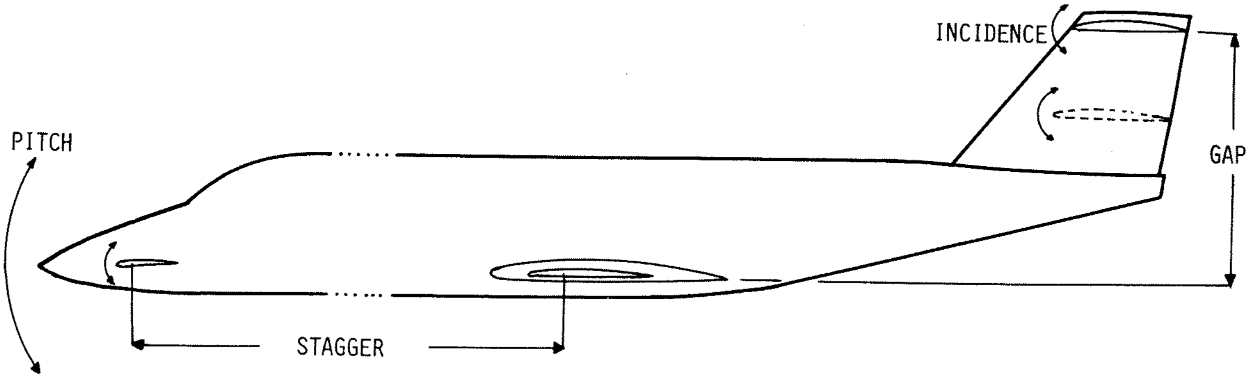


Figure 2 - Model Configurations.

Firstly, data for C_m, referred to $0.25c_1$, versus C_L is studied to compare values at the zero-lift condition and to compare neutral points. The C_{m_o} values are independent of cg location and the pitching moment slopes are used to estimate the neutral points for the various configurations. This data can also be used to compare the pitching moment characteristics for various configurations at the same static margin by simple rotations about the zero-lift points[14]. It should be noted that a static margin of 5% is the recommended minimum for adequate static stability[15].

In the second approach, $C_{m_{cg}}$ versus C_L curves are given for center of gravity locations that are determined for the various configurations from an analysis of the component position and weight balance. This data provides a realistic comparison between the configuration pitching moment characteristics for plausible center of gravity locations.

III. Results

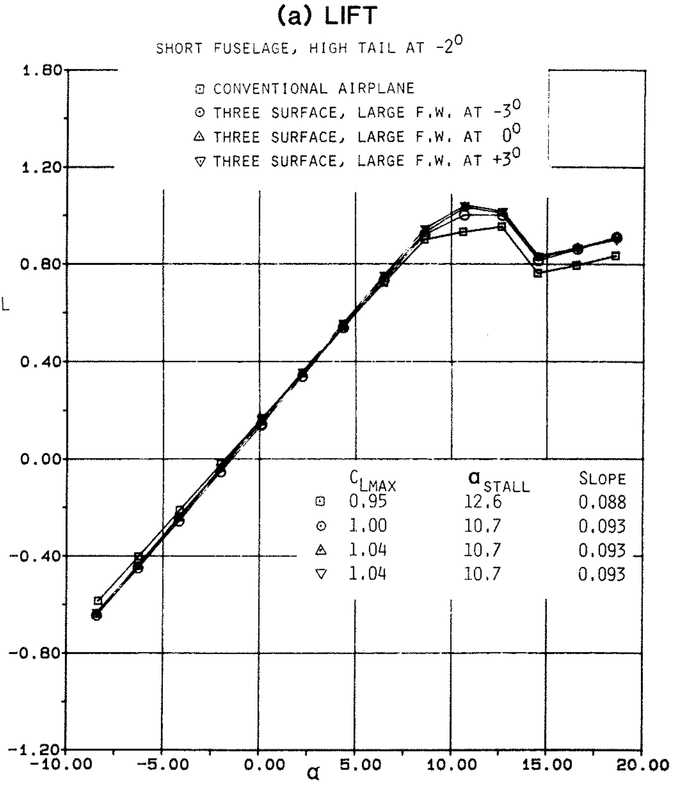
The reduced data is presented here in the form of plots of lift coefficient versus angle of attack; pitching moment coefficient, drag coefficient and lift to drag ratio versus lift coefficient. For convenience, pertinent tables are superimposed on some of the plots.

Comparison between TLC and CVA

Figure 3 shows a comparison between the CVA and the TLC. The characteristics are for an unstretched aircraft with a high tail at a δ of $-2°$, with and without a large forward wing that can be set at three different incidence angles. The configurations have common fuselage, main-wing and vertical tail.

The overall lift characteristic is better for the TLC, indicating that the f.w. has a favourable effect on the flow over the main wing, a possibility mentioned by Feistel et. al.[10] during their study of canard-wing combinations. For subsonic aircraft, the gap, $g_{1,3}$ is an important determinant[10] of the main wing performance. However, in the present study, this gap effect was not stuied. The variation in $g_{1,2}$ is presented in a later subsection.

The lift curve slope for the TLC is higher and the maximum lift coefficient is 5% to 10% larger than that of the CVA. The stall break is gentler for the TLC (this is seen again later in Figure 6 (a)), but, stall occurs earlier. The angle of attack for zero lift is unchanged.

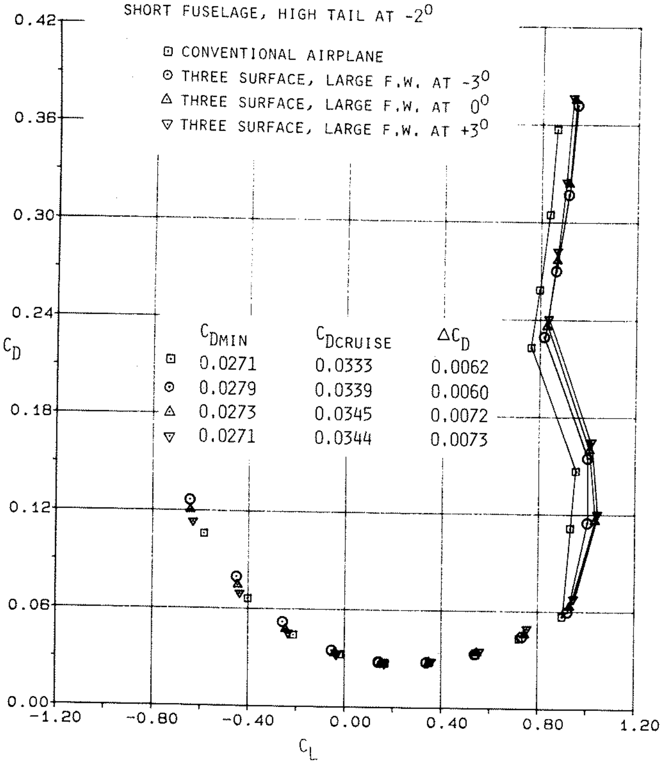

(a) LIFT

SHORT FUSELAGE, HIGH TAIL AT -2^0

	C_{LMAX}	α_{STALL}	SLOPE
⊡	0.95	12.6	0.088
⊙	1.00	10.7	0.093
△	1.04	10.7	0.093
▽	1.04	10.7	0.093

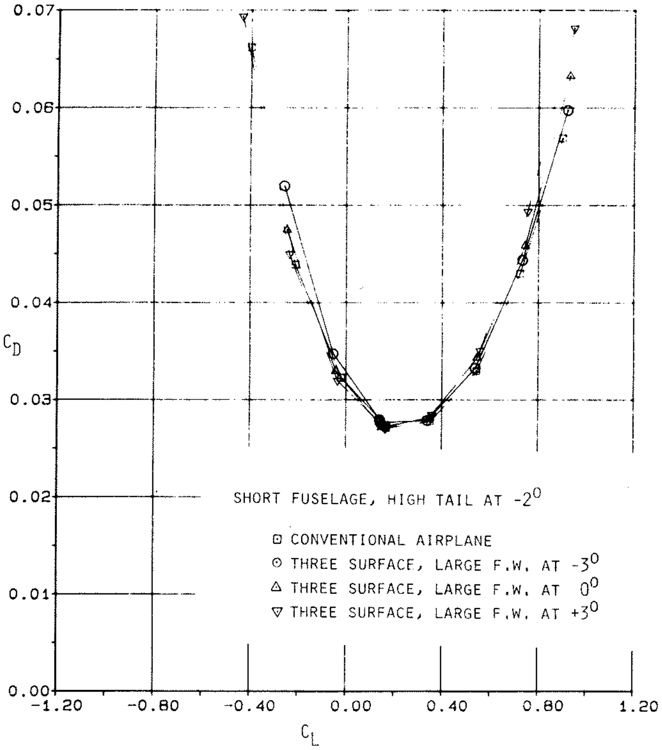
Figure 3 - Comparison of Aerodynamic Characteristics between TLC and CVA, and Effect of Forward Wing Incidence Variation.

The drag polars are shown in Figure 3 (b). The differences between the minimum drag values for the various configurations are all within ±0.0004, as indicated in the superimposed table. Two additional considerations must be noted here: the TLC has larger wetted area and the balance resolution for drag coefficient is ±0.0002. For the lift coefficient range, -0.2 to 0.8, including values in and around typical cruise (chosen as C_L = 0.55 here), the CVA has lower drag. This is shown for clarity in a separate plot Figure 3 (c).



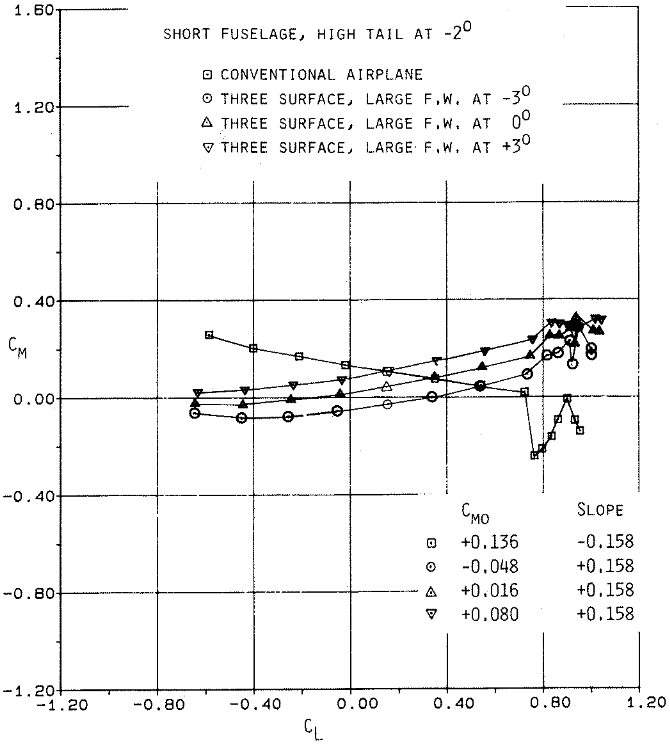
(b) DRAG

Figure 3 – Continued.



(c) DRAG

Figure 3 – Continued.



(d) MOMENT

Figure 3 – Continued.

The difference (ΔC_D in Figure 3 (b)) between the drag at some lift coefficient and the minimum drag gives a fair indication of the induced drag. An inherent assumption is that there is minimal separation and consequently neglible pressure drag at cruise. These values indicate that, at cruise, the TLC induced drag is probably marginally greater than the CVA induced drag.

Figure 3 (b) clearly shows the drag benefit at high (>0.8) lift coefficients, for the TLC over the CVA. This can be attributed to delaying of separation on the main wing due to the favourable presence of the forward wing. The results support Butler's[3] theoretical predictions regarding the lower drag at high lift conditions. This lift and drag data makes a case, assuming no major stability problems, for the possibility of using TLCs for STOL applications.

The pitching moment plots given in Figure 3 (d) are with respect to the $0.25c_1$. The neutral point for the CVA is $0.158c_1$ aft of this reference point and moves forward to $0.158c_1$ with the addition of the forward wing. As mentioned earlier, these curves may be rotated about their C_{mo} values for comparisons at the same static margin. The zero-lift pitching moment is highest for the CVA. For the TLC to fly in trim with the same, arbitrarily chosen, static margin and at the same design lift coefficient as the CVA, it would require considerable control surface deflection.

Alternatively, one may compare the levels of static longitudinal stability for some plausible cg locations, chosen in accordance with component weight balance criteria. From non-aerodynamic considerations alone, one would expect a chosen

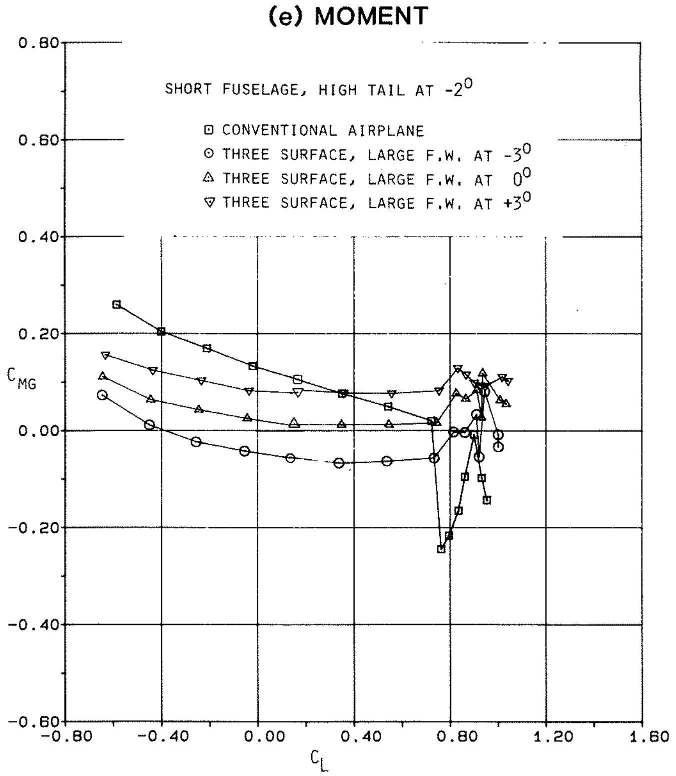


Figure 3 – Concluded.

practical cg for the original conventional configuration to move forward with the addition of the forward wing. For the large f.w. this forward shift is roughly $0.205c_1$. Thus if the conventional airplane were to have a "practical" cg at $0.25c_1$, i.e. a 16% static margin, the corresponding TLC cg would be at $0.045c_1$ and the static margin would be 4.7% which is below the recommended minimum. The resulting pitching moment plots for the two configurations are shown in Figure 3 (e). As expected, the C_{mo} values are the same as in Figure 3 (d). For the chosen "practical" cg locations, the CVA with the 16% static margin would require considerable control surface deflection for trim at cruise, while the TLC with the 4.7% static margin and with a f.w. with a δ of zero degrees, would require minimal control surface deflection.

At high lift conditions the pitching moment characteristics are nonlinear. However, the amplitudes of the fluctuations in pitching moment are smaller for the TLC, at all three incidence angles, than the amplitude of the fluctuations for the conventional airplane. This implies better pitch control at higher lift coefficients and hence better STOL characteristics.

This TLC has overall lift benefits and better high-lift drag characteristics than the comparable CVA with a minimal induced drag penalty at cruise. However, there is a static longitudinal stability penalty in terms of reduced zero-lift moment and lower static margin.

Effect of Variation in Forward Wing Incidence Angle

Figure 3 also shows the effect of variation in f.w. incidence angle. This variation has a minimal effect on the TLC lift, reflected in the C_{Lmax} values tabulated in Figure 3 (a), near stall. There is a marginal improvement in the high-lift drag characteristics with increase in f.w. incidence angle.

The incidence variation does not affect the neutral point of the TLC. However, C_{mo} increases with increasing forward wing incidence angle. This can be explained as follows. The major determinant for the zero lift condition is the main wing and the angle of attack at which this occurs was seen in Figure 3(a) to be roughly constant. At this configuration angle of attack, the forward wing will provide some lift which depends on its effective angle of attack. This forward surface lift and thus the moment due to it will both decrease with decreasing incidence angle. Note that C_{mo} is negative for the -3° incidence. The slope in the linear region of the characteristic does not change appreciably with incidence angle.

Effect of Variation in Gap

The importance of the forward gap, $g_{1\,3}$ has been discussed previously. This subsection deals with the effect of variation in $g_{1\,2}$, for a TLC with a f.w.-main wing combination with $g_{1\,3}$ close to zero. Although, for the sake of brevity, the actual CVA data is not presented it is important to note that the variation in $g_{1\,2}$ has significant effect on the aerodynamic characteristics of the CVA. The high tail CVA lift is better and the drag is less than the low tail CVA.

Figure 4 presents the characteristics of basically the same TLC as in the previous subsection, except that the forward wing incidence angle is fixed at 3° and the horizontal tail can

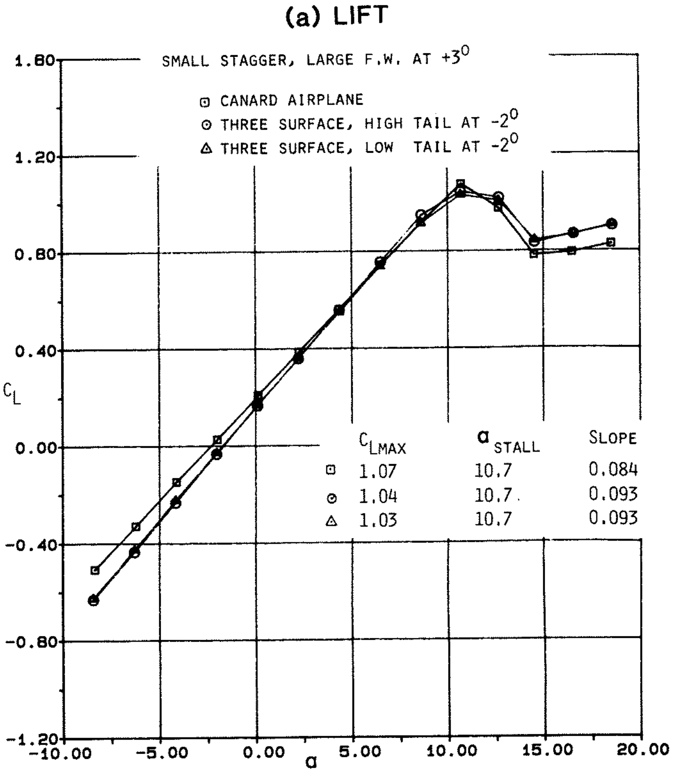


Figure 4 – Effect of Variation in Gap and Comparison Between the Aerodynamic Characteristics of TLC and CWC.

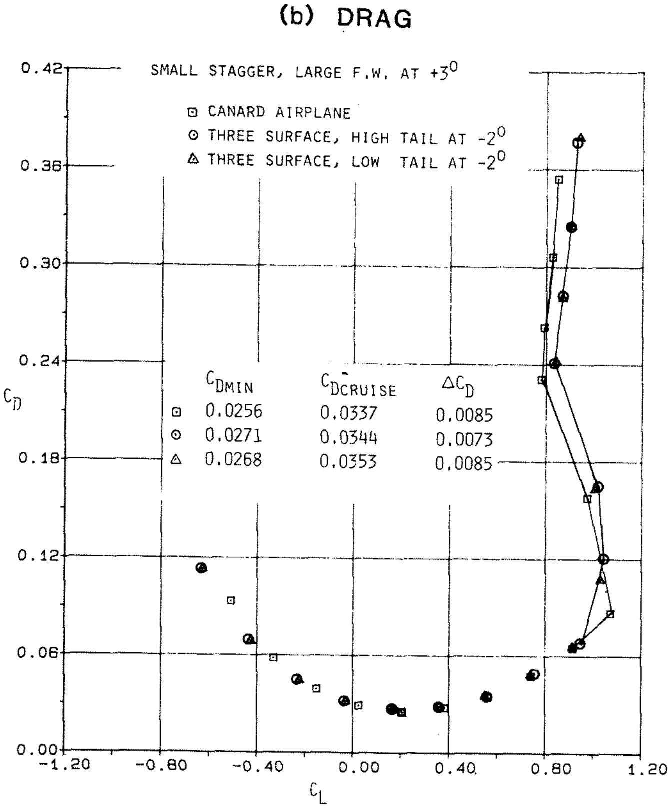
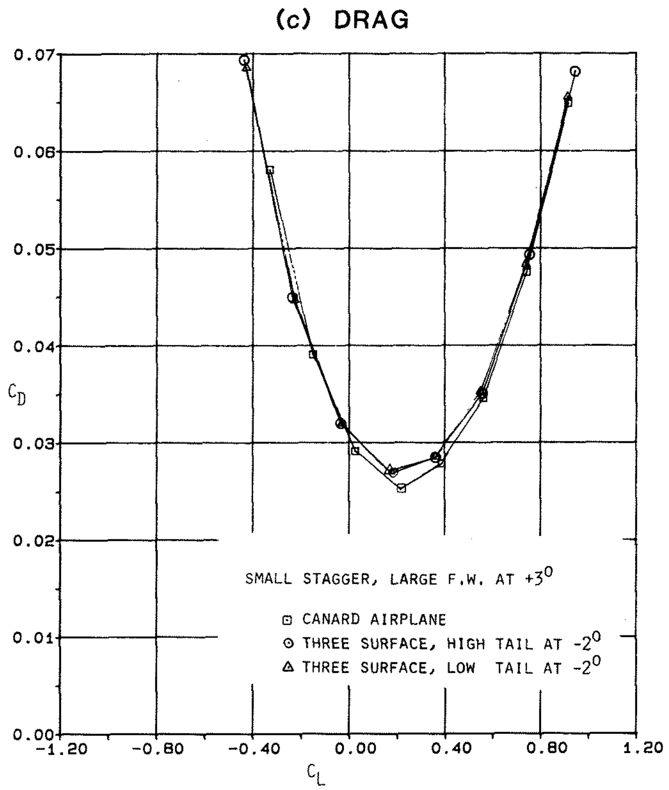

(b) DRAG

Figure 4 - Continued.


(c) DRAG

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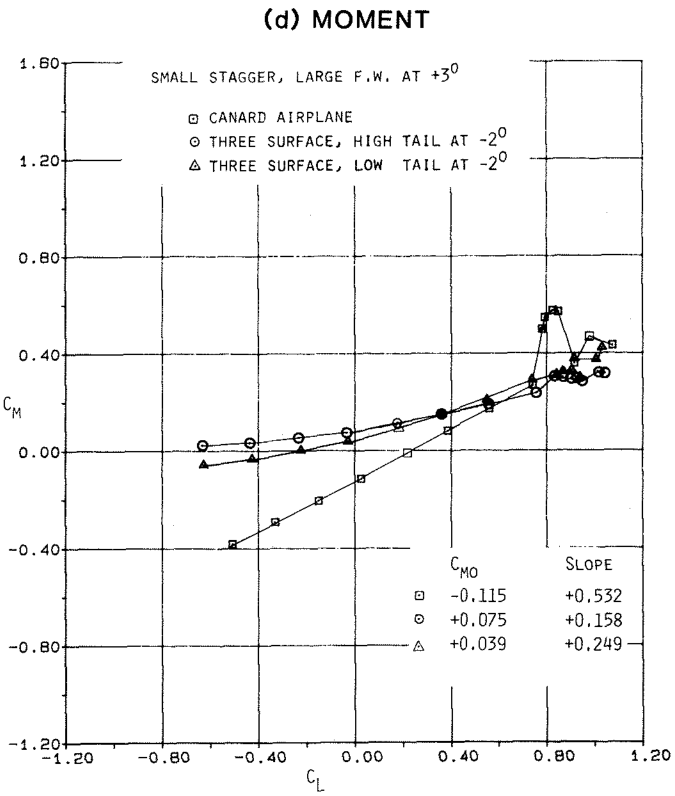
(d) MOMENT

Figure 4 - Continued.

be moved to provide the two different gaps shown in Figure 2 and whose values are given in Table II. The δ for the horizontal tail is -2°. Also presented is a TLC/CWC comparison that is discussed in the next subsection.

The effect of gap on the TLC lift curve is minimal (Figure 4 (a)). The maximum lift coefficient, lift curve slope and stalling angle of attack do not change appreciably with gap. As can be seen in the drag polars of Figures 4 (b) and (c), the drag characteristics are largely, except for ΔC_D at cruise, unaffected by gap. These plots have shown that the change in gap has minimal effect on the overall lift and drag characteristics of the TLC. This may be attributed to the favourable presence of the forward wing as follows. Since the primary contributor to lift is the main wing, the forward wing probably provides additional downwash to delay the flow separation on the main wing. The forward wing and main wing wake are probably well below the lowest horizontal tail position.

The minimal effect of gap could possibly lead to simplifying assumptions, regarding the aft gap, for future theoretical models as most of the current TLC literature gives some consideration to the variation in gap. On the other hand, it could be purely coincidental.

The C_m curves (Figure 4 (d) show positive C_{mo} decreasing with a decrease in gap. The neutral point for the high tail is $0.158c_1$ ahead of the quarter-chord point. For the low tail it is $0.249c_1$ ahead. Further, the low tail will require more control surface deflection for trim at the chosen cruise C_L of 0.55. In both cases the curves are somewhat nonlinear in the high C_L range. Since the overall lift and drag are minimally affected by the change in gap, the difference in the pitching moment characteristics probably arise purely from the different moment arms, provided by the different gaps, for the drag of the aft lifting surface.

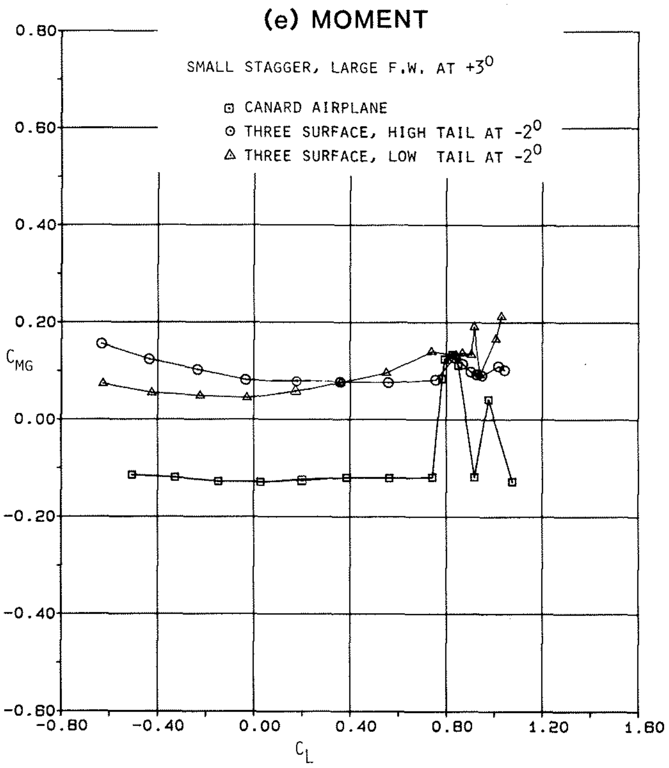

Figure 4 - Concluded.

An interesting sidelight is seen in the pitching moment curves w.r.t. the "practical" cg location, given earlier as $0.205c_1$ ahead of the quarter-chord location. At this point the low gap TLC has an unstable characteristic, while the high gap TLC has a stabilizing characteristic.

Comparison between TLC and CWC

The TLC has a better overall lift characteristic than the CWC. These configurations have a common fuselage and vertical tail. The TLC has a higher lift curve slope and also a gentler stall break. The stalling angle of attack is the same but the CWC maximum lift is 3% higher.

At high lift conditions, Figure 4(b) shows the TLC to have better drag characteristics than the CWC. The minimum drag for the CWC is lower. This would be expected as the CWC has smaller wetted area. The fact that the CWC has fewer interfering surfaces probably does not contribute to this difference as the previous subsection showed the minimal effect of gap $g_{1\,2}$ on the aerodynamic characteristics. At a typical cruise lift coefficient, the ΔC_D indicate that the TLC high tail induced drag is probably less than the CWC induced drag, while the low gap induced drag is probably the same as that for the CWC. This may be viewed in the perspective of Selberg and Rokhsaz's[9] finding that the overall induced drag benefit may not be sufficient to be of primary concern in the configuration selection process. The expanded view of the polar, Figure 4 (c), shows the differences in total drag more clearly with the CWC having overall lower drag in and around typical cruise conditions.

The pitching moment, Figure 4 (d) shows the negative zero-lift moment for the CWC. As expected, the neutral point for the CWC is much further ahead, $0.532c_1$ in front of $0.25c_1$, than those for the TLC. The CWC would require considerable control surface deflection for trim at typical cruise. The TLC probably would be easier to control at the high C_L conditions, as evidenced by the smaller fluctuations in pitching moment. This is a desirable characteristic for a passenger aircraft.

A simple weight balance shows that the removal of the horizontal tail moves the cg forward by $0.317c_1$. The pitching moment curves for the TLC with a cg $0.205c_1$ forward of the quarter -chord and the CWC with a cg $0.522c_1$ forward of the quarter chord are given in Figure 4 (e). For these probable, yet impractical, cg locations the CWC static margin is 1%.

In summary, one may say that this TLC has some distinct aerodynamic advantages over the CWC in the high C_L ranges, but has more overall drag at cruise. From the point of view of static stability for the given common main-wing, fuselage and vertical tail, both the TLC and the CWC have smaller zero-lift moments and further forward neutral points than the CVA.

Effect of Variation in Stagger

The effect of a change in stagger, $s_{1\,3}$, between the forward and main wing of the TLC's is shown in Figure 5. The values for the two staggers were given earlier in Table II. The configuration has a high tail and a large forward wing set at an incidence angle of 3°. Results are shown for tail incidence angles of -2° and -4°. The effect of the variation in tail incidence angle is discussed in the next subsection.

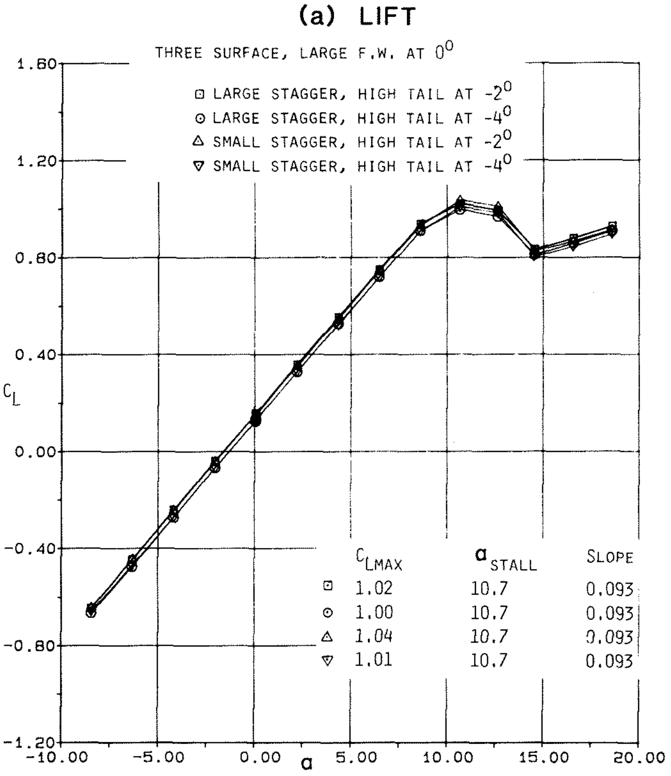

Figure 5 - Effect of Stagger on the Aerodynamic Characteristics of TLC, and Effect of Variation in Tail Incidence Angle.

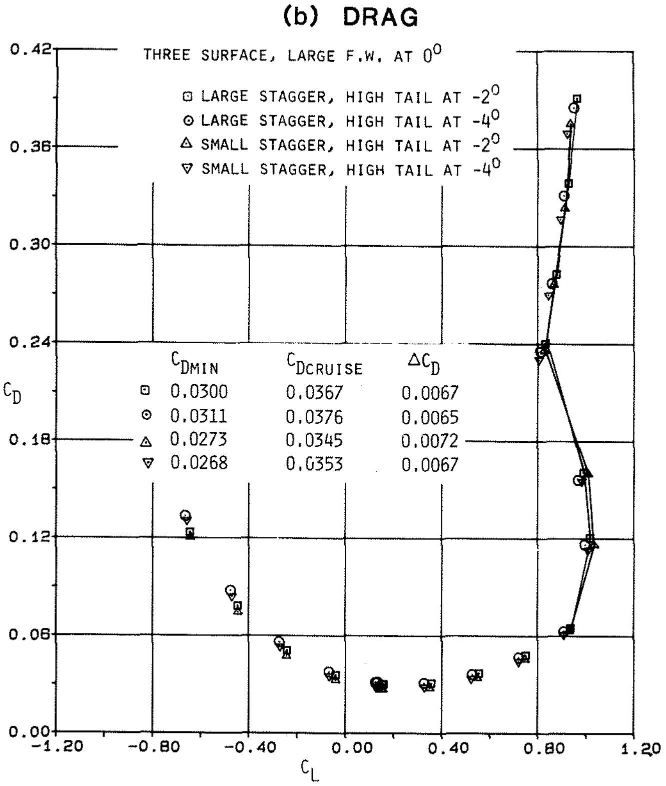
(b) DRAG

Figure 5 – Continued.

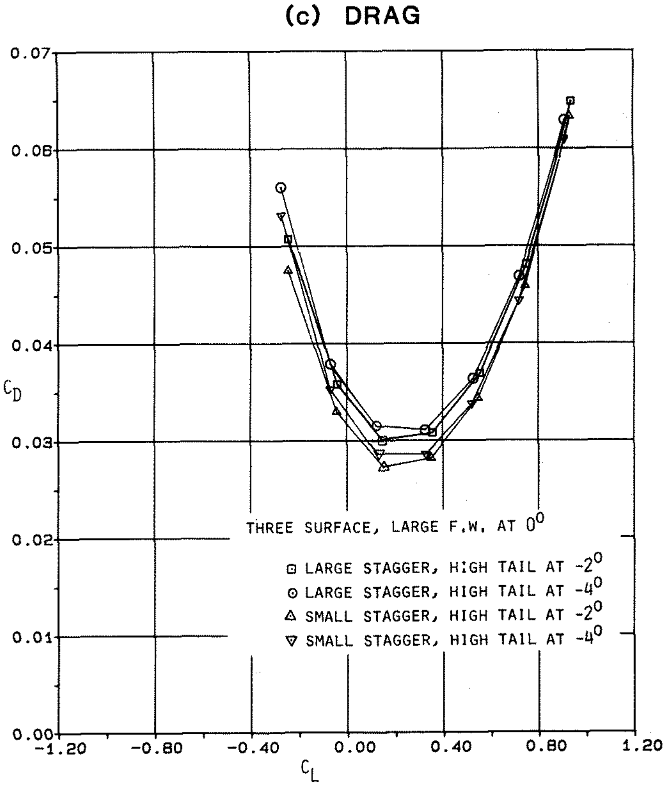
(c) DRAG

Figure 5 – Continued.

Figure 5 (a) shows the relatively small effect of stagger on the lift characteristics. The stalling angle of attack and lift curve slope are unchanged. There is a less than 2% decrease in the C_{Lmax} in going from the small to the larger stagger. It was stated in an earlier subsection that the forward wing has a favourable effect on the flow over the main wing. A comparison between the lift characteristics in Figures 3 and 5 shows that this is true for both stagger values. However, as Figure 5 (a) shows, this favourable effect would be expected to decrease somewhat as the forward wing is moved further away from the main wing.

The effect on drag is minimal in the high lift regions (Figure 5 (b)). The overall drag in and around cruise, Figure 5 (c), is understandably higher for the large stagger because of the larger fuselage wetted area available. However, if the ΔC_D values are a fair indication, the induced drag at cruise is unaffected by the stagger.

The pitching moment, w.r.t. $0.25c_1$, in Figure 5(d) is seen to have a decrease in zero lift moment with an increase in stagger. Further, the neutral point for the large stagger is roughly 15% ahead of the neutral point for the small stagger. The pitching moment curves for the larger stagger have larger fluctuations in the high lift region. From nonaerodynamic criteria, one would find the cg of the longer body to be 0.095 ahead of the cg for the shorter body. This distance is small because the fuselage plug is inserted close to the original cg. The corresponding C_{mg} curves given in Figure 5(d) show the small positive static margin for the small stagger (4.7%) and the negative (-2.5%) static margin for the large stagger.

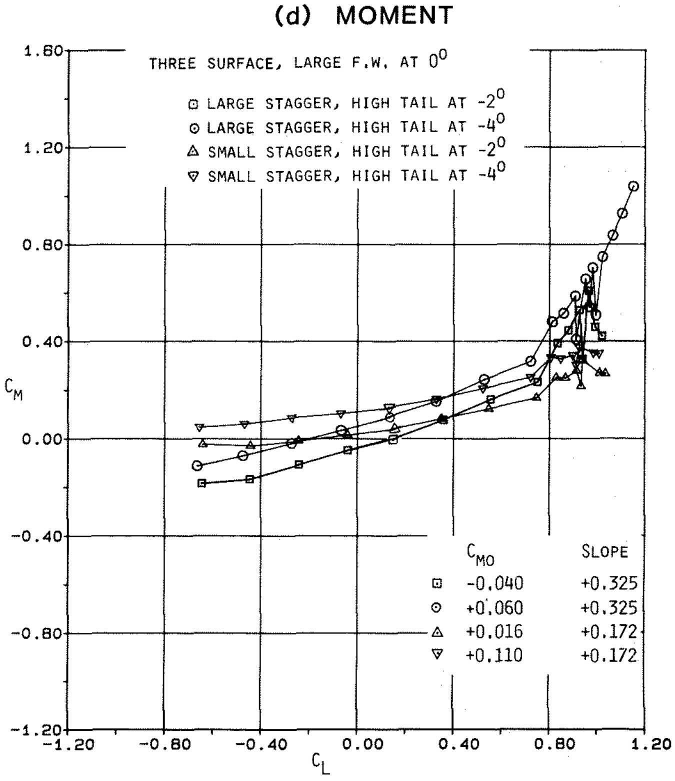
(d) MOMENT

Figure 5 – Continued.

From these data one may conclude that the small stagger results in better aerodynamic and stability characteristics.

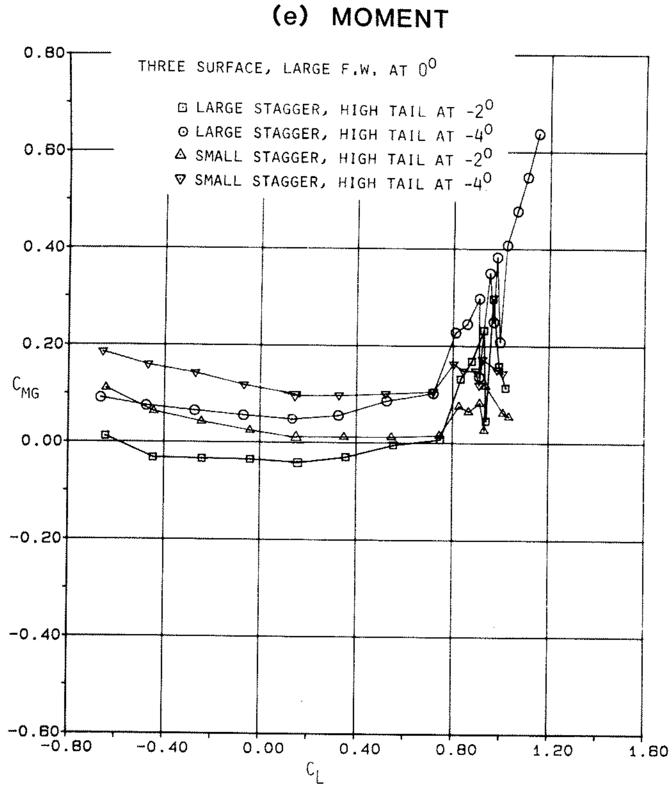

Figure 5 – Concluded.

Effect of Variation in Tail Incidence Angle

This effect is partially presented in Figure 5. Although for clarity all three tail incidence angles were not simultaneously presented in the coefficient plots, the effect of variation in tail incidence angle merits some discussion. Further, it should be noted that the following discourse is confined to high tail configurations. Low tail inferences can be made from a synthesis of this subsection with the effect of gap presented earlier.

A variation in the incidence angle of the horizontal tail marginally affects the lift and drag. The stalling angle of attack and lift curve slope do not change with tail incidence angle for all the configurations studied. Also, there is a marginal decrease in C_{Lmax} and an increase in C_{Dmin}, when the tail incidence angle is decreased from 0° to -4°. For example, for the conventional configuration, the C_{Lmax} decrease is 5% and the C_{Dmin} increase is 20 counts. There is an overall increase in lift with increasing incidence angle and the angles of attack at which zero lift occur are all within one degree of each other, for the three tail incidence angles. There is a slight improvement in high-lift drag with an increase in tail incidence angle.

The basic pitching moment characteristics remain the same but only the zero lift pitching moment increases with a decrease in tail incidence angle. The reason for this change is similar to that given when discussing the effect of a variation in forward wing incidence angle.

Effect of Variation in Forward Wing Span

In the previous subsections, results have been presented for a TLC with a forward wing whose span is the same as that of the horizontal tail. Figure 6 shows a comparison between the aerodynamic characteristics of a stretched TLC with a forward wing of span b_2 and those of a stretched TLC with a forward wing of span $0.75b_2$. In both cases the forward wing is at an incidence angle of 3° and the gap, $g_{1\,3}$, and stagger, $s_{1\,3}$, are not changed. The tail is high and at an incidence angle of -2°. The data for a conventional airplane (identical except that it lacks the forward wing) have been superimposed for comparison.

There is an overall improvement in the lift characteristic, Figure 6 (a), of the TLC, with an increase in the forward wing size. The lift curve slope and maximum lift coefficient both increase with an increase in the forward wing size. The favourable effect of the large forward wing on the main wing was discussed earlier. These results show that the small forward wing too is a favourable addition, only it is less effective.

The large forward wing also shows better high-lift performance with lower drag than the small forward wing (Figure 6 (b)). Both configurations are still better in the high lift region than the conventional aircraft. In and around cruise, Figure 6 (c), the TLC with the large forward has slightly higher total drag, probably because of larger wetted surface area. The ΔC_D show no change with span, implying no change in induced drag.

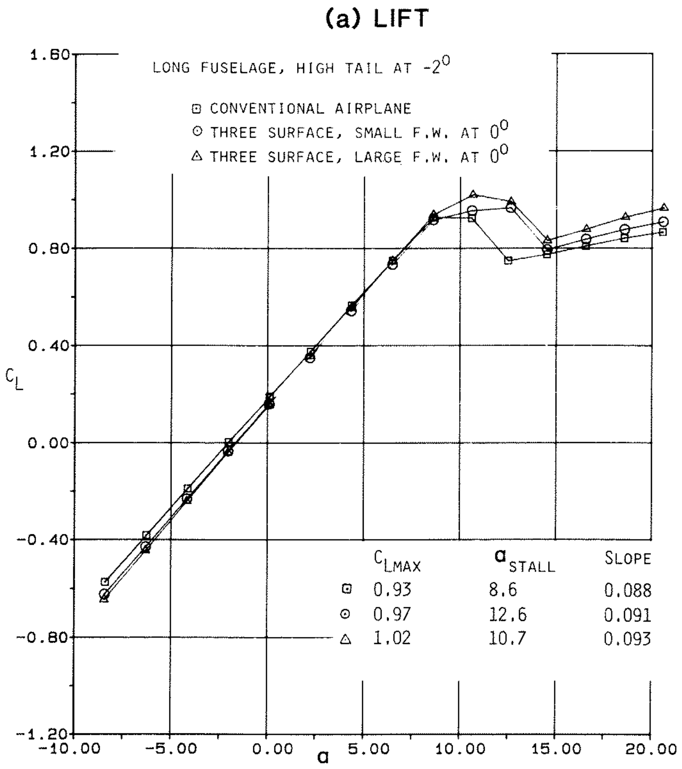

Figure 6 – The Effect of Variation in Forward Wing Span on the Aerodynamic Characteristics of a TLC.

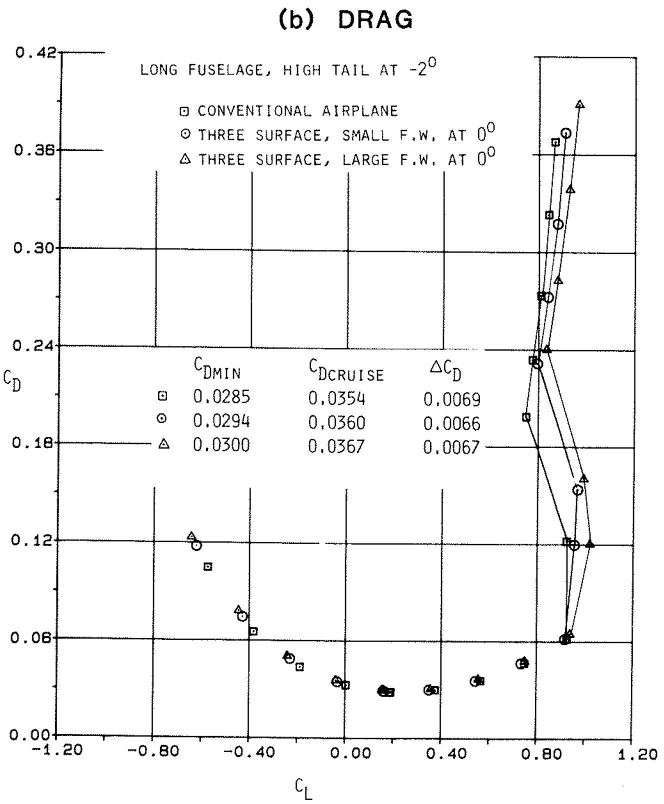
(b) DRAG

Figure 6 – Continued.

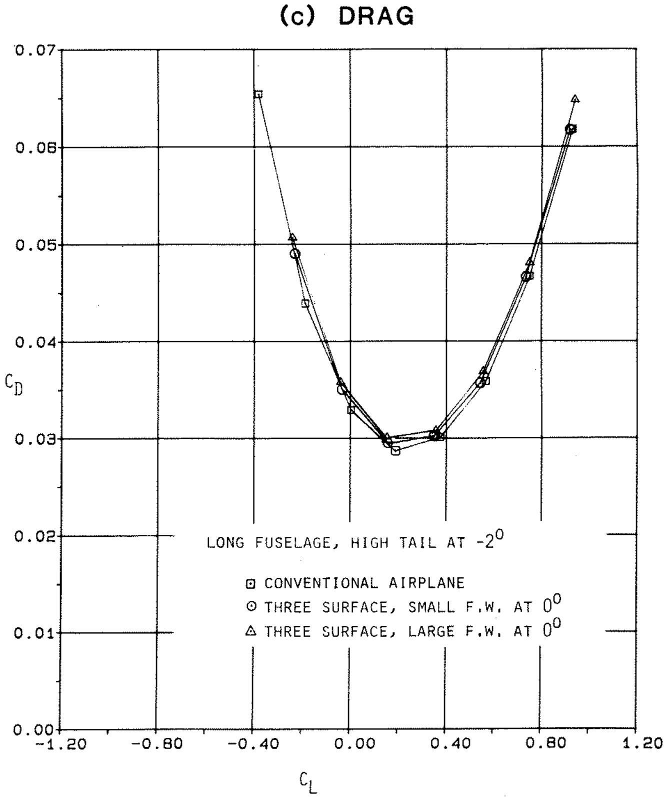
(c) DRAG

Figure 6 – Continued.

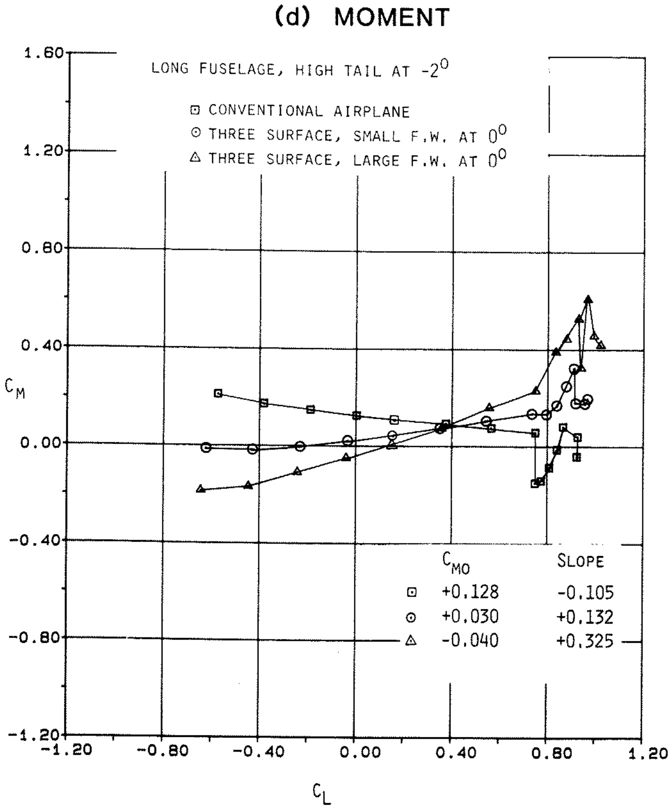
(d) MOMENT

Figure 6 – Continued.

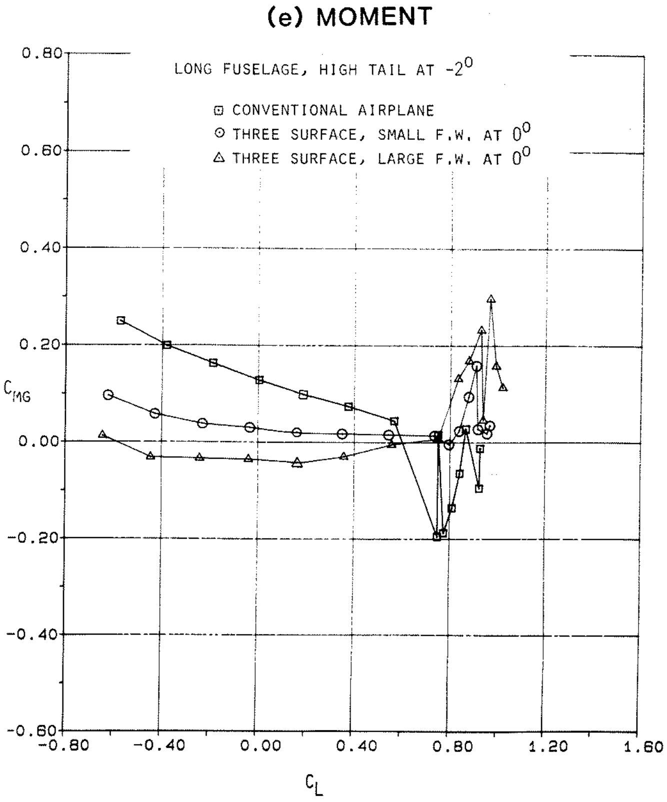
(e) MOMENT

Figure 6 – Concluded.

The pitching moment, w.r.t. $0.25c_1$, in Figure 6 (d) shows that the zero-lift moment decreases with f.w. size and is negative for the large span. The neutral point moves forward 20% with an increase in span. A possible cg for the TLC with the large span would be $0.3c_1$ ahead of the reference point. The corresponding cg for the TLC with the small forward wing would be $0.169c_1$ ahead of the reference point. The $C_{m_{cg}}$ curves for these cg locations are shown in Figure 6 (e). The static margins for the chosen cg locations are -2.5% for the large forward wing and 3.7% for the small forward wing.

In summary, a decrease in the size of the forward wing leads to better drag and longitudinal stability, but has adverse effects on the drag characteristic in the regions of high lift.

Performance comparison of Various Configurations

A composite of the lift to drag ratio for the four major configurations; CVA, TLC with small stagger, CWC, and TLC with large stagger; is given in Figure 7. At cruise, the lift/drag ratios are all between 13 and 16. The CVA has the highest and is followed by the CWC. The TLC with the large f.w. has the lowest cruise performance. For the high lift conditions, the order is reversed, reinforcing the view that the TLC is suitable for STOL applications.

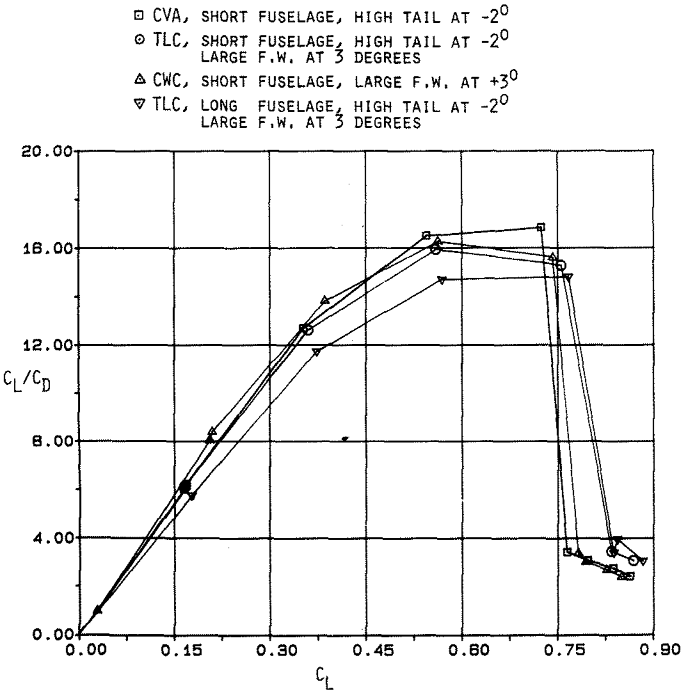

Figure 7 - Performance Comparison of Various Configurations.

IV. Comparison with Analytical Predictions

A comparison between inviscid theory and experiment is currently underway and will be published at a later date. Figure 8 shows a typical panelized version of the model. This panelization is for the stretched fuselage with the high aft- wing and small forward wing. Both the fore and aft wings are at zero degrees incidence angles. The model shown is comprised of 990 panels with panel concentration at the aerodynamically important components of the airplane. The main wing comprises roughly 40% of the total panels, with the fore and aft wings both accounting for another 25% of the total. The code being used is the vortex separation aerodynamics panel method program (VSAERO) developed by Maskew[16]. The main focus of the comparison is a parametric study between the lift, drag and pitching moment of the various configurations.

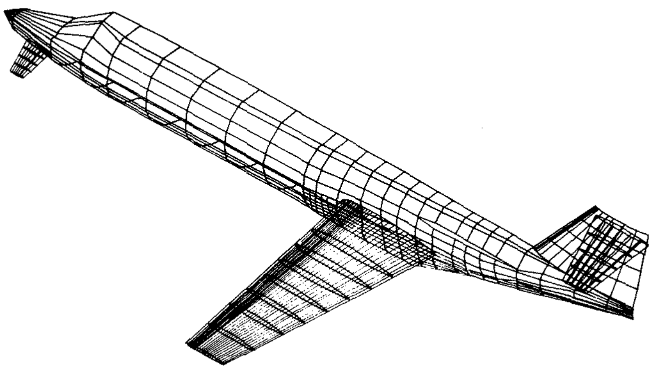

Figure 8 - Panelized Model of TLC with Extended Fuselage.

V. Conclusions

A series of wind tunnel experiments have been carried out to investigate the lift, drag and static longitudinal stability for a three-lifting surface configuration. From the tests, the following conclusions regarding the aerodynamic characteristics of the three-lifting surface configuration may be drawn.

1. The three lifting surface configuration has better lift, over the angle of attack studied, than either the conventional or canard configurations with identical fuselage, main-wing and vertical tail. Further, the overall lift characteristic improves with an increase of the incidence angle of either the forward or aft lifting surfaces, a decrease in (forward/main wing) stagger, and an increase in the size of the forward wing. There is no change in lift with a variation in the aft/main wing gap.

2. In and around cruise, the three lifting surface configuration drag is greater than the drag of either the conventional or canard configurations. Cruise drag increases with an increase in forward wing incidence angle, a decrease in aft wing incidence angle, an increase in (forward/main wing) stagger, an increase in forward wing span, and a decrease in (aft/main wing) gap.

3. At high lift conditions, the three surface configuration has better drag characteristics than either the conventional or canard configurations. There are high-lift drag benefits with an increase in forward wing incidence angle, an increase in aft wing incidence angle, an increase in stagger between the forward and main wing, and an increase in forward wing size. However, there is no change in this high-lift drag with a change in the (aft/main wing) gap.

4. The three surface zero-lift moment is lower than that of the conventional configuration but higher than that of the canard airplane. Zero-lift moment increases with an increase in the forward wing incidence angle, decrease in aft wing incidence angle, increase in aft/main wing gap, decrease in stagger between the forward and main wing, and a decrease in forward wing size.

5. The three surface configuration neutral point is ahead of the conventional configuration neutral point and is aft of the canard configuration neutral point. The neutral point does not change with a change in either forward or aft lifting surface incidence angle. The neutral point moves forward with a decrease in aft to main wing gap, increase in forward to main wing stagger, and an increase in forward wing span.

6. The three surface has the best lift to drag ratio at high lift conditions but the lowest lift to drag ratio at cruise. The tail-aft configuration is best at cruise and lowest at high lift conditions. A small stagger between the forward and main wing is favourable for three surface cruise performance but not for high lift performance.

Further analysis is currently underway to compare these results with results derived from the theoretical models proposed by previous researchers and with data from a panelized version of the wind tunnel model.

Acknowledgements

This research was supported by N.A.S.A - Langley through grant NAG(1) - 344, with grant monitor Joe Stickle. The authors wish to thank Don Howe and Eric Kendall, of Gates Learjet, for their help and suggestions. The models were supplied by Gates Learjet Corporation which also bore all model modification and transportation expenses.

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