Trimming Advanced Fighters for STOL Approaches

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Recent low-speed wind-tunnel tests of two powered advanced fighter configurations with short takeoff and landing (STOL) capability provided the opportunity to examine two different methods of generating the nose-up pitching moments required to maintain longitudinal trim during approach conditions. The pitching moments were generated by a small direct-lift nose jet on a supersonic cruise configuration and by a blown high-lift canard on an advanced multirole fighter configuration. Results of these investigations indicate that at nominal approach conditions (i.e., military power, main nozzle deflections about 40 deg and angle of attack about 15-16 deg) the nose jet and the blown high-lift canard provide sufficient nose-up pitching moment to allow the respective configurations to be trimmed. Neither configuration could be trimmed at approach conditions without these devices.

Nomenclature

$\bar{c}$	= mean aerodynamic chord, ft.
C_D	= drag coefficient, drag/qS
C_L	= lift coefficient, lift/qS
C_m	= pitching-moment coefficient, pitching moment/$qS\bar{c}$
C_T	= thrust coefficient, static thrust/qS
C_μ	= canard blowing coefficient, ideal thrust/qS
HT	= horizontal tail
i_c	= canard incidence angle, deg
NPR	= nozzle pressure ratio, P_t/P_∞
P_t	= nozzle total pressure, lbf/ft^2
P_∞	= freestream static pressure, lbf/fr^2
q	= freestream dynamic pressure, $\frac{1}{2}\rho V^2$, lbf/ft^2
S	= wing area, ft^2
V	= velocity, ft/s
α	= angle of attack, deg
γ	= flight path angle, deg
δ	= deflection angle, deg
ρ	= density, slugs/ft^3

Subscripts

fc	= canard flap
K	= Krueger flap
N	= main nozzle

Introduction

A FUNDAMENTAL design requirement for any aircraft is to provide adequate control power for trimming the aircraft for any operational flight condition. Previous reports have indicated that meeting this requirement becomes more difficult for high-performance aircraft that are also seeking STOL capability.[1-4] The use of thrust vectoring nozzles (which are generally located aft on conventional-type configurations) and highly loaded flap systems to generate the necessary levels of lift and drag for STOL performance produces nose-down pitching moments that can greatly exceed the trim capability of conventional aerodynamic control surfaces (i.e., horizontal tails or canards) at the low speeds and high power settings required for STOL operations.[5-15] Alternate methods of generating nose-up pitching moments are required if trimmed STOL approach conditions are to be maintained.

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Previous work has shown that a vectoring and reversing (multifunction) nozzle on an F-15 configuration could produce large pitching-moment increments by differentially vectoring the exhaust at military power.[16] Analysis has also shown that a small direct-lift nose jet could be used to obtain trimmed approach conditions for a powered wing-canard research configuration.[17]

Recent low-speed wind-tunnel tests of two powered advanced fighter configurations with STOL capability provided an opportunity to examine two alternative methods for generating the nose-up pitching moment required to maintain trim during approach conditions. This paper will present the results of these investigations and show that either a direct-lift nose jet on a supersonic cruise configuration or a blown high-lift canard on an advanced multirole fighter configuration can provide the required pitching-moment increments to allow trimmed STOL approach conditions. Neither configuration can be trimmed without these devices.

Nose Jet

A low-speed wind-tunnel investigation was conducted in the NASA Langley Research Center 4×7-m tunnel to determine the effects of vectoring the main nozzles on the longitudinal aerodynamics of a supersonic cruise fighter configuration.[6,7] Part of this investigation was a detailed study of the possibility of using a small direct-lift nose jet to provide the nose-up pitching moment needed to maintain longitudinal trim during STOL approach conditions. A nose jet or remote augmented lift system (RALS) was added to an existing model as shown in Fig. 1. Because of the long moment arm from the model reference center to the RALS location, the nozzle was sized to produce the required pitching moment with a relatively small lift force (about 10-15%) of total thrust. Since the RALS is intended only as a trimming device, it could be sized for a much lower thrust level than a typical lift engine for vertical/short takeoff and landing (V/STOL) configurations where the forward lift engine is sized to produce 30-40% of total lift.

The powered longitudinal aerodynamics for the supersonic cruise configuration are presented in Fig. 2. These data are for two main nozzle deflections, 30 and 60 deg at $C_T = 0.75$ (correspopnding approximately to military power), without the RALS or any other means to trim the configuration. (Also shown is a power-off curve as a reference point.) If the data are examined at an approach angle of attack around 15-16 deg then several observations can be made. The powerful effect of high thrust on longitudinal aerodynamics is indicated by the increase in C_L and nose down C_m as thrust is increased from

$C_T = 0$-0.75 at $\delta_N = 30$ deg or the nozzle is vectored from $\delta_N = 30$-60 deg. Along with these effects, drag is significantly shifted to negative values (i.e., excess thrust) at $C_T = 0.75$ and $\delta_N = 30$ deg, and is shifted toward the positive values when δ_N increases from 30 to 60 deg (i.e., thrust is vectored away from the drag direction toward the lift direction). Here the problem of generating high lift and drag while maintaining longitudinal trim is quite evident. When $\delta_N = 30$ deg, the nose-down increment in C_m is in the range that could be trimmed with conventional aerodynamic surfaces. However, there is insufficient drag (excess thrust) to allow a normal descent, but when δ_N is increased from 30 to 60 deg to increase drag to positive values, then the resulting very large nose-down pitching moment is beyond the trim capability of any aerodynamic control or even a reasonably sized direct-lift nose jet. Even with $\delta_N = 60$ deg at $\alpha = 16$ deg, the lift-to-drag ratio would allow only very shallow descent angles, but the addition of landing gear or speed brakes (which the model did not have) would increase the drag and allow proper glide slopes for an operational approach.

When thrust or nozzle vector angles are increased, the increments in C_L, C_D, and C_m are all nearly equal to the vector components of the thrust, i.e., there are little or no thrust-induced effects from the main nozzles.[3,6,9] Therefore, the trim analysis is based on a calculated nozzle deflection of 43 deg which gives a calcualted pitching-moment increment

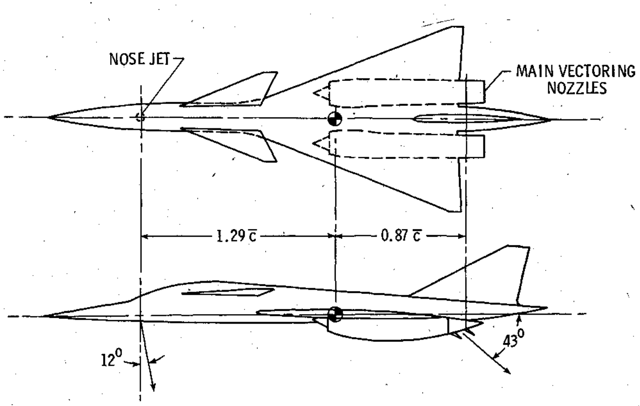

Fig. 1 Sketch of supersonic cruise fighter configuration showing location of main vectoring nozzles and nose jet.

equal to half the difference between $\delta_N = 30$ and 60 deg. This is still a sizeable pitching moment exceeding 0.3 throughout the angle-of-attack range and will exceed the trim capability of either the canard alone or the nose jet above. In order to have confidence in the trim analysis, the lift, drag, and pitching-moment increments from the nose jet were estimated and compared with data at $C_T = 0.75$ and $\delta_N = 30$ deg. As shown in Fig. 3 the estimates of C_D and C_m are quite good, with the estimate for lift being slightly higher than the data. Since the data indicate no change in lift from nose jet off to nose jet on, it would appear that the pressures induced by the nose jet on the bottom of the configuration are canceling the direct lift. This is not unusual and is seen as "suck down" on many VTOL configurations. In fact, since there is no lift loss greater than the direct lift, the interference effects of the nose jet would be considered minimal. With the lack of induced effects from either main nozzles or nose jet, the confidence in the accuracy of the trim analysis is high.

As mentioned previously, the baseline data for Fig. 4 is calculated with C_L, C_D, and C_m based on $\delta_N = 43$ deg at $C_T = 0.75$. The other curves in the figure were calculated by applying incremental data for the nose jet and canard. These increments, shown in Fig. 5, were calculated from data for the basic powered configuration with $\delta_N = 30$ deg with and without nose jet thrust and for the unpowered configuration with the canard set at $i_c = 0$ deg and $\delta_{fc} = 0$ deg and with the canard set at $i_c = 15$ deg and $\delta_{fc} = 30$ deg. At an angle of attack of about 14 to 16 deg (or C_L from 1.2 to 1.3), a combination of 15% thrust nose jet ($C_T = 0.113$), 15% pitch instability ($\partial C_m / \partial C_L$), and a 15 deg canard incidence (with $\delta_{fc} = 30$ deg) provides more than adequate trim for the configuration with $C_T = 0.75$ and a 43 deg nozzle deflection. Since only about 7 or 8 deg of canard incidence is required to trim the configuration and the canard is effective to about 20 deg incidence, it would appear that a good margin of control power is still available. As before, the drag level is not sufficient to produce a glide slope between -3 and -6 deg but adding the drag for landing gear and speed brakes should place the drag level in the proper range for approach.

When using a canard and/or nose jet to generate pitching moments for trim, it is desirable that the downwash from the canard on the wing or the interaction between the jet and the underside of the fuselage not create significant lift losses. As mentioned, for this configuration, the nose jet produced a positive lift increment or at least zero lift loss. The canard also

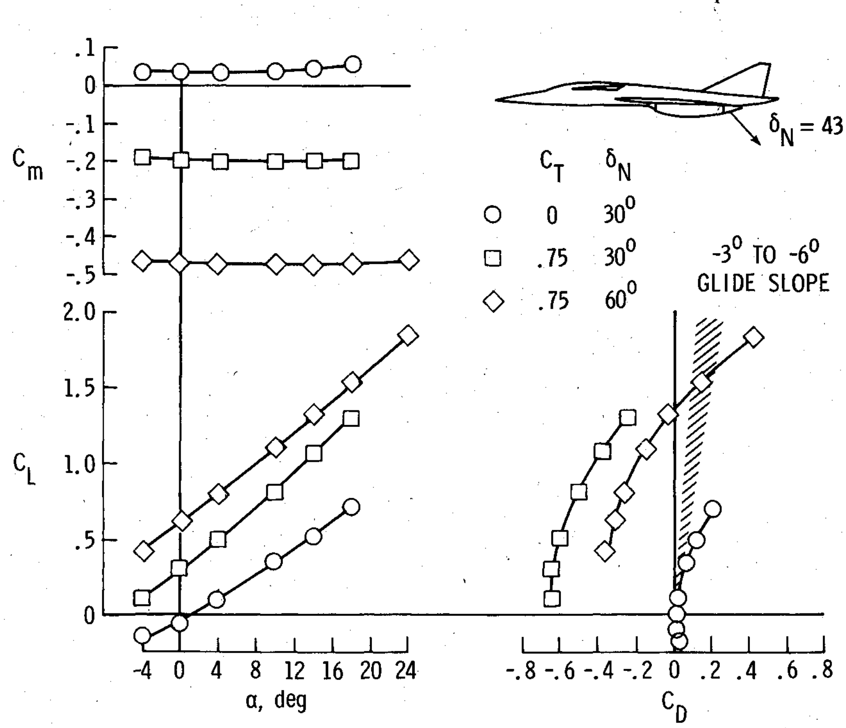

Fig. 2 Effect of thrust coefficient and main nozzle vector angle on the longitudinal aerodynamics of the supersonic cruise fighter configuration.

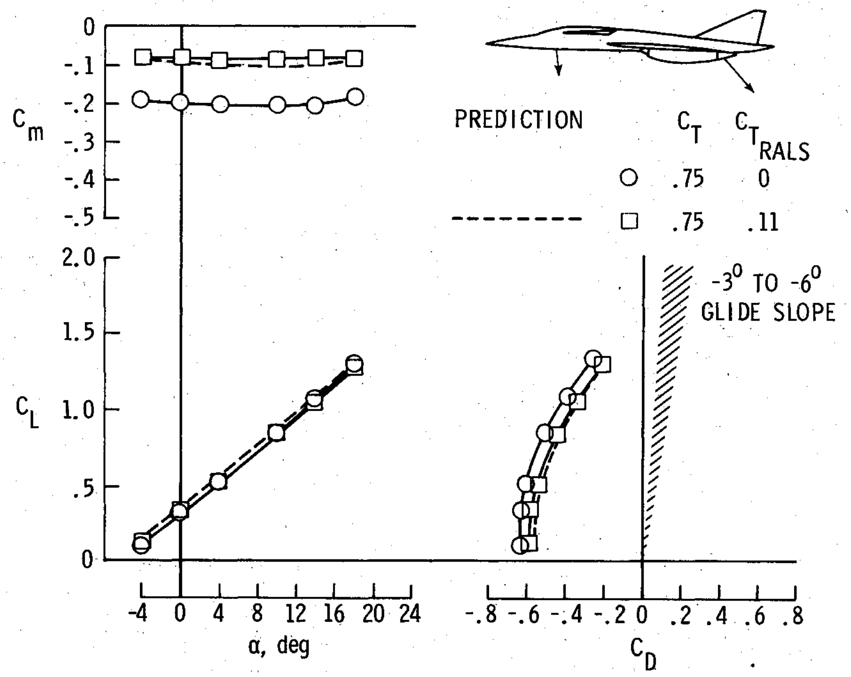

Fig. 3 Comparison of predicted and experimental longitudinal aerodynamics for supersonic cruise fighter configuration with main nozzles vectored 30 deg and nose jet on.

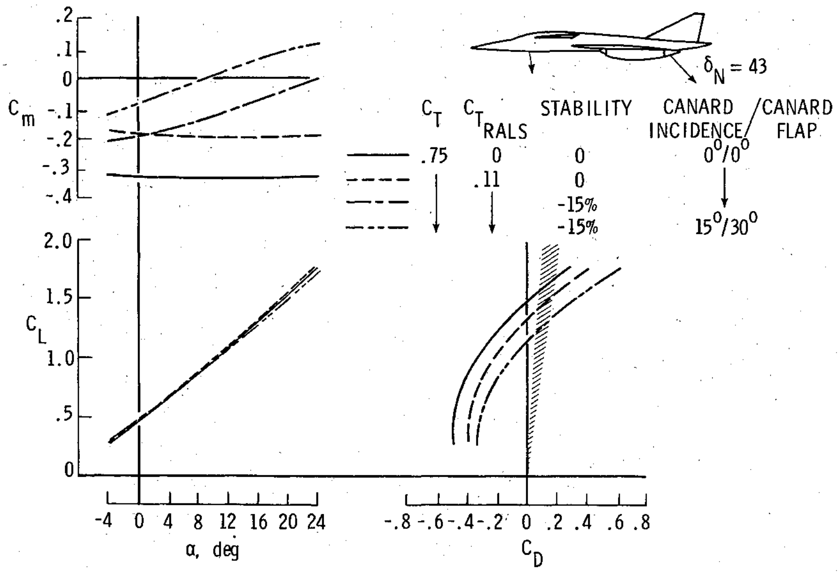

Fig. 4 Trim analysis of the supersonic cruise fighter configuration with $C_T = 0.75$ and main nozzles vectorized 43 deg.

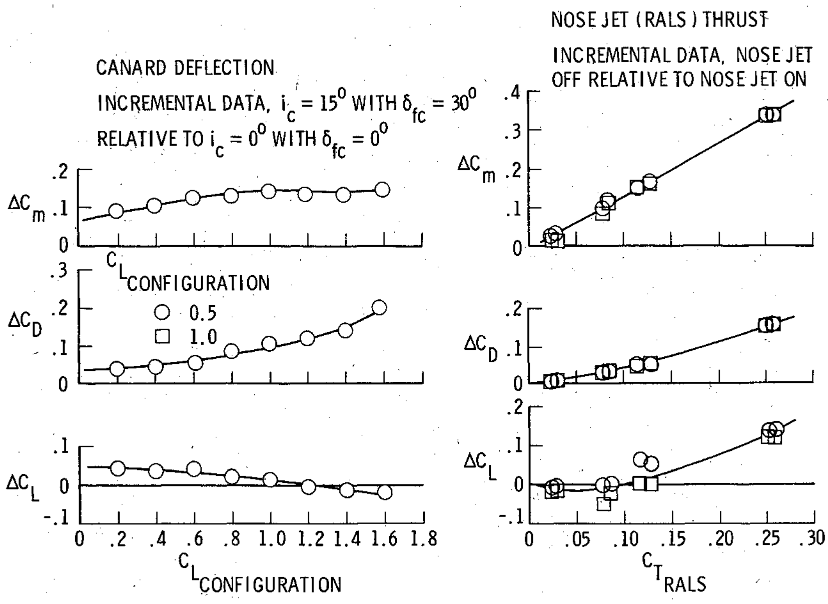

Fig. 5 Increments in the longitudinal data for the supersonic cruise configuration due to canard deflection and nose jet (RALS) thrust.

produced net lift increases over most of the C_L range with only small losses at $C_L \geq 1.6$. Thus, the downwash from the canard would not appear to be unduly loading the main wing.

In summary, this configuration can be trimmed at $C_L = 1.3$ with $C_T = 0.75$ and $\delta_N = 43$ deg with a C_D such that approach glide slopes between -3 and -6 deg are possible. Also, there is control power remaining from the canard since only 7-8 deg of incidence are required for trim. The nose jet is required, however, because even with a 15% unstable configuration, the canard is inadequate for trim at this power setting of $C_T = 0.75$ and $\delta_N = 43$ deg. The investigation showed that a properly positioned nose jet can provide the pitching-moment increment with a slight lift increase and no change in stability while leaving most of the canard control authority available for control. The nose jet has the disadvantage of being an extra piece of equipment carried for use only during a small portion of the flight. The weight and volume penalty must be considered against the relative simplicity and straightforward effectiveness of this device.

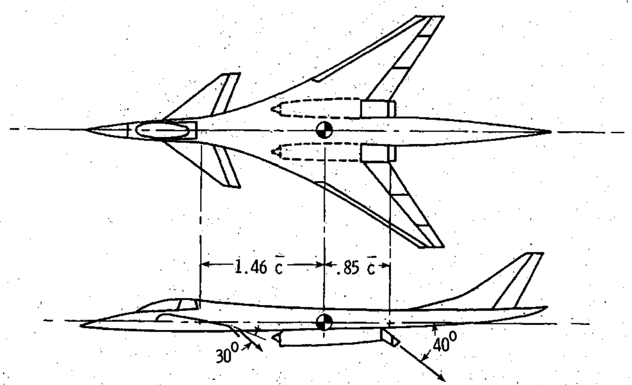

Fig. 6 Sketch of an advanced fighter configuration showing locations of main vectoring nozzles and blown high-lift canard.

Blown High-Lift Canard

The aerodynamics of a blown canard on the longitudinal aerodynamics of an advanced fighter configuration[18] with vectoring main nozzles (Fig. 6) was investigated in a wind tunnel investigation conducted in the Langley 4×7-m tunnel. A major intent of this investigation was to determine the effect of using high-lift canard (blown trailing-edge flap and leading-edge Krueger flap) to obtain longitudinal trim when the main nozzles were vectored. The full-span nozzle for the blown canard flap was sized for boundary-layer control on the flap rather than jet-flap effects (i.e., low rather than high blowing coefficients).

As in the previous powered-lift investigations, the effect of thrust with the main nozzles vectored 40 deg is to increase lift and produce large nose-down pitching moments (see Fig. 7).

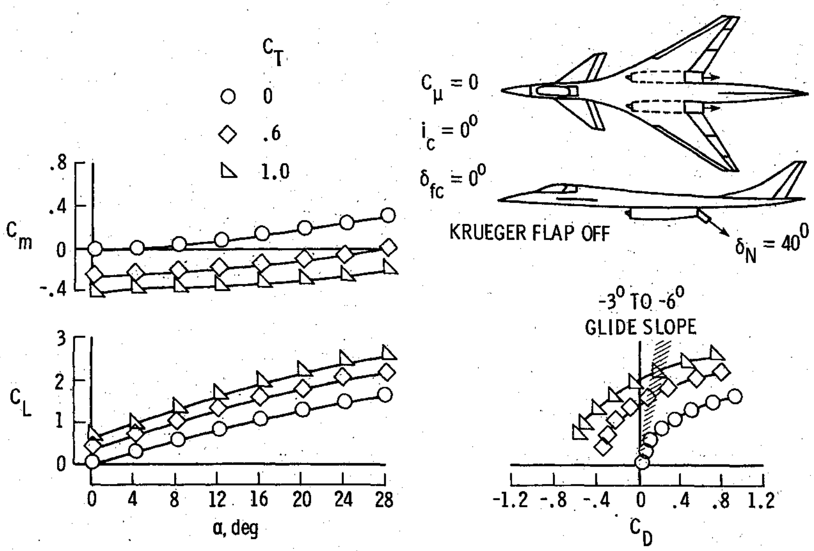

Fig. 7 Effect of thrust on the longitudinal aerodynamics of an advanced fighter configuration with $\delta_N = 40$ deg.

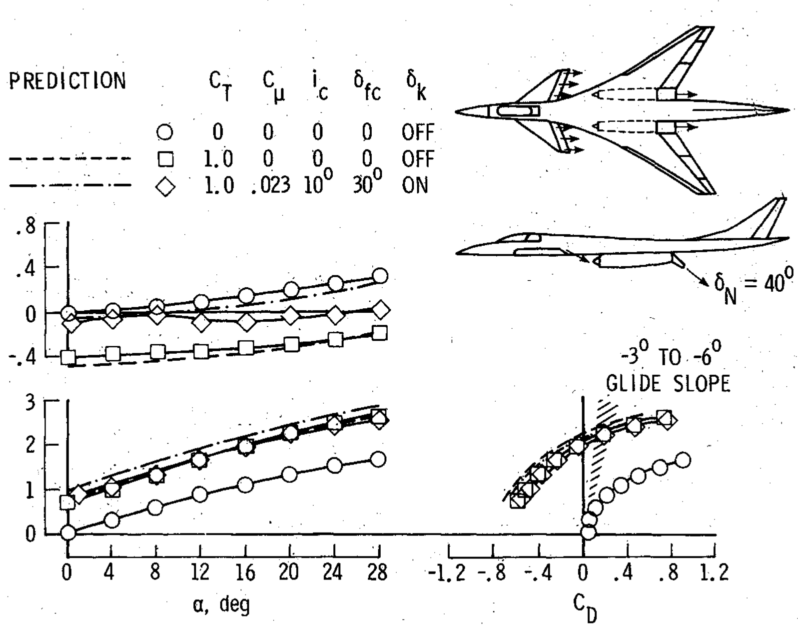

Fig. 8 Comparison of predicted and experimental effects of the blown high-lift canard on the longitudinal aerodynamics of an advanced fighter configuration with $\delta_N = 40$ deg and $C_T = 1.0$.

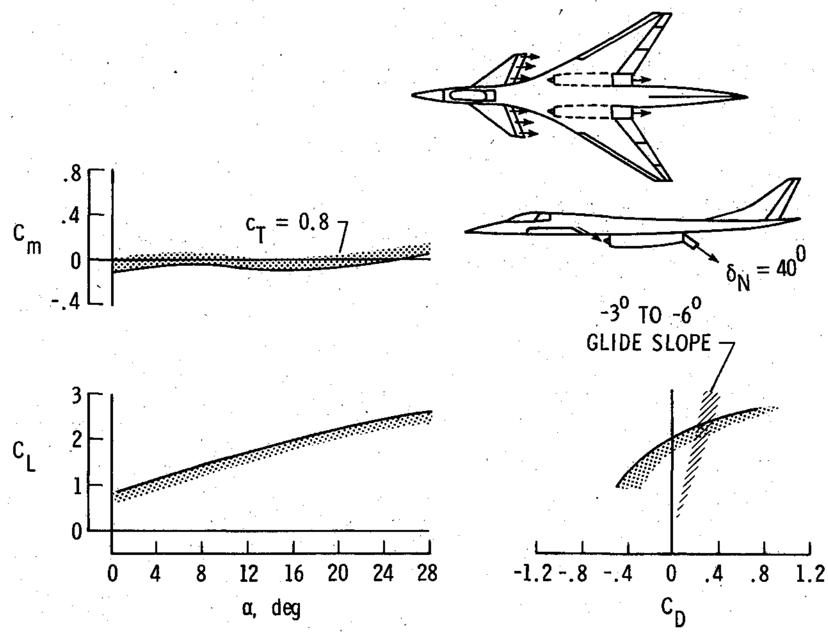

Fig. 9 Effect of military power on the approach aerodynamics of an advanced fighter configuraiton with $\delta_N = 40$ deg, $C_T = 1.0$, $C_\mu = 0.023$, $i_c = 10$ deg, $\delta_{cf} = 30$ deg, and δ_k on.

Here, as in the preceding discussion of the supersonic cruise configuration, the drag is slightly low for normal approach angles, but the configuration was without landing gear or speed brakes which would provide the needed drag.

The effect of the blown canard is shown in Fig. 8. Here, as in the previous discussion, the objective is to obtain a trim point at an angle of attack of about 16 deg with sufficient lift and drag for approach and some control power remaining from the canard. As in the trim analysis for the supersonic cruise configuration, the aerodynamics of the configuration with the blown canard were estimated as a guide and confidence builder that the trimmed data were correct (see Fig. 8). In the figure, the estimates for the configuration aerodynamics with main nozzles alone are quite good (again no significant induced effects). The estimates with the blown canard are high for lift across the angle-of-attack range above $\alpha = 10$ deg. This would indicate that the downwash from the canard when the flap is attached by the BLC blowing is unloading the wing and canceling the lift increase on the canard. The overprediction of pitching moment at high angles of attack shows that the canard is separating and not carrying the predicted lift, thus producing less nose-up pitching moment. As shown in the figure, the blown canard produces nearly trimmed pitching moments across the entire angle-of-attack range tested with the main engine power at $C_T = 1.0$ and $\delta_N = 40$ deg. Also, the lift curve with and without the blown canard is almost unchanged, again indicating that the downwash from the canard is unloading the wing in a manner which almost directly cancels the increasing lift on the canard. Even with the slight increase in drag from the blown canard, the additional drag increment from the landing gear and speed brakes wil be needed for approach.

Since $C_T = 1.0$ is probably a slightly higher landing thrust setting than would be applicable for this configuration, the data are shown again in Fig. 9 with a shaded area indicating the effect of reducing C_T to 0.8. Here, the blown canard will maintain trim across the complete angle-of-attack range and the canard would still have 10-15 deg of nose-up travel remaining to provide a measure of pitch control. Also, lift and drag now appear to be quite adequate for approach.

This concept produced the required nose-up pitching moment with no loss in configuration lift and with a slight increase in longitudinal stability and left about half the canard authority available for control. The blown high-lift canard is perhaps one of the most elegant approaches for providing additional trim capability. The extra canard control power is obtained with very little thrust diversion from the engine, the equipment integrates nicely into the existing configuration, and the capabilty may be useful for other high angle-of-attack flight conditions. The only apparent disadvantage is the weight and complexity of the ducting for the blowing system.

Concluding Remarks

It has been shown that a small nose jet on a supersonic cruise configuration and a blown high-lift canard on an advanced multirole fighter can provide the nose-up pitching moment required for longitudinal trim when the main nozzles are vectored at high thrust levels. These configurations, while trimmed, also had lift and drag values that would allow STOL approaches with military power settings.

Conceptually, both concepts are relatively straightforward and had minimal interference effects on the overall configuration aerodynamics while generating the pitching moments needed for trim. The usefulness of either concept would be determined by the trade of specific aircraft requirements vs the weight and complexity of the system.

Acknowledgments

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