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Airframe Effects on a Top-Mounted Fighter Inlet System

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Inlet flowfield and compressor-face performance data were obtained for a 0.095-scale model of a fighter-attack aircraft configuration with twin top-mounted inlets. Tests were conducted at Mach numbers from 0.6 to 2.0 and at angles of attack and sideslip up to 27 and 12 deg, respectively. Reynolds number was held constant at 9.8×10^6/m. The effects on inlet location, wing leading-edge extension planform area, canopy-dorsal integrations, and variable incidence canards were determined. The results show that distortion at the compressor face when maneuvering is generally low (20% or less) at Mach numbers up to 0.9. However, at Mach numbers of 1.2 and above, maneuverability may be restricted because of high distortion or low pressure recovery (80% or less) or both.

Introduction

RECENT fighter-attack aircraft studies[1,2] have shown that configurations with top-mounted inlets have significant potential advantages over configurations with more conventionally mounted inlets. Among these advantages are reduced ingestion of hot gases and debris, reduced radar cross section, and better weapons integration. The studies also identified problem areas related to the ingestion of low-energy and/or distorted flow at angle of attack.

The twin-engine top-mounted inlet configuration identified in Ref. 1 was based on a detailed aerodynamic analysis by Northrop in a program jointly sponsored by Ames Research Center and the David Taylor Naval Ship Research and Development Center.[3] An aerodynamic force model of this configuration was constructed and tested in a wind tunnel. The model had flow-through ducts with limited pressure instrumentation in the throat. Initial testing suggested reasonably good inlet performance.[4] However, good inlet performance cannot be verified without compressor-face measurements. As a result, the present investigation was initiated to measure both the inlet flowfield properties and the performance at the compressor face. Similar results were obtained in earlier work,[5,6] but were limited to flowfield surveys or to low speed ($M = 0.25$). Some results from this current investigation have been published in Ref. 7.

The aerodynamic force model from Ref. 3 was modified for the present inlet performance test. Instrumentation to measure the inlet flowfield and internal duct and compressor-face performance was added. The ducts were modified so that they could accommodate remotely controlled mass-flow control plugs and could be positioned at three different longitudinal fuselage stations. Other modifications allowed investigation of canard and canopy-off configurations as well as the different wing leading-edge extension (LEX) options which had been included on the original model. All configurations were tested at Mach numbers of from 0.6 to 2.0 and at angles of attack and sideslip up to 27 and 12 deg, respectively.

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Model and Instrumentation

A layout of the model is shown in Fig. 1. The model was tested with the inlet located at 30, 44, and 70% of the projected wing root chord, henceforth referred to as the forward, mid-, and aft locations, respectively. The midlocation (44%) was chosen as the baseline inlet location for the investigation of all model configuration variables. Note that the LEX designated baseline was used for the inlet location testing. This LEX was also installed for the investigation of leading- and trailing-edge flap deflections.

The model was instrumented with 18 area-weighted total-pressure probes, four circumferential static orifices, and six Kulite dynamic transducers at the compressor face. The flowfield was surveyed with a rake that had 45 total-pressure probes. Other instrumentation was included and the details are shown in Ref. 7.

Results

Compressor-face results are presented in terms of total-pressure recovery and maximum minus minimum total-pressure distortion. Flowfield results are presented as pitot pressure contours and as average pitot pressure recovery and maximum minus minimum pitot pressure distortion. Most of the results shown are for 0-deg sideslip angle, and data are shown for one duct only since there was no serious asymmetry problem. Results at other Mach numbers, at angles of sideslip other than zero, and for other distortion parameters, including dynamic distortion, are shown in Ref. 7.

The 18 total-pressure tubes at the compressor face give a good configuration to configuration comparison of total pressure recovery and distortion. Detailed measurement of the duct internal performance would require additional instrumentation which was beyond the scope of this investigation.

Inlet Location

Inlet performance measurements were made with the inlet located at three different fuselage stations. Performance at these locations (30, 44, and 70% of projected wing root chord) is compared in Fig. 2 for three Mach numbers—0.6, 0.9, and 1.2. Pressure recovery and distortion are shown as functions of engine-airflow ratio for angles of attack and sideslip of 0 deg. Note that the value of 1.0 on the abscissa corresponds to design airflow conditions for a candidate engine. At design airflow conditions, pressure recovery at each Mach number is approximately the same for all inlet locations. At other airflow conditions, there is some variation in pressure recovery because of the inlet location at $M=0.9$ and 1.2. Distortion variations are less than 0.02 between all inlet locations at $M=0.6$ and 0.9, and the variations reach 0.05 at $M=1.2$. All distortion variations are considered to be small.

Angle-of-attack effects were investigated at design engine-airflow conditions, and these results are shown in Fig. 3. At angles of attack up to 15 deg, pressure recovery is generally higher with the inlet in the aft location; at higher angles, pressure recovery is generally higher with the inlet in the midlocation. Distortion is considered to be acceptably low for all conditions (0.20 or less), except for high angles at $M=1.2$ with the inlet aft. Overall, no inlet location is clearly better in terms of higher pressure recovery and lower distortion. However, because of wind tunnel test time constraints, the midlocation was selected for the investigation of other configuration variables, principally because the earlier force testing was done with the inlet at this location.

Canopy-Dorsal Integration

A notable feature of the midinlet location data in Fig. 3 is the drop in recovery at angles of attack between 4 and 15 deg. This was thought to be at least partially a result of canopy-dorsal integration, and, therefore, a canopy-off configuration was tested. The mold lines for this configuration are shown in Fig. 4. Note that there is still a downward slope to the dorsal upstream of the inlet. This tends to promote local flow acceleration at supersonic speeds but is still a reduced flow disturbance compared with the canopy-on configuration.

Results for the canopy-on and canopy-off configurations are compared in Fig. 5. Pressure recovery increases and the drop in pressure recovery between angles of attack of 4 and 15 deg is almost eliminated by removing the canopy. Distortion is acceptably low for both configurations. Adversely, canopy-off pressure recovery at $M=1.2$ is lower at high angles of attack.

Some insight into the canopy-off pressure recovery improvement between 4 and 15 deg is shown by the flowfield contour maps in Figs. 6a and 6b. Canopy-on and canopy-off contours are shown for $M=1.2$ at an angle of attack of 10 deg, where the pressure recovery increment is large. Note that the inlet capture area highlight is indicated and the relative position of the fuselage is shown below Fig. 6b. Canopy-on results show a strong vortex with low-energy core flow, as evidenced by the low pitot pressure. Canopy-off results show no evidence of a vortex, but do show a relatively small region of boundary-layer flow. These results show that the canopy configuration has a strong influence on the strength of the vortex.

Wing Planform

The work reported in Refs. 2 and 5 showed the importance of the wing leading-edge extension (LEX) that produces a vortex system to counteract upper fuselage flow separation. These studies also correlated vortex effectiveness with LEX planform size and shape. LEX effectiveness was investigated further during this study. The LEX configurations investigated (Fig. 7) included 1) the baseline LEX, 2) an alternate LEX with 60% of the baseline planform area, and 3) LEX off.

Results from the LEX investigation are shown in Fig. 8. Of the two configurations with a LEX, neither is clearly better than the other. Pressure recovery is higher with the alternate LEX at low to moderate angles of attack and is generally higher with the baseline LEX at high angles of attack. Distortion is generally about the same for both LEX configurations. Performance is clearly better for both LEX configurations than without the LEX, particularly at high angles of attack and at $M=1.2$.

The way in which the LEX configurations affect inlet performance is indicated by the flowfield contours shown in Figs. 9a-c. Contours are shown for the baseline and alternate

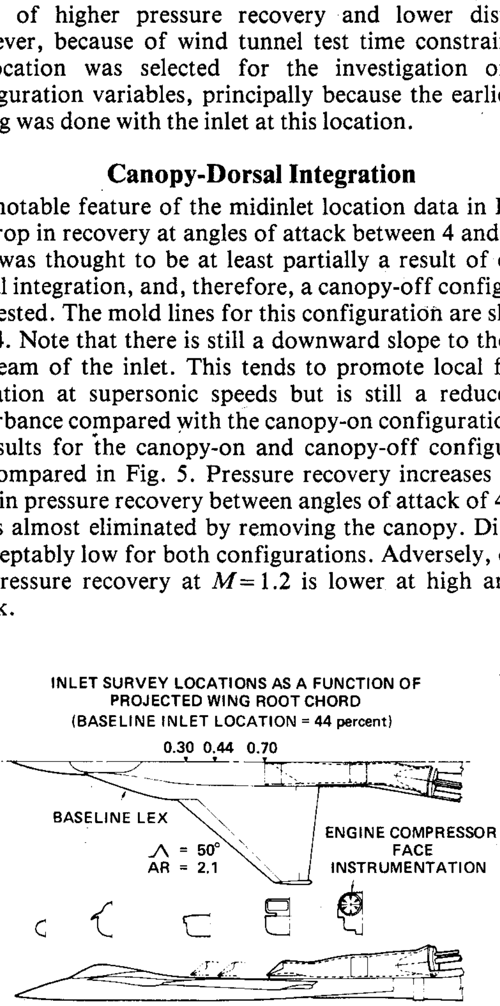

Fig. 1 Model layout.

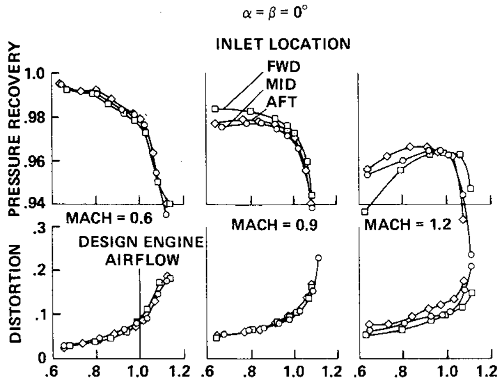

Fig. 2 Effect of engine airflow ratio on compressor-face performance.

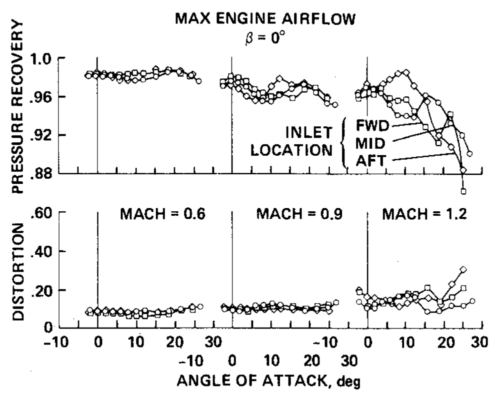

Fig. 3 Effect of inlet location on compressor-face performance.

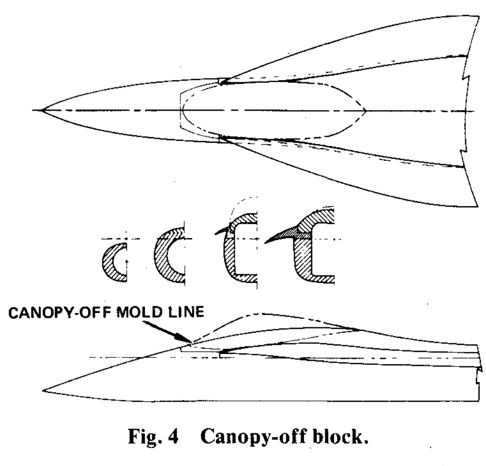

Fig. 4 Canopy-off block.

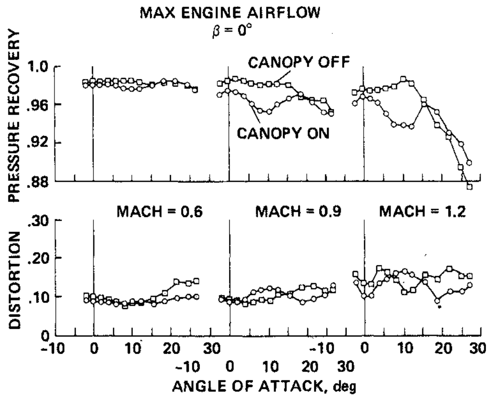

Fig. 5 Effect of canopy on compressor-face performance.

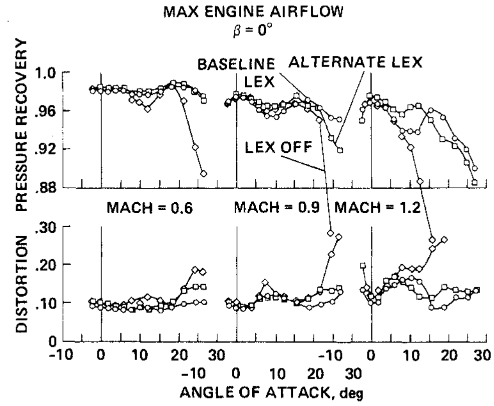

Fig. 8 Effect of LEX planform on compressor-face performance.

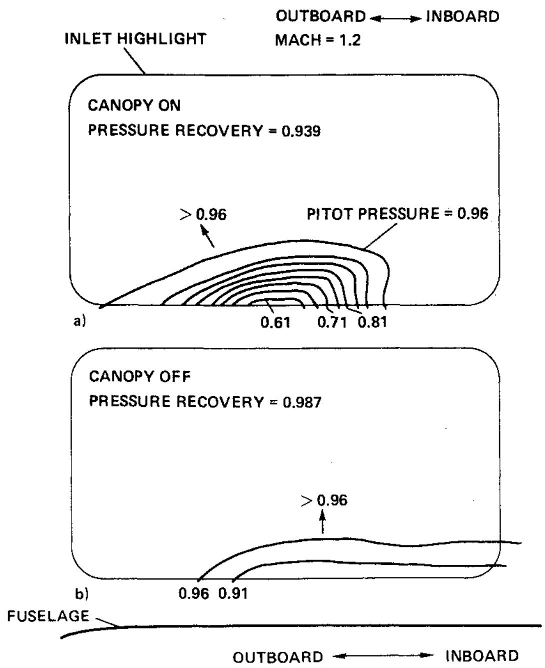

Fig. 6 Flowfield pitot-pressure contours: Mach 1.2, $\alpha = 10$ deg, $\beta = 0$ deg.

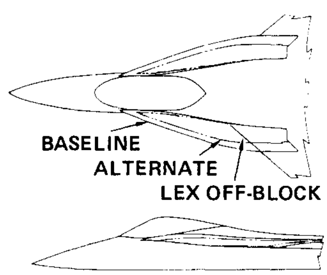

Fig. 7 Wing leading-edge extension (LEX) planform options.

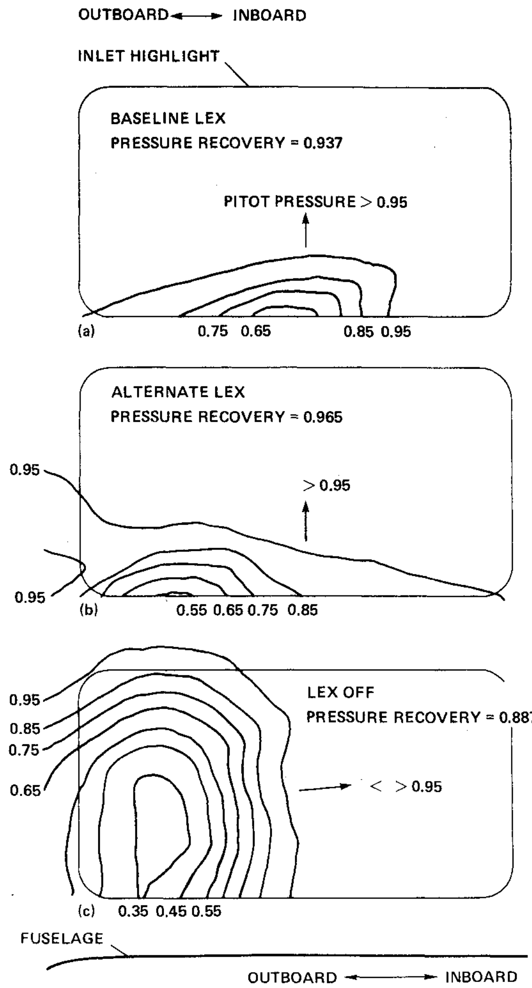

Fig. 9 Flowfield pitot-pressure contours: Mach 1.2, $\alpha = 12.4$ deg, $\beta = 0$ deg.

LEX and for LEX-off at $M = 1.2$ and at an angle of attack of 12.4 deg. These contours result in the indicated pressure recovery at the compressor face. Note the vortex located at the lower inlet center with the baseline LEX. This vortex migrates outboard and appears to gain in strength with the alternate LEX. The vortex is greatly strengthened and moves upward with the LEX removed. There appears to be an anomaly between the indicated vortex pitot pressures and the pressure recovery at the compressor face. The pressure recovery would be expected to be higher with the baseline than with the alternate LEX because the area of vortex flow is smaller and the core pressure is higher. Such is not the case, however. Furthermore, the pressure recovery with the LEX off should be lower than indicated since there is a large region of very low pitot pressure. More will be said about these anomalies later. These results show that the LEX configuration has a strong influence on both the vortex strength and location.

Canards

The effect of canards on inlet performance was investigated, and the configuration used is shown in Fig. 10. Analysis indicated that this configuration with a dihedral angle would couple the canard vortex system with the wing flowfield for vortex lift enhancement. Note that the canard could be deflected about a 15-deg rotation axis.

The canard and LEX are not installed at the same time. Therefore it is intended that the canard provide the same benefit as the LEX, that is, delay upper fuselage flow separation at high angles of attack. Inlet performance for the undeflected canard and baseline LEX configurations is compared in Fig. 11. At $M=0.6$, the pressure recovery is the same for both configurations. At $M=0.9$, pressure recovery is higher for the LEX configuration at low angles of attack (0-10 deg) but is lower at moderate angles of attack (10-17 deg). At $M=1.2$ there is a large penalty with the canard at all angles of attack. Distortion tends to be higher for the canard configuration at all Mach numbers and angles. Overall, the present canard arrangement is not as effective as the baseline LEX in controlling upper fuselage flow separation.

Inlet performance with the canard deflected and undeflected is compared in Fig. 12. The -10-deg deflection angle approximates the angle required for trim at $M=0.9$ and an angle of attack of 10 deg. The results show considerable recovery or distortion penalties or both when the canard is deflected to -10 deg, especially at transonic speeds.

Leading- and Trailing-Edge Flaps

Inlet performance comparisons with flaps deflected and undeflected are shown in Fig. 13 for Mach numbers of 0.9 and 1.2. These data show that pressure recovery actually increases when leading- and trailing-edge flaps are deflected 30 deg, and that distortion is virtually unchanged. These and other results indicate that flap deflections do not adversely affect inlet performance on this configuration.

Inlet Flowfield

It was previously mentioned that there was an anomaly between the flowfield data and the corresponding inlet performance at the compressor face. Pressure recovery and distortion at the flowfield rake station and at the compressor face are compared in Fig. 14. Note that at angles of attack up to 12 deg, there is roughly a constant recovery decrement from flowfield to compressor face at each Mach number, corresponding to a nearly constant duct loss. At higher angles, however, the decrement decreases and actually reverses at $M=0.9$ and 1.2. This is not possible because there must be some duct loss from flowfield to compressor face.

At this time, it is believed that the individual pressure tubes on the flowfield rake are too closely spaced, thus leading to probe-to-probe interference at high angles of attack. Additionally, cone probe measurements of local angles of attack and sideslip indicate local angles outside the calibration range of the rake (± 20 deg). Of greater significance than the

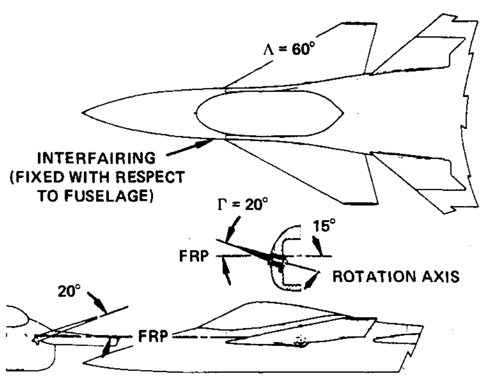

Fig. 10 Close-coupled variable incidence canards.

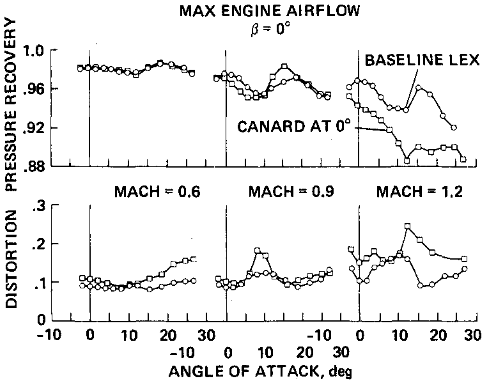

Fig. 11 Effect of canard on compressor-face performance.

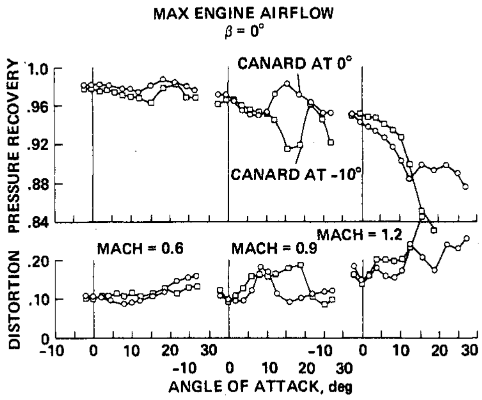

Fig. 12 Effect of canard deflection on compressor-face performance.

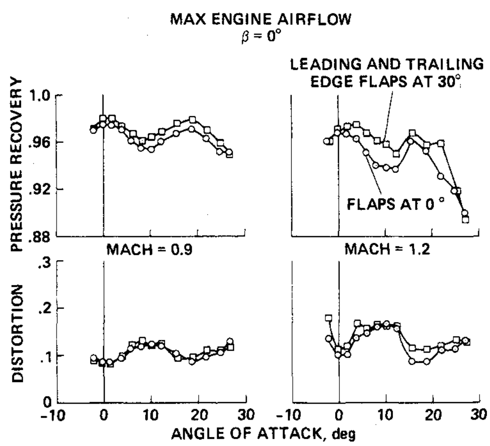

Fig. 13 Effect of flap deflections on compressor-face performance.

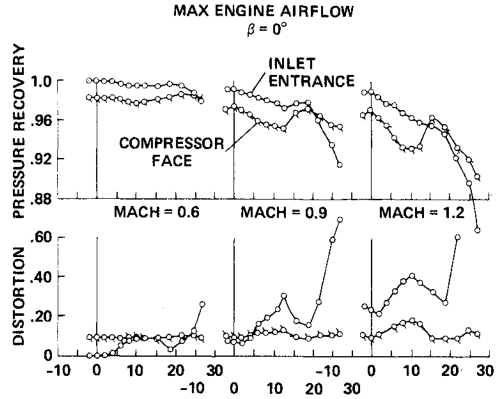

Fig. 14 Flowfield and compressor-face performance.

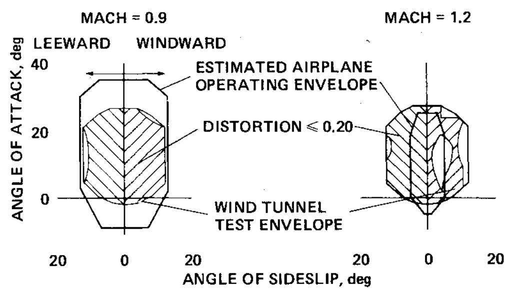

Fig. 15 Distortion-limited operating envelopes, baseline configuration.

pressure recovery results is the fact that distortion, as measured at the inlet entrance, gives little or no indication of what the distortion will be at the compressor face, even at low angles of attack where data are within the calibration range. For instance, at $M = 0.9$, distortion, as measured by the flowfield rake, increase considerably with increasing angle of attack, while at the compressor face, it is nearly constant at 10%.

Performance at Sideslip Angles

Compressor face distortion is shown in Fig. 15 as a function of both angle of attack and sideslip. Results are shown as a distortion limited operating envelope for the windward and leeward inlets at Mach numbers of 0.9 and 1.2, respectively. The test data angle of attack/sideslip envelope and a typical fighter aircraft angle of attack/sideslip operating envelope are outlined. Crosshatching within the test data envelope indicates angle of attack/sideslip combinations where distortion is less than or equal to 20%. A value of 20% is used because this paper has defined a distortion of 20% or less as being acceptably low. Note that at Mach number 0.9, the operating envelope is greater than the test data envelope, while, at Mach number 1.2, the test data envelope generally more than covers the operating envelope. At Mach number 0.9, distortion is greater than 20% for both the windward and leeward inlets in small regions of the test data envelope. Moreover, distortion may be high in large regions between the test data and airplane operating envelopes. At Mach number 1.2, distortion is greater than 20% over larger regions of the test data envelope than at Mach number 0.9. However, only the windward duct has distortion greater than 20% within the airplane operating envelope. Other data, not presented, show that pressure recovery can be quite low (70% to 80 deg) for either inlet, even though distortion is acceptably low.

Concluding Remarks

Inlet flowfield and compressor-face performance data have been obtained for a model of a fighter-attack aircraft with twin top-mounted inlets. Examination of the results leads to the following observations:

1) No longitudinal inlet location is clearly better at subsonic and transonic Mach numbers in terms of higher inlet pressure recovery and lower distortion.

2) When the canopy is reduced in size (canopy-off configuration), inlet pressure recovery generally increases and distortion generally decreases. These effects, which are greater at the higher Mach numbers, occur because the LEX-body vortex is either reduced in strength or is redirected outboard from the inlet.

3) When a LEX is used, inlet pressure recovery increases and distortion decreases. These changes are most pronounced at higher angles of attack. They occur because a LEX effectively mixes high-energy flow with the very-low-energy core flow that is produced by the LEX-off canopy-body vortex.

4) The canard is not as effective as the LEX in controlling fuselage forebody flow separation at high angles of attack. At its current stage of development, the canard is not a satisfactory upper-surface flow-control device for this configuration.

5) Deflecting wing leading- and trailing-edge flaps does not result in inlet performance penalties on this configuration.

6) The measurement of inlet flowfield properties did not necessarily provide consistent indication of the performance at the inlet compressor face.

7) At the current stage of development, the canopy of this configuration causes high distortion or low pressure recovery or both. However, results from the investigation of canopy-off, LEX, and inlet-location configurations indicate that reconfiguring the canopy-LEX-body juncture, in conjunction with careful attention to inlet location, might cause the canopy-LEX-body vortex to be reduced in strength and/or to pass outboard of the inlet.

References

[1] Nelms, W.P., "Studies of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft," AIAA Paper 78-1511, Los Angeles, Calif., 1978.

[2] Williams, T.L. and Hunt, B.L., "A Comparative Assessment of Top-Mounted and Conventional Inlet/Airframe Integrations," NASA CP-2162, Part 2, Tactical Aircraft Research and Technology Conference, Langley Research Center, Hampton, Va., Oct. 21-23, 1980.

[3] Gerhardt, H.A. et al., "Study of Aerodynamic Technology for VSTOL Fighter/Attack Aircraft—Vertical Attitude Concept," NASA CR-152131, 1978.

[4] Nelms, W.P. and Durston, D.A., "Preliminary Aerodynamic Characteristics of Several Advanced STOL Fighter/Attack Aircraft Concepts," Paper 80-1178 presented at the SAE Aerospace Congress and Exposition, Los Angeles, Calif., Oct. 13-16, 1980.

[5] Rhoades, W.W. and Surber, L.E., "Top Mounted Inlet Flow Field Testing for Future Fighter Aircraft," Paper 79-1147 presented at the AIAA/SAE/ASME 15th Joint Propulsion Conference, Las Vegas, Nev., June 18-20, 1979.

[6] Williams, T.L. and Hunt, B.L., "Top Inlet Feasibility for Transonic-Supersonic Fighter Aircraft Application," AIAA Paper 80-1809, Anaheim, Calif., 1980.

[7] Williams, T.L., Nelms, W.P., and Smeltzer, D.B., "Top-Mounted Inlet System Feasibility for Transonic-Supersonic Fighter Aircraft," Paper CP-301 presented at the AGARD Symposium on Aerodynamics of Power Plant Installation, Toulouse, France, May 11-14, 1981; see also NASA TM-81292.