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HYBRID UPPER SURFACE BLOWN FLAP PROPULSIVE-LIFT CONCEPT FOR THE QUIET SHORT-HAUL RESEARCH AIRCRAFT

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16. Abstract

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Abstract

The hybrid upper surface blowing concept consists of wing-mounted turbofan engines with a major portion of the fan exhaust directed over the wing upper surface to provide high levels of propulsive lift, but with a portion of the fan airflow directed over selected portions of the airframe to provide boundary layer control. NASA-sponsored preliminary design studies identified the hybrid upper surface blowing concept as the best propulsive lift concept to be applied to the Quiet Short-Haul Research Aircraft (QSRA) that is planned as a flight facility to conduct flight research at low noise levels, high approach lift coefficients, and steep approaches. Data from NASA in-house and NASA-sponsored small and large-scale wind tunnel tests of various configurations using this concept are presented.

Nomenclature

b	=	wing span
BLC	=	boundary layer control
C_L	=	lift coefficient, $\frac{L}{qS}$
$C_{L_{\alpha=0}}$	=	lift coefficient at zero angle of attack
$C_{L_{\alpha=-2°}}$	=	lift coefficient at an angle of attack of −2°
$C_{L_{max}}$	=	maximum lift coefficient
C_l	=	rolling-moment coefficient, $\frac{\text{rolling moment}}{qSb}$
C_n	=	yawing-moment coefficient, $\frac{\text{yawing moment}}{qSb}$
C_T	=	thrust coefficient, $\frac{\text{gross thrust}}{qS}$
C_μ	=	blowing momentum coefficient, $\frac{\text{gross thrust from BLC nozzle}}{qS}$
L	=	lift
P_{t_E}/P_∞	=	pressure ratio, $\frac{\text{total pressure at engine nacelle exit}}{\text{tunnel static pressure}}$
q	=	free-stream dynamic pressure
S	=	wing area
V	=	velocity
W/S	=	wing loading
α	=	angle of attack
δ_F	=	deflection angle of the trailing edge flap

Introduction

Early studies of low cost propulsive-lift research aircraft led to the concept of the hybrid upper surface blowing system. In this concept, the major portion of the turbofan exhaust air is blown over the upper surface of the flaps to provide lift augmentation, but a portion of the turbofan air is used for boundary layer control. In the various applications of the concept, the blowing for the boundary layer control may be applied to the leading edge, the flap knee, the flap trailing edge, the aileron, or to combinations of these locations. Figure 1 shows the arrangement of this type of hybrid upper surface blowing system schematically.

The Quiet Short-Haul Research Aircraft (QSRA) is a propulsive-lift aircraft intended to be used as a facility for terminal area operations flight research directed toward the development of design and certification criteria. It is a modification of the C-8A Buffalo and uses four YF-102 turbofan engines and an advanced propulsive-lift wing. Features of the QSRA include a steep approach capability at high lift coefficients and at low noise levels with margins for safe engine-out operation.

Preliminary design studies, summarized in references 1 and 2, identified the hybrid upper surface blowing system as the preferred propulsive-lift concept for the QSRA.

Small and large-scale experimental programs were initiated to study the aerodynamics of these concepts for application to the QSRA. This paper reports some of the results of these experimental programs.

Small-Scale Hybrid Upper Surface Blowing Tests

A series of small-scale wind tunnel tests of the trailing edge blowing version of the upper surface blowing (USB) concept was conducted by the Lockheed-Georgia Company. The tests were conducted under contract to Ames Research Center and are reported in reference 3. Figure 2 is a photograph of the model used in these tests and Fig. 3 presents the principal dimensions of the model. Significant data concerning the effects of nacelle chordwise location, nacelle nozzle configuration, flap knee blowing, and flap trailing edge deflection were obtained.

Figure 4 summarizes the results of a series of tests to study the effect that USB exhaust nozzle chordwise position has on lift coefficient. For the three positions tested, the effect was small but showed that a forward location resulted in a higher lift coefficient. Configuration studies showed that structural and balance considerations limited how far forward the nacelle/engine could be located, and, since the aerodynamic effect is small, these factors would predominate in the selection of a chordwise location. All other factors being equal, however, a forward location would be preferred. Figure 5 shows the results of a study of the effect of various nozzle configurations. The basic nozzles were rectangular in cross section with an aspect ratio

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of 4.0. A deflector plate was attached to the top surface of the exit nozzle and tested at deflections of 0°, 10°, and 20°. These deflections resulted in "kickdown" angles of 20°, 30°, and 40°, respectively. In addition, the nozzle was tested with the deflector set at 10° and with side plates added to inhibit spanwise flow. The data showed that the plates used to inhibit spanwise spreading were detrimental to performance and that the higher nozzle deflector plate deflections improved performance. This is believed to be due to spreading of the jet efflux which results in a more favorable ratio of jet height to flap radius. Low values of this parameter have been shown to improve turning of the jet efflux.

The effect of various trailing edge flap blowing arrangements is summarized in Fig. 6.

Variation number 1 was a conventional upper surface blowing arrangement and variations 2, 3, and 4 consisted of USB in combination with internal blowing at the flap knee, at the flap trailing edge, and at both of these locations simultaneously. Data were taken for nozzle pressure ratios ranging from 1.2 to 1.6. The effect of pressure ratio at a constant value of thrust coefficient was found to be negligible. As shown in Fig. 6, the greatest improvement in lift coefficient occurred as a result of internal blowing at the flap knee. Data presented later in this paper, and the results of other studies, indicate that this phenomenon is configuration-sensitive and that flap-knee blowing would not result in large increases in lift coefficient for USB systems in which the ratio of jet height to flap radius is small. An advantage of flap-knee blowing is that smaller radius flaps may be used in order to simplify structural and mechanical design. As will be shown later, other techniques are also available to permit the use of smaller flap radii.

Figure 7 shows the effect of deflection of a small control flap, located at the trailing edge of the main flap, for various thrust coefficients at an angle of attack of 0°. A flap of this sort is useful as a flight path control device because it has relatively low hinge moments and can be actuated at high rates.

A comparison of the slopes of the lines for the three thrust coefficients in Fig. 7 shows that the effectiveness of the control flap increases with increasing thrust coefficient. The basic data from which Fig. 7 was derived showed that at a thrust coefficient of zero (no USB blowing) the control flap was almost completely ineffective. Thus, the mechanism by which the control flap provides flight path control is primarily one of variation in the flow turning angle and is thus equivalent to thrust vectoring.

Large-Scale Hybrid USB Tests

Based on the above results, an existing 42-ft wing span model was modified for a large-scale test of the flap-knee, boundary-layer-control (BLC) version of the hybrid USB concept.

A photograph of this model is shown in Fig. 8 and the principal dimensions are given in Fig. 9. The model was powered by five JT15D-1 engines. Four of the engines were used to provide for conventional upper surface blowing and the fifth engine was used to provide for independently variable flap-knee BLC. The aileron was undrooped and was not blown. Fixed leading edge slats were provided as was a variable control flap at the trailing edge of the main flap. The USB engine nozzles were configured to represent a nozzle using a separate core exhaust (split flow) that was not turned with the main "fan" flow; a special nozzle was required to accomplish this since the JT15D-1 engine is a mixed flow engine. The results of this test program are presented in reference 4.

The objective of the large-scale tests was to evaluate the effect of various configurations on performance, with particular emphasis on engine-out performance. Initial testing was directed at determining the optimum nozzle deflector plate position. Figure 10 shows the result of this evaluation with the number 4 engine inoperative. These data show that increased deflector plate deflection improved the available lift coefficient and also reduced the engine-out rolling moment. With all engines operative, there was a similar increase in lift coefficient but, of course, there were no asymmetric lift forces to generate a rolling moment. As discussed earlier in connection with the small-scale tests, the higher deflector plate deflections appear to provide a more favorable ratio of jet height to flap radius, thus improving flow turning; improved flow turning results in the higher lift coefficient. The spreading of the flow (which reduces the jet height) also improves spanwise distribution in the engine-out case and thereby reduces the engine-out rolling moment.

An investigation was made to determine the effectiveness of flap-knee BLC. Figure 11 presents the results of this investigation for the all-engines-operative case at a thrust coefficient of 2.0 and for two main flap deflections. At the low flap deflection (representative of a takeoff flap setting), the effect of BLC ($C_\mu = 0.14$) on lift coefficient was negligible. However, at the high flap deflection (representative of a landing flap setting), a substantial improvement in lift coefficient was observed at $C_\mu = 0.13$. Figure 12 shows the effect of BLC ($C_\mu = 0.17$) for the same flap deflection and thrust coefficient, but with the number 4 engine inoperative. In this case the improvement in lift coefficient is less but the stalling angle of attack has been increased and both rolling and yawing moments have been reduced. Figure 13 is similar to Fig. 12 except that thrust coefficient has been reduced to a value of 1.0, $C_\mu = 0.084$, and the trailing edge control flap has been deflected 20°. This is the equivalent of a greater main flap deflection and a more severe turning requirement. In this case, a greater improvement in lift coefficient occurs but of more importance are the relatively large reductions in rolling and yawing moments. These data show that flap-knee BLC can be beneficial, but that the benefits to be derived are highly configuration-dependent.

As with the small-scale model, the use of a trailing edge flap for flight path control was investigated. Figure 14 shows the variation in flight path angle as a function of control flap deflection for a thrust coefficient of 1.0 at an angle of attack of 0°. A comparison of these data with the data presented in Fig. 7 shows that for the same thrust coefficient ($C_T = 1.0$), the control flap was more effective on the small-scale model than on the large-scale model. This is probably due to the differences in configuration, particularly flap deflection (60° vs 82°). It should be noted that the "nominal" flight paths shown in Figs. 7 and 14 are not as steep as those normally envisioned for STOL aircraft during approach. This is because of the fact that the models were not configured as complete aircraft and, therefore, did not have all of the sources of drag that would be present in an actual aircraft. In the large-scale model, for example, there was no landing gear or horizontal tail and the model was untrimmed longitudinally. The QSRA studies[1,2] showed that steep approaches can be achieved at approach speeds that are compatible with short field operation (60 to 70 knots) when the drag of an appropriately configured airplane is accounted for.

Small-Scale Semi-Span Hybrid USB Test

A small-scale wind tunnel test program was conducted by The Boeing Company to determine the effectiveness of vortex generators and internal blowing BLC to improve the engine exhaust jet turning over the USB flap system. Results of the test, which was conducted under contract to Ames Research Center, are reported in reference 5. Figure 15 is a photograph and Fig. 16 is a sketch of the model used in this test. The jet exhaust nozzle was a low aspect ratio cruise type.

Installation of vortex generators in the engine exhaust just forward of the USB flap knee resulted in a significant increase in lift coefficient as shown in Fig. 17 for a flap setting representative of a typical approach/landing configuration. The effectiveness of the vortex generators improves with increasing jet energy. For example, vortex generators increase C_L by 1.0 at approach thrust and, at high thrust levels ($C_T = 3.0$), the C_L improvement is 2.3. The lift coefficient levels are compared at $\alpha = -2°$ to avoid nonlinearities in C_L vs α and to represent the higher geometric angles of attack of interest since angle of attack, in this quasi-two-dimensional test configuration, represents much higher angles of attack for a three-dimensional case because vortex effects on downwash are minimal with this model/tunnel configuration. The increased C_L is partly due to improved flow attachment over the USB flap and partly due to spreading of the jet exhaust by the vortex generators. Both the jet spreading effect and the improved jet turning can be seen in the oil flow photographs of reference 5.

Compared to vortex generators, BLC blowing at the knee of the USB flap was less effective except at low engine power settings. Figure 18 shows that C_L increased by about the same amount at approach thrust for both methods of boundary layer control; however, C_L improvement was only 0.6 at $C_T = 3$ for BLC blowing at the flap knee.

A comparison of boundary layer control when using vortex generators and when using blowing at the USB flap knee is shown in Fig. 19 for a flap setting of 35°/60°. The two methods show an equivalent improvement in C_L at approach thrust and show an advantage in using vortex generators at the higher engine thrust levels. Blowing BLC at the aft USB flap segment was also investigated. The results, presented in Fig. 20, show that blowing at this location was more effective than blowing at the flap knee and was more effective than vortex generators at approach thrust power settings; vortex generators are shown to be superior BLC devices at high power settings. It should be noted, however, that ducting air to achieve blowing at this aft flap segment is very difficult in an actual aircraft. Blowing at the aft flap location is superior to blowing at the flap knee because blowing at the aft flap segment adds momentum to the jet flow in an area where the boundary layer is close to separation.

Presented in Figs. 21 and 22 are outboard engine-out data that show USB blowing to be more effective in improving the lift than vortex generators. This is due mainly to the BLC blowing enhancing the flow qualities in the flap region located behind the inoperative engine. The combined use of vortex generators and blowing at the flap knee further improves the lift, as shown in Fig. 22.

Concluding Remarks

Three series of wind tunnel tests were completed to provide basic data on the characteristics of several variations of the hybrid upper surface blowing concept. These data show that the hybrid-USB concept can provide improvements in performance and reductions in engine-out rolling and yawing moments. However, the characteristics observed are highly configuration-sensitive. Accurate prediction of the characteristics of a specific configuration will require wind tunnel tests of a representative powered model.

References

[1] "Quiet Propulsive Lift Research Aircraft Design Study," NASA CR-137557, Oct. 1974.

[2] "Quiet Short Haul Research Aircraft Design Study," NASA CR-137554, Sept. 1974.

[3] Waites, W. L. and Chin, Y. T., "Small Scale Wind Tunnel Investigation of Hybrid High Lift Systems Combining Upper Surface Blowing With the Internally Blown Flap," NASA CR-114758, June 1974.

[4] Carros, R. J., Boissevain, A. G., and Aoyagi, K., "Aerodynamic Characteristics of a Large-Scale Hybrid-Upper Surface Blown Flap Model Having Four Engines," NASA TM X-62460, July 1975.

[5] Feifel, Winfred M., "Small Scale Wind Tunnel Test of Internal Blowing for a Swept Wing Modified Buffalo Aircraft, NASA CR-137564, Oct. 1974.

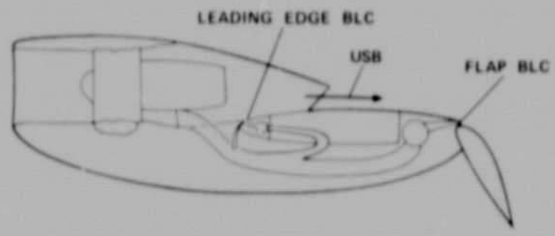


Fig. 1 Example of hybrid USB propulsive lift concept.

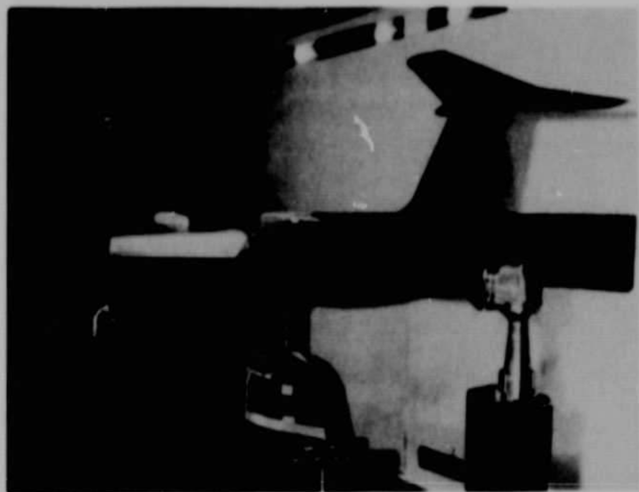


Fig. 2 Small-scale model in the Lockheed V/STOL Wind Tunnel.

	WING	HORIZ. TAIL	VERT. TAIL
ASPECT RATIO	7.731	4.52	1.449
TAPER RATIO	0.509	0.37	0.55
AREA METER² (FT²)	0.503 (6.494)	0.210 (2.264)	0.124 (1.339)
AIRFOIL SECTION	GELAC TAC/STOL	NACA 64-012 MOD	NACA 64-012 MOD

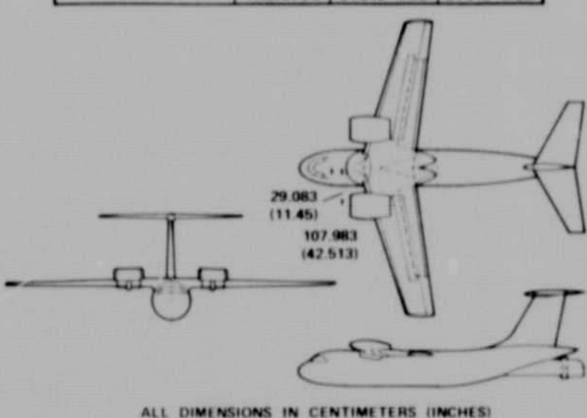


Fig. 3 Geometric details of the small-scale hybrid USB wind tunnel model.

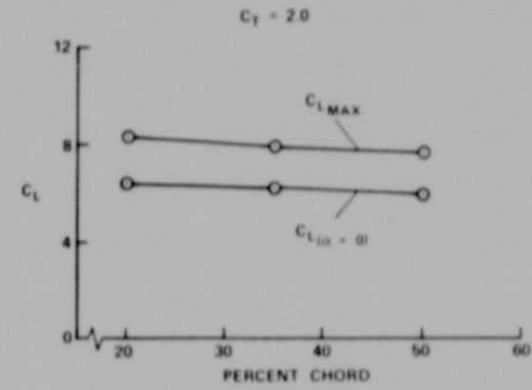


Fig. 4 Effect of nozzle exit location on lift coefficient.

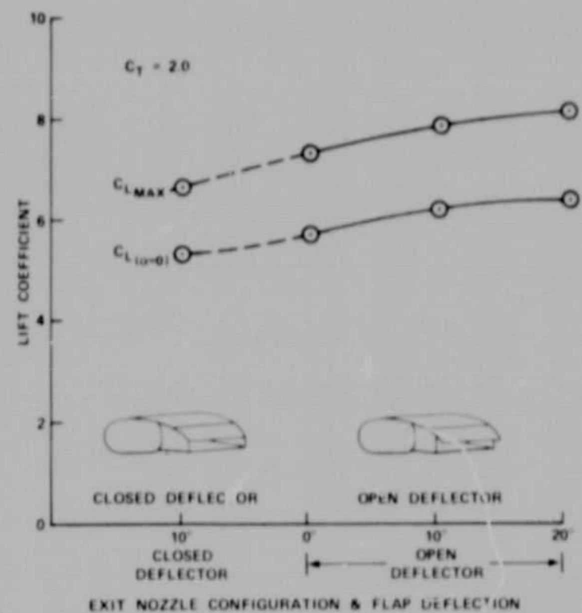


Fig. 5 Effect of exit nozzle configuration on lift coefficient.

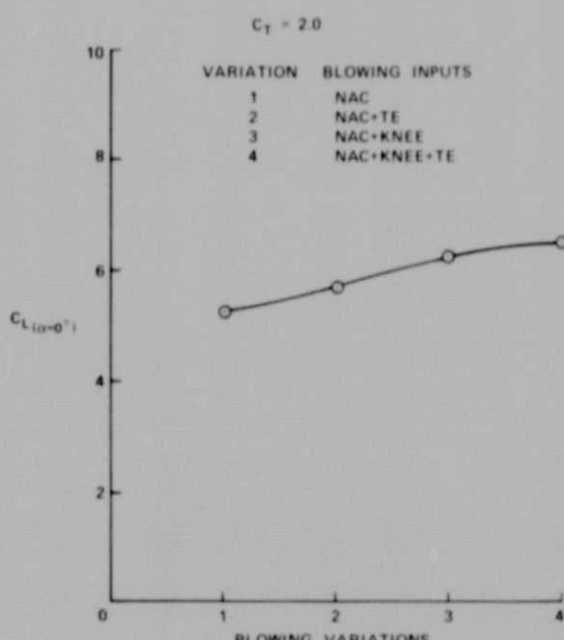


Fig. 6 Effect of blowing location on lift coefficient.

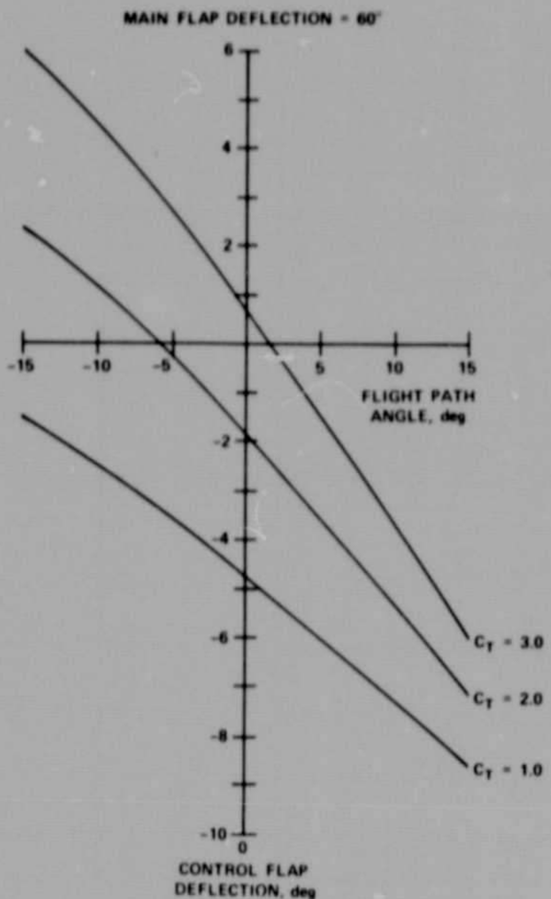


Fig. 7 Effect of control flap deflection on flight path angle.

Fig. 8 Large-scale model in the Ames 40- by 80-Foot Wind Tunnel.

ITEM	WING	V. TAIL
AREA SQ. FT.	230.0	68.0
ASPECT RATIO	8.00	1.20
TAPER RATIO	0.30	0.74
SPAN FT.	42.895	9.042
ROOT CHORD FT.	8.250	8.645
TIP CHORD FT.	2.475	6.397
MAC FT.	5.881	7.577
SWEEP (C/4) DEG	27.5	38.5
TAIL VOL. COEFF.		0.12
AIRFOIL SECTION	65A-4[2]	0012
POWER PLANT	4 P&W JT15D-1 ENGINES	

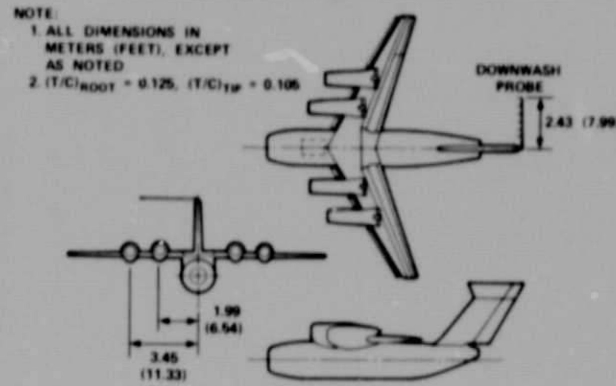


Fig. 9 Geometric details of the large-scale hybrid-USB model.

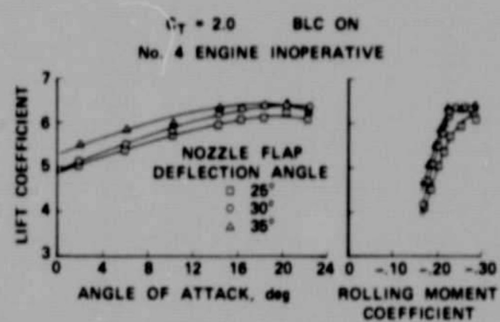


Fig. 10 Effect of nozzle flap deflection on lift coefficient and rolling moment coefficient with critical engine inoperative.

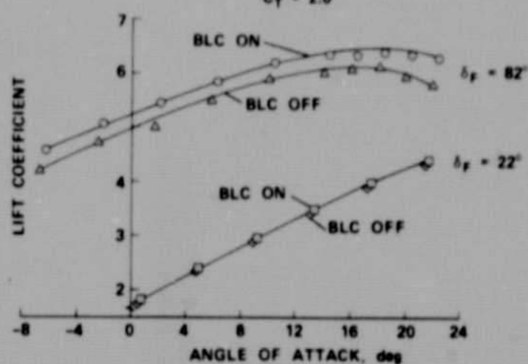


Fig. 11 Effect of BLC blowing on lift coefficient.

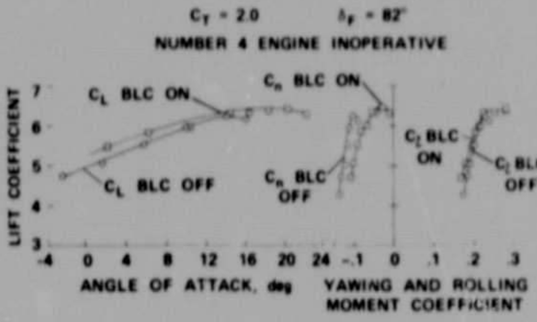


Fig. 12 Effect of flap knee blowing BLC on lift coefficient, rolling moment coefficient, and yawing moment coefficient with critical engine inoperative.

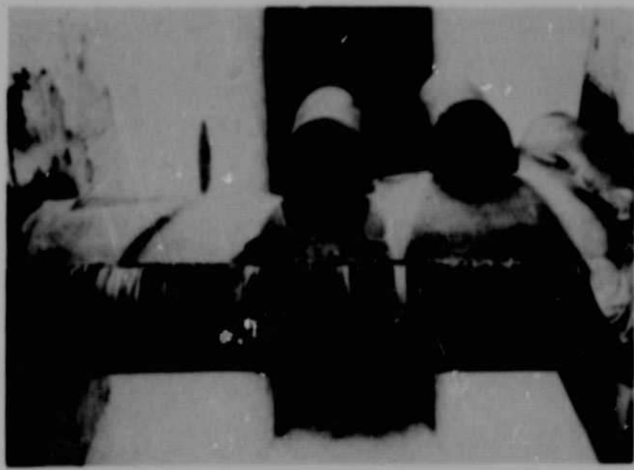


Fig. 15 Small-scale semi-span model in 3 × 8 foot Boeing Research Wind Tunnel.

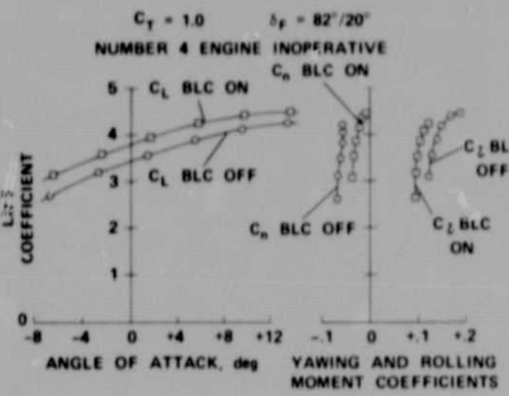
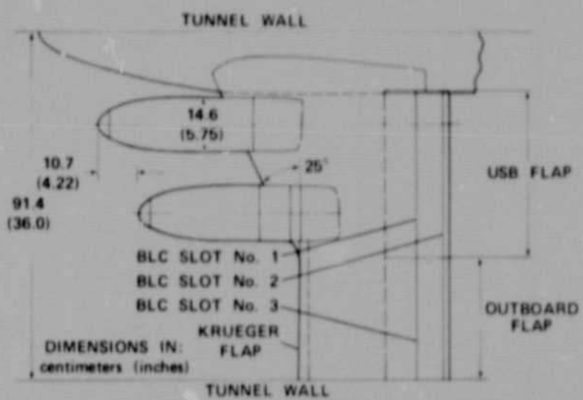


Fig. 13 Effect of flap knee blowing BLC on lift coefficient, rolling moment coefficient, and yawing moment coefficient with critical engine inoperative.



(a) General arrangement of the model.

Fig. 16 Small-scale semi-span model description.

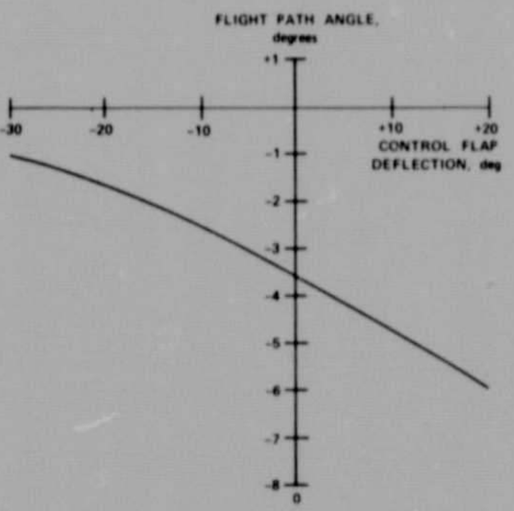
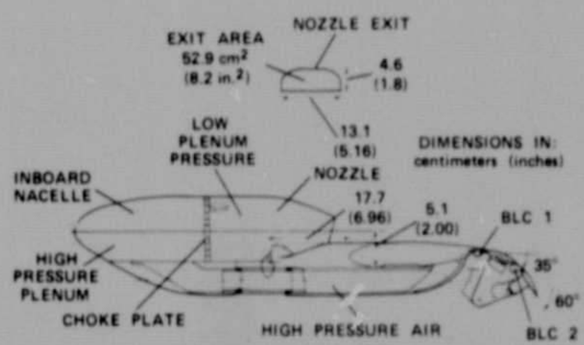


Fig. 14 Effect of control flap deflection on flight path angle: $C_T = 1.0$, $\delta_F = 82°$, W/S = 65 lb/ft^2, V = 70 knots.



(b) Details of the nacelle, wing, and flap arrangement.

Fig. 16 Concluded.

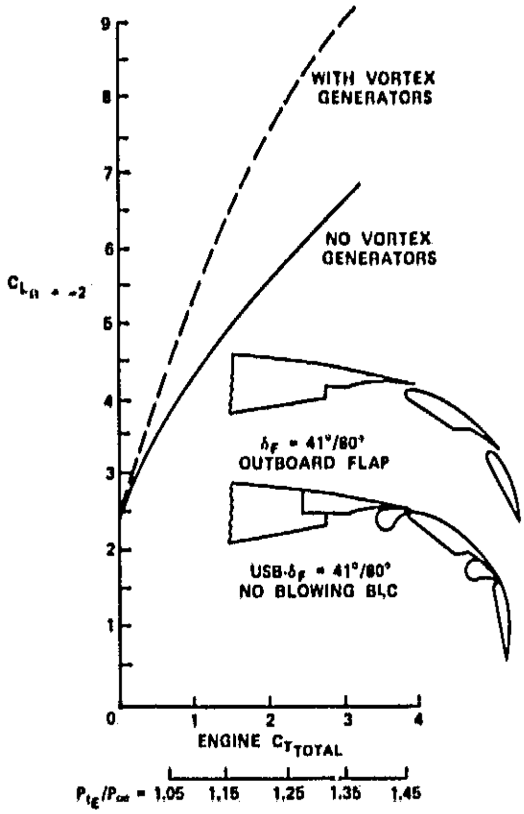


Fig. 17 Effect of vortex generators on lift coefficient.

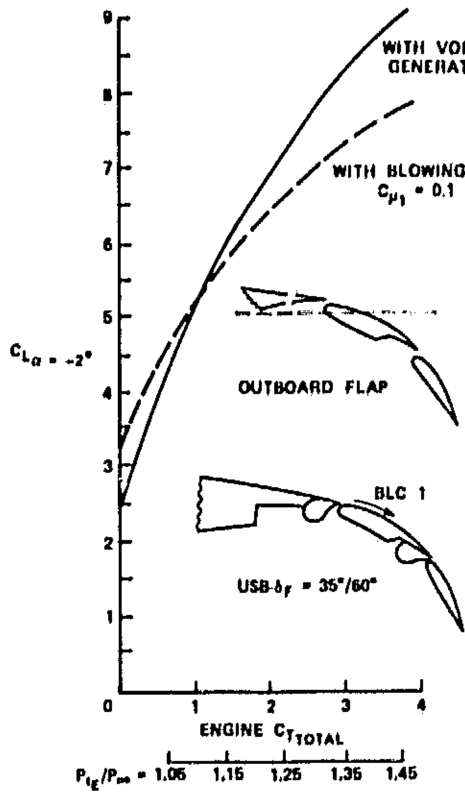


Fig. 19 Comparison of vortex generators with flap knee blowing BLC.

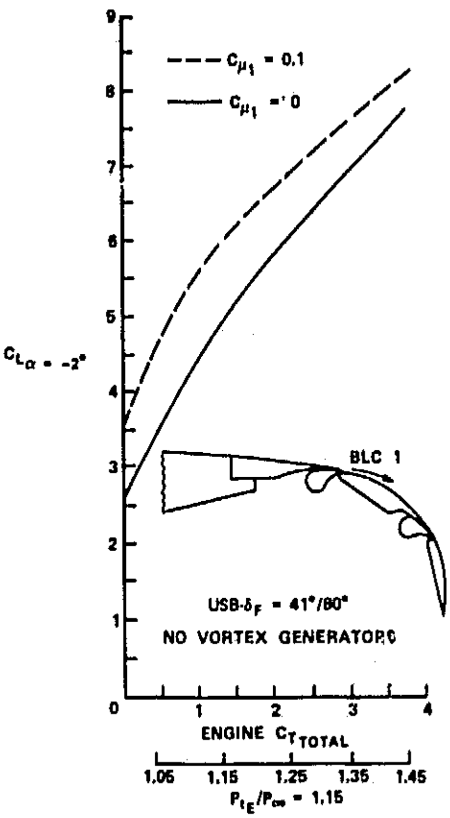


Fig. 18 Effect of flap knee blowing BLC on lift coefficient.

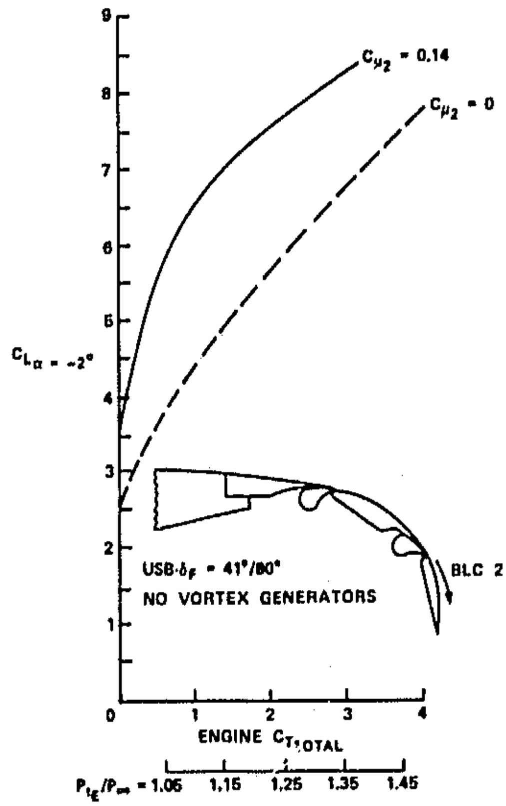


Fig. 20 Effect of blowing BLC at the aft-flap segment on lift coefficient.

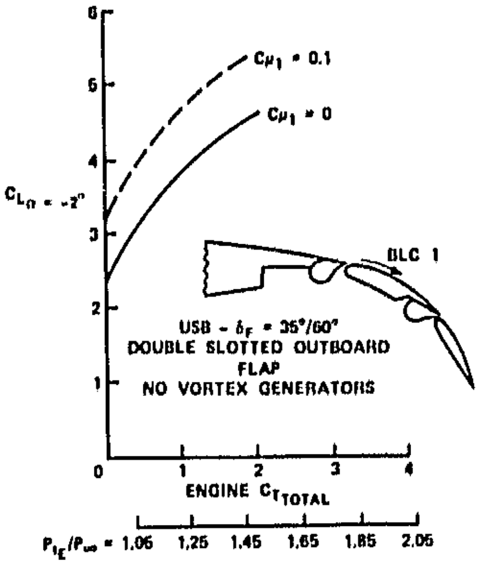


Fig. 21 Effect of flap knee blowing BLC on lift coefficient with the outboard engine inoperative.

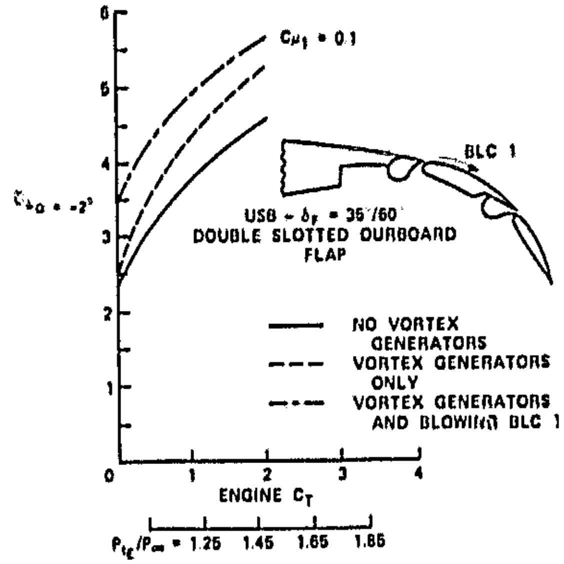


Fig. 22 Effect of vortex generators and flap knee blowing BLC on lift coefficient with the outboard engine inoperative.