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Effect of Side Fences on Powered-Lift Augmentation for USB Configurations

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The aerodynamic characteristics of the external upper surface blowing (USB) propulsive-lift configuration using side fences for enhancement of engine exhaust flow attachment over a wing and USB flap surface were studied by wind-tunnel experiments. Results were compared with those attained either by using the system without special devices or by using vortex generators. It was concluded that the USB propulsive-lift system using side fences had a superior potential for attaining high and efficient powered-lift performances.

Nomenclature

$A\!\!R_e$	= aspect ratio defined as nozzle area A divided by square of nozzle height $h = A/h^2$
$\bar{c}$	= mean aerodynamic chord of wing
C_D	= drag coefficient defined as drag force divided by qS
C_j	= thrust coefficient defined as engine thrust T divided by qS
C_L	= lift coefficient defined as lift force divided by freestream dynamic pressure times wing area = lift/qS
$C_{L\max}$	= maximum lift coefficient
C_M	= pitching moment coefficient defined as pitching moment divided by $qS\bar{c}$
C_p	= pressure coefficient defined as ΔP divided by jet dynamic pressure at nozzle exit $= \Delta P/0.5\rho U_{\rm jet}^2$
CEI	= critical engine inoperative (outboard engine out)
F_A	= axial force
F_N	= vertical force
N_1	= simulator engine fan rotor speed, rpm
OEI	= one engine inoperative (inboard engine out)
q	= freestream dynamic pressure $= 0.5\rho U_\infty^2$
S	= wing area
T	= static thrust force based upon engine calibrations with flaps removed $= \sqrt{F_N^2 + F_A^2}$
α	= angle of attack, deg
β_u	= nozzle kickdown angle, angle between horizontal and top surface internal leaving angle, deg
γ	= flight-path angle, deg
ΔP	= static pressure difference relative to ambient pressure P_0
δ_f	= USB flap deflection angle, deg
δ_j	= jet turning angle, deg
η_j	= jet turning efficiency

Introduction

AIRCRAFT design for short takeoff and landing (STOL) requires high values of maximum lift with appropriate lift/drag ratios. External upper surface blowing (USB) is one of the primary concepts for producing the powered high lift required for STOL operations. Powered-lift augmentation during low-speed STOL operations is derived by deflecting the turbofan engine exhaust flow adjacent to the wing/flap upper surface by Coanda principles.

One of the difficulties with USB-STOL aircraft relates to the attachment of the engine exhaust flow to the wing and extended USB flap surfaces during low-speed operations.

Some of the important parameters governing jet exhaust turning characteristics are the thickness of the wall jet and the radius of curvature of the flap upper surfaces, which are directly dependent upon the USB nozzle wing/flap geometry. The major aerodynamic design efforts in the USB configuration, powered by high-bypass ratio turbofan engines, have been directed to the area of the engine nozzle and the USB flaps.

At low speed, a relatively wide and thin exhaust jet results in better attached flow turning and hence powered-lift augmentation, which is usually accomplished by designing the turbofan engine nozzle exit geometry to have a higher aspect ratio with a higher nozzle kickdown angle.

In general, optimal USB designs which will enhance jet turning at low-speed STOL operations will degrade overall efficiency at high-speed cruise operation. High-aspect-ratio nozzles increase nacelle cruise drag and high kickdown nozzle designs result in a cruise drag penalty associated with nozzle boat-tail flow separation.[1]

To overcome the problem of these two incompatible design demands, several flow attachment devices that are retractable during cruise operation have been developed for USB-STOL applications. Vortex generators and USB nozzle side doors on the YC-14 (Ref. 2) are typical examples. However, some defects in the performance of vortex generators have been noted. One particular problem is that the installation of vortex generators has resulted in noise increases and thrust losses.[3] Also, retracting vortex generators during cruise or takeoff operation requires several actuator mechanisms, which brings up the problem of additional weight and structure complexity.

Following the concept of "the simpler the better," and in order to fulfill aeroacoustic design demands that attachment devices should bring about efficient powered lift with cleaner flow deflections,[3] we have developed side fences as an alternative solution for enhancing Coanda attachments applied to the USB-STOL propulsive-lift system.

Mechanisms for enhancing Coanda attachment by side fences and vortex generators may be qualitatively compared as follows: The installation of side fences prevents ambient air, which causes exhaust flow separation, from flowing in and under the jet exhaust, while vortex generators, which are installed on wings at an incidence angle of about 30 deg, prevent it by directing the exhaust flow toward regions where the flow separates to create an outward velocity component. Side fences are installed essentially parallel to the exhaust

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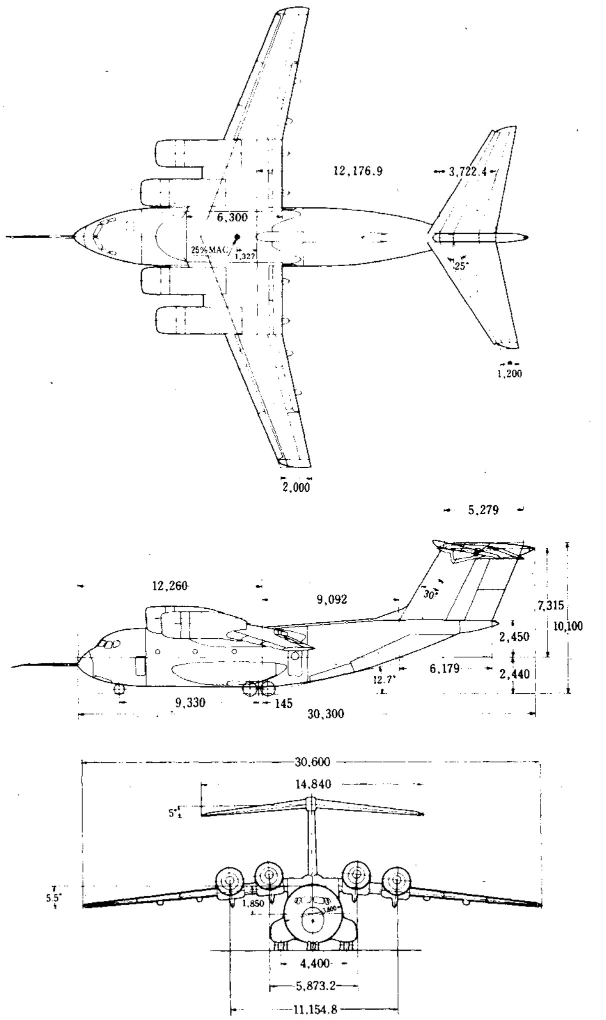

Fig. 1 General view of NAL quiet STOL research aircraft.

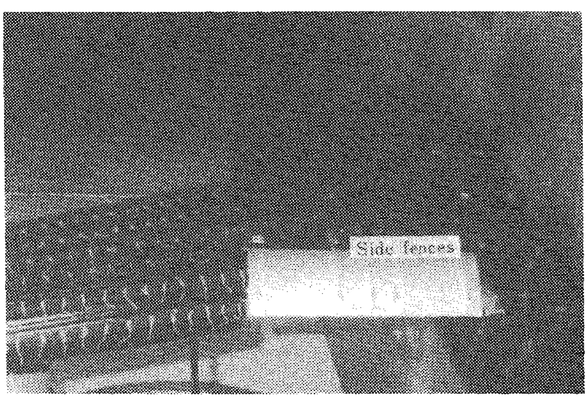

Fig. 2 Basic model configuration with side fences installed.

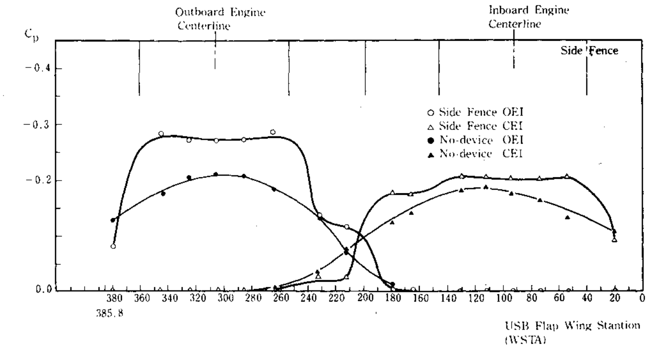

Fig. 3 Spanwise static pressure profiles along midchord line of USB flap ($\delta_f = 60$ deg, $\beta_u = 19$ deg).

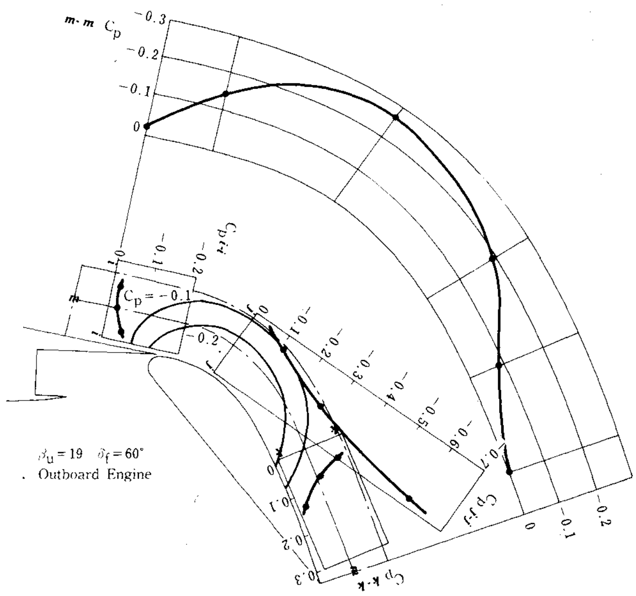

Fig. 4 C_p profiles and contours on side fence surface.

flow, which results in efficient jet turning without much loss of engine thrust, and does not necessitate retraction during cruise operation.

In the present paper we attempt to summarize the principal results and conclusions concerning the effect of side fences on powered-lift aerodynamic performances as ascertained by wind-tunnel experiments.

Results and Discussion

A research program has been undertaken at the National Aerospace Laboratory (NAL) to determine the effect of side fences on the powered-lift aerodynamic characteristics of a four-engine USB configuration. The 8%-scale semispan model used in this study simulates the NAL Quiet STOL Research Aircraft (see Fig. 1), which has a nominal quarter-chord wing sweep back angle of 20 deg. The inboard and outboard engine nacelles are located at 23.8% [wing station (WSTA) = 92] and 79.2% (WSTA = 306) of USB flap span (385.8 mm), and 40.0% and 36.6% of wing chord, respectively.

Simulator engines equipped with D-shaped exhaust nozzles ($A\!R_e = 2.63$, $\beta_u = 19$ deg) were supplied with high-pressure air from the fuselage and control valves to permit simulation of the exhaust flow characteristics of turbofan engines.

During wind-on aerodynamic tests, aileron and wing leading-edge boundary-layer controls were incorporated to delay the wing stall to higher maximum lift.

A photograph of the wind-tunnel installation for the basic model configuration is presented in Fig. 2.

As preliminary studies, a number of static experiments were conducted to obtain the jet turning performance and static pressure distributions on the upper surface of the USB flap and inner surface of the side fence. Figure 3 presents the spanwise static pressure profiles along the midchord line of the USB flap in terms of a pressure coefficient C_p where negative values indicate suction pressures. The C_p profiles compared in Fig. 3 are for the landing flap $\delta_f = 60$ deg configuration with and without side fences installed. The locations of the five side fences installed are at WSTA = 40, 147, 200, 254, and 360, respectively. The height of the side fence is 15 mm, which is approximately 30% of the maximum height of the D-shaped USB nozzle, h. An increase in

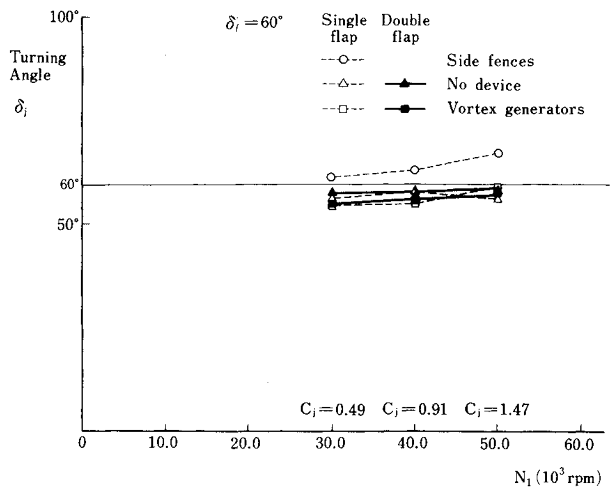

Fig. 5 Effect of side fences on the jet turning performance.

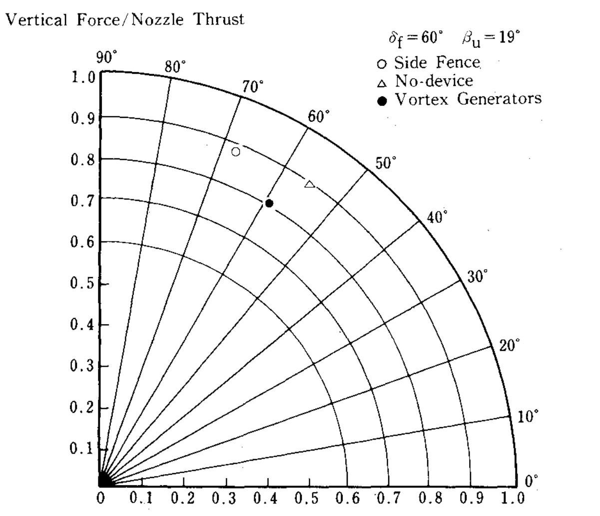

Fig. 6 Thrust vectoring performance.

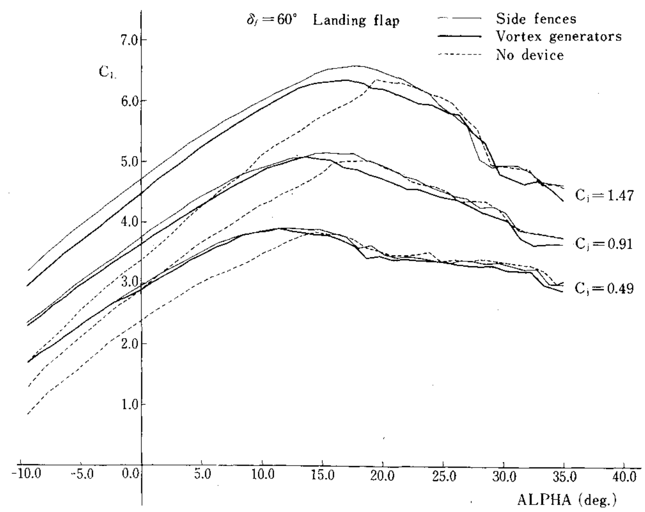

Fig. 7 Effect of side fences on lift characteristics ($\delta_f = 60$ deg, $\beta_u = 19$ deg).

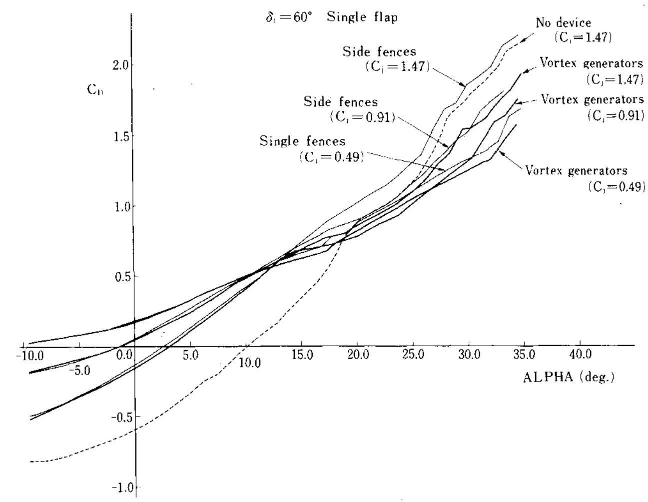

Fig. 8 Effect of side fences on drag characteristics ($\delta_f = 60$ deg, $\beta_u = 19$ deg).

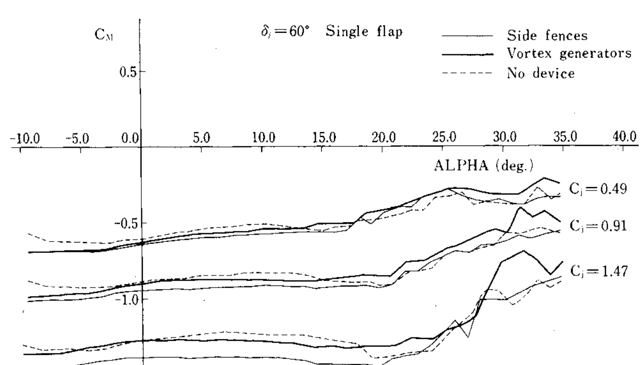

Fig. 9 Effect of side fences on pitching moment coefficient ($\delta_f = 60$ deg, $\beta_u = 19$ deg).

negative C_p values within the confines of side fences can be shown.

Figure 4 presents C_p profiles and their contours on the inner surface of the side fence at the location WSTA = 360 for the landing flap configuration $\delta_f = 60$ deg. Higher negative values of C_p occurred in the vicinity of fore portions of the USB flap (surface curvature being large), indicating that the fence plays its dominant role there. In view of the results indicated in Fig. 4, it may be possible, by tailoring the side fences, to further reduce the size of side fences without deteriorating their performance. The results provide a basis for understanding the effect of side fences in enhancing exhaust flow attachment.

Figure 5 shows the effect of side fences on static jet turning performance for the landing flap configuration $\delta_f = 60$ deg, compared with the typical deployment of vortex generators [with an incidence angle of 30 deg and an aspect ratio (chord to span) of 2.5]. The results are presented in terms of the jet turning angle δ_j as functions of the simulator engine's fan rotor speed N_1. The installation of side fences provides about 10 deg improvement. Also, values of the jet turning angle δ_j tend to increase with increasing fan rotor speed, except where no attachment devices were used.

Figure 6 presents the customary polar plot that summarizes the thrust vectoring performance at fan rotor speed $N_1 = 50{,}000$ rpm. The USB configuration with side fences achieves higher jet turning efficiency ($\eta_j = 0.89$) compared with vortex generators ($\eta_j = 0.80$).

The aerodynamic characteristics for the corresponding landing flap USB configuration in the low-speed wind-tunnel experiment ($U_\infty = 30$ m/s) as a plot of the lift coefficient C_L and the drag coefficient C_D against the angle of attack α are presented in Figs. 7 and 8, respectively. The data are shown for the thrust coefficient $C_j = 0.49$, 0.91, and 1.47. The dramatic improvement in lift characteristics by the installation of side fences is shown in Fig. 7. Also, side fences

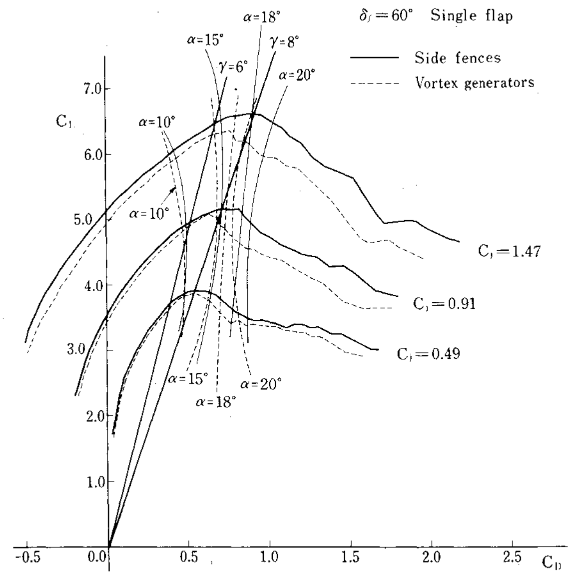

Fig. 10 Lift-drag polars for the landing flap configuration.

achieved a lift performance superior to vortex generators; i.e., an increase in both maximum lift coefficient $C_{L_{max}}$ and stall angle of attack can be seen. As indicated in Fig. 8, side fences induced considerable drag, compared with vortex generators, in the high angle of attack range for the landing flap USB configuration.

Figure 9 presents the pitching moment coefficient C_M against angle of attack α for the landing flap configuration with the horizontal tail off. As indicated in the pitching moment plots, the USB configuration with side fences paid a slight penalty for its superior lift performance; i.e., higher negative pitching moments were observed compared with vortex generators.

The lift-drag polars for the landing flap configuration $\delta_f = 60$ deg, as shown in Fig. 10, indicates that configurations using either side fences or vortex generators have the positive drag necessary for descent in the required high lift range; however, the landing configuration with side fences installed has better descent capability than with vortex generators. For example, with the flight path angle $\gamma = -8$ deg and the thrust coefficient $C_j = 0.91$, side fences achieved $C_L = 5.2$ at an angle of attack $\alpha = 15$ deg, while in order to arrest this descent at the same flap setting with the same thrust in a configuration using vortex generators, the required approach angle of attack goes beyond the stall angle of this configuration with a decrease in C_L (=4.8).

Concluding Remarks

The fundamental aspects concerning the effect of side fences on powered-lift augmentation for USB propulsive-lift configuration have been presented. From the comparisons we have made of configurations using side fences, those using vortex generators and those using no special devices, we conclude that the USB propulsive-lift concept using side fences for enhancement of engine exhaust flow attachment has promising potential for attaining very high and efficient powered-lift performances.

References

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