AIAA-90-3009 Propulsive Lift Augmentation by Side Fences as Applied to Japan’s Experimental STOL Aircraft, ASKA
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Propulsive Lift Augmentation by Side Fences as Applied to Japan’s Experimental STOL Aircraft, ASKA

Masatoaka MAITA*, Katsumi TAKEDA*, Hamaki INOKUCHI**, Takashi INOUÉ**, Kosumichi KURIYAMA**

Abstract

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 / USB flap surface were studied by static ground experiment of Quiet STOL Experimental Aircraft ASKA. Results were compared with those attained by other attachment devices such as vortex generators, and also by the previous sub-scale wind tunnel studies.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta ) (( \delta_{ELJ} ))</td>
<td>Exhaust flow turning angle (deg)</td>
</tr>
<tr>
<td>( \eta ) (( \eta_{ESA} ))</td>
<td>Exhaust flow turning efficiency</td>
</tr>
<tr>
<td>( C_{D} )</td>
<td>Drag coefficient</td>
</tr>
<tr>
<td>( C_{L} )</td>
<td>Lift coefficient</td>
</tr>
<tr>
<td>( \mu )</td>
<td>Friction coefficient</td>
</tr>
<tr>
<td>( F_R )</td>
<td>Resultant force, ( \sqrt{T_{NL}^2 + T_{FR}^2} )</td>
</tr>
<tr>
<td>( T_{NL} )</td>
<td>Normal force acting on aircraft (kg)</td>
</tr>
<tr>
<td>( T_{FR} )</td>
<td>Axial force acting on aircraft (kg)</td>
</tr>
<tr>
<td>( T_{NL,M} )</td>
<td>Engine nozzle thrust (kg)</td>
</tr>
<tr>
<td>( \theta_{FL} )</td>
<td>USB flap deflection angle (deg)</td>
</tr>
<tr>
<td>( \theta_{FL,M} )</td>
<td>Outboard flap deflection angle (deg)</td>
</tr>
<tr>
<td>( N_{I} )</td>
<td>Engine fan rotor speed (rpm)</td>
</tr>
<tr>
<td>( N_{I,M} )</td>
<td>No.1 engine fan rotor speed (rpm)</td>
</tr>
<tr>
<td>( W_{P} )</td>
<td>Fuel weight (kg)</td>
</tr>
<tr>
<td>( W )</td>
<td>Aircraft weight (kg)</td>
</tr>
<tr>
<td>( w_{i} )</td>
<td>Initial aircraft weight (kg)</td>
</tr>
<tr>
<td>( \phi )</td>
<td>Aircraft altitude angle (null) (deg)</td>
</tr>
<tr>
<td>( \phi_{b} )</td>
<td>Aircraft altitude angle (pitch) (deg)</td>
</tr>
<tr>
<td>( W_{C,D} )</td>
<td>Normal force at no external load (J=1), at left board main landing gear (J=2), at left board main landing gear (J=3), at right board main landing gear (J=4), at right board main landing gear (J=5) (kg)</td>
</tr>
<tr>
<td>( F_{AL} )</td>
<td>Axial force at left board main landing gear</td>
</tr>
<tr>
<td>( F_{AR} )</td>
<td>Axial force at right board main landing gear</td>
</tr>
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</table>

National Aerospace Laboratory, Science and Technology Agency of Japan had conducted research and development program of the Quiet Short Take Off and Landing Experimental Aircraft ASKA, which was designed for flight investigation into powered lift terminal area operations, first flew in 1985 and has flown over 160 hours since. The aircraft configuration features a wide body within aft leading cargo ramp, a swept-back wing with leading edge slats, trailing edge flaps and spoilers, a high 5° tail to position the horizontal tail above the nacelle and engine exhaust wakes, and extended bulges. The wing trailing edge flaps system are composed of inboard USB flaps located directly behind the engines, quadruple-slotted flap outboard of USB flaps and dropped ailerons at the wing tips. The boundary layer controls are incorporated at the wing leading edge slats and ailerons.

The general arrangement of the NAL-QSTOL Experimental Aircraft ASKA is shown in Figure 1.

ASKA was powered by four FJ710-656/8 turbofan engines which had a bypass ratio of 6.5, rated at approximately 4500kg static thrust\(^{34}\), utilizing propulsive lift system.

Aircraft design for STOL requires high values of maximum lift with appropriate lift/drag ratios. ASKA employed the external upper surface blowing (USB) concept for producing the powered high lift required for low speed STOL operations.

Powered lift augmentation is derived by deflecting the turbfan engine exhaust flow adjacent to the wing / flap upper surface by Canada 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.

The design of the engine nozzle was one of the key element in developing the USB propulsive.
lift system. In addition to achieving effective thrust deflection during low-speed operation, the nozzle must provide the low drag and/or high thrust capabilities for high speed cruise operation and furthermore satisfactory area match with the FJ417/606S turbofan engines.

At low speed, a relatively thinner exhaust jet results in better attached flow turning and thereby provides higher powered lift augmentation, which is usually accomplished by designing the nozzle exit geometry to have a higher aspect ratio with a higher kickdown. Optimal USB nozzle designs which will enhance exhaust jet turning performance at low-speed STOL operation, however, will often degrade overall efficiency at high speed cruise operation, i.e., high aspect ratio nozzles increase nacelle drag and high kickdown nozzle designs result in a cruise drag penalty associated with nozzle boot -tail flow separation.  

To overcome the problem of these incompatible design demands, several flow attachment devices that are retractable during cruise operation have been developed for USB-STOL application. Vortex generators and USB nozzle side doors on the YC-14 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 have resulted in noise increases and thrust losses. Also, retracting vortex generators during cruise or take off 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 acoustic design demands that attachment devices should bring about efficient powered lift with cleaner flow deflections, we have developed side fences as an alternative solution for enhancing Canada attachments applied to the USB-STOL propulsive lift system for the experimental aircraft ASKA.

![Photograph 1 Side fences installed on the propulsive lift system of ASKA](image)

The engine exhaust D-shaped nozzle was designed to have moderate aspect ratio of AR=3.29 with lower kickdown angle of 19 deg. The engine nozzle selected was equal to the FJR Engine nacelle diameter, which was necessary to keep cruise drag low. The kickdown angle of 19 deg. reduce the boot-tail drag and/or wing scrubbing drag, which was lower nozzle kickdown angle than that used in YC-14, ASKA or other known investigations for USB propulsive system.

The nozzle height to fore flap radius ratio is 0.94. The ability to develop satisfactory exhaust flow turning with such a high nozzle to flap radius ratio or low nozzle kickdown was achieved by using the device, side fence. In the NAL-QSTOL total of eight side fences were installed on the propulsive lift system of the left -wing and right-wing sides. (cf., Photograph1) The height of side fence was 160mm which was...
approximately 30 percent of the maximum height of D-shaped nozzle, D.

Side fences were installed essentially parallel to the exhaust flow, which results in efficient turning without much loss of engine thrust, and do not necessitate retraction during cruise or takeoff operations.

Through the development of USB propulsive-lift system using side fences for enhancing the exhaust flow attachment, a number of static rig experiments on the thrust vectoring performances as preliminary studies have been undertaken to establish the basic requirements and objectives of the propulsion system. The first screening configurations are checked and for further configuration development and optimization, a series of wind tunnel experiments have been followed up, which then confirmed wind on performances with complete aircraft sub-scale models. These wind-tunnel tests defined and verified the effectiveness of the control surfaces and effects of engine out and/or other failure conditions and provided a data base for the flight simulation. The relevant full-scale testing were performed in the NAL-QSTOL propulsion system ground rig test using the actual FJ710/600 turbofan engine to evaluate the effectiveness of the wind-tunnel model test data.

Actual ground test by applying side fences to NAL-QSTOL experimental Aircraft ASKA was carried out to confirm the effectiveness of the previous studies.

In the present paper, we attempt to summarize the principal results on the aerodynamic characteristics of the external upper surface.

flowing propulsive-lift configuration using side fences for enhancement of engine exhaust flow attachment as ascertained by the ground test of NAL-QSTOL experimental aircraft ASKA.

II. Ground Test Apparatus and Procedure

Figure 2 shows ASKA's ground test apparatus.

The lift and thrust forces acting on ASKA were determined by the axial and normal forces acting on the main and nose landing gears. The normal forces were measured, using three sets of load pads (a square steel plate equipped with calibrated strain gage flexure posts at each corner) at each banding gear station. The axial forces were measured, using two sets of load cells (strain gage type) at each main landing gear. The load cells were connected to the landing gear's tie-down forks through universal joints, while the other end of load cells were connected to the anchor plates through turn buckles.

The friction force between wheels and the load pads were measured by towing the airplane with a tow car through a load cell in advance. Instead of bolting the anchor plates directly on the paved ground, 12 steel plates (1500mm × 3050mm × 32mm), consisting of small steel plates and bolts reinforced by I-beam, were substituted for the ground. The anchor plates were bolted on the plates. Steel shields were located under the USB flaps.

![Figure 2: Ground Test Apparatus](image-url)
to prevent engine exhaust jet from impinging on the measuring equipments during engine operation with high-flow turning angles. These shields also prevented the hot exhaust gas from recirculating into the engine.

The strain gauge output data were acquired into ASKA's onboard flight data system and recorded continuously.

Temperature and sound pressure measurements over the wing/USB flap surfaces and fuselage were carried out by using the ASKA's aircraft data system.

ASKA is equipped with high-speed data system composed of transducers, signal-conditioning equipments, telemetry transmitter, and data recorders. This data system is capable of data acquisition, telemetering data in real time to a ground data facility, and recording both aircraft and ground instrumentation data for post-test analysis.

The meteorological data such as wind speed and direction, air temperature, and barometric pressure were reported by radios from control tower of the test site.

III. Results and Discussion

In Figure 3, the typical data output of the ground test measurements were presented, where the symbols in the graphs were described in the nomenclature.
Figure 3  Typical data output of the ground test measurements (side fences, $\delta_{i_{\text{fence}}}=40^\circ$)

In Figures 4 and 5, thrust vectoring performances are presented, where the exhaust flow turning angle $\delta_j$ in degrees and the thrust flow turning efficiency $\eta_j$ are expressed in polar coordinate, and the lift force $T_{2R}$ (vertical) and the drag force $T_{2A}$ (axial), both divided by the nozzle thrust $T_{2N}$, are expressed in Cartesian coordinate. The turning angle $\delta_j$ and the turning efficiency $\eta_j$ were defined as:

$$\delta_j = \arccos \left( \frac{T_{2R}}{T_{2A}} \right)$$

$$\eta_j = \frac{F_g}{4T_{2A}}$$

where:

$$T_{2R} = \begin{pmatrix} \cos \theta & 0 & 0 & -\sin \theta \\ \sin \theta \cos \phi & \cos \theta & \sin \theta \sin \phi & \cos \phi \\ 0 & -\cos \theta \sin \phi & \sin \theta & \sin \phi \cos \theta \\ 0 & 0 & 0 & 1 \end{pmatrix} T_y$$

$$T_{2A} = F_{\text{A}} + F_{\text{A'}} + \mu(W-T_z)$$

$$T_z = W_{\text{CG}} + W_{\text{CG}} + W_{\text{CG}} + W_{\text{CG}} + W_{\text{CG}} + W_{\text{CG}} + W_{\text{CG}}$$

and $T_{2N}$ were obtained from FJR 710/600S engine data map in terms of corrected fan rotor speed $N_1$.

Figure 4  Thrust vectoring performances for side fences configuration.

Figure 5  Thrust vectoring performances for vortex generators configuration.

As compared to the case of the typical deployment of the vortex generators (The chord to span ($=150$ mm) aspect ratio 2.5 installed with an incidence angle of 30deg. with respect to the engine centerline axis located on the main wing trailing edge, Figure 4), the propulsive-lift system with side fences installed achieved higher jet turning with lesser loss of exhaust thrust. For the cruise flap configuration, no substantial differences in turning efficiencies which included wing/USB flap scrubbing and losses by the attachment devices themselves, between the cases with and without side fences was found.
whereas the efficiency decreased by approximately 5\% by the deployment of vortex generators. These results were quite consistent to the previous results of sub-scale model and full-scale static rig test.

Figure 6 presents the sound pressure on the wing and USB flap surfaces and fuselages for the case of side fences, while Figure 7 presents the case of typical deployment of vortex generators. It could have been noted that high impact pressures occurred in the outer vicinity of vortex generators on the main wing surfaces.

As could be shown in the Figures, higher sound pressure levels near the USB flap trailing edge as well as on the fuselages were observed for the case of vortex generators, as compared to the case of side fences. Hence the exhaust jet / USB flap trailing edge interacted noise was considered as one of the dominant noise sources for low frequency ranges of the USB STOL aircraft\(^6\), the side fences concept considered to be superior to the vortex generators in aeroacoustics aspect.

Figures 8 and 9 present surface temperature profiles over the wing / USB flap and fuselages for the side fences configuration (\(\delta_{\text{USB}}=40^\circ\)) and the vortex generators configuration respectively.

It was noteworthy that increases in temperature on the wing/USB flap surfaces and fuselages were observed, which was also the defects in the performance of vortex generators in view of the protection of the wing and fuselage structure.
IV. Concluding Remarks

The aerodynamic characteristics of the external upper surface blowing propulsive-lift configuration using side fences for enhancement of the engine exhaust flow attachment over a wing/USB flap surfaces were studied by the static ground experiment of Quiet STOL Experimental Aircraft ASKA. We have confirmed that the results were quite consistent with the previous results as ascertained by wind tunnel experiment and full scale rig test. From the comparisons we have made of configurations using either side fences or vortex generators, we concluded that the USB propulsive-lift concept with side fences achieved effective enhancement of the exhaust flow attachment as well as effective enhancement in the aspects of aeroacoustics and structural thermal load.

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