EFFECT OF LATERAL BLOWING ON AERODYNAMIC CHARACTERISTICS OF LOW ASPECT-RATIO WINGS AT HIGH ANGLES OF ATTACK

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Abstruct. Measurements of aerodynamic characteristics of clipped delta wings having low aspect ratio are made in a wind tunnel at subsonic/transonic Mach numbers to investigate feasibility for enhancement of wing performance due to the lateral blowing. It is shown that the blowing brings about a considerable lift-increase in wide ranges of angles of attack and free stream Mach numbers without serious degradation of lift to drag ratio. The aerodynamic mechanism of the lift-augmentation is deduced to be attributed to the two processes. The one is the circulation enhancement that results from a favorable modification of the pressure on the upper surface of the wings and takes place at low angles of attack. The another cosists in that the blowing enhances the leading-edge vortex so as to delay its breakdown and occurs at high angles of attack. Moreover, it is emphasized that the lateral blowing is more efficient for increase of lift than the so-called spanwise one in the sense of the blowing momentum.

Introduction

The canard-wings and strakes are often used in many types of supersonic aircrafts having low aspect-ratio and swept leading-edge wings to improve the aerodynamic performance at low speed flights. In contrast with the conventional high lift devices the blowing seems to offer another method available for lift-augmentation of the low aspect ratio wings, namely, the spanwise blowing[1] and the lateral one[2,3]. in the former a small jet is applied directly into core of the leading-edge vortex to delay its breakdown, and in the latter a small sonic jet is injected from the root of and in the direction parallel to the trailing-edge for enhancement of the wing circulation.

This study has the purpose of not only clarifying the aerodynamic feasibility of the lift-increase due to the lateral blowing but examining its aerodynamic mechanism. A series of surface pressure measurement, force tests and flow visualiztion are conducted in a wind tunnel at subsonic/transonic Mach numbers using half-wing models. Based on the present results, the aerodynamic mechanism of the lift-augmentation is deduced with emphasis on the improtance of the blowing location.

Experiment

Experimental Facility and Models. The experiment was conducted in a blowndown type transonic wind tunnel having 60cm × 60cm square test section. The tunnel covers the range of free stream Mach number from 0.3 to 1.3 continuously.

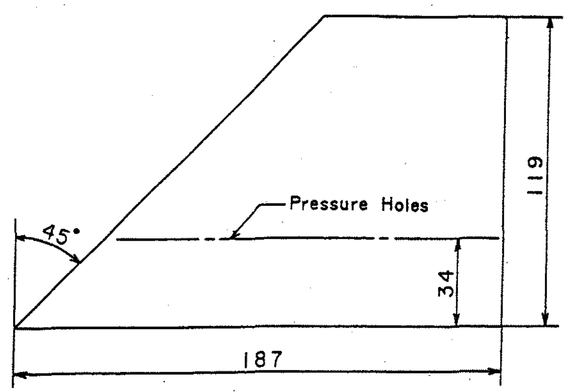


Fig.1(a). Half-wing model.

Fig.1(a) shows planform and main sizes of the two half-wing models. They have a trapezoidal planform with aspect ratio of 0.933. The one is made of circulararc airfoil having 12% thickness (CAW-model) and the another consists of 11% supercritical wing section (SCW-model).

The force tests were carried out using a balance of side wall type. The experimental setup for the force tests

was so designed that thrust of the jet did not interfere with the balance.
The model was supported by the balance attached to a turning plate, which was fixed in the frame of a glass window. Three sonic nozzles with exit diameter of 2, 3 and 4mm, respectively, were used to investigate the effect of the blowing momentum. Each nozzle was made in an appropriate small disk fitted to the turning plate (see Fig.1(b)). The axis of the nozzle locates at 2.5mm vertical distance downwards from the trailing-edge in the root section of the wing model. Therefore, the change of model attitude was made by rotation of the turning plate.

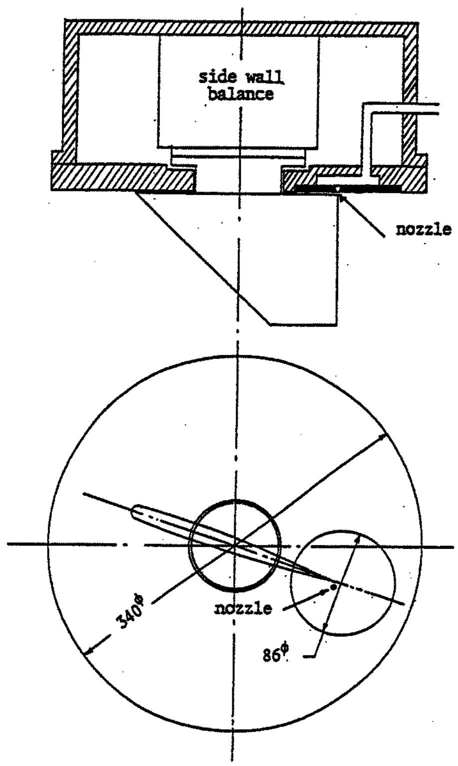


Fig.1(b). Experimental setup.

Measurement. The aerodynamic data such as lift, drag and pitching-moment were measured in the ranges of Mach number from 0.3 to 1.3 and the angle of attack from -5° to 35°. However, it must be noted that the force test at the transonic region was limited to a range of small angle of attack only ($|\alpha| < 6°$) because of shortage in capacity of the pitching moment sensor of the balance. Date acquisition was carried out using sweep mode of either angle of attack or Much number, and the sampling interval of the date was 2.5° in the former, whereas it was 0.05 in the direction of decreasing Mach number in the latter. The chordwise distribution of the surface pressure was measured using the SCW-model at $\eta = 0.286$, where η means the nondimensional spanwise distance defined as y/b, and where b denotes the span of the half-wing model.

Results and Discussions

Fig.2 shows a typical example of the lift-augmentation that the lateral blowing brings about at M = 0.3, where CL, α , Xj and Pj are lift coefficient, angle of attack, blowing lacation and stagnation pressure (MPa) of jet flow, respectively. Cj means blowing momentum coefficient defined by the equation

$$C_j = 2\, m_j u_j / \{(\rho u^2)_\infty S_w\} \qquad (1)$$

where m, u, ρ and Sw denote mass flow rate, velocity and density of the flow and wing area, respectively, and the subscripts j and ∞ are conditions at the nozzle exit and in the free stream.

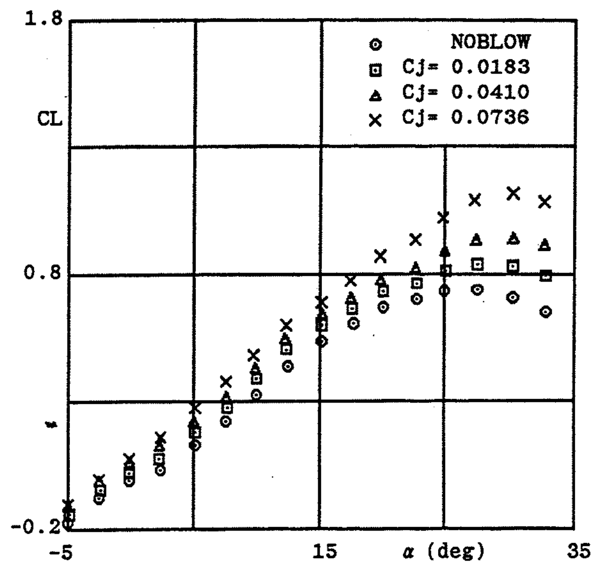


Fig.2. Aerodynamic data change with incidence
M = 0.30, Xj=1.00L, Pj=1.077, CAW-0.12

It is evident in the figure that the lateral blowing surely brings about a considerable amount of lift-increase that can be controlled distinctly by regulation of the blowing momentum.
The same is true qualitatively for other subsonic/transonic Mach numbers irrespective of the airfoil shape, and it may be concluded that the blowing is capable of increasing not only the

maximum lift but also the stall angle of the wing, as shown in Fig.3, where Pj is fixed at 1.078MPa and Dj denotes the exit diameter of the nozzle.

Fig.4 shows the response of the drag to the blowing, where CD is the drag coefficient. Since the blowing augments the lift, the drag increases in general in the light of the conventional understandings of the induced drag. However, it must be pointed out in the figure that the drag seems to diminish in case the angle of attack is small. To confirm this in detail the drag curves in the range of small angle of attack are presented using enlarged axes in Fig.5. A particulat attention must be paid to the marvelous fact that the blowing brings about a slight but distinct decrease of the drag for small negative angles of attack even if the lift may increase, although the drag-reduction is not so significant yet.

To examine this circumstance the associated L/D ratio is presented in Fig.6, where L and D denote the lift and drag forces, respectively. It must be noted that the drag-reduction due to the blowing increases the L/D ratio apparently to a significant extent in the range $|\alpha| \leq 6°$, beyond which it seems to be nearly insensitive to the

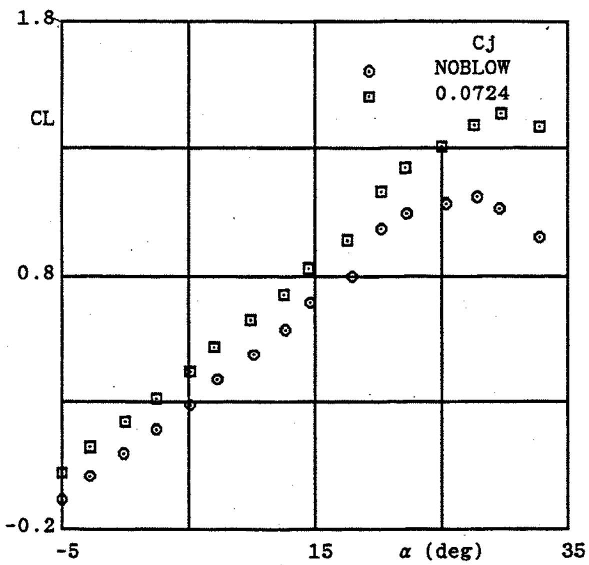


Fig.3. Aerodynamic data change with incidence
M = 0.31, Dj=4(mm), Xj=1.00L, SCW-0.11

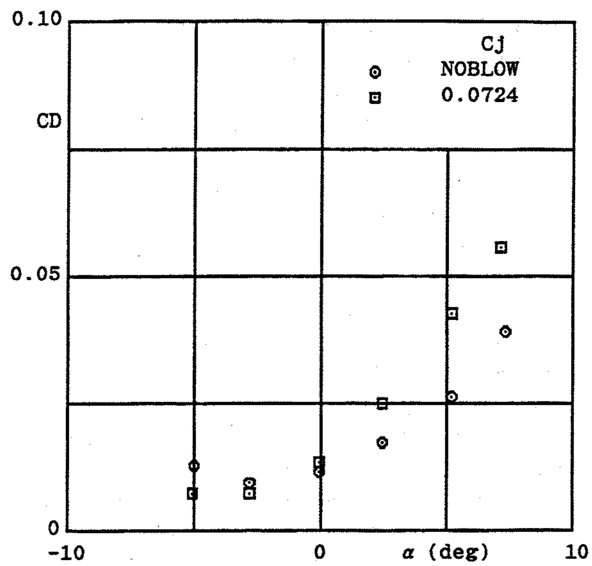


Fig.5. Aerodynamic data change with incidence
M = 0.31, Dj=4(mm), Xj=1.00L, SCW-0.11

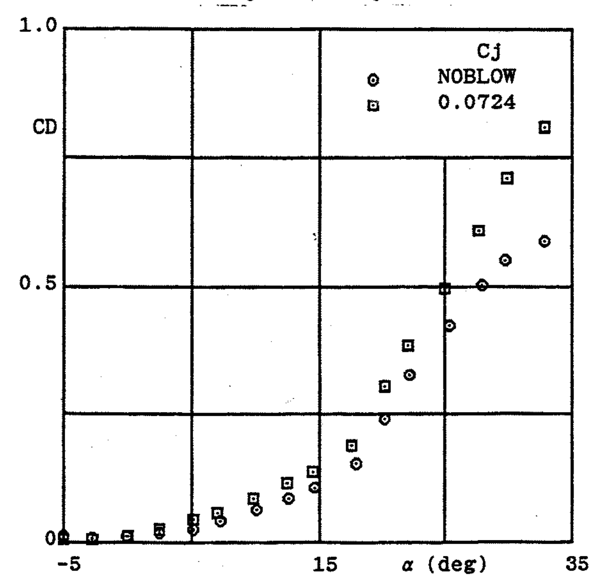


Fig.4. Aerodynamic data change with incidence
M = 0.31, Dj=4(mm), Xj=1.00L, SCW-0.11

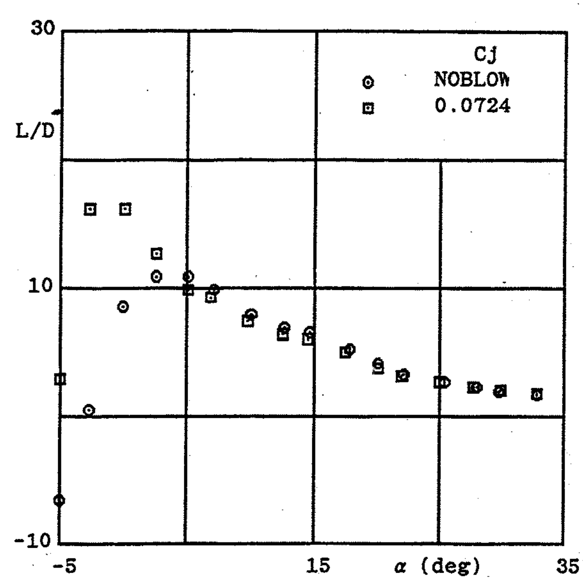


Fig.6. Aerodynamic data change with incidence
M = 0.31, Dj=4(mm), Xj=1.00L, SCW-0.11

blowing. However, the seemingly unfavorable response of the drag does not contradict the blowing effectiveness itself, because it gives rise not only to a considerable lift-increase but to a certain reduction of even the minimum drag without serious degradation of the associated L/D performance of the wing.

The lateral blowing seems to move the location of the center of pressure a little downstream from the nonblowing position, and this is clearly observed in the result shown in Fig.7, where Xcp denotes the nondimensional chordwise distance within the root section of the wing. However, it must be stressed that the regression of Xcp is not so large as to result in serious difficulty with respect to the stability trimming.

The present results mentioned in the foregoing paragraphs seems to lead to the deduction that the aerodynamic mechanism of the lift-increase due to the blowing consists in the two physical processes, that may be summarized as follows. In the case of small angle of attack, the blowing contributes to increase the lift by means of circulation enhancement. It is done in such a way that the blowing accelerates the ptential flow on the upper surface in the vicinity of the trailing-edge, and this, in turn, induces so preferable reduction of the surface pressure as to result in a considerable increase of suction there.

On the other hand, it seems that the blowing is little affective to the pressure on the lower surface except for very vicinity of the trailing-edge, where a small pressure rise takes place because the jet acts like an obstacle blocking the main stream. This statement seems to be supported reasonably by a chordwise distribution of surface pressure shown in Fig.8. The pressure modification on the upper surface is increasingly conspicuous as the angle of attack grows, whereas the pressure on the lower surface seems insensitive to the change of angle of attack.

Despite the fact that the lift-increase due to circulation enhancement tends presumably to vanish as the growing angle goes beyond 20°, the lateral blowing can still support a considerable lift-increase in the way that it affects the vortex flow at the leading-edge to delay its breakdown so as to preserve a high vortex-lift to a higher angle of attack. Of course, this is another type of physical process for the lift-increase that differs from the one observed at small angles of attack, and may be justified evidently in the light of the results shown in Figs.9 to 10, where the chordwise distributions of the surface pressure and the associated visualization of the flow patterns on the upper surface at α = 30° are presented, respectively.

As the angle of attack grows, the

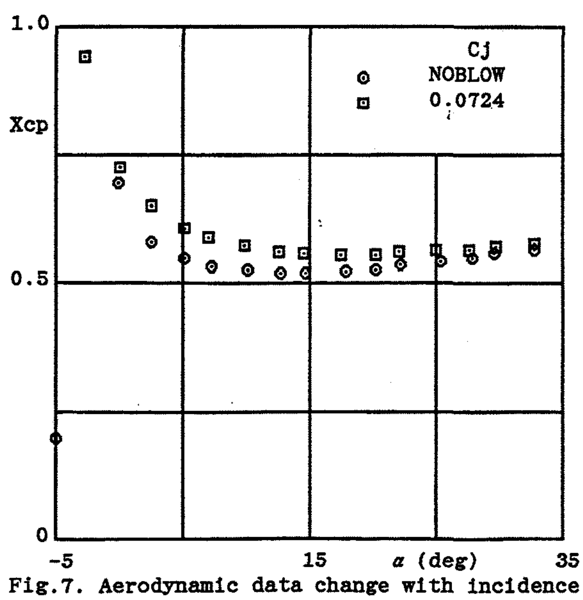


Fig.7. Aerodynamic data change with incidence
M = 0.31, Dj=4(mm), Xj=1.00L, SCW-0.11

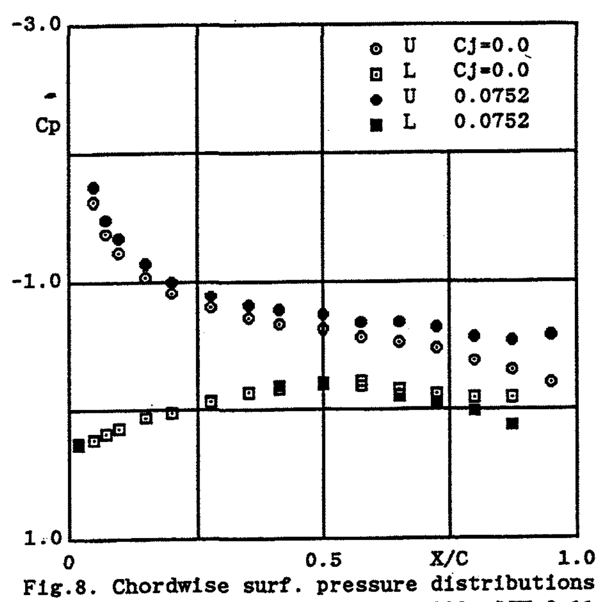


Fig.8. Chordwise surf. pressure distributions
M = 0.30, α = 15.3, η =0.286, SCW-0.11

blowing becomes increasingly effective for enhancement of vorticity of the swirling flow at the leading-edge,and the breakdown bubble shrinks itself so considerably that the suction recovery at the leading-egde si considerable at η = 0.286. In the noblowing cases, on the contrary, the swirling flow breaks itself down near the wing root to make a large bubble, resulting in a large reduction of leading-edge suction, as shown in Figs.9 and 10(a). This clearly suggests a noteworthy fact the lateral blowing has the essentially same physical process for lift-increase as the so called spanwise one in case the angle of attack is high enough. Therefore, it seems to be another interest to examine which is more effective for the lift-augmentation between those two blowing methods in the sense of efficiency of the blowing momentum.

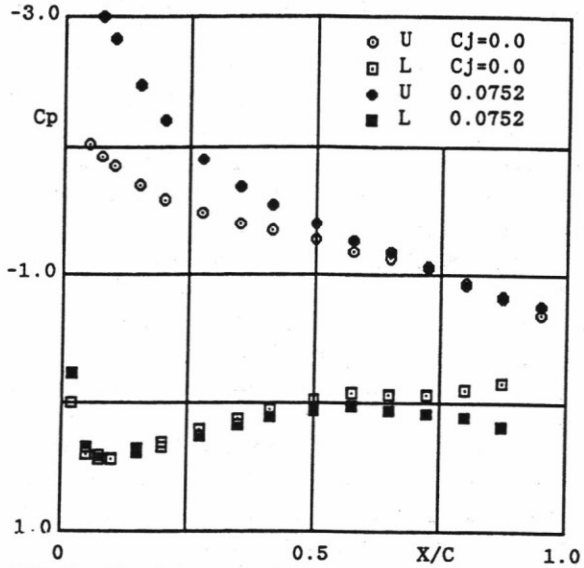
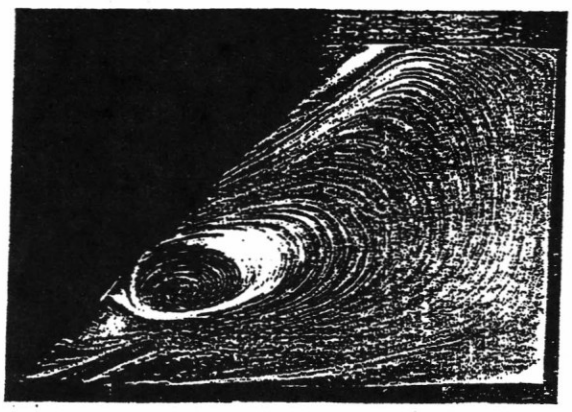
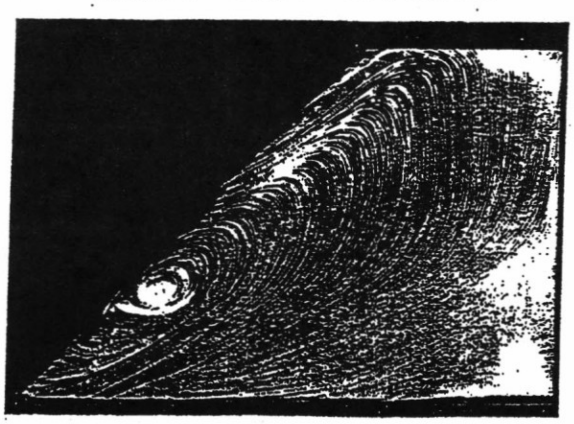


Fig.9. Chordwise surf. pressure distributions
M = 0.30, α = 29.9, η =0.286, SCW-0.11



10(a). M = 0.3, α = 30°, Noblow.



10(b). M = 0.3, α = 30°, Pj = 1.078(MPa).

Fig.10. Oil flow visualization

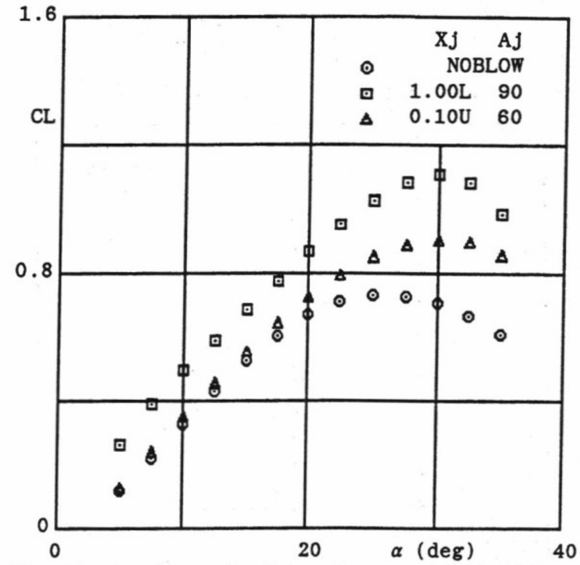


Fig.11. Aerodynamic data change with incidence
M = 0.30, Pj=1.083, Dj=4(mm), CAW-0.12

In Fig.11 are presented the lift-curves obtained, respectively, for the two blowing methods, where Aj denotes the angular direction of the jet, and where the symbols L and U means lower and upper wing surface, respectively. The figure indicates a noticeable fact that the lateral blowing is evidently more effective for lift-augmentation than the spanwise one, and this may be justified from the viewpoint that, if the angle of attack is small, the former affects the flow so effectively as to induce a favourable improvement of the pressure on the upper surface, whereas the latter has little effect on the lift-augmentation because of no serious breakdown of the leading-edge vortex yet. In this sense, the result in Fig.11 should be regarded as an experimental evidence indicating the importance of the blowing location.

It remains to discuss the effect of blowing on the aerodynamic characteristics of low aspect ratio wings at transonic speeds. Fig.12 presents the effect of the blowing on C_L-M curves for the SCW-model ,at $\alpha = 0°$ and the corresponding C_D-M curves are shown in Fig.13. In the light of the results presented in those figures, it must be emphasized that the blowing is still effective for not only the increase of the lift but also alleviating the well known shock stall in C_L-M curves that may be encountered often in the transonic region. Moreover, an attention must be paid to an unexpected fact that the blowing seems to cause a conspicuous drag-reduction compared with the noblowing cases if the free stream Mach number exceeds 0.95. This is also true of other angles of attack in case the absolute angle does not grow beyond 6°.

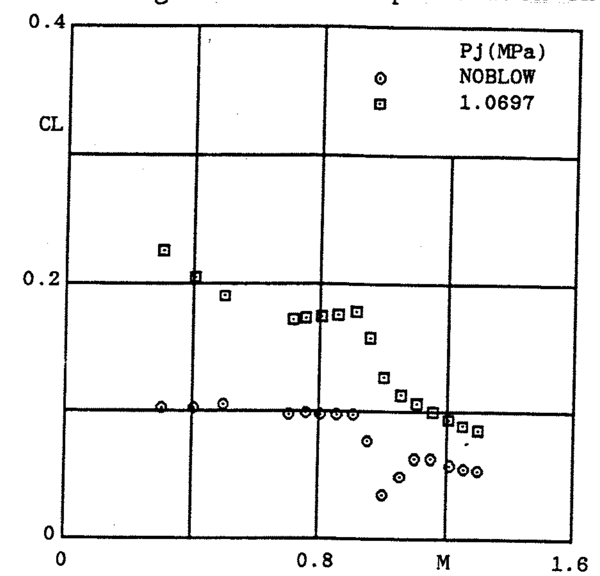


Fig.12. Aerodynamic data change with Mach numb
α = 0.0, Xj=1.00L, Dj=4(mm), SCW-0.11

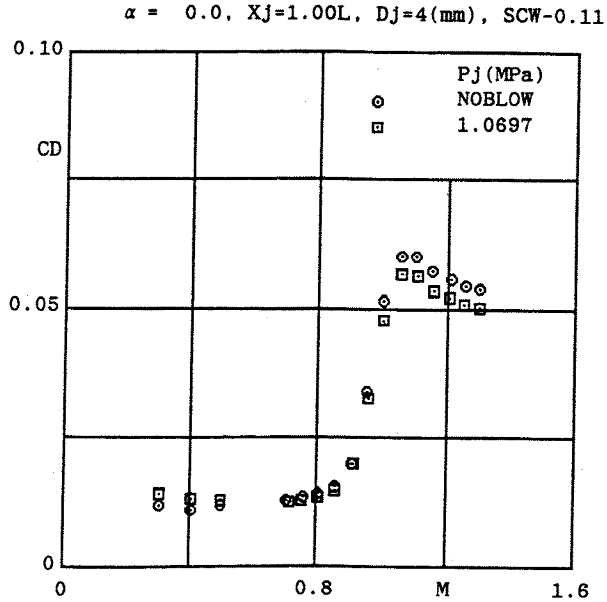


Fig.13. Aerodynamic data change with Mach numb
α = 0.0, Xj=1.00L, Dj=4(mm), SCW-0.11

So far as the C_L-α curve is concerned, the lift-increase due to the blowing seems, at a glance, to result from such a simple reason that the blowing causes a slight shift of the zero point of the effective angle of attack. However, it is not true from viewpoint of the present result that the blowing certainly decreases the minimum drag distinctly, although no experimental evidence may be presented to justify the statement directly. However, as an indirect evidence, the blowing effect on the L/D ratio for the SCW-model at M = 1 is shown in Fig.14. It is clear that the transonic result seems to be similar qualitatively to the subsonic one (see Fig. 6), indicating that the effect of blowing on drag-reduction is preserved in the transonic range and makes an appearance to the order of a significant magnitude. However, it must be noted that the drag increases with the blowing if the absolute angle of attack grows beyond 6°. Anyway, a considerable lift-increase as well as an appreciable drag-reduction due to the blowing seems to suggest obviously the feasibility for improvement of the aerodynamic performances such as drag divergence Mach number and maneuverability of the transonic aircrafts having low aspect-ratio wings.

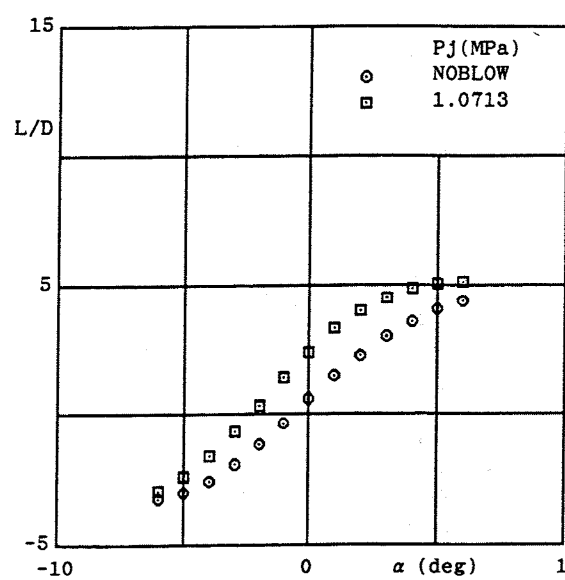


Fig.14. Aerodynamic data change with incidence
M = 1.00, Xj=1.00L, Dj=4(mm), SCW-0.11

Conclusion

At the low subsonic Mach numbers the lateral blowing is effective for not only lift-augmentation but improvement of stall characteristics of low aspect-ratio wings at high angles of attack. Despite the spontaneous drag-increase in general, the blowing still seems to offer a useful method for lift-augmentation, because the corresponding L/D ratio does not undergoes serious degradation in the sense that it remains nearly insensitive to the blowing. In the range of small angles of attack, the lateral blowing brings about a considerable lift-increase, whereas it yields an appreciable drag-decrease compared with the nonblowing cases. This is also true for higher subsonic and even transonic Mach numbers, at which the decrease of drag becomes of the order of an appreciable magnitude.

The present results reveal that the mechanism of the lift-augmentation due to the blowing consists in the two fluid dynmaic proceses. The one is the circulation enhancement that results from favorable improvement of the pressure on the upper surface of the wings and occurs at relatively low angles of attack. The another is the enhancement of the vortex at the leading-edge and takes place at high angles of attack.

References

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