IMPROVEMENT OF AERODYNAMIC CHARACTERISTICS OF NEXT-GENERATION SST WING BY LATERAL BLOWING

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Abstract

An experimental study on the improvement of aerodynamic characteristics of an arrow wing by lateral blowing in low and high speed flow, has been conducted. An arrow wing, which is one of the baseline configurations of next-generation SST, is selected for the experiments. As compared to the delta wing, it is known that an arrow wing has higher the ratio of lift to drag and improvement of stability in low speed region because of the supersonic leading edge. However for being economically feasible more L/D is required for the development of SST. The lateral blowing is realized by injecting a pair of steady jets in a direction parallel to the trailing edge of the wing. The experiments have been performed in the transonic and supersonic wind tunnel located at ISAS under the testing conditions of M_∞ *(free-stream Mach number)= 0.3~2.3, Re unit (unit Reynolds number)=* $1.06\times10^7 \sim 3.10\times10^7$ *[1/m],* α *(angle of attack) =-15°~30° and* C_j *(jet momentum coefficient) = 0.0084~0.0316. The results show that the* C_L *and L/D are increased by applying lateral blowing while* C_D *is slightly increased for positive* α*. The results suggest that the lateral blowing can be useful for the improvement of aerodynamic characteristics of the arrow wing in low and high speed flow.*

Nomenclature

C_L	Lift coefficient
C_D	Drag coefficient
C_{My}	Pitching moment coefficient
L/D	The ratio of lift due to drag
C_j	Jet momentum coefficient
Re	Reynolds number
P_j	Jet-plenum stagnation pressure [Pa]
P_s	Free-stream static pressure [Pa]
S_j	Area of jet nozzle exit [cm^2]
S_w	Area of the wing planeform [cm^2]
α	Angle of attack [°]
M_∞	Free stream Mach number
D	Diameter of jet-nozzle exit [mm]

Subscript

j	Jet blowing condition
s	Static condition
w	Wing
∞	free stream

1 Introduction

Recently research for developing the supersonic transportation becomes very active in Japan. It is said that an arrow wing is favorable to a high speed airplane. [1][2] However much higher L/D performance is requested at all flight regions in terms of the economical demand. There are many devices for the increment of L/D, such as leading flaps and trailing flaps to obtain the highest C_{LMAX}. And they have already come into practical use. However these mechanical high lift systems are passive method of high L/D. On the other hand there are many kind of technique to utilizing a secondary flow such as blowing. And they are categorized mainly by blowing direction, position and their concepts. Most researches are conducted in order to reinforce the characteristic leading edge separated-vortex quite directly. [3][4][5] In the present study active control of aerodynamic characteristics of SST wing is investigated by using the lateral blowing, which was for the first time proposed by K.Karashima. He introduced the significant increase of L/D as for a trapozoidal wing-body model with the wing section of the supercritical airfoil. [6] Also we'll confirm the aerodynamic effects by applying lateral blowing to an arrow wing model at Mach number from 0.3 to 2.3 in this study. These characteristic qualities of the lateral blowing are the nozzle position and blowing direction. This direction of blowing is perpendicular to the free stream direction and parallel to trailing edge. So this lateral blowing does not directly act on lift and drag forces of the model. A singular point near the trailing edge gradually influences the flowfield around the wing and the model through the boundary layer even if the flow is in supersonic. And the final purpose of ours is to reveal the mechanism of flow by lateral blowing.

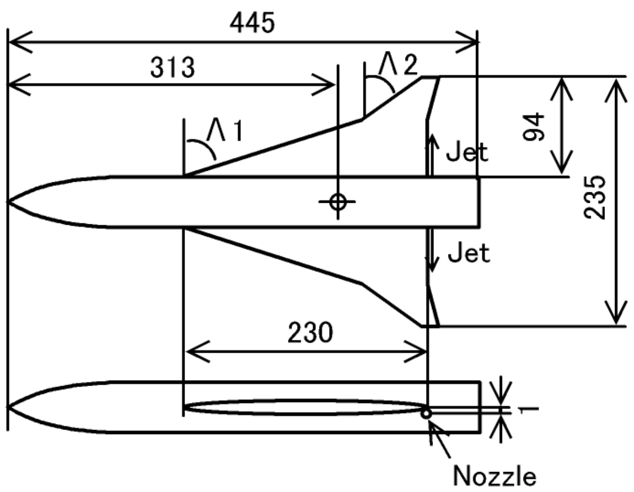

Figure 1. Testing model dimension

2 Experimental apparatus and procedures

2.1 Wind tunnel

The tests were conducted in transonic and supersonic wind tunnel of ISAS (Institute of Space and Astronautical Science, Japan). Each tunnel has a 600[mm]×600[mm] square test-section and is blowdown type. The transonic and supersonic wind tunnels are capable of Mach numbers sweep from 0.3 to 1.3 and from 1.5 to 4.0 respectively. The sting type of balance is used in this study and is put in the testing model, which is mounted by sting.

2.2 Model and instrumentation

The testing model in this study is the wing-body combination as shown Figure 1. The body consists of a circular cylinder and conical apex and the planform of the wing configuration is an arrow wing. In addition, the wing has no twist, camber or dihedral. Wing parameters are shown in Table 1.

Table 1 Arrow wing planform parameters

Aspect ratio (AR)	1.91
Swept angle Λ1	72.7°
Swept angle Λ2	52.2°
Airfoil section	Circuler arc airfoil
Thickness ratio	6%
Root chord length	230 mm
Semi span length	94 mm

The feasibility of lateral blowing was suggested by an early investigation of the technique performed by K.Karashima on a trapezoidal wing (swept angle of 45°) at Mach number of 0.3. [6] Lateral blowing is realized by injecting a pair of sonic-jets in parallel to the trailing edge of the arrow wing. Thus the nozzle is located at the junction between the trailing edge of wing and the fuselage of the model. The jet is injected in parallel to and along with the trailing edge. The schematic diagram of experimental system is shown in Figure 2. An air compressor as the source of the jet supply is located out of the test section, and a compressed air is loaded to the connector behind the model through the tube.

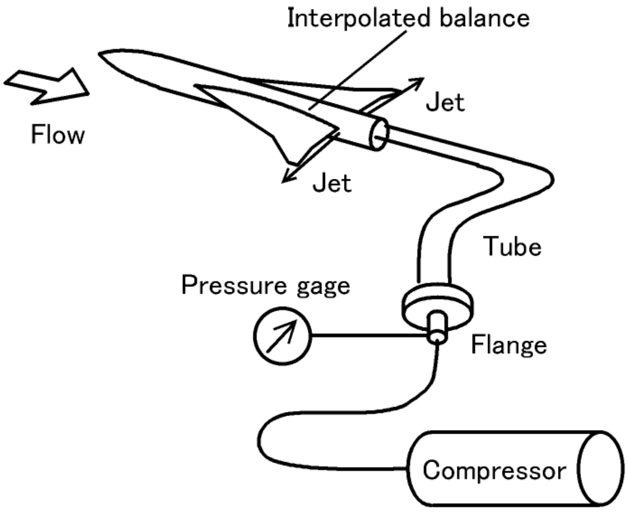

Figure 2. Schematic diagram

2.3 Test conditions

Test conditions for the present experiment are shown in Table 2. Lift, drag and pitching moment are measured both in subsonic and supersonic flows. Also, the surface oil flow pictures on the wing have been taken at Mach number of 0.3. (α=10°, 20° and 30°)

Table 2. Test conditions

Case	M_∞	C_j	Re	Nozzle Diameter
1	0.3	0.02105	4.770E+06	2 mm
2	0.4	0.01240	6.119E+06	2 mm
3	0.5	0.00842	7.338E+06	2 mm
4	0.7	0.00498	9.318E+06	2 mm
5	0.9	0.00365	1.066E+07	2 mm
6	1.0	0.00330	1.105E+07	2 mm
7	1.1	0.00306	1.134E+07	2 mm
8	1.3	0.00282	1.149E+07	2 mm
9	1.5	0.00210	1.604E+07	2 mm
10	1.7	0.00231	1.457E+07	2 mm
11	2.0	0.00211	1.628E+07	2 mm
12	2.3	0.00221	1.642E+07	2 mm
13	0.3	0.02103	4.606E+06	3 mm
14	0.3	0.03146	4.686E+06	3 mm
15	0.9	0.00365	1.062E+07	3 mm
16	0.9	0.00562	1.076E+07	3 mm
17	2.0	0.00212	1.364E+07	3 mm
18	2.0	0.00315	1.362E+07	3 mm

In measuring aerodynamic forces and moments of the present model, the strength of blowing power is restrained because of the tank capacity of the using compressor. Thus the maximum values of jet plenum stagnation pressure P_j, which we can stably and steadily get, are restrained 1.079 MPa at nozzle diameter equals 2mm and 0.716 MPa at the case of 3mm respectively. And we have to prepare a parameter in order to evaluate the results accurately. So we'll use the jet momentum coefficient C_j as the primary parameter to identify blowing rate, that is represented as follows;

$$C_j = \frac{\dot{m}_j u_j}{\frac{1}{2}\rho U_\infty^2 S_w} = \frac{P_j S_j}{\frac{1}{2}\rho U_\infty^2 S_w} = \frac{2}{\gamma}\frac{P_j}{P_s}\frac{S_j}{S_w}\frac{1}{M_\infty^2}$$

where subscpirt j , ∞ denotes jet blowing and free stream conditions respectively. From Case 1 to Case 12, the value of P_j equals 1.079MPa and the nozzle diameter is 2mm. Among 12 cases it is found that C_j decreases in inverse proportion to M_∞^2 as shown in Figure 3-(a).

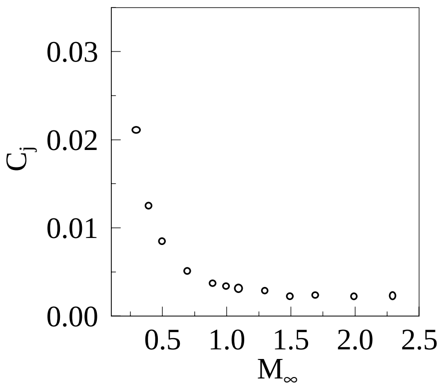

Figure 3-(a). C_j vs M_∞ at D=ϕ2mm

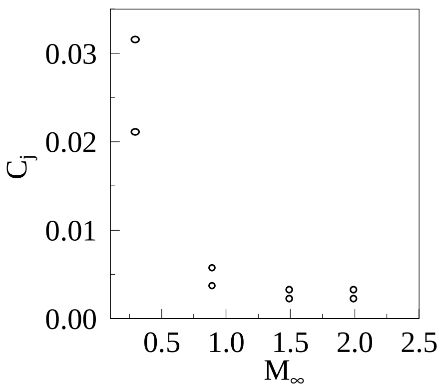

Figure 3-(b). C_j vs M_∞ at D=ϕ3mm

In order to investigate the effects by changing the value of C_j, experiments were conducted from Case 13 to Case 18. Figure 3-(b) shows C_j curves related with M_∞ in 6 Cases of the nozzle diameter D = 3 mm.

And at Mach number of 0.3 by comparing Case 1 (C_j = 0.02105) with Case 13 (C_j = 0.02103), differences of nozzle size becomes clear, in the same way to compared Case 5 with Case 15, Case 11 with Case 17.

3 Results and discussion

3.1 From Case 1 to Case 12

To begin with, we'll inspect the results in cases with the nozzle diameter = 2 mm from Case 1 to Case 12.

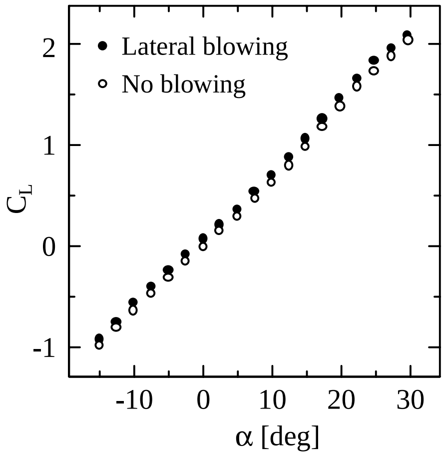

Figure4-(a). C_L vs α at M_∞=0.3(Case1)

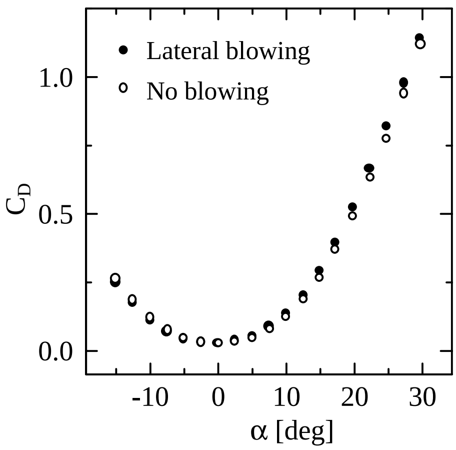

Figure4-(b). C_D vs α at M_∞=0.3(Case1)

In those cases P_j is kept constant 1.079MPa. So, C_j is smaller as free stream Mach number is increased as shown in Figure 3-(a).

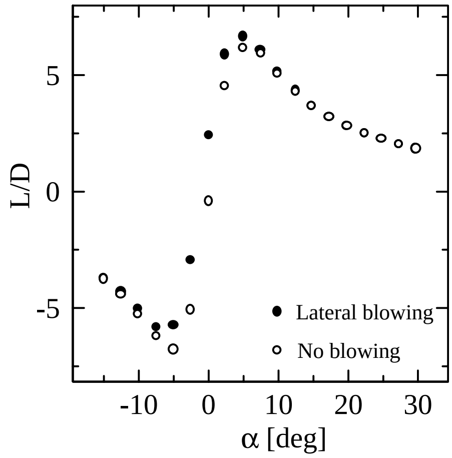

Figure4-(c). L/D vs α at M_∞=0.3(Case1)

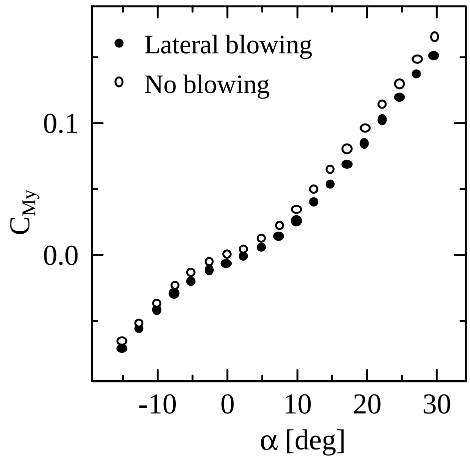

Figure4-(d). C_{My} vs α at M_∞=0.3(Case1)

The effects of the lateral blowing on lift, drag, pitching moment and lift due to drag curves at Mach number of 0.3 are presented in Figure 4-(a) through Figure 4-(d) respectively. Note that black and white circle respectively denotes with and without lateral blowing. Then Figure 4-(a) shows that almost the same rate of increasing C_L is observed between α= -15° and α= 30°. C_D characteristics as indicated in Figure 4-(b) shows that the curve with blowing intersects one without blowing near α= 0°. In other words, at positive angle of attack the increase of drag is measured. On the other hand at negative angle, the decrease of drag is indicated. As above two results, significant increase of L/D is observed at relatively low angle of attack. From Figure 4-(d), pitching-down tendency is found by applying the lateral blowing. Those features of C_L, C_D, L/D and C_{My} curves are verified to become similar curves in subsonic and transonic region (from Case 2 to Case 5). The qualitative behaviors are well characterized by 4 curves of Figure 4.

And then turning to changing our point of view, aerodynamic characteristic related with the free stream Mach number especially at α= 2.5°, at which a remarkable increase of L/D is indicated, is shown in Figure 5.

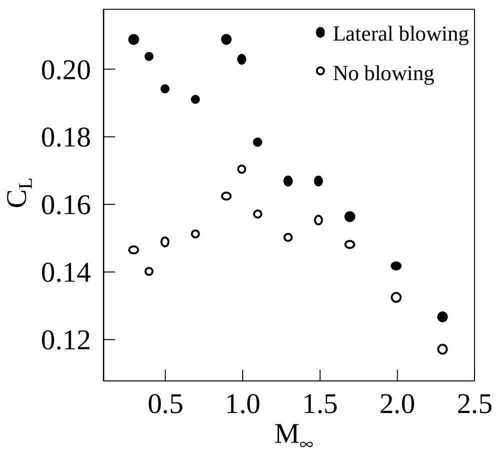

Figure5-(a) C_L vs M at α = 2.5°(Case 1~12)

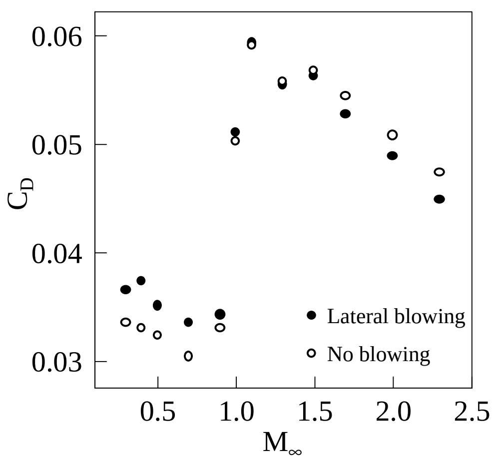

Figure5-(b) C_D vs M at α = 2.5°(Case 1~12)

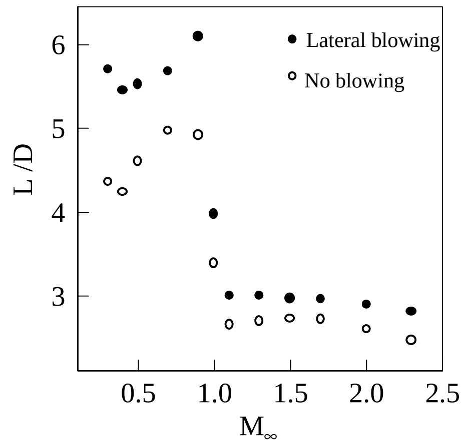

Figure5-(c) C_L vs M at α = 2.5°(Case 1~12)

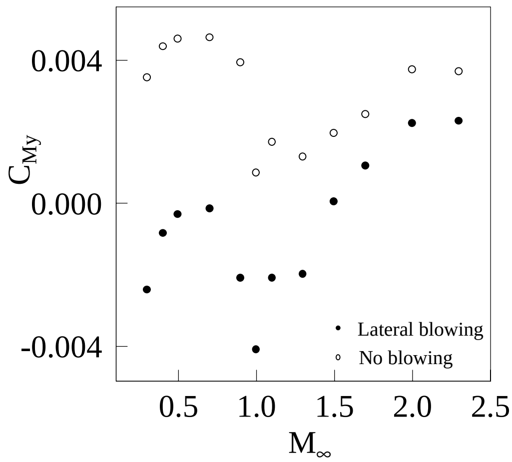

Figure5-(d) C_L vs M at α = 2.5°(Case 1~12)

Note that black and white circle respectively denotes with and without lateral blowing. The increase of C_L by lateral blowing is observed for all Mach number region as shown in Figure 5-(a). Higher increase is observed especially in subsonic flow. Also in supersonic flow slight increase of C_L is indicated. While C_D increases in subsonic region, as contrast to supersonic flow C_D decreases in Figure 5-(b). For that reason L/D also increases for all the velocity. In the pitching moment characteristics, the nose of the model is pitching downward by lateral blowing. As shown in those figures, the effects of lateral blowing are also verified from Mach number of 0.3 to 2.3, though the rate of change is smaller as Mach number increases.

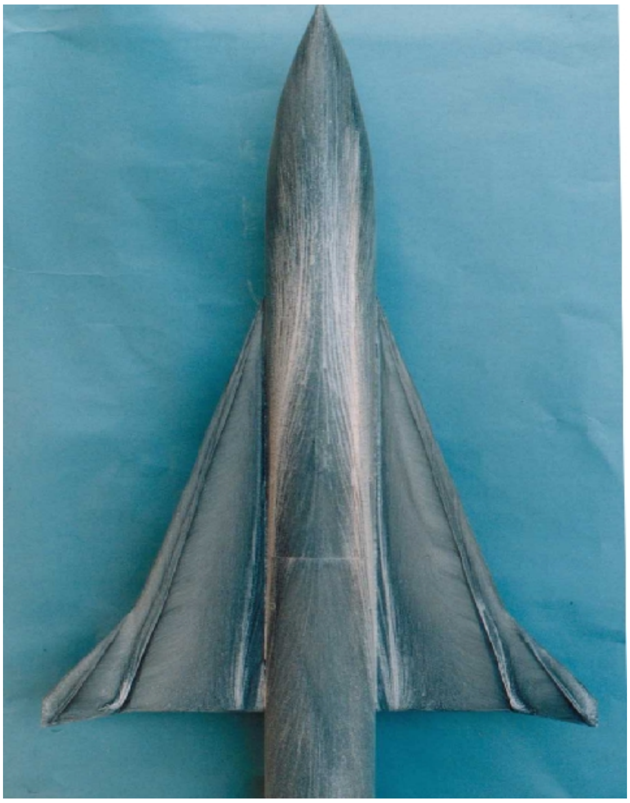

Figure 6-(a) Top view with lateral blowing (α=10°, M_∞=0.3 at Case1)

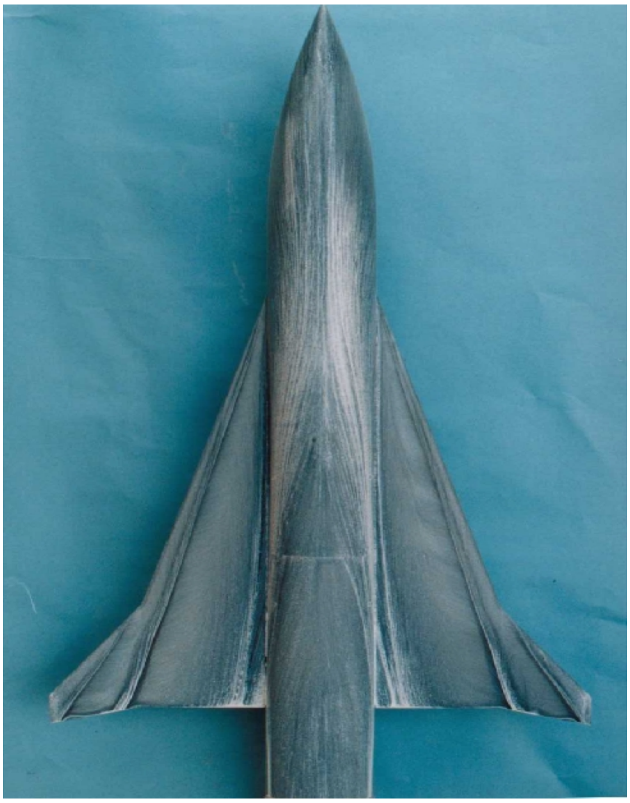

Figure 6-(b) Top view without blowing (α=10°, M_∞=0.3 at Case1)

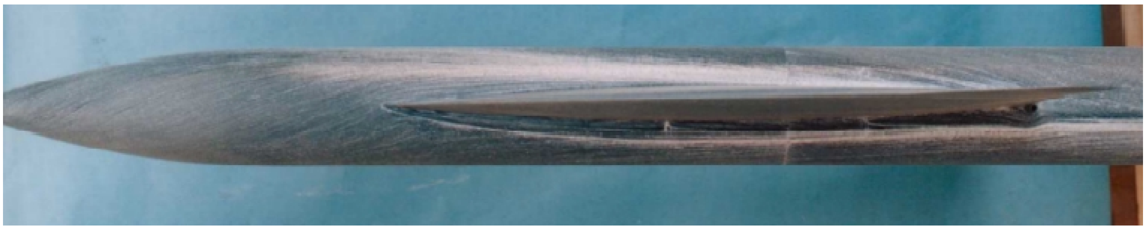

Figure 6-(c) Side view with lateral blowing (α=10°, M_∞=0.3 at Case1)

Figure 6-(d) Side view without blowing (α=10°, M_∞=0.3 at Case1)

3.2 Oil flow visualization

Next, the surface streamlines at α=10°, M_∞=0.3 are obtained by the use of an oil flow technique as shown in Figure 6. Comparing those pictures with the lateral blowing and without blowing, it is clear that two streamlines are different. Side view of those pictures shows downward flow near the trailing edge where the jet nozzle is located. Also top view of picture with lateral blowing shows slightly converging surface flow over the wing is observed. As flow near the trailing edge is dammed up in applying lateral blowing, pressure on the lower of wing becomes bigger. Also vortex structure formed by interaction among free stream, jet flow and wing makes flow near the trailing edge accelerate downward. As the results, lift of the model is increased. Because jet flow widens along with trailing edge and expands backward, the influence on wing directly by jet's wake is comparatively small. So, increment of drag becomes somewhat small. To understanding the flowfield near the nozzle exit including the structure of jet wake is very important for revealing the mechanism of the lateral blowing.

3.3 From Case 13 to Case 18

The influence of jet momentum is also investigated. The result of lift coefficients at the free stream Mach number of 0.3 with two different values of C_j is shown in Figure 7. As C_j is increased, the increment of C_L is larger. However the contribution by increasing C_j becomes small. Thus it is expected that there exists the effective value of C_j like a upper limit. Additionally as an interesting result, compare Case 1 with Case 13. In those case the value of C_j is equivalent, but jet plenum stagnation pressure P_j is not equal. Lift coefficients curve is shown in Figure 8. The difference of two lift curves is very small, but the difference can not be ignored. Figure 8 indicates the influence by differences of P_j rather than the nozzle size. The lift at the nozzle diameter = 2mm is slightly higher than one at 3mm. And P_j is related with jet flow structure. The bigger P_j, the influence of jet structure more far reaches to the wing tip. So it is necessary to capture the behavior of this jet flow structure to reveal the mechanism.

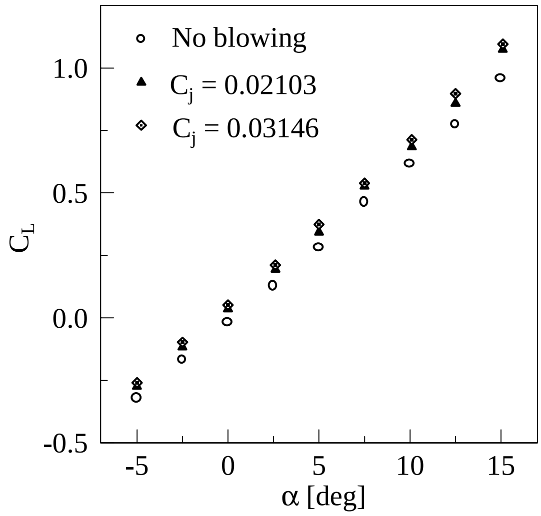

Figure7. Effect of C_j (Case 13 and 14)

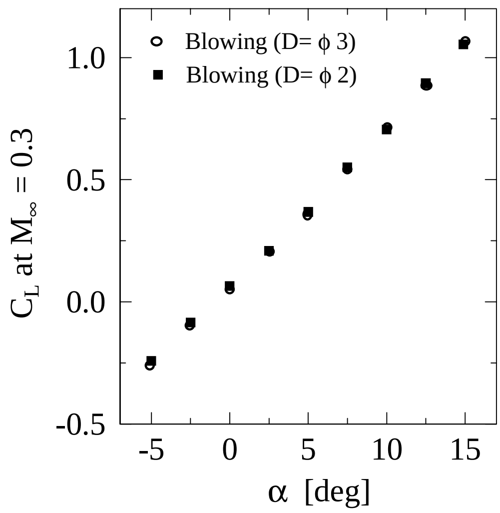

Figure 8. Effects of nozzle diameter

4 Concluding remarks

A study has been conducted to examine the aerodynamic effects by applying lateral blowing to the SST model. The conclusions of the present study are summarized as follows:

1) Significant increase of L/D is observed at lower angle of attack at Mach number from 0.3 to 2.3.
2) In supersonic region drag coefficient decreases somewhat slightly by lateral blowing.
3) According to surface streamline of the model, pressure on the lower of wing becomes bigger and flow near the trailing edge is accelerated downward.

For further study

Surface pressure measurement on the arrow wing in order to understand the flowfield formed by interaction among lateral blowing, arrow wing and shock wave are in progress. Also flow visualization of the jet wake for the understanding of the vortex structure to approach the mechanism is in progress. Those efforts are devoted to the understanding of the flow mechanism of lateral blowing.

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