Experiments on a Two-Dimensional Impinging Jet on a Wedge*

(Turbulence Properties and the Energy Balance)

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Turbulence properties and the balance of turbulence energy in a two-dimensional impinging jet on a wedge are investigated. The angles between the wedge surface and the jet axis ϕ are 30° and 45° . The profiles of u'/U_m , v'/U_m and $\overline{q^2}/2U_m^2$ in the fully developed flow region are larger than those of the two-dimensional wall jet, but the profile of w'/U_m is almost the same as that of the two-dimensional wall jet, and all profiles exhibit no similarity. Each term of the production, dissipation and diffusion in the turbulence energy equation is larger than that of the two-dimensional wall jet except for the advection term. The production and the diffusion terms in the case of $\phi=45^\circ$ are larger than those in the case of $\phi=30^\circ$. The pattern of the isopleths of $\overline{q^2}/2U_j^2$ in the impinging region differs for each case of $\phi=30^\circ$ and 45° .

Key Words: Impinging Jet, Turbulent Wall Jet, Wedge Flow, Turbulence Intensity, Reynolds Stress, Turbulent Energy, Energy Balance

1. Introduction

In this research the subject is a flow field produced by impinging against a wedge as shown in Fig. 1. A flow field of this kind is important in relation to the problems of the impinging jet heating of a burner, or painting technology, for example⁽¹⁾. The authors have already examined the mean flow properties of this flow field⁽²⁾ and the turbulence properties in the case of a wedge placed symmetrical to the jet axis; ie., $\phi=45^\circ$ ⁽³⁾. The distribution of the turbulent intensity and of the Reynolds stress near the vertex of the wedge, particularly in the impingement and developing region, showed a difference from those of the two-dimensional wall jet.

Studies treating related problems are the experiments by Kobayashi and Fujisawa on the turbulence pro-

perties of a two-dimensional wall jet⁽⁴⁾ and of the wall jet along a concave and convex wall^{(5)~(8)}. Also, the turbulent energy balances of a two-dimensional wall jet and of a free jet were examined by Fujisawa⁽⁹⁾ and Fujisawa and Shirai⁽¹⁰⁾, and Masuda and Andoh⁽¹¹⁾ respectively. Osaka et al.⁽¹²⁾ investigated the turbulent energy balance of the two-dimensional wall jet subjected to the disturbance produced by a cylinder.

Experimental results of the flow field of a jet impinging on a wedge placed at an angle in relation to the jet axis are reported here mainly in connection with the turbulent intensity and Reynolds stress distributions. We also discuss the turbulent energy balance in comparison with the symmetrical case and the usual wall jet case.

Nomenclature

x, y, z : coordinate system with the origin at the wedge vertex (Fig. 1); z is the spanwise direction
 b_j : height of the nozzle (=10 mm)
 U, V : x and y components of mean velocity, respectively
 U_j : mean velocity at the nozzle exit

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- U_m : maximum value of U at respective x
 u, v, w : x, y and z components of fluctuating velocity, respectively (prime means rms-value)
 $y_{0.5}$: half width of the jet (y -coordinate of $U = U_m/2$ in the outer layer)
 y_m : position of the maximum velocity (y -coordinate of $U = U_m$)
 ϕ : angle between the wedge surface and the jet axis
 ψ : stream function
 ε : dissipation rate
 ν : kinematic viscosity

2. Experimental Apparatus and Procedures

The experimental apparatus used and the Reynolds number set for this experiment were the same as those in the previous report⁽²⁾ ($Re = U_j b_j / \nu = 2.2 \times 10^4$). The measurement of various quantities was carried out by setting the angle ϕ of the wedge surface at 30° and 45° . For measuring fluctuating velocity u and v and Reynolds stress $-\overline{uv}$, an X probe (sensitive part: tungsten wire $5 \mu\text{m}$ in diameter and 1 mm in length) and constant temperature hot-wire anemometers were used. Fluctuating velocity w was measured by the rotary probe method using an I-type probe. At that time, in order to increase the accuracy of measurement, we turned the probe to 0° , $\pm 22.5^\circ$ and $\pm 45^\circ$ in the direction of the main flow, and from the five sets of obtained data, we determined w by the least squares method.

3. Experimental Results and Discussion

3.1 Mean velocity V and streamlines

Figure 2 shows the change in distribution of the mean velocity V in the downstream direction. For comparison with the representative velocity for the case of $\phi = 45^\circ$ reported previously, its distributions are presented in the figure. In the respective cases of both incidental angles, near the vertex of a wedge, V becomes negative and its magnitude is about 5% of U_j for $\phi = 30^\circ$, which is considerably smaller than the value of V , about 15% of U_j for $\phi = 45^\circ$. For each

Fig. 1 Flow pattern around the wedge and coordinate system ($L = 150 \text{ mm}$, $\theta = 90^\circ$)

value of ϕ , the V -component first exhibits a negative value and then changes to the flow having a positive V -component in the downstream direction. But the x -position where the V -component changes its sign is different in each case. Thus in the case of $\phi = 45^\circ$, V becomes positive in $x/b_j \geq 4$, while in the case of $\phi = 30^\circ$, it becomes positive in $x/b_j \geq 6$, so the position is nearer the vertex if ϕ is larger. In the developing region, in the downstream part where $x/b_j \geq 15$, and the mean flow properties become the same as those of the two-dimensional wall jet, V for the case of $\phi = 30^\circ$ is slightly smaller than that for $\phi = 45^\circ$.

Figure 3 shows the streamlines for the case of $\phi = 30^\circ$ obtained by the integration of U in the y -direction in comparison with the velocity vector. The value of the respective streamline is shown using the dimensionless quantity as $\psi/b_j U_j$. Near the vertex of the wedge, streamlines are considerably bent along the wedge surface, and thereafter they spread slightly in the downstream direction. Near the vertex of the wedge, the tangential direction of the streamlines and the direction of the velocity vector agree well, and as seen from the slightly curved streamlines, it may be said that the flow is similar to the wall jet along a concave surface.

3.2 Turbulence properties

Figure 4 shows the change in distribution of the z -direction component of the turbulence intensity w'/U_m in the downstream direction. In Fig. 4 also, the results of $\phi = 45^\circ$ are shown by broken lines. Because the distributions of the x - and y -component were similar to the result in the case of $\phi = 45^\circ$, as shown in

Fig. 2 Distribution of mean velocity V

Fig. 3 Streamlines and velocity vector

the previous report, only the distribution of w'/U_m is presented here. As shown in the figure, the turbulence intensity is large near the wall of the vertex of the wedge in the case of $\phi=30^\circ$, but it decreases in the downstream direction. In the fully developed flow region, the distribution has a small maximum value near the wall and the outer region. This distribution trend was also observed in the distributions of the x -component of the turbulence intensity as shown in the previous report⁽³⁾. However, the distribution of $\phi=45^\circ$ is somewhat different from that of $\phi=30^\circ$ near the vertex of the wedge ($x/b_j=0.3, 0.6$), but it exhibits almost the same distributions in the part downstream from there.

In Fig. 5, the change in distribution of turbulence energy ($\overline{q^2}/2U_m^2$, $\overline{q^2}=\overline{u^2}+\overline{v^2}+\overline{w^2}$) in the downstream direction is shown. The broken lines in the figure indicate the distribution in the case of $\phi=45^\circ$. Near the vertex of the wedge ($x/b_j=0.3\sim 1.0$), the distribution is considerably different from that of $\phi=45^\circ$, and the values of $\phi=45^\circ$ are considerably larger than those of $\phi=30^\circ$. However, in the part further downstream from that section, the change due to ϕ very rarely occurs.

Figure 6 shows the change in the distribution of negative Reynolds stress $\overline{uv}/U_m^2$ (hereinafter referred to simply as Reynolds stress) in the downstream direction. Like in the previous result, in the present case of $\phi=30^\circ$, the distribution of Reynolds stress downstream of $x/b_j\geq 10$ shows an adequate distribution corresponding to the shearing stress value on the wall. Whereas in the case of $\phi=30^\circ$ $\overline{uv}/U_m^2$ has a negative value near the wall in the region of $0.6\leq x/b_j\leq 3$ slightly downstream from the vertex of the wedge,

Fig. 4 Distribution of turbulence intensity (w'/U_m)

in the case of $\phi=45^\circ$, the negative value is shown more upstream, in the region of $0.3\leq x/b_j\leq 2$. Also, near the vertex of the wedge, the positive maximum value of $\overline{uv}/U_m^2$ becomes considerably large when $\phi=30^\circ$ as compared with the case of $\phi=45^\circ$, and the distribution tendency is different; but both distributions almost reach agreement once around $x/b_j=3$. Thereafter, in the direction downstream, the distributions tend to be somewhat different, and the positive maximum value of $\overline{uv}$ becomes somewhat small for ϕ

Fig. 5 Distribution of turbulent energy

Fig. 6 Distribution of Reynolds stress ($\overline{uv}/U_m^2$)

$=30^\circ$, compared to the case of $\phi=45^\circ$.

In order to examine the similarity of a flow field like this, we show in Figs. 7~9 the similarity distributions of various turbulence quantities in the developing region ($x/b_j \geq 15$). These figures also present the experimental results of the usual two-dimensional wall jet⁽⁴⁾ and the two-dimensional wall jet along a concave wall^{(5),(6)}, as well as the result after passed along a convex wall⁽⁸⁾. Moreover, in order to compare the distributions in the cases of $\phi=30^\circ$ and 45° of the present results, the results for $\phi=45^\circ$ are shown as I symbols (of which the upper end corresponds to the values at $x/b_j=25$, and the lower end corresponds to the values at $x/b_j=15$).

First, Fig. 7 shows the dimensionless distribution of the z -component of the fluctuating velocity. As mentioned in the previous report⁽³⁾ according to Kobayashi and Fujisawa⁽⁴⁾, the distribution of v'/U_m in a two-dimensional wall jet had showed evidence of its similarity, but those of u'/U_m , w'/U_m did not. In the case of $\phi=30^\circ$ in the jet impinging against the wedge, u'/U_m , v'/U_m are not similar as in the case of $\phi=45^\circ$. As also shown in the figure, the distribution of w'/U_m is not similar, whereas the profiles of the mean velocity U/U_m exhibited the best similarity related to $y/y_{0.5}$ in this measurement range⁽²⁾. Just as in the previous report⁽³⁾, u'/U_m and v'/U_m in $\phi=30^\circ$ show a very large value compared with those in the two-dimensional wall jet. But as shown in the figure, w'/U_m of both $\phi=30^\circ$ and 45° have almost the same value as those in a two-dimensional wall jet, and the distributions resemble each other. However, the value of w'/U_m in a wall jet after having passed a convex wall becomes larger than that of the present result, but in the case of the wall jet along a concave wall becomes smaller than that of the present result.

Figure 8 shows the dimensionless distribution of the turbulent energy in the fully developed flow region. In the turbulent energy distribution expressed

Fig. 7 Dimensionless distribution of turbulence intensity (w'/U_m)

in such a dimensionless way, no similarity exists either in the present flow field or in the usual two-dimensional wall jet. Also, in the present flow field, even in the fully developed flow region, the turbulence energy becomes fairly large as compared with the two-dimensional wall jet and the wall jet along a concave wall. Further, in the present results, the difference of distribution due to angle ϕ is small.

The dimensionless distribution of Reynolds stress in the fully developed flow region is shown in Fig. 9. According to Kobayashi and Fujisawa⁽⁴⁾, the distribution of $\overline{uv}/U_m^2$ in a two-dimensional wall jet becomes similar in the downstream part, but in the jet impinging against a wedge, there is no similarity even in the fully developed flow region, and the values are fairly large compared with that of the wall jet. The result of the wall jet having passed a convex wall shows about the same values of $\overline{uv}/U_m^2$ as the present result, but the value of a wall jet along a concave wall is considerably smaller than that of the present result. Besides, compared with the case of $\phi=45^\circ$ in the previous report, the distribution in $\phi=30^\circ$ of the present experiment shows a somewhat smaller value.

Next, we attempt to investigate the state of development in the downstream direction using the typical turbulence values. In Fig. 10, the change in the maximum turbulence energy in the outer layer of the jet in the fully developed flow region and the value of the turbulence energy at the position of $y_m/2$ are compared with the result of the two-dimensional wall jet of Kobayashi and Fujisawa⁽⁴⁾ and the case of $\phi=45^\circ$ in the present results. Here, $\bar{x}$ represents the x -coordinate from the virtual origin based on the half-width in the case of the present results, and it corresponds to the x -coordinate from the origin at the nozzle exit in the case of the two-dimensional wall jet. Both the maximum turbulent energy in the present results and the value of the turbulent energy at the position of $y_m/2$ have values larger than those of the

Fig. 8 Dimensionless distribution of turbulent energy

usual two-dimensional wall jet. Also, the difference due to angle ϕ is barely observed.

Figure 11 shows the change in the maximum Reynolds stress in the outer layer in the fully developed flow region toward the downstream part, as well as the result of a two-dimensional wall jet^{(4),(13)}; the case of $\phi=45^\circ$ in the present results is also shown. The maximum value of $\overline{uv}/U_m^2$ becomes large in the present results compared to that of a two-dimensional wall jet, and in the present results, the maximum value of $\overline{uv}/U_m^2$ becomes large in $\phi=45^\circ$ compared to the result in $\phi=30^\circ$.

When the above dimensionless distribution and change of the maximum value in the downstream direction are considered, in spite of the similarity in the mean velocity distribution, the various quantities of turbulence do not show a similarity in the range of the present experiment. This suggests that the effects of the strong pressure gradient exerted by the vertex of the wedge and the bend of streamlines apparent in Fig. 3 remain in the turbulent field. Tentatively, we assume that the height of a streamline of $\phi/b_j u_j = 1.4$ at $x/b_j = 0.3$ corresponds with the thickness of the boundary layer δ , and that the ratio of δ to the radius of the curvature R of the streamline can be estimated to be $\delta/R \approx 0.4$; this corresponds to the boundary layer subjected to the strong effect of curvature as in Bradshaw's criterion⁽¹⁴⁾. Also, as the turbulent field is subjected to a large influence from the flow field distortion when it approaches a body⁽¹⁵⁾, in a case like this, such a change remains to be investigated in detail.

Figure 12 shows the isopleths of turbulent energy in comparison with the case of $\phi=45^\circ$; in order to observe the correspondence with the mean flow, we also show the positions of the maximum value width y_m and half-width $y_{0.5}$ in the figure. As seen from the figure, in both angles of ϕ near the vertex of the

Fig. 9 Dimensionless distribution of Reynolds stress ($\overline{uv}/U_m^2$)

wedge, there is a high peak of turbulence energy around the middle of y_m and $y_{0.5}$. Moreover, the influence of this high peak of turbulence energy spreads to the downstream part; thus, it is considered that the effect of the turbulence energy generated at the vertex of the wedge is exerted until the considerably downstream part.

3.3 Turbulent energy balance

In order to inquire further into the turbulence structure in this flow, we investigated the turbulent energy budget. In the first place, the measurement was made in the mixing layer near the rectangular nozzle of $80 \text{ mm} \times 80 \text{ mm}$; the layer can be regarded as two-dimensional. The turbulent energy budget in this flow is estimated and compared with the result of Wygnanski and Fiedler⁽¹⁶⁾, who, assuming similar profiles for the mean and fluctuating quantities, transformed the

Fig. 10 Change in turbulent energy in the x -direction

Fig. 11 Change in maximum values of Reynolds stress in the x -direction

Fig. 12 Isopleths of turbulent energy ($q^2/(2U_j^2)$)

turbulent energy equation into

$$\begin{aligned} & \frac{\overline{uv}}{U_0^2} \frac{\partial}{\partial \eta} \left(\frac{U}{U_0} \right) - \eta \frac{\partial}{\partial \eta} \left(\frac{U}{U_0} \right) \left(\frac{\overline{u^2}}{U_0^2} - \frac{\overline{v^2}}{U_0^2} \right) \\ & + \frac{1}{2} \frac{\partial}{\partial \eta} \left(\frac{\overline{q^2}}{U_0^2} \right) \left(\frac{V}{U_0} - \eta \frac{U}{U_0} \right) + \frac{1}{2} \frac{\partial}{\partial \eta} \left(\frac{\overline{vq^2}}{U_0^3} \right) \\ & + \frac{1}{2} \eta \frac{\partial}{\partial \eta} \left(\frac{\overline{uq^2}}{U_0^3} \right) - \eta \frac{\partial}{\partial \eta} \left(\frac{\overline{p'u}}{\rho U_0^3} \right) + \frac{\partial}{\partial \eta} \left(\frac{\overline{p'v}}{\rho U_0^3} \right) \\ & + \frac{x}{U_0^3} \varepsilon = 0, \end{aligned} \quad (1)$$

where U_0 is the main flow velocity, η the similarity variable $[\eta = (y - y_{0.5})/\bar{x}]$, p' the fluctuating pressure, and ε the turbulent energy dissipation. The first and second terms on the left-hand side of Eq. (1) are the productions for the turbulent energy, the third is the convection term, the fourth to the seventh are the diffusion terms (the sixth and seventh are pressure transport terms), and the eighth term is the turbulent energy dissipation. Wygnanski et al. estimated the production, convection and diffusion except for the pressure transport, assumed the dissipation $\varepsilon = 9\nu (\partial u / \partial x)^2$ from the measured values, and determined the pressure transport terms as the residual of Eq. (1).

In the present experiment, it was difficult to measure the triple correlations, because the instruments used were analog ones, and simultaneous measurement of u , v and w was not carried out. Therefore the production, convection and dissipation terms were calculated from the measured values, and the total diffusion terms were determined from the remainder of Eq. (1). For the estimation of the dissipation, assuming local isotropy and Taylor's hypothesis, we used Eq. (2) as follows.

$$\varepsilon = 15 \frac{\nu}{U^2} \left(\frac{\partial u}{\partial t} \right)^2 \quad (2)$$

However, the actual value of the turbulent dissipation was multiplied by a constant determined such that the integral of the diffusion as the residual of Eq. (1) over the cross section became zero⁽¹⁷⁾, which is a property of the diffusions for the wall jet mentioned later, and of the flow field allowable for the boundary layer approximation. The results of comparison are shown in Fig. 13. The present result is shown with solid lines, and the result of Wygnanski et al. is shown with chain lines. The production terms of the present result agree very well over the whole region of the jet with those of Wygnanski et al., and the convection term agrees well except for the outer edge of the jet in the region $\eta > 0$. However, in total diffusion terms and the dissipation term, considerable disagreement is observed. The broken lines in Fig. 13 are the results of Wygnanski et al. for the case in which the dissipation is altered by the present authors by a certain rate according to which the integral of the diffusion terms

with respect to η over a cross section becomes zero. Although, according to Eq. (1), the integral of the total diffusion over the cross section does not become zero, the fifth and sixth terms are small and can be neglected, so the integral of the diffusion terms becomes zero for a good approximation. The diffusion terms of Wygnanski et al. corrected in this way agree well with the result of the present experiment. However, the dissipation terms in our experiment are somewhat larger than the corrected value of Wygnanski et al. From the above-mentioned result, except for the region where the measurement accuracy is difficult to obtain near the outer edge of a jet (particularly, the mean velocity V), this measurement is considered reliable.

The equation for the turbulent energy of a two-dimensional wall jet is given as follows⁽⁴⁾:

$$\begin{aligned} & \frac{U}{2} \frac{\partial \overline{q^2}}{\partial x} + \frac{V}{2} \frac{\partial \overline{q^2}}{\partial y} + (\overline{u^2} - \overline{v^2}) \frac{\partial U}{\partial x} + \overline{uv} \frac{\partial U}{\partial y} \\ & + \frac{\partial}{\partial y} \left(\frac{\overline{vq^2}}{2} + \frac{\overline{vp'}}{\rho} \right) + \varepsilon = 0 \end{aligned} \quad (3)$$

The first and second terms are the convection terms, the third and fourth terms the production, the fifth the diffusion, and the sixth the dissipation term. When ε is to be determined from Eq. (2), the differentiation of the x component of the fluctuating velocity u with respect to time is obtained by means of a purpose-built differentiator (which has a linear frequency characteristic of up to 5 kHz). The convection and production terms in Eq. (3) are calculated from the measured values of the mean velocity, turbulent intensity and Reynolds stress. The diffusion is obtained as a residual of Eq. (3), in which the measured values of the convection, production and dissipation terms are substituted, as in the case of the jet mentioned earlier. Also, the dissipation term is corrected from the value obtained from Eq. (2) so that the integral of the diffusion over the cross section of the wall jet becomes zero⁽¹⁷⁾.

In Figs. 14(a) and (b), the distributions of the

Fig. 13 Comparison of turbulent energy balance in the mixing layer

convection, production, diffusion and dissipation terms in Eq. (3) are shown in the case of $\phi=30^\circ$ and in the range $(x/b_j \geq 5)$, where the mean velocity is in accord with the logarithmic distribution of Kobayashi and Fujisawa, as a typical example of the turbulent energy balance examined at 14 cross sections. Each term in Fig. 14 is made dimensionless using the maximum velocity U_m and the half-width $y_{0.5}$ of the wall jet. Figure 14(b) shows the energy balance at $x/b_j=20$ which is representative of a fully developed region; the present result is indicated by solid lines, and the result of an ordinary two-dimensional wall jet is shown for reference with broken lines. Production increases in the downstream region more than in the upstream region of $x/b_j=5$. The profile of the production takes a minimum value around y_m , but no negative production occurs within the range of x/b_j shown here. The convection is a gain at the position of $x/b_j=5$ across the whole layer, but changes into a loss in the part downstream. Also, dissipation increases downstream, but in the fully developed region of $x/b_j \geq 15$, it was confirmed that the dissipation changed little in the x -direction, and was nearly the same at $x/b_j=20$; no further increase downstream was observed. Also, in the range $x/b_j \geq 10$, the positions at which the absolute values of the production and the diffusion took their maximum values nearly coincided.

In Fig. 14(b), the turbulent energy balance in the fully developed flow region is compared with that of a two-dimensional wall jet. The production term in the present flow is much larger than that of a two-dimensional wall jet, and the other terms, except the convection, are also larger in the present result, although the tendency in the distribution to change is similar. The result for a wall jet along a concave wall by Kobayashi and Fujisawa^{(5),(6)}, which is not given here, indicates that each of the production, convection, diffusion and dissipation values in that flow is smaller than that of the two-dimensional wall jet, and that only the convection was smaller than the present one. As in the case of a two-dimensional wall jet, in this flow the turbulent energy production around y_m is smaller than the turbulent dissipation; the turbulent energy in this part is gained by advection from upstream, and by diffusion from the central part of the wall jet. The gain of the turbulent energy by the diffusion in the present flow is appreciable in comparison with the two-dimensional wall jet.

Figure 15 shows a comparison of the turbulent energy budget in the fully developed flow region ($x/b_j=20$) for $\phi=45^\circ$ given in the previous report for $\phi=30^\circ$. The production and diffusion terms are much larger for $\phi=45^\circ$ than for $\phi=30^\circ$, and dissipation is also larger. However, the tendency of the distribution

of each term in both flows to change is similar.

4. Conclusions

The turbulence properties and the turbulent energy budget in a two-dimensional air jet impinging on a wedge are experimentally examined for the case in which the angle of a wedge surface is 30° , including the case complementary of 45° reported previously. The following conclusions are obtained.

(1) Similar to the case of $\phi=45^\circ$ reported earlier, in the case of $\phi=30^\circ$, the dimensionless profiles of u'/U_m , v'/U_m and $\overline{uv}/U_m^2$ in terms of $y/y_{0.5}$ in the fully developed flow region after impingement on the wedge take considerably larger values than those of an ordinary two-dimensional wall jet. The value of w'/U_m is of about the same order as that of the two-dimensional wall jet. There is no similarity in all the dimensionless profiles for the Reynolds stress and each component of the fluctuating velocities.

(2) The dimensionless distribution of the total turbulent energy in terms of $y/y_{0.5}$ in the fully developed flow region does not show a similar profile, and takes a value higher than those in the two-dimensional wall jet. The difference in this value with respect to the angle of the wedge surface ϕ is not appreciable.

(3) The isopleths of the turbulent energy exhibit a difference in their patterns between the case of $\phi=30^\circ$ and 45° near the vertex of a wedge. This difference

Fig. 14 Turbulent energy balance ($\phi=30^\circ$)

Fig. 15 Turbulent energy balance ($\phi=45^\circ$, $x/b_j=20$)

shows that the effects of pressure gradient, streamline curvature, turbulence field distortion when approaching a body and so on are important near the vertex of a wedge.

(4) The turbulent energy balance in the wall jet after impinging on a wedge is examined. In the range of $x/b_j \geq 5$, the production and the dissipation increase in the downstream direction, but the advection changes from a gain across the whole layer at the upstream position to a loss in the downstream part. In the fully developed flow region, all terms of production, dissipation and diffusion except for the convection are considerably larger than those in a two-dimensional wall jet. Also, the terms of production and diffusion are higher in the case in which the angle of wedge surface equals 45° , compared with the case of $\phi=30^\circ$.

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