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On the numerical near-wall corrections of single hot-wire measurements

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The present paper numerically investigates the near-wall correction of velocity readings when using hot wires to measure the flows very close to walls. It is found that the near-wall correction is necessary not only for the conducting wall but also for the adiabatic wall. For an infinitely long 5-μm diameter hot wire, measurement error begins to appear at $Y^+ < 5$ for an infinitely conducting wall and at $Y^+ < 2$ for an adiabatic wall. In addition to the distance from wall, the wire diameter also exerts significant influence on the velocity measurements. However, provided the flow is two-dimensional (2-D), the effect of operating overheat ratio seems to be insignificant.

Keywords: wall effects; near-wall corrections; hot wire

Introduction

In experimental studies of near-wall turbulence, it is often necessary to conduct measurements with hot-wire anemometers very close to the wall. With the proximity of hot wire to the wall, distortion of the flow field and heat transfer characteristics from the hot wire occur, resulting in serious measurement errors. A number of experimental investigations on the near-wall effects on hot-wire measurements have been performed but with diverse results. Wills (1962) suggested the incorporation of an additional empirically determined heat loss term that is a function of the distance from the wall and Reynolds number, to the conventional heat loss from hot-wire equation to account for the wall effect in laminar flow. For turbulent flow, half of the laminar correction is suggested without physical explanation. Oka and Kostic (1972) together with Hebbar (1980) confirmed that the correction could fall to a single curve of $\Delta U/U_\tau = f(Y^+)$ for different wire diameters when the velocity and distance from the wall are normalized by the wall parameters of U_τ and ν/U_τ, respectively. The existence of such correction curve implies implicitly that the near-wall effects are independent of Reynolds number and wire diameter. Krishnamoorthy et al. (1985) demonstrated the importance of the wire diameter and overheat ratio on the near-wall effects. Singh and Shaw (1972) pointed out that the correction is independent of the wall conductivity, but Bhatia et al. (1982) showed otherwise.

In view of the inherent experimental difficulties of the near-wall measurements, it is obvious that a numerical experiment to study the near-wall effects would be an attractive alternative especially with the advent of computational fluid dynamics and computer hardware technology. Piercy et al. (1956) employed potential theory to study the two-dimensional (2-D) flow past a hot wire near an infinitely conducting wall. Their results largely underpredict the experimental correction. Bhatia et al. (1982) included the viscous effect in their formulation. They considered the wire as a point heat source and numerically solved the disturbed temperature field with an assumed linear velocity profile. The initial temperature profile was based on Lauwerier's (1954) solution of the energy equation without the viscous dissipation term and wall effects. Their results underpredict the near-wall correction for $Y^+ < 2.5$ and overpredict for $Y^+ > 2.5$ when compared to previous experimental results of Oka and Kostic (1972) and Hebbar (1980). It should be noted that, in their calculation, the momentum equation was not solved, and the influence of the wire diameter was neglected, because it was assumed as a point. The influence of wire diameters are known to be important experimentally (see Wills 1962; Krishnamoorthy et al. 1985). The interference between the wire diameter and the wall would alter the flow field and influence the heat loss from the hot wire. Thus, it is essential to solve the momentum and energy equations as a coupled problem.

The present paper aims to overcome the deficiencies of the previous computational methods by solving the full Navier–Stokes equation together with the energy equation using an NEC supercomputer. Some of the important parameters, such as wall conductivity, wire diameters, distance from the wall, and overheat ratio on the near-wall measurements are investigated.

Theoretical formulation

The present theoretical formulation assumes steady, incompressible, 2-D flow past an infinitely long circular wire that is aligned parallel to the wall and normal to the flow. The wire is subjected to a velocity field varying linearly with distance from the wall, similar to that found in the viscous sublayer. Because the frequency response of the hot wire is much higher than the velocity fluctuation frequency in the viscous sublayer of a turbulent boundary layer flow, the unsteady approaching flow can be treated as a quasisteady flow. In this way, the present steady flow formulation, which greatly reduces the complexity and computing time, can be used to resolve the heat transfer characteristics from the wire near a wall, and the near-wall correction computed can be applied to turbulent flow on a point-by-point basis to construct

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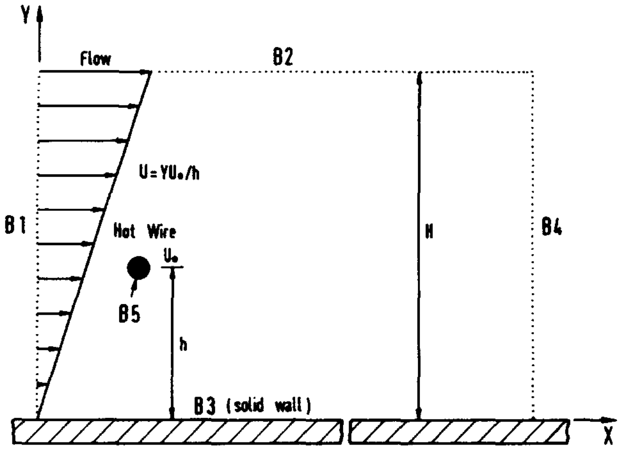

Figure 1 Schematic drawings of computing region

the instantaneous velocity. From the corrected near-wall instantaneous velocity, the instantaneous wall shear stress, near-wall turbulence intensity, and higher-order turbulence statistics can be deduced (Chew et al. 1994). With a modern high-speed data-acquisition system, it can be done easily in a postprocessing, nonreal-time manner. Two extreme types of wall with simple boundary conditions are investigated. One has infinite conductivity in which $T = T_\infty$ at the wall. The other has zero conductivity in which $\partial T/\partial Y = 0$ at the wall. These boundary conditions are identical to those adopted by Bhatia et al. (1982).

The control volume of consideration is schematically drawn in Figure 1. The properties of fluid, including density, viscosity, conductivity, etc., are taken as constants and referenced at the mean film temperature. Note that the body force is expressed as the temperature difference, instead of density difference, according to Boussinesq's assumption. The following governing equations are used to describe the flow.

Vorticity–stream function equation:

$$U\frac{\partial \Omega}{\partial X} + V\frac{\partial \Omega}{\partial Y} = \nu\left(\frac{\partial^2 \Omega}{\partial X^2} + \frac{\partial^2 \Omega}{\partial Y^2}\right) \mp g\beta\frac{\partial T}{\partial X} \tag{1}$$

$$U = \frac{\partial \psi}{\partial Y}, \qquad V = -\frac{\partial \psi}{\partial X}, \qquad \nabla^2\psi = -\Omega \tag{2}$$

Energy equation:

$$\rho C_p\left(U\frac{\partial T}{\partial X} + V\frac{\partial T}{\partial Y}\right) = k\left(\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2}\right) + \mu\left(\frac{\partial U}{\partial Y}\right)^2 \tag{3}$$

where all of the symbols in Equations 1–3 are defined in the conventional ways. The "−" before the buoyant force term in Equation 1 indicates the case that the hot wire is above a horizontal solid wall, while "+" refers to flow under a solid wall. The corresponding boundary conditions in Figure 1 are defined as follows:

$$\begin{array}{llll} \text{B1:} & X = X_s, & U(Y) = (U_o/h)Y, \quad V = 0, & T = T_\infty \\ \text{B2:} & Y = H, & U = (U_o/h)H, \quad V = 0, & T = T_\infty \\ \text{B3:} & Y = 0, & U = V = 0, & T = T_\infty \text{ or } \partial T/\partial Y = 0 \\ \text{B4:} & X = X_e, & \partial U/\partial X = \partial V/\partial X = 0, & \partial T/\partial X = 0 \\ \text{B5:} & & U = V = 0, & T = T_w \end{array} \tag{4}$$

Here U_o is the velocity at the height of h, which is also the location of the hot wire. The operating temperature of the hot-wire and free-stream temperature are T_w and T_∞, respectively. Note that for simplicity, we have imposed a constant streamwise velocity and zero vertical velocity on the top boundary B2. Provided that the boundary B2 is set to be far away from the hot wire, we reckoned that the heat transfer characteristics from the wire to the free stream in the presence of the solid wall along the boundary B3, which is of central interest to the present work, will not be very much affected by the above specification on B2. (Alternatively, the results can be viewed as the study of the convective heat transfer from the hot wire to the free stream and the near wall in a Couette flow field with the top boundary set at sufficient far distance from the wire.)

To normalize the governing equations, the following wall parameters are chosen to be the reference scales according to the previous experimental and theoretical near-wall corrections:

Velocity etc.:

$$U^+ = U/U_\tau, \qquad V^+ = V/U_\tau, \qquad F = \psi/\nu, \qquad W = \nu\Omega/U_\tau^2 \tag{5a}$$

Temperature:

$$Q = (T - T_\infty)/(T_w - T_\infty) \tag{5b}$$

Coordinates:

$$X^+ = XU_\tau/\nu, \qquad Y^+ = YU_\tau/\nu \tag{5c}$$

The governing equations are nondimensionalised and transformed into the following:

Vorticity-stream function equation:

$$U^+\frac{\partial W}{\partial X^+} + V^+\frac{\partial W}{\partial Y^+} = \nabla^2 W \mp \left(\frac{\mathrm{Gr}}{\mathrm{Re}_\tau^3}\right)\left(\frac{\partial Q}{\partial X^+}\right) \tag{6a}$$

$$\nabla^2 F = -W \tag{6b}$$

Energy equation:

$$U^+\frac{\partial Q}{\partial X^+} + V^+\frac{\partial Q}{\partial Y^+} = \frac{1}{\mathrm{Pr}}\nabla^2 Q + \mathrm{Ec}\left(\frac{\partial U^+}{\partial Y^+}\right)^2 \tag{7}$$

Boundary conditions:

$$\begin{array}{ll} \text{B1:} & X^+ = X_s^+, \quad U^+ = Y^+, \quad V^+ = 0, \\ & \text{hence } F = 0.5Y^{+2} \text{ and } W = -1, \text{ and } Q = 0 \\ \text{B2:} & Y^+ = H^+, \quad U^+ = H^+, \quad V^+ = 0, \\ & \text{hence } F = 0.5H^{+2} \text{ and } W = -1, \text{ and } Q = 0 \\ \text{B3:} & Y^+ = 0^+, \quad U^+ = V^+ = 0, \\ & \text{hence } F = 0 \text{ and } Q = 0 \text{ or } \partial Q/\partial Y^+ = 0 \\ \text{B4:} & X^+ = X_e^+, \\ & \partial U^+/\partial X^+ = \partial V^+/\partial X^+ = \partial W/\partial X^+ = \partial Q/\partial X^+ = 0 \\ \text{B5:} & U^+ = V^+ = 0, \quad F = F_{\mathrm{const}}, \\ & \text{a constant on the hot-wire surface, and } Q = 1 \end{array} \tag{8}$$

where

$$\mathrm{Gr} = g\beta(T_w - T_\infty)\frac{d^3}{\nu^2}, \qquad \mathrm{Pr} = \mu\frac{C_p}{k},$$

$$\mathrm{Re}_\tau = \frac{U_\tau d}{\nu}, \qquad \mathrm{Ec} = \frac{U_\tau^2}{C_p(T_w - T_\infty)}$$

Here Gr and Pr are the Grashof and Prandtl numbers, and Re_τ and Ec are the modified Reynolds and Eckert numbers, respectively, whose characteristic velocity is the friction velocity U_τ instead of free-stream velocity. The friction velocity is taken to be the undisturbed quantity at the inflow. In our subsequent calculations, the average Nusselt number is defined as follows:

$$\mathrm{Nu} = \frac{1}{A}\oint \frac{qd}{k(T_w - T_\infty)}\,\mathrm{d}A = \frac{H}{\pi k(T_w - T_\infty)} \tag{9}$$

where H is the heat flux through the closed circulation that surrounds the wire, and d is the wire diameter.

Numerical implementation

Because of the difference in geometry between the circular wire and flat wall, the mesh system used by Lewis (1979) in his study of steady flow between a rotating circular cylinder and fixed square cylinder is adopted for the present work. The surface of the cylindrical hot wire is divided into equal arc length at a nominal interval of $\pi/36$. Rectangular grids in the flow domain then intersect the cylinder surface at these collocated points. The rectangular meshes are distributed nonuniformly throughout the flow domain so that they are much denser around the wire and the wall for better spatial resolution in the calculation of the flow field and the associated heat flux from the hot wire.

Following Lewis (1979), a central finite difference approximation to the governing equations with the difference correction (to ensure second-order accuracy) is used for discretization of the governing equations in the present work. The interested reader should refer to the original paper for details regarding the implementation of the finite difference forms. As similarly carried out in Lewis, the boundary condition for the vorticity term pertaining to the hot-wire surface and the wall in the solution of the vorticity-transport equation is derived using Taylor series expansion for the stream function (or velocity terms), the velocity boundary conditions and Equation 6b. In this way, the elliptic Equations 6 and 7 combined with the boundary conditions specified are solved iteratively using the method of successive over-relaxation (SOR) with relaxation parameter ω_F. The numerics are programmed in double-precision, and the iteration is continued until the maximum difference between the respective values of F (and W) on successive iterations is less than ε_F (and ε_w), which is set at 10^{-4}.

In the numerical implementation, the hot wire is set at $X^+ = 0$, the inflow is taken at $X^+ = -5.0$, and the outflow is set far downstream between $X^+ = 60 \sim 80$ (Bhatia et al. 1982). The distance of the wire from the wall ranges from $Y^+ = 0.5$ to 8.0; the accompanying typical nondimensional diameter of the wire is around $d^+ (\equiv U_\tau d/\nu) \cong 0.125$. The top boundary (B2) is set at a distance of 10 wall units above the wire. Different grid sizes are used in the computation with equal arc length interval on the wire ranging from $\pi/18$ to $\pi/36$ and smaller. It is found that the results are fairly grid invariant and the present work is carried out nominally for equal arc length interval of $\pi/36$ on the hot-wire cylinder. A single typical run for one configuration using the NEC SX-1A supercomputer takes between 20 to 50 CPU minutes, depending on the wire diameter and friction velocity.

Results and discussions

The heat loss from a circular cylinder in uniform flow, i.e., without wall effects was computed at the low Reynolds number range normally encountered in near-wall hot-wire measurements. The numerical code is easily altered to reflect uniform velocity field at the inflow boundary (B1), and the bottom boundary (B3) where the wall resides is replaced with a similar boundary condition as reflected in B2. Results of the computation are plotted in term of Nusselt number (Nu) *versus* Reynolds number (Re, based on free-stream velocity and diameter of wire) in

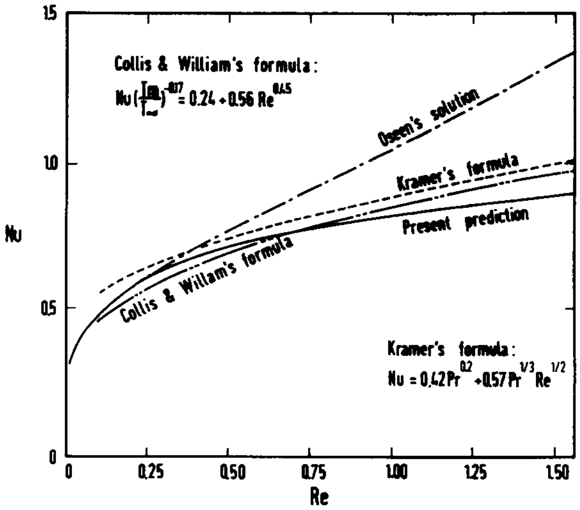

Figure 2 Heat transfer from a circular cylinder in uniform flow

Figure 2 and compared to Oseen's solution and Kramer's experimental formula for Reynolds number ranging from 0.1 to 40,000. Also shown is the empirical formula based on experiments put forth by Collis and Williams (1959). Our results agree with Oseen's solution for Re < 0.25, but the deviation increases with increasing Reynolds number for Re > 0.25, which can be attributed to the failure of linear assumption of Oseen's solution. They are slightly lower than those given by Kramer's formula. The discrepancies may be caused by the three-dimensional (3-D) effect in measurement, which is neglected in the present 2-D theoretical formulation. The resolution of the experimental formula at such low Reynolds number range may also be poor. When compared to Collis and Williams formula, our computed Nu assumes a slightly larger quantity for the range of Re < 0.67 and shows a slower increase with Re for Re > 0.67. Generally, the reasonable agreement with experimental results augers well for the theoretical formulation and numerical method adopted in the present investigation. The results obtained in Figure 2 are important, because they form the reference against which the subsequent computations with wall effects are compared in order to obtain the near-wall corrections.

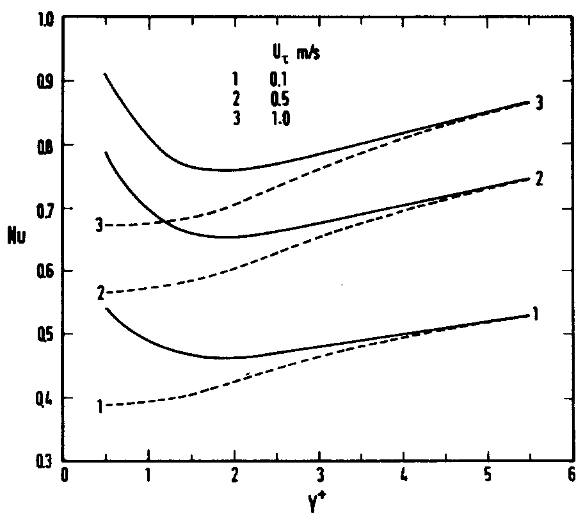

Figure 3 Heat losses at different shear rates for conducting (solid lines) and adiabatic (dashed lines) walls for a 5-μm diameter hot wire

Influence of wall conductivity

The heat loss from the hot wire near an infinitely conducting wall ($T = T_\infty$ at the wall) and an adiabatic wall ($\partial T/\partial y = 0$ at the wall) are computed at different distances Y above the wall for a hot wire of 5-μm diameter at different friction velocities $U_\tau = 0.1$, 0.5, 1.0 m/s and an overheat temperature of $\Delta T = (T_w - T_\infty) =$ 250°C. The results are plotted in Figure 3 as Nusselt number *versus* Y^+ where $Y^+ = U_\tau Y/\nu$. The two different conductivities represent the extreme wall conditions where the boundary conditions can be easily specified, and the results obtained form the upper and lower limits of the influence of wall conductivity. It should be noted that in the viscous sublayer, $Y^+ = U^+$ and so at a particular friction velocity, Y^+ is linearly related to the Reynolds number (Re) based on the wire diameter d; i.e., $\mathrm{Re} = Y^+\mathrm{Re}_\tau$. The results in Figure 3 for heat loss with near-wall effects, which agree qualitatively with those from Bhatia et al. (1982), can then be compared to those in Figure 2 for heat loss without wall effects directly.

It can be deduced from Figure 2 that for flow without wall effects, the heat loss decreases rapidly with decreasing Y, because the velocity and, hence, Reynolds number is lower at smaller Y. In Figure 3, at larger distance from the wall ($Y^+ > 5$), a similar amount of heat is lost by the wire to both kinds of walls. However, as the wire is positioned increasingly closer to the wall, the influence of the conducting wall, which is compounded by the distortion of the velocity field caused by the presence of the wire, causes the heat transfer to increase significantly. A similar feature can also be found for the adiabatic wall as Y^+ decreases; however, it is less pronounced. However, the heat loss from the wire near an adiabatic wall is still higher than the case without the wall. Noting that in the latter where there is no heat transfer to the adiabatic wall, this provides the evidence that the presence of the wire must have distorted the velocity field and altered the heat transfer characteristics of the wire. The effect of wire diameter cannot be neglected as in the case of Bhatia et al. (1982). Their numerical solution with a point heat source representing the wire would not be able to detect the near-wall effects for adiabatic wall, which led to their conclusion that "no corrections are suggested in the vicinity of non-conducting walls." The present finding is also contrary to that of Singh and Shaw (1972) who contended that the near-wall effects are independent of wall conductivity.

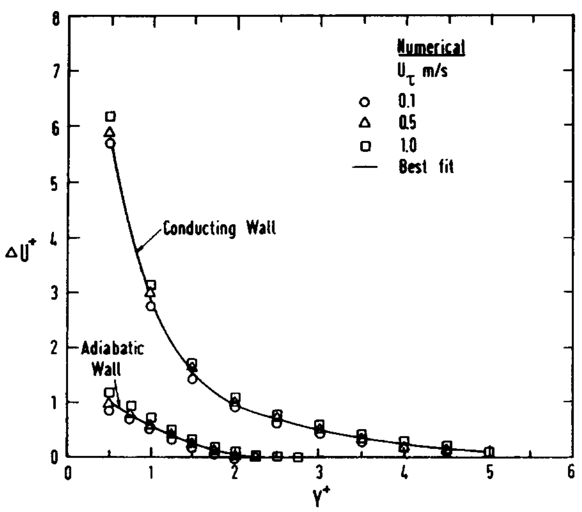

Figure 4 The correction curves for conducting and adiabatic walls for a 5-μm diameter hot wire

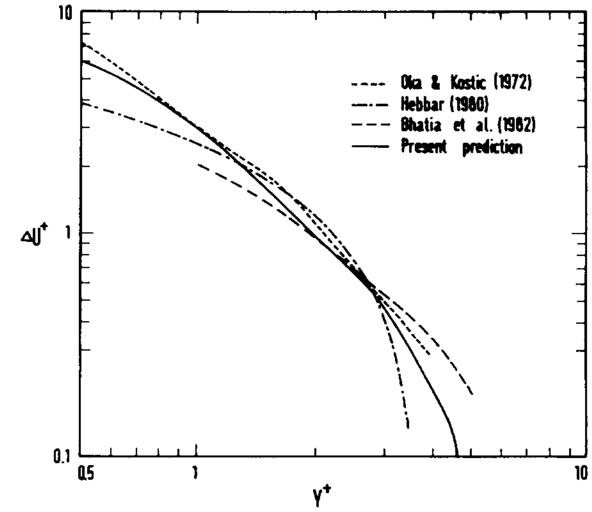

Figure 5 Comparison with previous results for a 5-μm diameter hot wire near conducting walls

The heat loss for flow with higher friction velocity is higher, as expected. In the viscous sublayer, a higher friction velocity is related to higher approaching velocity to the wire resulting in higher overall heat loss.

The near-wall effects on the velocity measurements can be obtained from the results in Figures 2 and 3, which represent the cases with and without wall effects. The discrepancies in velocity measurements caused by the near-wall effects normalized by the friction velocity ΔU^+ are plotted against Y^+ in Figure 4 for the cases of infinitely conducting wall and adiabatic wall. The results indicate that for a wire with a certain diameter operating at a constant overheat ratio near a wall of fixed conductivity, the ΔU^+ *versus* Y^+ data for different friction velocity collapse onto a single correction curve quite well. The influence of U_τ is barely discernable, which is similar to the findings of Bhatia et al. (1982) for their conducting wall; albeit, with a point heat source representing the hot wire. The correction curve plotted in Figure 4 is useful, because it enables the prediction and correction of measurement errors attributable to near-wall effects. It shows that the measurement errors are much larger for conducting wall than adiabatic wall, and errors for other types of wall should theoretically fall somewhere in between the two. It is important to note that when using hot wire of 5-μm diameter, measurement error will begin to appear at $Y^+ < 5$ for an infinitely conducting wall and at $Y^+ < 2$ for an adiabatic wall. These findings are in agreement with the experimental findings of Bhatia et al. (1982) and Chew et al. (1995).

Comparison with previous results

The present prediction of correction curve for hot wire of 5-μm diameter near a conducting wall is compared to the experimental data of Oka and Kostic (1972) based on a 5-μm wire, Hebbar's (1980) data obtained using a 3.8-μm wire, and the theoretical prediction of Bhatia et al. (1982) in Figure 5. Bhatia et al.'s calculations generally underpredict the correction for $Y^+ < 2.5$ and overpredict for $Y^+ > 2.5$ when compared with the experimental data. The present prediction agrees reasonably well with experimental results, although it is for an infinitely conducting wall. As more heat is lost to the infinitely conducting wall, we can expect that the calculated curve should overpredict the correction based on experiments. However, the experimental data may suffer from 3-D effects, because the length to diameter ratio of the wire is finite. Some of the heat will be lost to the prongs, which cannot be removed through calibration in free stream, because the interference between the prongs and the wall alters the flow pattern and, hence, the heat transfer characteristics of the prongs. The additional heat loss to the prongs attributable to wall interference effects could have more than accounted for the reduced heat loss to the noninfinitely conducting walls, hence resulting in the discrepancies. In such a case, we can only try to minimize the 3-D effects caused by the prongs by having as large a length-to-diameter ratio (L/d) as possible. For Oka and Kostic, the L/d used for the wire is only 200; whereas in Hebbar, it is estimated to be about 300.

Another point worth noting is that our computed correction curve for the 5-μm diameter wire somewhat bears a better overall agreement with the experimental result of Oka and Kostic (1972) who used a 5-μm hot wire as opposed to Hebbar's (1980) curve based on a 3.8-μm hot wire. As discussed in the next section, wire diameter does have an influence on the correction curve and may account for this observation.

Influence of wire diameter

The influence of wire diameter on near-wall measurements has been the subject of much controversy. Wills (1962) showed experimentally that the additional heat loss from the wire attributable to wall effects is related to the ratio of distance from the wall to wire diameter (Y/d) and Reynolds number. The influence of wire diameter is, thus, implicitly implied. Although the choice of dimensionless parameter Y/d may be suitable to study the heat loss from circular cylinder near a wall in general, it is not quite suitable for near-wall correction of hot-wire measurements, because the heat loss is a function of friction velocity. In turbulent flow, the friction velocity is time dependent. Because the heat loss varies with friction velocity nonlinearly the computation of mean heat loss or other mean correction factors becomes impossible unless it is done in a postprocessing, nonreal-time manner digitally. As shown earlier, the preferred dimensionless parameters for near-wall correction of hot-wire measurements are ΔU^+ and Y^+, because the correction is independent of friction velocity. The collapsed correction curve is, thus, unique to a particular measurement configuration.

It is logical to deduce that at a fixed distance away from the wall, a larger diameter hot wire would cause larger wall effects. This was observed experimentally by Krishnamoorthy et al. (1985). With the choice of ΔU^+ and Y^+ as the dimensionless parameters, the effect of wire diameter on heat loss must be represented by another dimensionless parameter. Zemskaya et al.

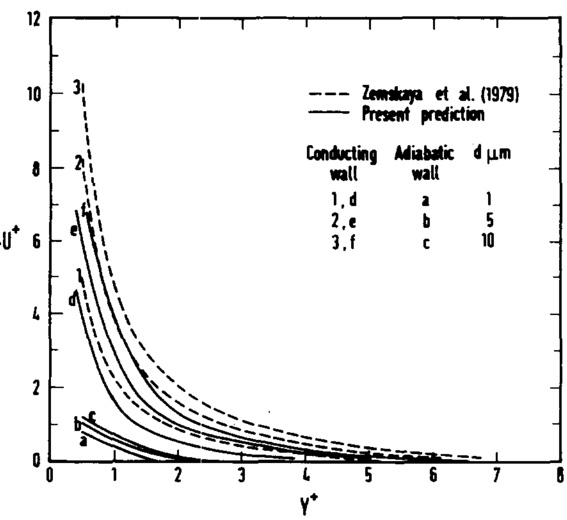

Figure 6 Influence of wire diameters on the correction

(1979) modified ΔU^+ and Y^+ by $(d^*/d)^{0.15}$ where d^* is the reference diameter of 4.4 μm and correlated an empirical correction formula based on the new dimensionless parameters.

The computational results presented so far are for $d = 5$ μm. To examine the influence of wire diameters, additional results are generated for $d = 1$ μm and 10 μm with infinitely conducting and adiabatic walls. The results are presented in Figure 6 and compared with the empirical correlation of Zemskaya et al. (1979). Both our results for the conducting wall and Zemskaya et al.'s proposed correlation based on data obtained near the steel wall indicate that the influence of wire diameter is large and cannot be neglected. The trend of larger correction (i.e., ΔU^+) for larger wire diameter is clearly discernible. The difference in the correction curves with respect to wire diameter that becomes larger for smaller Y^+ is also observed and can be attributed to the stronger effect on the flow field and accompanying heat transfer characteristics as the wire moves closer to the wall. It leads to nonsymmetrical distortion of the velocity profile and temperature wakes (Shi and Chew 1992). The above observations for the conducting wall are equally valid for the case of the adiabatic wall. It may partly explain the observation made by Bhatia et al. (1982) that no correction is required for their adiabatic wall, because in their computation, the hot wire is of zero diameter.

Influence of overheat ratio

To investigate the influence of operating overheat ratio of the hot wire, computation was done for a wire of 5-μm diameter near an infinitely conducting wall for temperature difference of 50, 100, and 250°C between the hot wire and fluid. However, no apparent influence is observed when the overheat ratio changes resulting in essentially the same correction curve as reflected in Figure 4 (not shown). This is in apparent contradiction to the findings of Krishnamoorthy et al. (1985), which reflect a significant influence of overheat ratio of a hot wire in near-wall measurements.

A possible explanation for the discrepancies is that in the present 2-D formulation, the ratio of heat loss to the fluid and to the wall remains independent of the overheat ratio for a particular measurement configuration. Thus, the near-wall effects on hot-wire measurement are the same at different wire temperature. In the experiment of Krishnamoorthy et al. (1985), the length-to-diameter ratio of the wire is only 200, and some additional heat will be lost to the prongs causing a deviation from two-dimensionality. The amount of heat loss to the prongs must be proportional to the wire temperature and cannot be removed by calibrating the hot wire in the free stream. The amount of heat loss to the fluid is small in the near-wall region where the velocity is low. The 3-D effect caused by proportionally larger heat loss to the prongs than the fluid becomes more pronounced as the wall is approached. The observed dependence on overheat ratio of the near-wall correction by Krishnamoorthy et al. is, thus, the result of deviation from two-dimensionality. This is discussed further in Chew et al. (1995).

The negligible influence of overheat ratio on near-wall correction is not obvious, because it is intuitive to expect a hotter wire would cause larger measurement error. The present computation demonstrates the importance of keeping the length-to-diameter ratio of the wire as large as practically possible in near-wall measurement in order to minimize 3-D effects and reduce the influence of overheat ratio.

Concluding remarks

The present paper shows how computation method can be used as a tool to complement physical experiments in the study of different wall materials and its influence on the heat transfer characteristics of a near-wall hot wire of various wire diameters. The numerical results provide correction curves for limiting cases of infinitely long wire, infinitely conducting wall, and infinitely nonconducting wall. For an infinitely long 5-μm diameter hot wire, measurement error begins to appear at $Y^+ < 5$ for an infinitely conducting wall and at $Y^+ < 2$ for an adiabatic wall. Our results also reveal the trend of decreasing correction curve as the wire diameter decreases and the invariance of overheat on the correction curve, provided the 3-D effects are minimized. It is imperative to note the relative importance of the various parameters on near-wall measurements. This information together with the computed correction curves can be used as references by experimenters to plan their near-wall measurements with hot wire in a most practical way in order to minimize the errors.

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