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Determination of Skin Friction Coefficient by Using Hot Wire Anemometry

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ABSTRACT

In this paper, the velocities profile for models are to be measured for determination of the skin friction coefficient of each case, which subsequently evaluate the effect of riblets on a smooth plate regarding the turbulent boundary layer drag reduction on the plate surface.

U_τ will change at small increments inorder to align the experiment curve to its theoretical curve to ensure the accuracy of C_f.

C_f value for the smooth surface and for the riblet surface will apply, then will see C_f for riblet surface is higher than that of the smooth surface for experiment when use different sandpapers old for smooth surface and new-brand for riblet surface but C_f for riblet surface must be lower than smooth surface.

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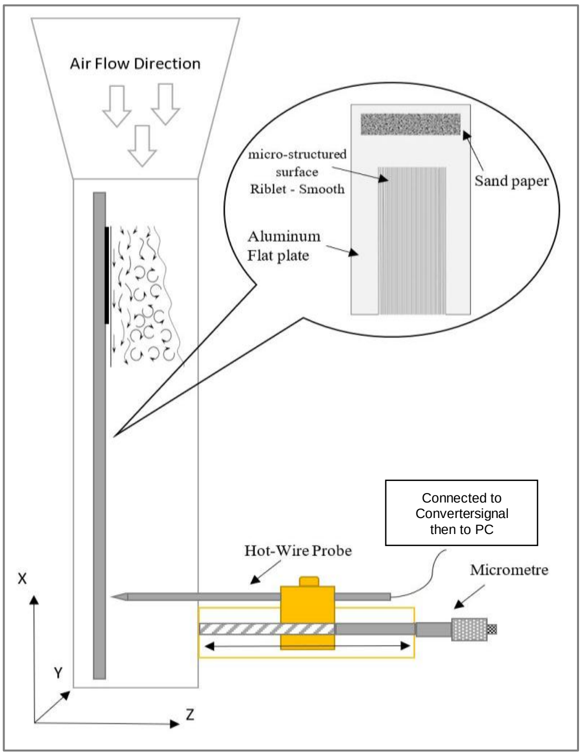
I. INTRODUCTION

Theaccuracy of local skin friction coefficient has prominent importance on performance of a fluid that is flowing over a surface, in fluid dynamics [1]. In this paper , the skin friction coefficient behaviour of flat plates with two different surfaces (smooth and riblet) are investigated though utilising hot wire anemometry to measure the turbulent velocity profile of the flat plate models. Therefore, the velocities profile for each model are to be measured for determination of the skin friction coefficient of each case, which subsequently evaluate the effect of riblets on a smooth plate regarding the turbulent boundary layer drag reduction on the plate surface.

Hot wire anemometry

The most common method is hot wire anemometry to study the instantaneous velocity of a turbulent flow, which is applicable to many engineering fields, and the main principle is associated with measuring of fluid velocity based on the rate of heat transfer over a wire with higher temperature than that of the fluid passing over it. A hot wire anemometry functions as a fluid passes over an electrically heated wire, it removes some of the energy from the heated wire. Hot wire anemometer operates at two different configurations; constant current anemometry (CCA) and constant temperature anemometry (CTA) [2].



Test equipment

To present the experimental work, test rig is constructed through fitting the test equipment to the AIR FLOWBENCH AF10. List of test equipment as following.

- A single hotwire anemometer (normal) for measuring of turbulent flow velocity
- 290mm x 150mm flat aluminium plate (smooth)
- 290mm x 150mm flat aluminium plate (riblet)
- A manual traverse unit to provide platform for the anemometer and for measuring y distance of the probe from the plate (which is Z in data).
- FC0510 Micromanometer is for measuring of air flow velocity through connecting to the pilot tube.
- Dantec Dynamics system for data recoding in relation to location of the probe.

State of boundary layer flow turbulent is initiated through placing a sandpaper above the area where the flow was measured. The air flow bench is used to provide air flow at constant rate during the experiment, and the free stream velocity at the inlet of the air flow bench was measured about 20m/s. The flat plates are placed in an enclosed chamber to ensure that the air flow does not dissipate as it flow over the plate, hence providing accurate reading of the velocity.

The anemometer probe was initiated by setting it to the plate as close as possible, using the manual traverse. Measurement of the velocity started from 0.05mm from the plate, and distance is increased by increment of 0.2mm for first 11 iterations and then increment was increased to 0.4mm for next 8 iterations after that increment was increased to 0.5mm for next 8 iterations and the last 3 iterations were increased by 0.75mm to complete 30 iterations. The procedure for measuring of velocities were kept constant for both plates with smooth and riblet surfaces.

Collected data from the experiment are processed (filtered) through signal conditioner to prepare for the A/D converter to convert signal from analogue to digital, which then interpreted through PC software for data analysis [2].

II. DISCUSSION EXPERIMENTAL RESULTS

Collected data from the experiment was presented in voltage, hence calibration is required in order to convert the data into velocity. With the provided calibration data, the calibration curve was plotted using the values for Umean and E, in order to obtain the polynomial liberalisation equation of CTA voltages, as shown in figure 1. The order of the equation increased to 4rd order for better computational time. In addition, King's law is another approach which can be used for calibration, which is described in terms of E^2=A+BU^n.

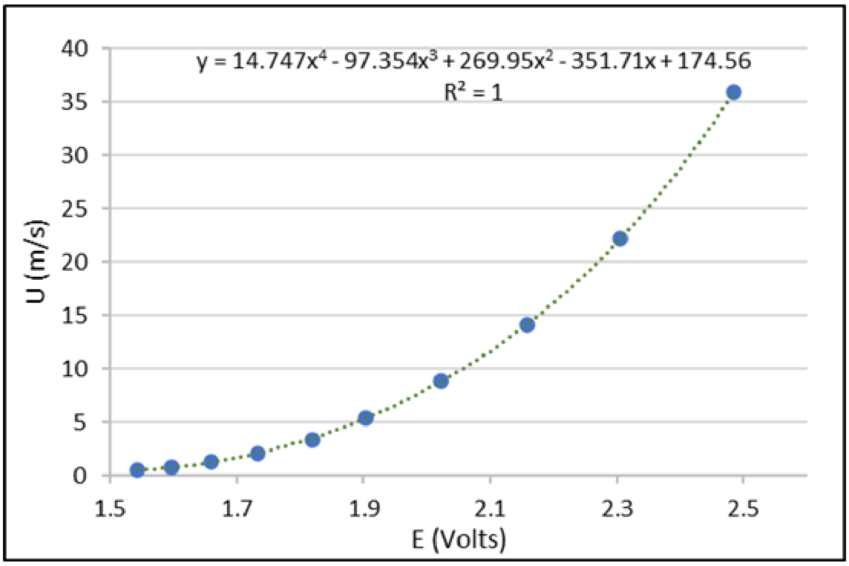


Figure 1 - Calibration curve for single hot wire

Next, velocities were calculated so the values can be used to determine the free stream velocity, u_e for smooth and riblet surface, as shown figure 2. From the graph, u_e for smooth and riblet are approximated to be 19.663m/s and 19.779m/s, respectively. However, the free stream velocities slightly lower than that of the measured free stream velocity (inlet) of approximately20m/s.

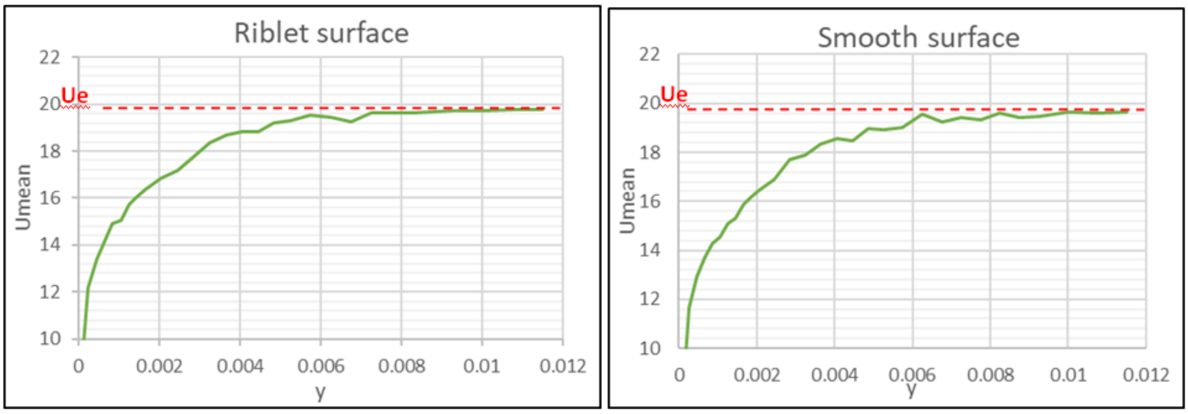


Figure 2- Mean velocity against distance between probe and plate

In order to compare the experimental and theoretical velocity profiles, non-dimensional velocity U+ and distance y+ values were calculated through applying the logarithmic law of the wall, which provides a good approximation for the entire velocity profile [3]. The ambient temperature was taken at 18.8℃ as it was measured during experiment, hence the kinematic viscosity, $\upsilon$of 1.5002x10^-5 m^2/swas considered.

$$Eq.\ 1 - U{+}U_+ = \frac{u}{u_\tau},Eq.\ 2 - y{+}y^+ = \frac{yu_\tau}{\nu},Eq.\ 3 - The\ Law\ of\ the\ wall \frac{u}{u_\tau} = \frac{1}{k}\ln\left(\frac{yu_\tau}{\upsilon}\right) + C$$

Where, $u_\tau$is friction velocity, $u$is the measured velocity, k is the Von Karman constant and C is a constant. The constant k=0.41 and C=5.

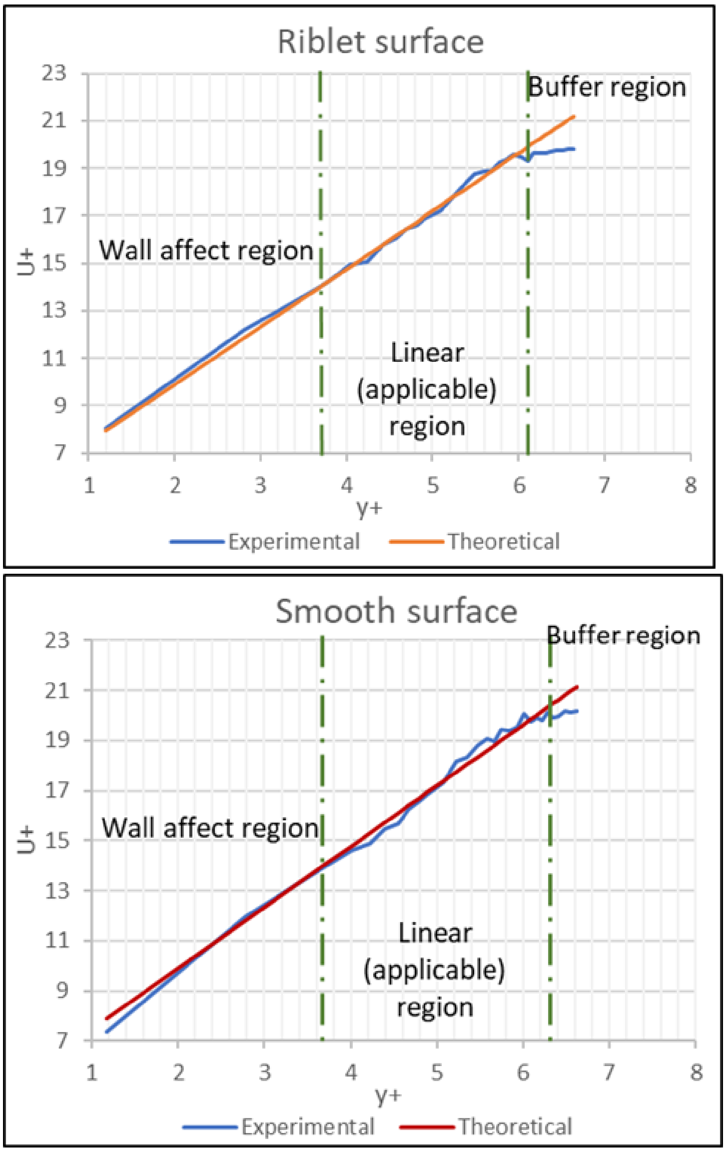


Figure 3 - Velocity profile of turbulent boundary layer for smooth and riblet surface

Illustrates in figure 3 U+ vs y+ plots for both surface, where by varying the friction velocity, u_τ the best fit between the experiment data with its theoretical data are obtained. For both surfaces, the linear region of the plot is assumed to be applicable however due to too much uncertainties in the experimental data, the plots suggest that the results were not accurate enough to deduct acceptable result. The u_τ for smooth and riblet surfaces are approximated to be 0.975 and 0.998, respectively, which subsequently used to determine the skin friction coefficient, C_f.

With the obtained $u_\tau$values for smooth and riblet surface, the skin friction coefficients were calculated using the equations 4 and 5.

$$\tau_w = \rho u_\tau^2 C_f = \frac{\tau_w}{0.5\rho u_e^2}$$

Eq.4 – Wall shear stress. Eq. 5 – Skin friction coefficient.

Where, τ_w is the wall shear stress and ρ is air density at ambient temperature. The skin friction coefficient for smooth was calculated to be 0.004918 and 0.005092 for riblet surface. In theory, riblet method is used to reduce the drag in turbulent flow through increasing downstream velocity of a fluid over a surface, hence decrease in skin friction coefficient. However, the calculated values for smooth and riblet surfaces were unexpected results because $C_f$riblet surface higher than the smooth surface that is because used old sandpaper for smooth surface but the riblet surface was new brand so the turbulent flow will not be same, in extension, the plots are suggesting there are too much fluctuation in the velocity profile and the buffer regions are presenting highest errors, which could possibly be due to the chaotic nature of turbulent flow.

Furthermore, there was significant error between the provided calibration data and experimental data, hence another set-off data was provided for the investigation. This could be main factor which causing the uncertainties in the results. Other errors could arise during the experiment is contamination of the probe whilst replacing of the plates as well as human error when adjusting the manual traverse, which could increase the resistivity of the hot wire, subsequently, effects the accuracy of data processing.

III. CONCLUSION

$u_\tau$was varied at small increments in order to align the experiment curve to its theoretical curve to ensure the accuracy of C_f.This is only an approximation of the value, which may defer from the actual value due to uncertainties that could occur in real life environment. According to [5], the expected $C_f$value for the smooth surface is 0.0044 and 0.0042 for the riblet surface, however the calculated values slight higher and unexpectedly, $C_f$for riblet surface is higher than that of the smooth surface for experiment because used different sandpapers old for smooth surface and new-brand for riblet surface but$C_f$for riblet surface must be lower thansmooth surface.

In conclusion, a number of uncertainties accounted for the cause of error during the experiment. Most significant error was due to the test equipment are not been calibrated properly, hence experimental data was not reliable.

For accurate results, it is preferable to calibrate the test equipment prior to the actual testing, which allows optimal testing conditions for operation and providing precise correlation between calibration curve and experimental data.

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