INCOMPLETE SIMILARITY IN A PLANE TURBULENT WALL JET ON A ROUGH SURFACE

Zhujun Tang[1], Noorallah Rostamy[1], Donald Bergstrom[1],
Jim Bugg[1] & David Sumner[1]
[1]*Department of Mechanical Engineering, University of Saskatchewan, Saskatoon, Canada*

Abstract The present study explores the hypothesis of incomplete similarity for a plane turbulent wall jet on a rough surface. Analysis of the outer and inner layers indicates that each region is characterized by a half-width which exhibits its own distinct dependence on the streamwise distance x from the slot, and a single self-similar structure for both regions does not exist. Comparison with the smooth wall case shows that the surface roughness modifies the streamwise variation of the half-width in both the inner and outer regions of the flow, although the effect in the outer region is minimal.

INTRODUCTION

The plane turbulent wall jet is a flow with many important practical applications in industry and the environment. It also remains of considerable interest from a theoretical point of view. Recall that a wall jet is characterised by an inner region that closely resembles a boundary layer, and an outer region that resembles a free jet. Typically, the maximum velocity and spread rate in the outer region of the wall jet are used as the appropriate scales for similarity analysis. George *et al.* [1] developed a similarity theory for the turbulent wall jet that resulted in a power law expression for the inner region using either inner or outer length scales. In contrast, Barenblatt *et al.* [2] concluded that the wall jet consists of two self-similar regions, i.e. an outer (or top layer) and an inner (or wall layer), separated by a mixing layer where the velocity is close to the maximum value. Furthermore, they suggested that the flow in each region develops in a distinct way so that full similarity of the entire flow does not exist. Rostamy *et al.* [3] performed LDA measurements of a plane turbulent wall jet on a smooth surface and obtained results which support the incomplete similarity theory of Barenblatt *et al.* [2]. The present paper performs a similar analysis for a turbulent plane wall jet on a transitionally rough surface and also observes incomplete similarity.

DISCUSSION OF PRELIMINARY RESULTS

The measurements used for the plane wall jet on the rough surface were obtained with a two-component laser Doppler velocimeter in the same facility and for the same flow conditions as those in reference [3]. The Reynolds number based on slot width and exit velocity was Re = 7500, and the flow was in the transitionally rough regime. The spread rates for the inner and outer regions were estimated from the mean velocity profiles, and then fitted to power laws of the following form for both the inner and outer layers:

$$y_{1/2} = A\, H^{1-\gamma}\, x^{\gamma}$$

where $y_{1/2}$ is the half-width, H is the width of the slot, x is the streamwise distance from the slot, and A and γ are the model coefficients. Figures 1 and 2 compare the half-widths on the smooth and rough surfaces in the inner and outer regions, respectively. In the inner region, the half-width is much larger on the rough surface. In contrast, the half-widths in the outer region are very similar, although the indication is that the half-width is slightly larger on the rough surface. Note that the differences observed in Figure 2 are very close to the level of uncertainty of the measurements, so any definitive conclusion is not possible. Figure 3 shows the mean velocity profile in the outer region at two different streamwise sections on the rough surface, where the half-width corresponding to the inner region is used as the length scale. The two velocity profiles clearly do not collapse, indicating that the inner scales do not capture the flow development in the outer region. The same profiles scaled with the outer half-width (not shown) do collapse to the same profile.

The full paper will provide a complete assessment of the similarity parameters in both the inner and outer regions for the plane turbulent wall jet on a transitionally rough surface.

References

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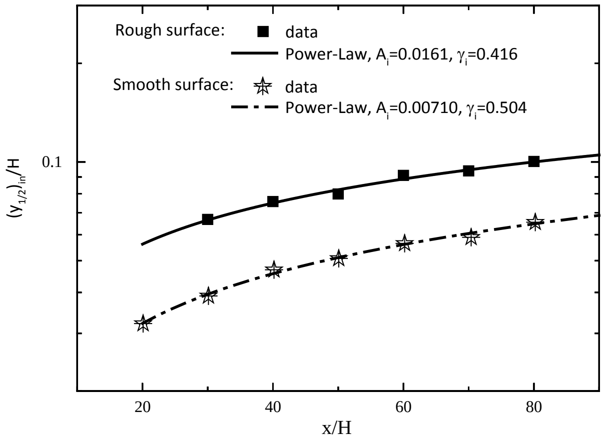

Figure 1. The wall jet spread rates in the inner region on smooth and rough surfaces.

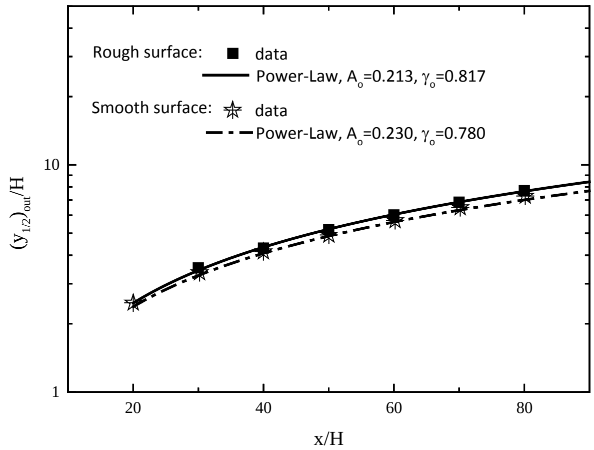

Figure 2. The wall jet spread rates in the outer region on smooth and rough surfaces.

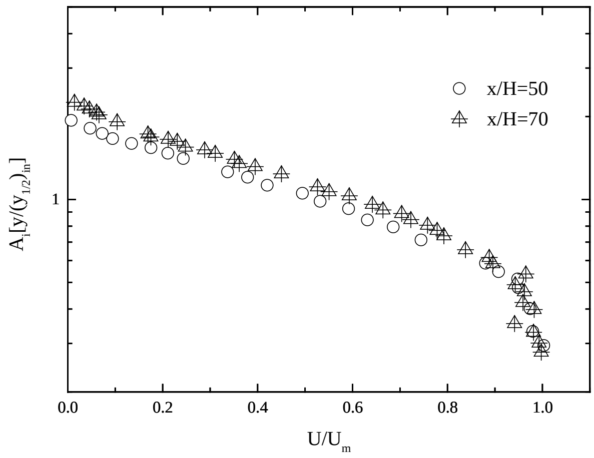

Figure 3. The mean velocity profiles on a rough surface in the outer region scaled with the inner length scale.