Application of Equilibrium Similarity Analysis on the Axisymmetric Wake

Peter Johansson, jope@tfd.chalmers.se
Thermo and Fluid Dynamics
Chalmers University of Technology
SE-412 96 Göteborg, Sweden

William K. George
University at Buffalo
Sate University of New York
Buffalo, New York 14260, USA

The axisymmetric wake is a flow of fundamental importance since it is one of the few shear flows where the Reynolds number decreases as the flow evolves. Also, the equations of motion governing the axisymmetric wake contain all of the important dynamical terms for turbulent flow away from surfaces. Hence the data from this flow form an important data base for developing turbulence models of all types, and an essential hurdle for them to overcome.

Historically, experiments focused on the far wake but the results were for a long time quite meager. One pioneering work was made by Hwang and Baldwin [3], who measured turbulence intensity and wake growth for a large span, $x/d = 5$ to $x/d \approx 900$. Because of the problems associated to anemometers and data aquisition, their data show significant scatter. More recently, researchers have focused on the near wake and the early development of the wake (e. g. Sirviente and Patel [7]) or on stability (e. g. Monkewitz [5]).

The following observations can be made from reported experiments:

- The effects of initial conditions do not vanish, even for large Reynolds numbers or large downstream distance.
- The growth rate of the wake does not in general behave as predicted by the classical similarity theory.
- The velocity profiles become similar, but the turbulence profiles does not.

The classical similarity analysis argues that the asymptotic wake is independent of its initial conditions, and depends only on the distance downstream and the drag. This argument was questioned by George [2], who also showed that, in fact, the classical analysis was based on assumptions that were not in general valid. A proper *equilibrium similarity analysis* demonstrated that solutions were possible which depended *uniquely* on the upstream conditions. The new theory was in striking agreement with the nearly concurrent experiments of Wygnanski et al. [8] on two-dimensional wakes. These showed dramatic differences between spreading rates and eddy structure which depended on the wake generator. George (1989) also showed that the axisymmetric wake would behave similarly, an actual prediction which was confirmed by a number of experiments, e. g. İlday et al. [4] and Cannon et al. [1].

George also predicted that the mean velocity profiles from the different experiments would be the same, if scaled by the centerline deficit velocity and velocity deficit half-width. This has been confirmed by experiments, e. g. Ostowari and Page [6], İlday et al. [4]. This result is very important, since previous researchers have often used such collapse to argue that wakes are independent of upstream conditions. The whole point of George's analysis, however, is that the differences only show up in the spreading rate, and the higher turbulence moments. While this has been confirmed beyond dispute for the two-dimensional wake, the data for axisymmetric wakes is far less extensive. Moreover, most of it has been taken at Reynolds numbers which are too low to really tell what is going on.

In this talk, we will extend George's equilibrium similarity analysis on the axisymmetric wake and show how it sheds some light on the previously unexplained experimental results. Also, requirements for future experiments are established to really sort out the remaining issues.

References

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