MCEN90018 Advanced Fluid Dynamics

Turbulent Boundary Layer Laboratory

NOTE: Please do not forget to bring a USB storage device to the lab so that you can take your data home with you

1 Aim

To measure the velocity profile of a turbulent boundary layer developing on a flat surface using hot-wire anemometry. The mean velocity profile will be used to determine the exact wall location, and to demarcate the inner, logarithmic and wake regions in the profiles.

Nomenclature

A	Universal constant in the logarithmic law of the wall
B	Large-scale characteristic constant in the velocity defect logarithmic law
C_f	Skin-friction coefficient
H	Shape factor
J	End of logarithmic region
P	Start of logarithmic region
Re_τ	Friction Reynolds number (Kármán number)
U_1	Mean free-stream velocity
U_τ	Friction velocity
δ_{99}	Wall-normal distance where $\overline{u}/U_1 = 0.99$
δ^*	Displacement thickness
u	Instantaneous streamwise velocity at particular point
$\overline{u}$	Time-averaged streamwise velocity
y	Wall-normal distance
κ	Kármán constant
ρ	Mass density
θ	Momentum thickness
ν	Kinematic viscosity
τ_w	Wall shear stress

2 Procedure

1. Measure atmospheric conditions so that you can determine:

$$\begin{aligned} \rho &= \frac{P}{RT} \quad \text{(Ideal gas law);} \\ \nu &= C_1 \frac{T^{1.5}}{\rho(T+110.5)} \quad \text{(Sutherland's law).} \\ C_1 &= 1.458 \times 10^{-6} \frac{kg}{ms\sqrt{K}}. \end{aligned}$$

2. Perform hot-wire pre-calibration at the free-stream

3. Move the hot-wire close to the wall from the free-stream. While doing so, observe the variation in the hot-wire signal using an oscilloscope.

4. Set the hot-wire sensor close to the wall.

5. Write a short pseudo-code to perform the measurement, sampling for 30 seconds at each wall-normal location desired.

6. Run the measurement. Record the full signal at each wall-normal position.

7. Perform hot-wire post-calibration at the free-stream.

3 Report

Please structure your report in a conventional lab report format. That is, include a section for Introduction, Methods, Discussion, and Conclusion. Address the following in your Discussion:

1. Plot the inner-scaled mean velocity profile using U_τ as velocity scale (as determined from the Clauser chart method). Also plot the outer-scaled mean velocity profile (in the form of velocity defect). Use conventional log-linear scaled axes for both plots. Demonstrate how you used the Clauser chart method to obtain the friction velocity U_τ.

2. Download the higher Reynolds number data provided on LMS. Compare this with your lower Re data. Discuss the collapse or lack of it using your knowledge of similarity in turbulent flows. Do you need to correct your initial wall position?

3. Plot the inner-scaled turbulence intensity (variance) profiles of your own data and of the high Reynolds number data provided.

4. From the previous two points, briefly discuss the Reynolds number trend that you observe.

5. For each of the profiles, determine the constants: A, κ, B, P and J. Highlight these constants in your plots.

6. Answer the following questions:

   6.1 What are some differences between laminar and turbulent boundary layers?

   6.2 What are the advantages/disadvantages of hot-wire anemometry compared to other velocity measurement techniques

   6.3 How well does King's law fit the calibration data for the hot-wire anemometer?

   6.4 Check the convergence of your data. Explain its relationship to sampling time and frequency. Provide a graph if necessary.

   6.5 What are the limitations of the Clauser-chart method? Find at least two alternative techniques to determine U_τ (and hence the τ_w) from the literature. Discuss the advantages/disadvantages of each method.

   6.6 Explain why the von Kármán momentum-integral equation is not useful for determining skin friction, C_f, from the data you have acquired in the lab.

   6.7 Using either hot-wire velocity profiles, provide a table of δ_{99}, δ^*, θ, H, C_f and ν/U_τ, $Re_{\delta_{99}}$, Re_x, Re_τ.

7. Observe the raw velocity signal at the wall height of $y/\delta_{99} \approx 0.9$. Describe (with a plot) the fluctuation pattern that appears in the signal. Then plot the probability density function of the velocity fluctuation and relate it to your signal observation. Try to explain the scenario with the help of a schematic diagram/drawing.

Your report should be concise and should not be more than 10 pages, and remember to include all citations.