Cover Page for Lab Report – Group Portion

Boundary Layer Measurements

Prepared by Professor J. M. Cimbala, Penn State University
Latest revision: 30 March 2012

Name 1: _____

Name 2: _____

Name 3: _____

[Name 4: _____]

Date: _____

Section number: ME 325._____   Group letter: (A, B, ...) _____

Score (For instructor or TA use only):

Lab experiment and results, plots, tables, etc. - Procedure portion	_____ / 45
Discussion	_____ / 15
Neatness & grammar	_____ / 10
TOTAL	**_____ / 70**

Comments (For instructor or TA use only):

Procedure

A. Operation of the water channel

To fill up and run the water channel, follow this procedure:

1. Set the Plexiglas cover plate containing the flat plate boundary layer apparatus onto the top of the channel test section.
2. Close both large drain valves – one on the bottom left side of the water channel, and the other on the PVC pipe to the right of the pump. Also, be sure the small brass drain valve on the clear Plexiglas end of the channel is closed.
3. Open the water channel fill valve (located adjacent to the drain valve).
4. Turn on the fill valve that supplies the fill garden hose. (This valve is located on the north wall of the room, to the left of the sink. Do not turn the valve on the right side of the sink – that one should stay open at all times.)
5. You should both hear and see the water channel begin to fill. Note that the right side of the channel is clear Plexiglas, and you can watch the water fill the channel. *Never leave the room while the channel is filling!*
6. Let the water rise until it just starts to lift up the Plexiglas cover plate at the top of the test section. Close the fill valve quickly so that the water does not overflow. The channel operates best if the water level is about a quarter inch *above* the top cover plate (i.e. the top cover plate should be completely submerged).
7. Turn on the cooling fan behind the motor. Run the fan throughout the experiment to prevent the motor from overheating. The low setting is typically good enough, but if the pump shuts off, try the high setting.
8. Turn on the pump motor controller circuit breaker switch (to the left of the water channel). Rotate the black handle ¼ turn clockwise so that it points vertically to ON.
9. Push the "RUN" button on the Toshiba frequency controller. The water should start flowing. You can adjust the speed with the control pad "up" and "down" arrow keys. A digital display on the frequency controller indicates the approximate freestream velocity (in m/s) in the water channel test section.
10. Run the channel at high speed (at a reading of around 1.0 on the control panel) for a few minutes to purge the water channel of air bubbles. Open the bleed valve on top of the channel to let some trapped air escape.
11. To shut off the flow at any time, simply push the "STOP" button on the Toshiba frequency controller.

To drain the water channel (Not now – do this when finished with your experiment):

1. Push the "STOP" button on the Toshiba frequency controller.
2. Turn off the pump motor controller circuit breaker. Rotate the black handle ¼ turn counter clockwise to the OFF position. *Never drain the system with the motor running.*
3. Open both drain valves. The channel will slowly begin to drain. Wait several minutes until the water is nearly all drained from the channel. (You can monitor the draining progress from the large Plexiglas cover on the far right side of the water channel.)
4. Open the small brass valve on the far end of the water channel (clear Plexiglas end) to allow the trapped water to drain into a bucket.
5. Turn off the wall-mounted fill valve that supplies the fill garden hose.
6. Briefly open and then close the water channel fill valve to release the pressure in the garden hose.

B. Operation of the Laser Velocimeter

1. Turn on the LV acquisition with the switch located on the bottom piece of equipment labeled "BSA F60 Flow Processor" on the LV electronics equipment rack. The laser must also be turned on with the key located above that switch on the piece of equipment labeled "FlowLite", and the shutter switch below the key must be turned to OPEN. Now carefully remove the lens cover on the fiber optic probe head, being careful not to scratch the lens.
2. Verify (visually) that the laser is on. *Do NOT look directly into the laser beam! Serious eye damage will result!* Special laser goggles that filter out laser light are available in the lab for your protection.
3. On the computer screen desktop, double click on BSA Flow Software icon to start the program. If this is the first time you have run this program under your unique log-in ID, continue. If you have run this program under your ID previously, skip to step 5.
4. You may see a message saying "BSA software to run for the first time. This is normal. A window will appear asking if you want to register the software now. Click "No".
5. In the "Getting Started" window, choose "Browse for an existing project". Then choose the directory "C:\ME325 this directory, choose the project: "RLSProject". If you have run this program under your ID previously, skip to step.
6. When the software is done loading, you will see several windows on the screen. In the window titled "Device List, R-click on Processor. In that menu, click on Device Configuration. This will start the Auto-Configuration Wizard. (If it does not start automatically, choose "Auto" in the window that comes up.) The Wizard will present a series of steps:

a) Choose "Next"
b) The window will say: "Searching for Processors". Then "Found Processor" Choose "Next".
c) The window will say: "Connected to Processor". Choose "Next".
d) The window will ask about a traverse. "None" should be selected. Choose "Finish".
e) If necessary, choose "Close" on the next window.

7. In the "Device List" window, R-Click on Processor. Choose "Connect to Processor".
8. A new window should appear at the lower right called "System Monitor". If it does not, R-click on Processor again, and choose "System Monitor".
9. In the "Device List" window, Click on "Optical PDA System".
10. In the "Properties" window (lower left), under "Beam System –U1", click on "Focal length". Use the downward pointing button to select "160.0 mm" from the drop down list. Now click on "Receiver focal length". Use the downward pointing button to select "160.0 mm" from the drop down list.
11. Click on "View" in the toolbar at the top of the screen. Click on "Start Page", which will bring that window to the front. Close that window to reduce clutter. Now Click at the upper right to enlarge the software to Full Screen.
12. Examine the windows on the screen. You should see: Project Explorer, BSA F/P Application, a Histogram graph, Properties, a Data List, a Moments List, the System Monitor, and Messages. Note that the Data List has columns for Arrival Time (AT), Transit Time (TT), and LDA1 (velocity in direction 1). Look at the columns in the Moments List and note that there is a column for LDA1 Mean. This is where the mean velocity in direction 1 will be reported for each data acquisition period. Currently, the set up is such that data are taken for 10 seconds. Each "burst" of LDV signal which results in a measured velocity during that period will be reported in the Data List. The mean velocity for that period will be reported in the Moments List.
13. Change the data format. In the toolbar at the top, Click on "Tools", then "Options". Choose the Data Formats tab.

a) Highlight "Velocity".
b) Click "Change".
c) Change the Unit to "m/s" and change the Precision to "4".
d) Click OK. Click OK again on the Options dialog box. A message box appears. Click OK. Data formats will change once data acquisition has begun.

14. Turn on the water channel at some medium flow rate (around 0.4 on the readout of the frequency controller).
15. Position the laser so that the focal volume (measurement volume – where the beams cross) is near the cross-stream centerline of the water channel.
16. Click on the BSA F/P Application tab. Then, from the top tool bar, select the icon that looks like a black arrow tip (►); this is the "Run" button. A dialog box will come up ---- Click on "Run --- Create New Data". Another dialog box will appear. Click on "Acquire". You should see "Running" at the bottom of the screen. Data acquisition will continue for 10 seconds. Observe the System Monitor window. You should see frequent "bursts" representing LDV signals from the measurement volume. As data is being taken, results should be posted in the Data List. In the "Run" mode, data acquisition will stop automatically after the 10 second period.
17. Wait for data acquisition to stop. In the top tool bar, select the icon which resembles two arrows in a circle. This starts the "Repetitive Mode" so that data are continually updated and displayed. Whenever you want to quit, click on the black square icon (■) on the top tool bar to stop data acquisition.
18. *Note*: When finished with the lab, or when the LV is not being used, turn the shutter dial to "closed". Leave all the electronics ON, When finished with the lab, close the BSA program and LOG OUT of the computer. ***To prevent eye injury, it is advisable to turn the shutter to "closed" whenever you are not taking data.***

C. Measurement of the Laminar Boundary Layer

1. Fill up and turn on the water channel as described above. Try your best to clear the top of the flat plate of air bubbles, as air bubbles will adversely affect the measurements. This can usually be accomplished by running the channel at high speed for a while. Tilting the plate up and down sometimes causes the bubbles to blow off as well. Turn on the LV system as described above. Use a cloth or paper towel to wipe away the bubbles if necessary.

2. Position the focal volume of the LV system to the desired downstream location (streamwise direction) by turning the *x*-traverse crank until the LV fiber optic head probe is at the black line located 18.0 inches downstream of the leading edge of the flat plate. The focal volume should be very close to the centerline of the water channel test section (cross-stream direction, along the laser beams), and it should be located about an inch above the flat plate (vertical direction). That is, the focal volume should be in the freestream region above the boundary layer and in the center of the channel.

3. Follow these instructions carefully in order to set the proper freestream speed of the water channel:

a) Adjust the water channel to a slow speed range, around 0.2 on the Toshiba frequency controller readout.
b) With the LV system operating, and the BSA software running in repetitive mode, the green light at the bottom of the LV instrumentation should be on. In the system monitor window, the burst-signal should be flashing,

indicating that data are being gathered (particles are moving through the focal volume, and the laser system is functioning correctly). If the burst-signal is *not* flashing, consult your instructor or TA for assistance.

   c) Monitor the average velocity, using the display on the computer screen. Adjust the frequency of the pump as necessary until the freestream velocity is as close to 0.20 m/s as possible ($U_\infty \approx 0.20$ m/s).

4. It is now necessary to define and set a reproducible zero in the y direction. Since there is some play in the traverse turning screw, follow these instructions carefully:

   a) With the LV system still operating in the repetitive mode, move the y traverse downward until the focal volume is blocked by the flat plate. The burst-signal should cease to flash, indicating that no data are being taken (no particles are crossing the focal volume).

   b) Carefully and slowly traverse upward until the focal volume just enters the flow field (just above the flat plate). The burst-signal should slowly flash, indicating that data are being obtained, but at a slow rate since the velocity very close to the wall is nearly zero (due to the no-slip condition).

   c) Traverse downward again and note the screw position when the burst-signal *stops* flashing. This is what we will call the **zero position** in the y direction (right at the wall). Enter that traverse reading here:

y-traverse reading at the zero position = _____ mm

   d) Traverse another 1/4 to 1/2 turn downward, then go back *up* to the position recorded above. This down-up motion will remove the "slop" or "play" in the traversing screw. The zero point is now accurate within a quarter turn of the traverse screw. From this zero point, always traverse upward, in the positive y direction.

   e) Adjust the y-traverse one quarter of a turn upward so that $y = 0.50$ mm. (***The traverse moves 2.0 mm for each full turn of the screw***.) The burst-signal should be flashing at random intervals, indicating that the system is taking data properly, although slowly).

(2) 5. Laminar boundary layer measurements will be taken at a freestream velocity of about 0.20 m/s. At this speed, calculate the Reynolds number and the boundary layer thickness (in units of mm) at the measurement location along the flat plate (18 inches).

$\mathrm{Re}_x =$ _____.

$\delta =$ _____ mm.

(1) 6. To obtain a nice, well-resolved velocity profile, a minimum of 20 data points should be measured within the boundary layer (not counting the data point at the wall, where the velocity is already known). Several additional data points should be measured outside the boundary layer as well. For 20 data points within the boundary layer thickness calculated above, calculate the traverse increment required:

$\Delta y =$ _____ mm.

(1) 7. Beginning with the traverse at 0.5 mm away from the wall, record both the distance from the wall and the mean speed u at several locations through the boundary layer, traversing upward with a Δy somewhat close to that calculated above. Be careful to subtract the zero-position traverse reading so that y is zero at the plate, and increases above the plate. *Hint*: It is usually easier to count turns of the traverse crank than to actually read the traverse position each time. You can either write down the data on a sheet of paper, or you can enter data directly into an Excel spreadsheet as you take data. (*Hint*: if you hold down the "Alt" key on the keyboard, and then hit the "Tab" key, you can easily toggle between the BSA software and Excel.) Continue collecting data points until you have clearly emerged from the boundary layer, and are back in the freestream region. Record the freestream velocity here (it should be close to the 0.20 m/s that you set previously, but the speed may have drifted somewhat between then and now):

$U_\infty =$ _____ m/s.

(4) 8. Create a table of your data in Microsoft Excel. There should be two columns: y location away from the plate (mm) and u (m/s). Label this table as "Table 2. Laminar Boundary Layer Profile", and attach it to your report.

9. Make copies of the data file (on a memory stick, floppy disk, on the desktop, etc.) so that the data can be analyzed later.

D. Measurement of the Turbulent Boundary Layer

1. With the LV system still operating in repetitive mode, and with the focal volume at least an inch or two above the flat plate, push the Toshiba control pad "up" arrow key until a speed of at least 1.2 m/s is reached, so that a turbulent boundary layer can be measured.

(1) 2. Record the freestream speed here:

$$U_\infty = \text{_____} \text{ m/s.}$$

(5) 3. Take data through the turbulent boundary layer in similar manner as those taken through the laminar boundary layer. Be careful to go all the way through the boundary layer, which is expected to be thicker now since the flow is turbulent. Save the results to a new Excel file, and print it out as you did for the laminar case. Label this table as "Table 3. Turbulent Boundary Layer Profile", and attach it to your report.

4. Make copies of the data file (on a memory stick, floppy disk, on the desktop, etc.) so that the data can be analyzed later.

5. Turn off the water channel so that the model can be replaced. It is okay to keep the LV system on, but close the shutter while changing models to avoid the possibility of stray laser light shining in someone's eye.

E. Measurement of the Boundary Layer on the Hull of a Model Submarine

1. Carefully remove the flat plate apparatus, and replace it with the model submarine apparatus. Be careful not to break the model – it is made of plastic and is somewhat delicate. Note that the submarine is mounted upside-down. The "sail" is the top part of the sub that sticks out of the water first when the sub surfaces. In this lab, we are interested in the boundary layer velocity profile both before and after the sail. Also note that since the model submarine is very light and buoyant, you may need to add some weight on top of the water channel test section in order to keep it from floating up.

(1) 2. Run the water channel at a reasonably high speed (around 0.7 m/s). Record the freestream speed here:

$$U_\infty = \text{_____} \text{ m/s.}$$

(5) 3. Position the focal volume of the LV approximately half-way along the model submarine (along the flat part of the hull just upstream of the sail – a red line is drawn on the submarine model at the desired location). Make sure that the focal volume is located at the middle of the hull (in the direction parallel to the laser beams) so that a proper boundary layer can be measured. Take data through the boundary layer in similar manner as those taken through the other two boundary layers. Note, however, that you will be marching *downward* instead of upward away from the wall since the model is upside-down. Save the results to a new Excel file, and print it out as you did for the other cases. Label this table as "Table 4. Model Submarine Boundary Layer Upstream of the Sail", and attach it to your report.

4. Repeat for the location just downstream of the sail for comparison. In this case, the wake of the sail will influence the boundary layer. Make sure you take data far enough away from the hull. Save the data and print out a table, as previously.

5. Make copies of all your data files (on a memory stick, floppy disk, on the desktop, etc.) so that the data can be analyzed later.

6. Turn off the water channel and close the LV shutter. Check with your instructor or TA to see whether or not you should drain the water channel and/or turn off the electronics.

Presentation of the Data

(10) 1. Plot your laminar boundary layer profile in nondimensional Blasius coordinates, $y\left(\dfrac{U_\infty}{vx}\right)^{\frac{1}{2}}$ (vertical axis) as a function of $\dfrac{u}{U_\infty}$ (horizontal axis). On your plot, include the predicted (Blasius) boundary layer profile for comparison. In the space below, show a sample calculation of the nondimensionalization. Make sure you label and number your figure, and attach it to your report and enter the figure number in the space below:

Sample calculations:

See Figure _____.

(10) 2. Plot your turbulent boundary layer profile in nondimensional coordinates y/δ (vertical axis) as a function of u/U_∞ (horizontal axis). (You will have to estimate δ from your data file; i.e., find the y-location where the streamwise velocity in the boundary layer is about 0.99 times U_∞. On your plot, include the predicted ($1/7^{\text{th}}$ power law) boundary layer profile for comparison. In the space below, show a sample calculation of the nondimensionalization, and your calculation of δ. Make sure you label and number your figure, and attach it to your report, and enter the figure number in the space below:

Sample calculations:

See Figure _____.

(5) 3. Plot the model submarine boundary layer profiles in dimensional (physical) coordinates y (vertical axis in mm) as a function of u (horizontal axis in m/s). It is best to put both profiles on the same plot for comparison. Make sure you label and number your figure, and attach it to your report, and enter the figure number in the space below:

See Figure _____.

Discussion

(5) 1. For your laminar boundary layer case, does the measured nondimensional velocity profile agree well with the Blasius profile? If not, discuss possible reasons for the discrepancies.

(5) 2. For your turbulent boundary layer profile, is the shape of the measured velocity profile similar to the predicted shape? If not, discuss possible reasons for the discrepancies. How might the turbulent results be improved in this lab?

(5) 3. Is the upstream submarine boundary layer profile more similar to the laminar or the turbulent boundary layer? Compare its shape to that of the flat plate boundary layers. For the case of a full scale (prototype) submarine, would you expect the boundary layer to be laminar or turbulent? Discuss. Also discuss the profile downstream of the sail. Can it properly be called a boundary layer?