MAE 135 Design Project # 1

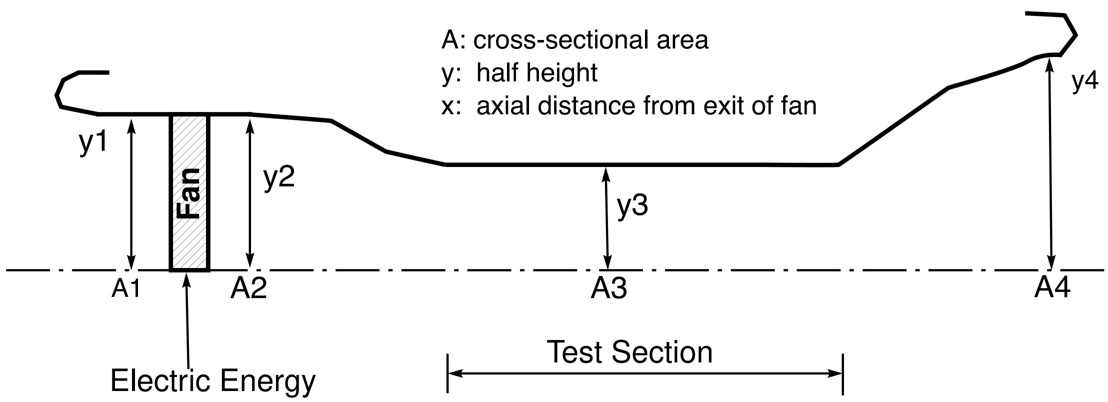
Preliminary Design (Sizing) of a Subsonic Wind Tunnel

Department of Mechanical and Aerospace Engineering

April 26, 2021

Due on Canvas 11:00pm Monday, May. 10, 2021

You have been chosen as the chief designer of a subsonic wind tunnel. The test section should have a $1.0m$(Height)$\times 1.0m$(Depth) cross-section and be a minimum $2m$ long with a design Mach number of 0.6. The tunnel is to be driven by a fan manufactured by **ABET ISENTROPIC, Inc**. This fan is guaranteed by **ABET** to do work on the working fluid isentropically. The diagram below shows a "blow down" wind tunnel. The fan is located upstream of the test section in a constant area section $A_1 = A_2$. The cross-sectional area of the test section is A_3. Air is exhausted back into the room at exit station 4. Design this wind tunnel. Assume standard air condition outside the tunnel.



1. Determine what you would choose for A_1 (which equals A_2), and A_4;
2. the lengths of the converging and diverging segments before and after the test section;
3. the total pressure ratio of the fan (p_{02}/p_{01}) and power rating for your fan, and therefore the rating of the motor you need to drive the fan.
4. the size of the building you need to house the tunnel.
5. What is the Reynolds number of your tunnel in the test section based on tunnel height?
6. Show that your design satisfy the mass and energy conservation laws between inlet and exit. Discuss the pros and cons of having a large exit cross-sectional area A_4. In each step, outline your objective and constraints and justify your design choices.
7. The depth of the tunnel is constant ($D = 1m$). The height is symmetric with respect to the centerline. The cross-sectional area change is achieved by choose the half height function $y(x)$. Design a smooth function to avoid excessive gradient in the converging and diverging part of the tunnel, especially in the diverging part, where there is adverse pressure gradient. Also, we need to maintain the flow in the test section to be as uniformly 1-dimensional as possible. In practice, we would need a round-rectangular transition duct to connect the fan exit to the tunnel section. For simplicity we neglect that part of the design.

8. Once you have determined your $y(x)$ either using a discretely defined array of (x, y) pairs or piecewise-continuous analytic formulas, calculate and plot the M, p, T, ρ, V as a function of x along the center-line of the tunnel based on quasi-1D flow.

9. The wind-tunnel is to be bolted to a foundation on the ground. Calculate the force that the bolts and the foundation have to withstand due to the 'thrust' of the tunnel.

10. (not required, 2% course grade bonus) Use the provided CFD software to compute the 2-dimensional flow starting from the exit of the fan to the exit of the tunnel with your given tunnel wall shape $y(x)$. Replot the same flow variables in Item 8 along the centerline and on the wall of the tunnel, compare them to your 1-D design. Plot the contours of the above flow variables throughout the wind-tunnel. Analyze and assess the quality of your design.

    This last part can take more time than all other items above. If you cannot afford the time, do not get started on this item. It is not required and I guarantee that the extra % points received by those who complete this part will not negatively impact the grades of those who do not attempt on this at all. The bonus points will be treated as absolutely bonus points, meaning only used to elevate your grades. Remember, I do not limit the number of people getting A or A+. Try it only if you are motivated, curious, have the time, and want to have some experience on more practical problems or preparing for some research experience later. A similar bonus part will be available for the second design project: Design of a Supersonic Wind Tunnel. Additional materials and tutorial sessions will be provided.

11. Complete a typed Design Report, detailing your design objectives, constraints, methods, results, assessments, and conclusions. Format of report will be outlined later.

Hints:

1. The flow from far upstream through the fan, test section, to the exit is isentropic even though there is work done between 1 and 2. You can still use the isentropic relation, but $p_{01} \neq p_{02}$, and $T_{01} \neq T_{02}$ because of work by the fan.

2. Far upstream, flow is stationary, $T = T_a$, $p = p_a$. Use standard conditions.

3. Down at the exit, p_4 must be equal to p_a due to dynamic balance, but you need to find T_4.

4. Use energy conservation. Do not forget to include mass flow rate in calculating the power need for the fan.

5. Use mass conservation. Use the form

$$\dot{m} = \Gamma \frac{p_0}{\sqrt{RT_0}} q(M) A$$

   which is always true as long as you are using local flow properties, p_0 and T_0. This will give you the needed area-Mach relations.

6. The limiting factor is the exit cross-sectional area A_4. Too large an A_4 will require a large building. A too small one, however, will demand a powerful fan. Discuss why from your equations.