MAE 135 Design Project # 2
Department of Mechanical and Aerospace Engineering
May. 18, 2021

Due 11:00pm Mon. May. 31, 2021

Preliminary Design (Sizing) of a Supersonic Wind Tunnel

You have been chosen as the chief designer of a supersonic wind tunnel. The test section has a cross-section of $0.5m \times 0.5m$ of length $1m$. The design Mach number of the test section is 2.0 and it is to be driven by a compressor manufactured by **UCI MAE 2022**. This compressor is guaranteed by **UCI MAE 2022** to do work on the working fluid with an adiabatic efficiency of $\eta = 0.92$. The adiabatic efficiency is defined as

$$\eta = \frac{(p_{02}/p_{01})^{\frac{\gamma-1}{\gamma}} - 1}{(T_{02}/T_{01}) - 1}$$

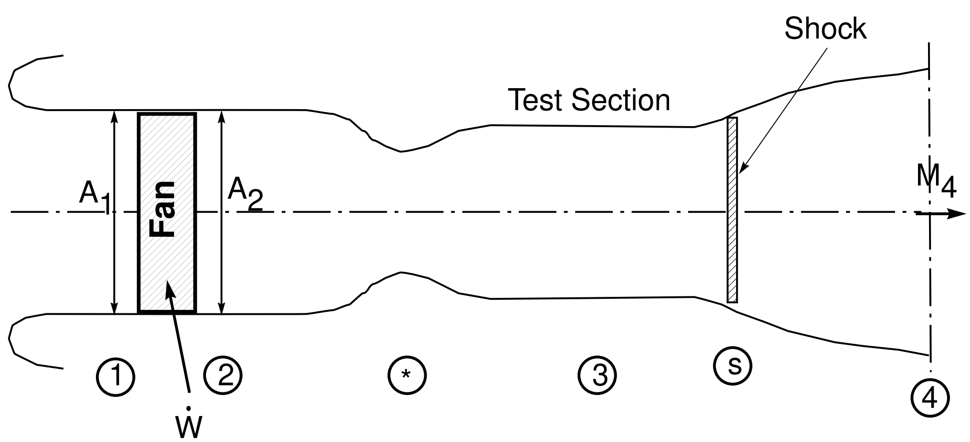

Figure 1: Single-throat Supersonic Tunnel

The above diagram shows a "blow down" single-throat supersonic wind tunnel. The compressor is located upstream of the throat section (with cross sectional area A_*). The cross-sectional area of the test section is A_3 (which should be as big as possible to accommodate large test models). You are to use the most simple-minded design: using a normal shock located at the end of the test section where the cross-sectional area A_s is very close to A_3. The air is exhausted back into the room at exit station 4. Use subscripts $s1$ and $s2$ to indicate conditions immediately before and after the normal shock, respectively.

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. What is the Reynolds number of your tunnel in the test section based on tunnel height?
5. 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.
6. The depth of the tunnel is constant ($D = 0.5m$). 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.
7. 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.
8. 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.
9. Complete a typed Design Report, detailing your design objectives, constraints, methods, results, assessments, and conclusions. Follow the same Report Format posted for the first Design Project.
10. (not required, 2% course grade bonus) To increase the efficiency and thus decrease the power need of the compressor, one may use a double-throat design shown in Fig. 5.11 in the textbook and reproduce below. Read Section 5.5 in textbook. Theoretically, one can have the second throat to be of the same size as the first one to slow down the flow from supersonic back to Mach number one and then further slow down the flow to supersonic using a diverging channel after the second throat. This is, however, not possible in practice because of the frictional loss in the test section that will cause total pressure loss and thus make the flow choke at the second throat before it does so at the first throat. Therefore, one needs to make the second throat larger than the first one. Even for an ideal flow without friction, there is also the starting problem as discussed in Section 5.5 of the textbook. We need to design the second throat to be large enough to allow the flow to 'swallow' a normal shock wave that could stand in the test second during the starting process of the tunnel. Design such a double-throat tennel. Determine the size of the second throat. And the Mach number M_{s1} at that location once the flow is started. Design the shock to be immediately after the second throat. Repeat Items 1 to 9 above.

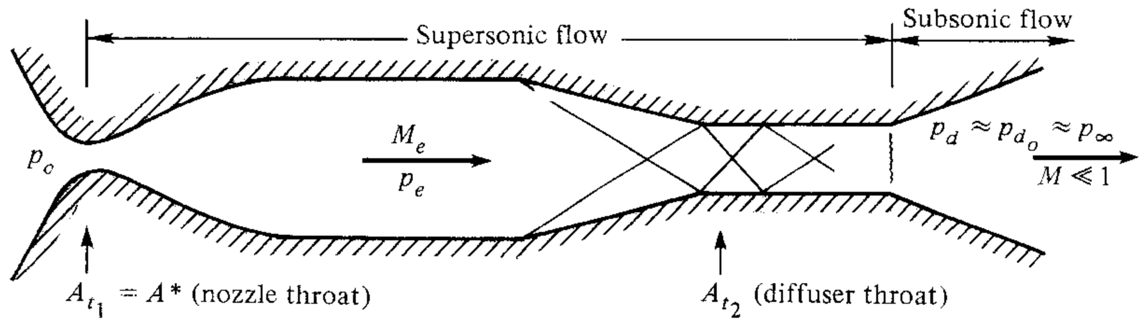

Figure 2: Double-throat Supersonic Tunnel (Fig. 5.11 in textbook)

11. (not required, 3% 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 in your report.

    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.