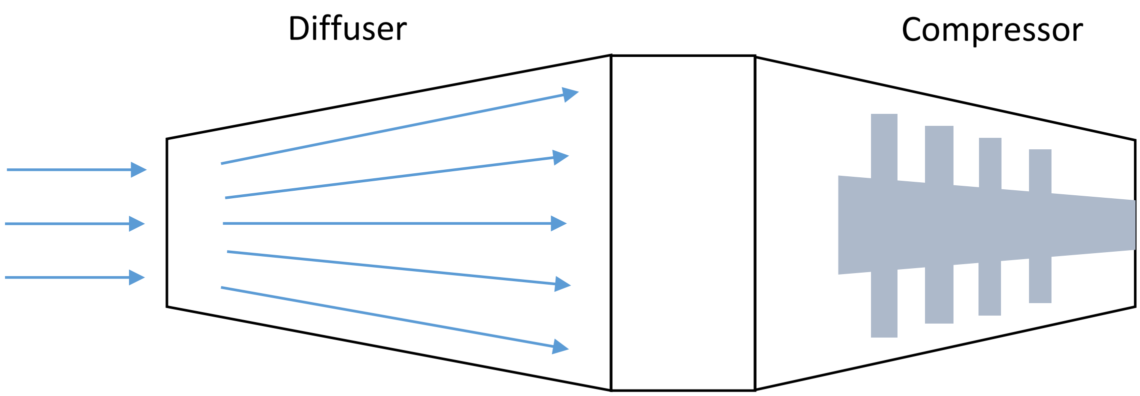
Compressor Analysis

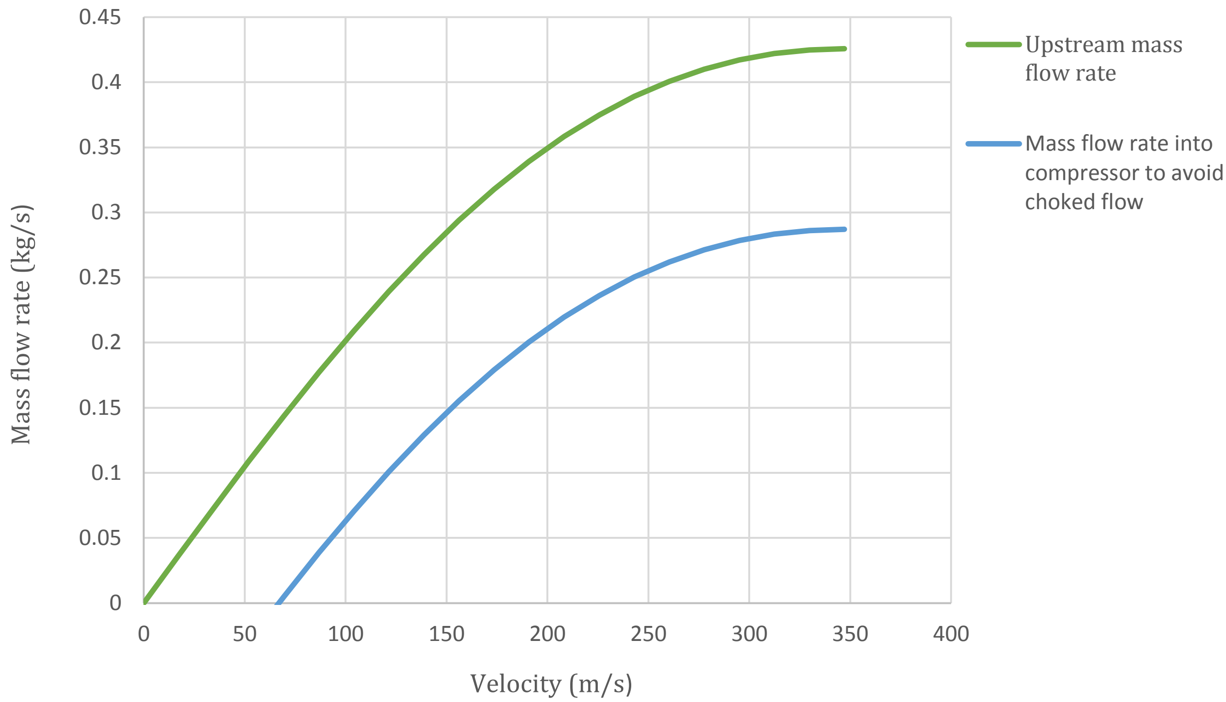
To avoid choked flow, an axial compressor will be attached to the front of the pod. In order to achieve suitable efficiency, a diffuser will be mounted to the front of the compressor which will slow air to speeds less than .65 Mach (1). This process is illustrated in Figure 1

Figure 1: Air enters the diffuser, which slows the speed of the air entering the compressor by expanding the cross-sectional area of flow.



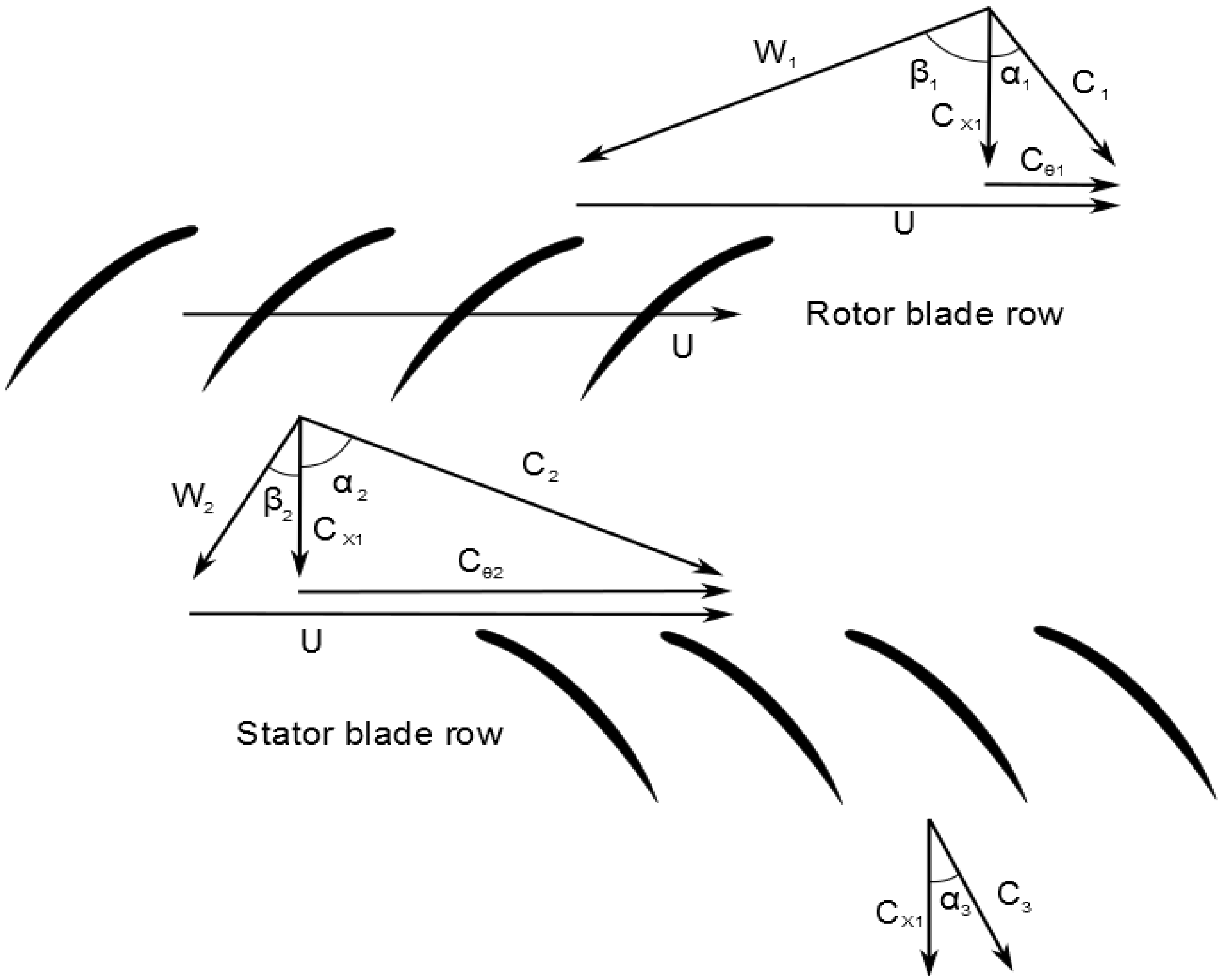
In order to determine the mass flow rate that the diffuser must take in to avoid choked flow, there are two mass flow rates that must be determined. These are the upstream mass flow rate and the choked mass flow rate. The difference between these two values is the minimum mass flow rate of air that must enter the compressor to avoid choked flow. All mass flow rate calculations assume compressible flow. Figure 2 shows the mass flow rate of air that must enter the compressor to avoid choked flow. As the velocity of the pod increases, the mass flow rate that must enter the compressor also increases.

Figure 2: The upstream mass flow rate and flow rate into the compressor are shown. Note that the bottom line shows the minimum mass flow rate that will avoid choked flow.



As air flows through the compressor, cascades of rotors and stators work to increase pressure by diffusing the air, converting velocity into pressure. The interaction between the air and the compressor blades are analyzed via diagrams known as velocity triangles, which show the relative and absolute air speeds based on airfoil geometry. Figure 3 illustrates this process.

Figure 3: Velocity triangle diagrams at rotor inlet and outlet. Air enters and leaves the rotor and stator with constant axial velocity C_{x1}.



Based on these velocity triangles, the torque acting on the rotor can be calculated. This torque is equal to the rate of change of the momentum of the flow through the rotor, which is given by the following:

$$T = m_{dot}(C_{\theta 1} - C_{\theta 2})r_m$$

where $C_{\theta 1}$ *and* $C_{\theta 2}$ are the relative portions of the rotor speed associated with the actual air speed, and r_m is the mean radius of the rotor. The power required to propel the air axially through the compressor at a constant axial speed C_{x1} is given by

$$P = m_{dot} U (C_{\theta 1} - C_{\theta 2})$$

where U is the speed of the rotor at the mean radius. The specific work for the compression stage can be determined from the power. This is calculated as follows:

$$W_{stage} = \frac{P}{m_{dot}}$$

The pressure rise through the compression stage can now be calculated. This value is determined by the change in ratio of outlet to inlet temperatures through the stage. The air temperatures at rotor inlet and outlet, T_{01} and T_{02}, are calculated by the following

$$T_{01} = T_{in} + \frac{{V_{in}}^2}{2c_p}$$

$$T_{02} = T_{01} + \frac{W_{stage}}{c_p}$$

Here, T_{in} and V_{in} are compressor inlet temperature and velocity. c_p is the constant pressure heat capacity of air. Finally, the pressure rise can be calculated by:

$$CPR = (\frac{T_{02}}{T_{01}})^{\frac{y}{y-1}}$$

The above process can be repeated for any number of rotor/stator stages to create a multi-stage axial compressor. Knowing the pressure ratio per stage is critical in the next design step, which is the design of the actual rotor and stator blade geometries. This process is tedious and is done through computer simulation. For this reason, a turbomachinery consulting companies will be contacted to create 3-D model of the compressor, based upon the number of stages and the required pressure ratio. This 3-D model will then be tested using advanced computational fluid dynamics software.

In the event that resources fall short and the cost to have a third-party design and manufacture an axial compressor is too high, alternative are being considered. Recommendations have suggested that a ducted fan may be suitable for this prototype pod. While the fan will not be able to compress enough air to supply the air bearings, it will still solve the choked flow problem that the pod will encounter. If this approach is taken, the onboard air tanks will be pre-pressurized and still be able to supply enough air to the air bearings for the duration of the pods testing phase on the test track.

References

1. Chin, Jeffrey C. "Open-Source Conceptual Sizing Models for the Hyperloop Passenger Pod." (n.d.): n. pag. NASA Glenn Research Center. Web. 14 Oct. 2015.

2. "Fluid Mechanics and Thermodynamics of Turbomachinery", S. L. Dixon and C. A. Hall, 2010, Hall, 6th ed.