Setup

The geometry was created in ANSYS Design modeler as specified in the report instructions. A plane of symmetry was used to reduce the computation time and to analyze the velocities at the midplane. Fine meshing was used with 10-layer inflation at the wall boundaries. A slow growth face sizing mesh control was imposed on the outlet to increase the accuracy of Task 2. Normal gravity was set in the downwards direction.

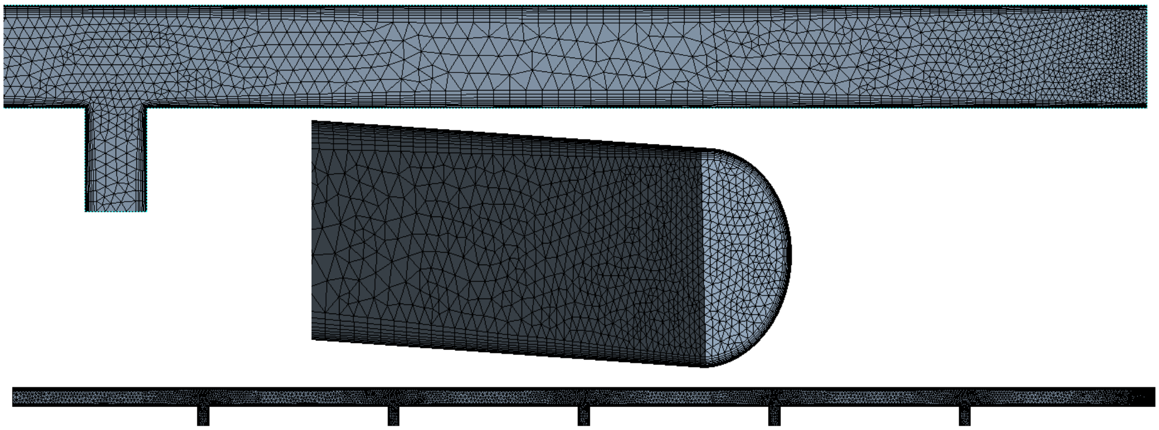


Figure 1. Meshing of the pipe.

Task 1

For Task 1, the outlet was set as a zero-gauge pressure outlet, which is the same outlet condition as the five smaller pipes.

Case 1

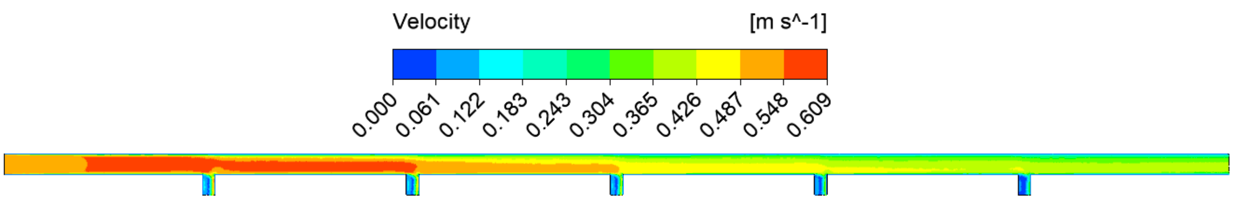


Figure 2. Velocity contour for case 1.

Mass Flow Rate	(kg/s)
outlet-1	-0.05415095
outlet-2	-0.049452726
outlet-3	-0.043828845
outlet-4	-0.036763735
outlet-5	-0.025345212
Net	-0.20954145

Figure 3. Mass flow rates for case 1.

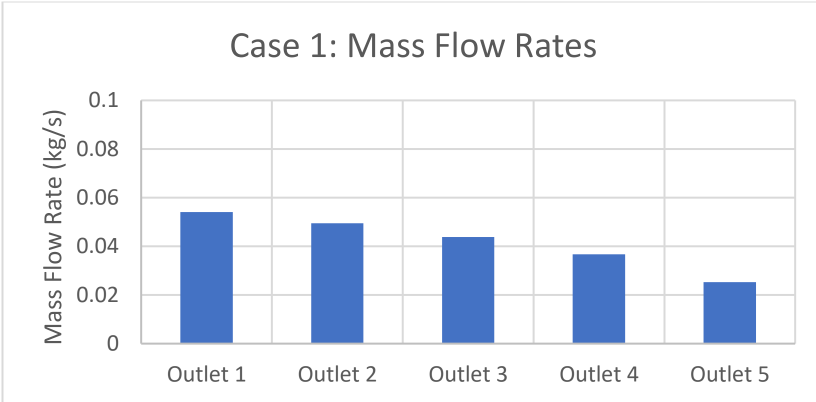


Figure 4. Mass flow rates for case 1.

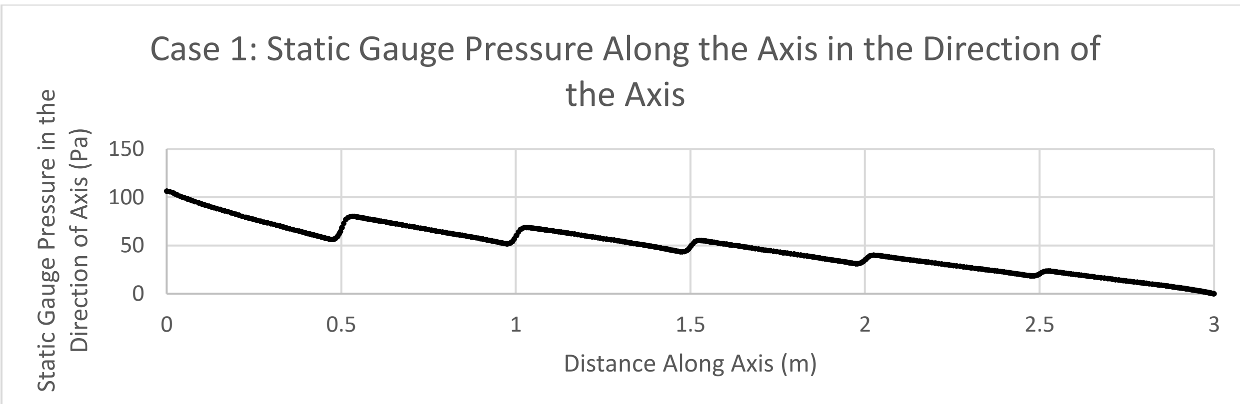


Figure 5. Static gauge pressure along the axis in the direction of the axis for case 1.

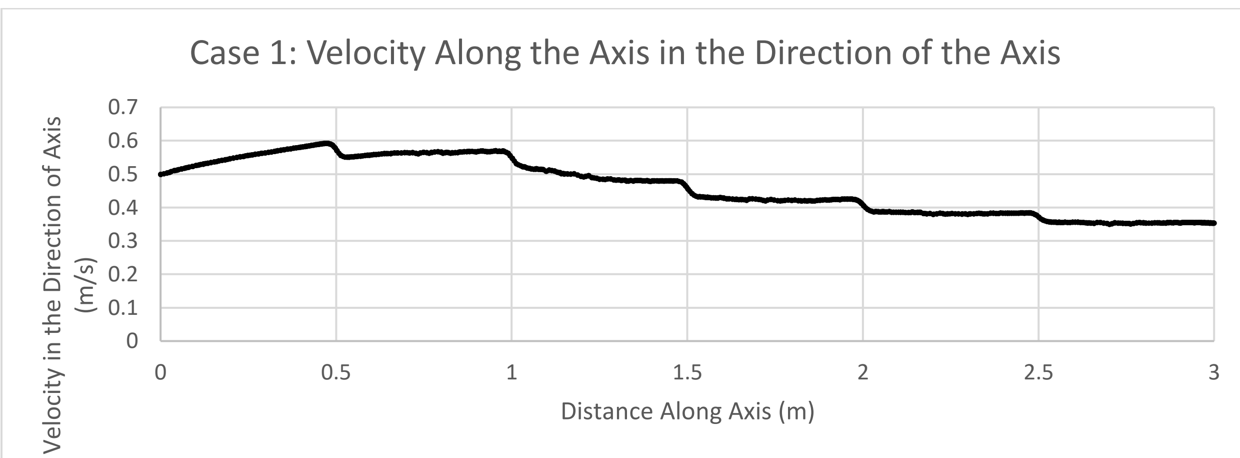


Figure 6. Velocity along the axis in the direction of the axis for case 1.

Case 2

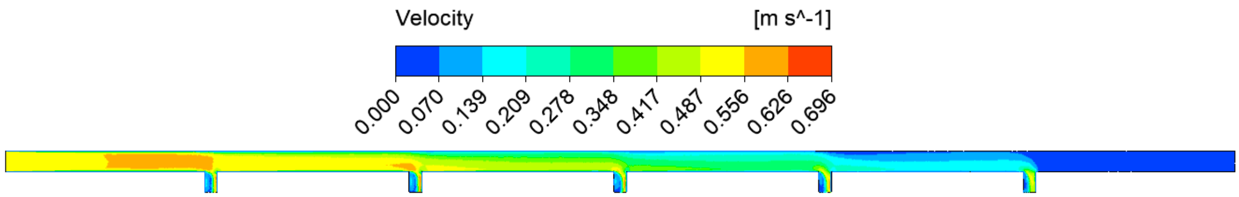


Figure 7. Contour plot of velocity for case 2.

Mass Flow Rate	(kg/s)
outlet-1	-0.075060762
outlet-2	-0.081849203
outlet-3	-0.092159294
outlet-4	-0.10915408
outlet-5	-0.12461476
Net	-0.48283809

Figure 8. Mass flow rates for the 5 outlet pipes in case 2.

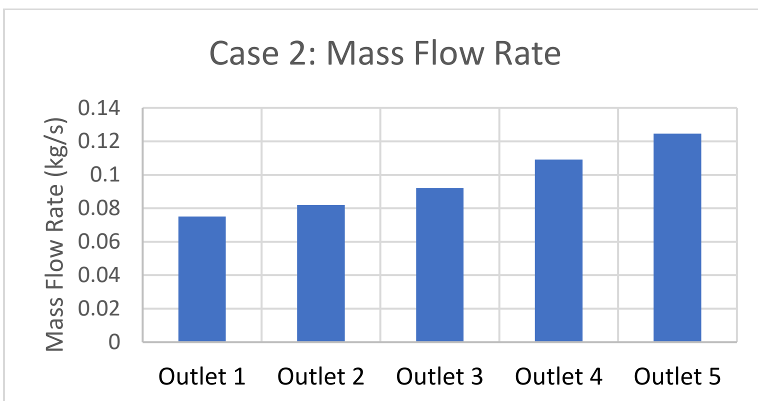


Figure 9. Mass flow rates for the 5 outlet pipes in case 2.

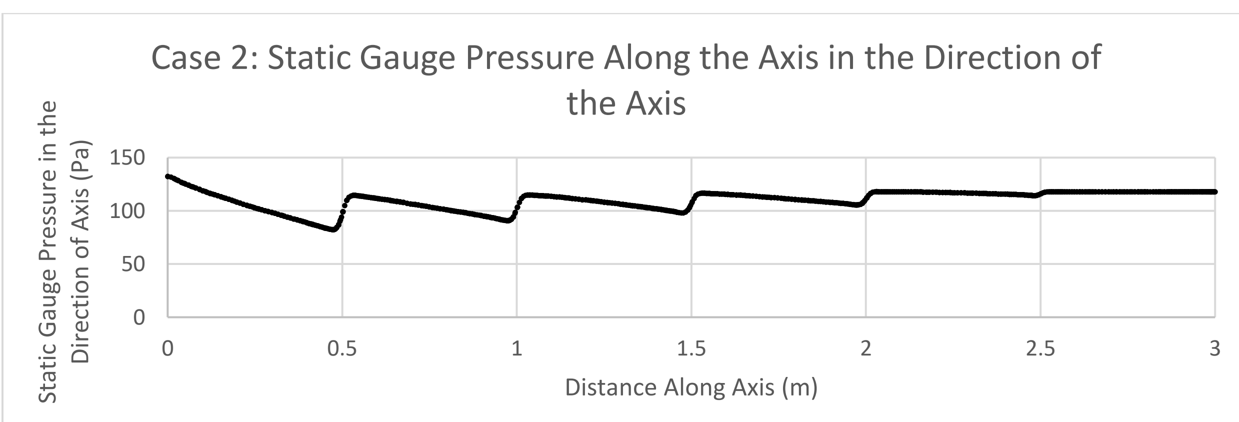


Figure 10. Static gauge pressure along the axis in the direction of the axis for case 2.

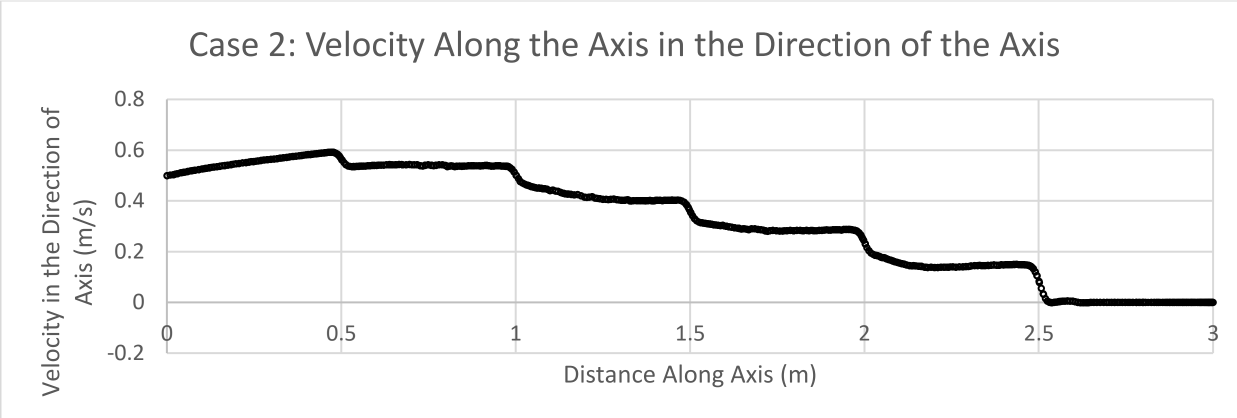


Figure 11. Velocity along the axis in the direction of the axis for case 2.

Task 2

i) Best case for uniform mass flow rates.

The best case with the smallest S index was with the outlet B completely closed and outlet diameters 1 through 5 set to 5 cm, 4.13 cm, 3.59 cm, 3.14 cm, and 2.92 cm, respectively. This obtained an S index of 0.0057. This value is already quite small, but could have been further reduced by continuing the iterative process I will describe in part (ii).

S Index for "Best Case"
0.0057

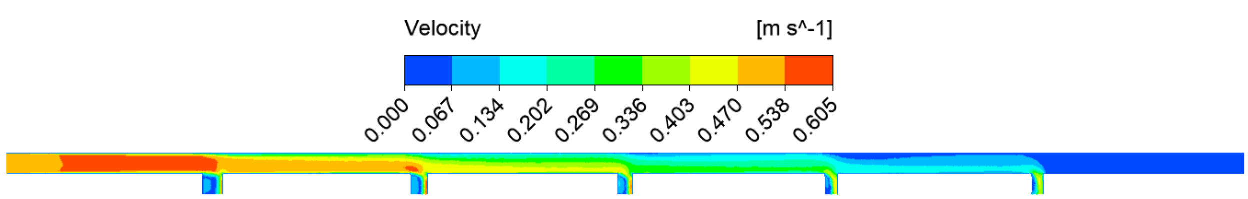


Figure 12. Velocity contour for the best-case scenario.

```
 Mass Flow Rate              (kg/s)
---------------- --------------------
        outlet-1         -0.096546993
        outlet-2         -0.095967621
        outlet-3         -0.095981143
        outlet-4         -0.096962482
        outlet-5         -0.097380988
---------------- --------------------
             Net          -0.48283923
```

Figure 13. Mass flow rates for the best-case scenario.

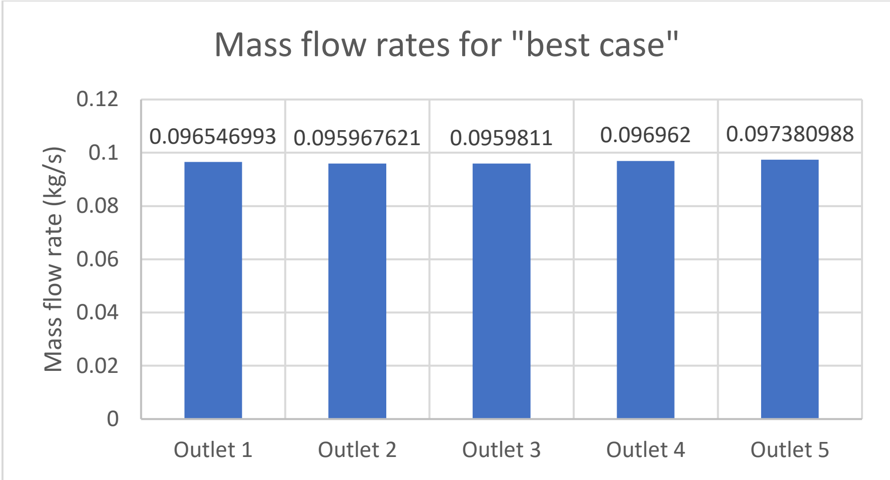


Figure 14. Mass flow rates for the best-case scenario.

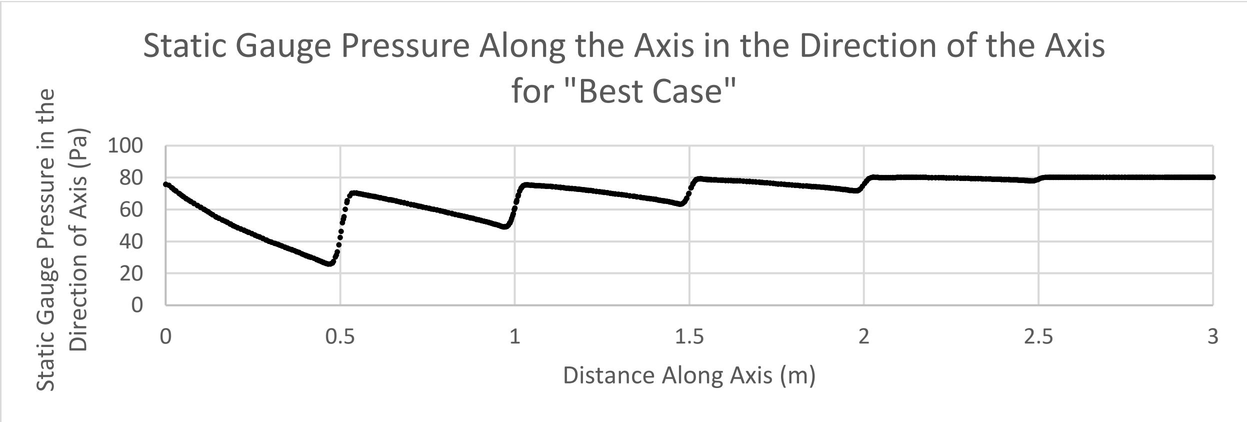


Figure 15. Plot of Static Gauge Pressure Along the Axis in the Direction of the Axis for "Best Case."

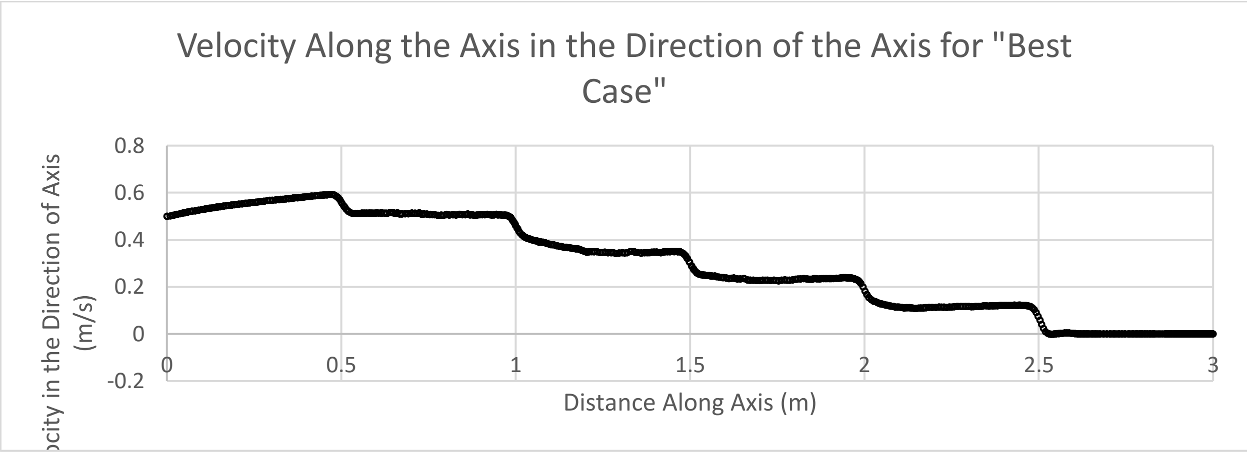


Figure 16. Velocity Along the Axis in the Direction of the Axis for "Best Case".

i) Process for finding the best case for uniform mass flow rates.

To find the conditions for the lowest S index in the most efficient way, I first thought I should optimize the B outlet opening, and then with that opening, optimize the pipe diameters. If necessary I could return to optimizing the B outlet opening with these new pipe diameters and continue in that fashion. In order to change the area of opening for outlet B, I split the outlet face into two parts as shown in Figure 17. The inner face was set as an outlet with zero-gauge pressure, while the outer face was set as a wall. The mesh size was increased near this outlet to increase the accuracy of the results. All the exact results are given in the appendix.

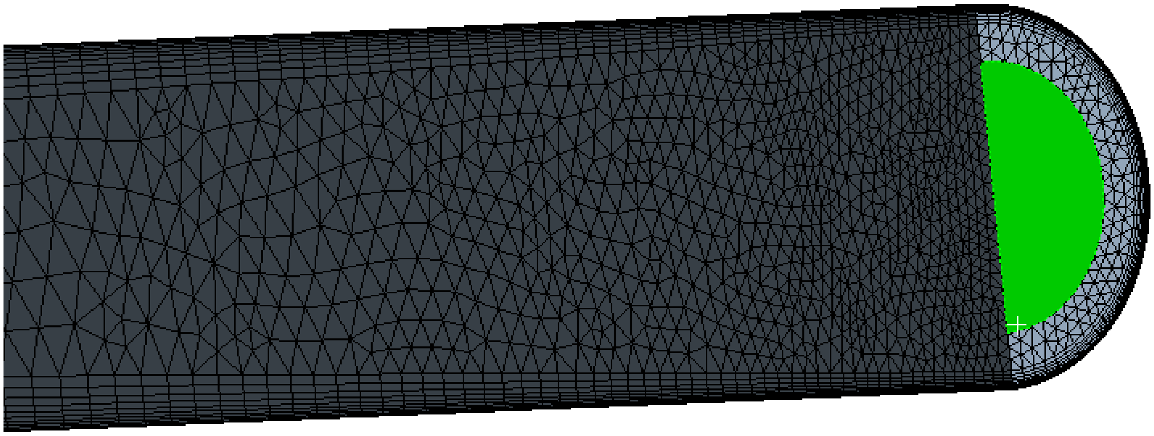


Figure 17. Meshing of the B outlet showing the refined mesh and the split face.

I started with 50% flow area and compared the results with case 1 and case 2. Case 1 with 100% flow area had an S index of 0.24, case 2 with 0% flow are had an S index of 0.187755, and the case with 50% flow area had the lowest index of 0.085. One of the velocity contours for the partial opening at outlet B is shown in Figure 18.

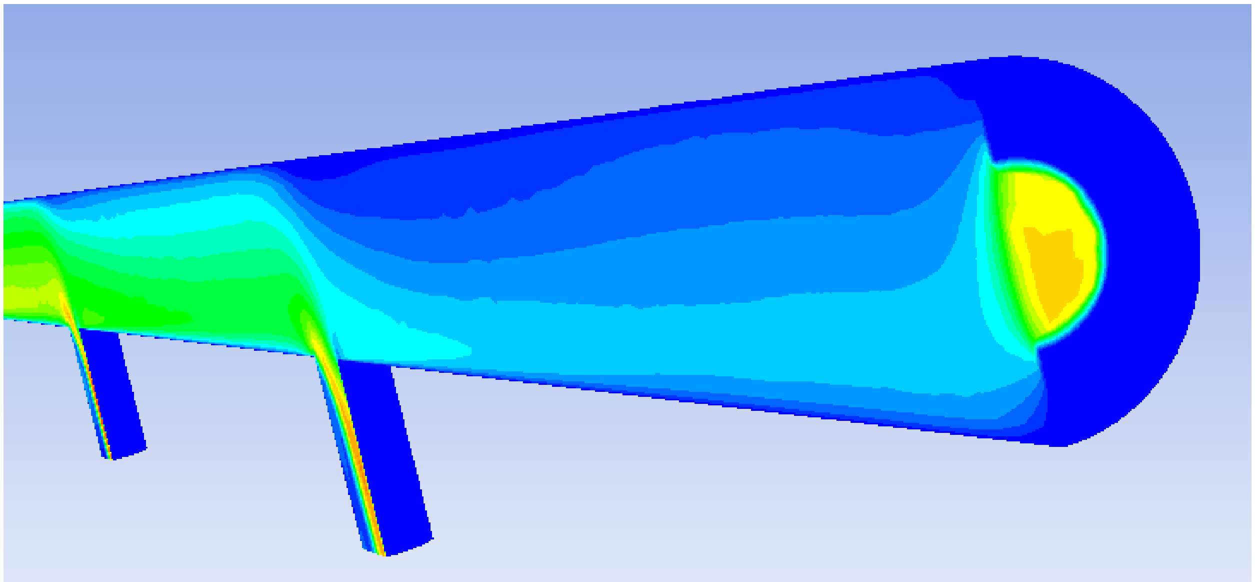


Figure 18. Velocity contour for partial opening at outlet B.

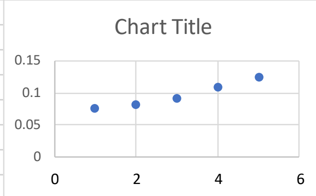
I then tried 25% flow area by adjusting the diameter of the split face, but surprisingly, this had an S index that was higher than both the 0% and the 50%. This indicates that the S-index has a multipeak relationship with the outlet flow area. I next tried 40% and 45% flow area, but both were still higher than 50%, so I switched sides and tried 60% flow area and the S index dropped to 0.025. I was looking for the spread of outlet flow values. The mass flow was increasing across each outlet for 0% flow area, but decreasing across each outlet for 100% area, so I hoped to find a condition in the middle where the flows were higher at the beginning and end, but dropped in the middle. Then I would be able to adjust the diameter of the outlets, to further refine the mass flow at the outlets.

However, I realized that the lowest S index could be achieved more easily when the mass flow was higher, because the relative error would be lower. So, I changed my strategy to what I should have done from the beginning. I set the outlet to be completely closed, which not only increases the mass flow rate through the other outlets, but also sets the mass flow rate to a constant value, eliminating a variable. With the outlet B closed, the mass flow rates tend to increase successively, so I set the first outlet 1 to the max diameter of 5 cm. I knew I could eliminate another variable by setting this diameter to a constant, and the best solution would have the 1st diameter as the largest. From this point on I would only adjust the other four diameters based on the results. I looked at the results of each iteration and adjusted based on the mass flow results. I would generally increase the diameter of the lower mass flow rate pipes, and decrease the diameter of the pipes with mass flow ratees greater than the average, keeping in mind that increasing flow in one pipe would decrease the flow in the pipes around it. Because I closed the B outlet, I knew what the mass flow rate through each pipe should be because it is constant, so I could also gauge my adjustments based on how off they were from that value. My adjustments became more refined as the number of iterations increased. I stopped once the S-index fell below 0.01, but I could have further refined the diameter sizes indefinitely to reach lower values. These trials were very easy to iterate because all I needed to do was change the diameters, and update the project.

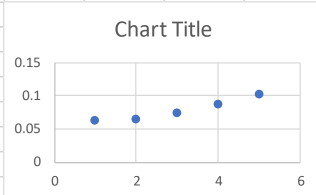
I set gravity in the downwards direction, which slightly affected the results of my project. I compared my results with Jack Miller's.

Appendix: S Indices and Plots of Mass Flow Rates Across Outlets 1-5 for Task 2

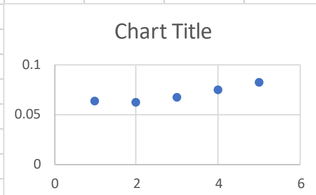
CASE 2 0% Area			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.075061	0.096568	0.000463
Outlet 2	0.081849	0.096568	0.000217
Outlet 3	0.092159	0.096568	1.94E-05
Outlet 4	0.109154	0.096568	0.000158
Outlet 5	0.124615	0.096568	0.000787
	0.482838	**S index:**	**0.187755**



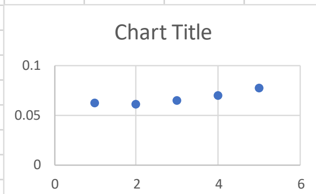
25% Area Flow D=0.025			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.063722	0.078431	0.000216
Outlet 2	0.064486	0.078431	0.000194
Outlet 3	0.073647	0.078431	2.29E-05
Outlet 4	0.087497	0.078431	8.22E-05
Outlet 5	0.102803	0.078431	0.000594
	0.392155	**S index:**	**0.189961**



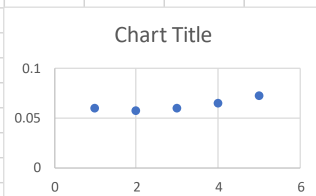
40% Area Flow D=0.03162			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.06353	0.070303	4.59E-05
Outlet 2	0.062778	0.070303	5.66E-05
Outlet 3	0.067498	0.070303	7.87E-06
Outlet 4	0.074768	0.070303	1.99E-05
Outlet 5	0.082941	0.070303	0.00016
	0.351516	**S index:**	**0.108334**



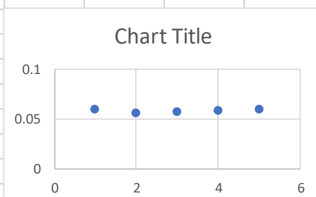
45% Area Flow D=0.0335			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.06281	0.067082	1.82E-05
Outlet 2	0.060909	0.067082	3.81E-05
Outlet 3	0.064537	0.067082	6.47E-06
Outlet 4	0.070166	0.067082	9.52E-06
Outlet 5	0.076986	0.067082	9.81E-05
	0.335408	**S index:**	**0.087035**



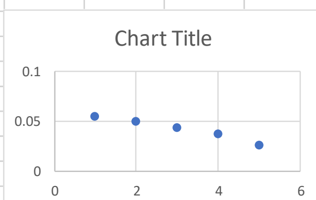
50% Area Flow D=0.035355			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.060313	0.062695	5.67E-06
Outlet 2	0.05681	0.062695	3.46E-05
Outlet 3	0.059292	0.062695	1.16E-05
Outlet 4	0.065109	0.062695	5.83E-06
Outlet 5	0.07195	0.062695	8.57E-05
	0.313473	**S index:**	**0.085412**



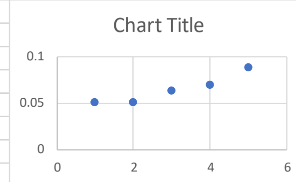
60% Area Flow D=0.0387			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.05999	0.058666	1.75E-06
Outlet 2	0.05639	0.058666	5.18E-06
Outlet 3	0.057718	0.058666	8.99E-07
Outlet 4	0.058946	0.058666	7.82E-08
Outlet 5	0.060288	0.058666	2.63E-06
		S index:	**0.024745**



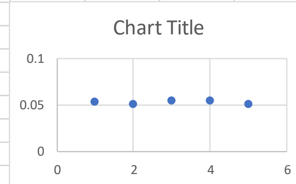
CASE 1 100% Area r=0.025			
	Mass Flow	M	(mk-M)^2
Outlet 1	0.054151	0.041908	0.00015
Outlet 2	0.049453	0.041908	5.69E-05
Outlet 3	0.043829	0.041908	3.69E-06
Outlet 4	0.036764	0.041908	2.65E-05
Outlet 5	0.025345	0.041908	0.000274
	0.209541	**S index:**	**0.241296**



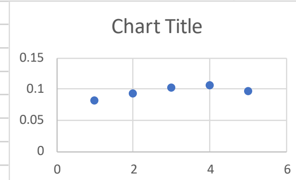
60% Area Flow DO=0.0387, 3D = 0.05			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.051184	0.064497	0.000177
Outlet 2	0.050567	0.064497	0.000194
Outlet 3	0.063164	0.064497	1.78E-06
Outlet 4	0.069505	0.064497	2.51E-05
Outlet 5	0.088066	0.064497	0.000555
		S index:	**0.214124**



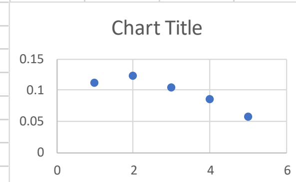
95% Area Flow DO=0.0387, 3D = 0.05			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.05324242	0.05291	1.1E-07
Outlet 2	0.050798882	0.05291	4.46E-06
Outlet 3	0.05425144	0.05291	1.8E-06
Outlet 4	0.055298992	0.05291	5.71E-06
Outlet 5	0.05095851	0.05291	3.81E-06
		S index:	**0.033685**



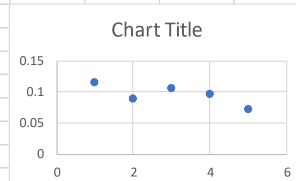
Outlet Area 100%, D1=.5, D2=.45, D3=.4, D2=.35, D5=.3			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.082511157	0.096568	0.000198
Outlet 2	0.093945965	0.096568	6.87E-06
Outlet 3	0.10209659	0.096568	3.06E-05
Outlet 4	0.10717162	0.096568	0.000112
Outlet 5	0.097114176	0.096568	2.98E-07
		S index:	**0.086363**



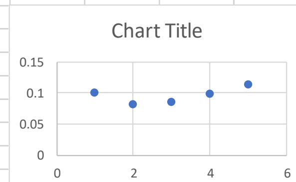
Outlet Area 100%, D1=.5, D2=.4, D3=.3, D2=.25, D5=.2			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.1114	0.096557	0.00022
Outlet 2	0.122778	0.096557	0.000688
Outlet 3	0.1047	0.096557	6.63E-05
Outlet 4	0.08559	0.096557	0.00012
Outlet 5	0.058316	0.096557	0.001462
		S index:	**0.234197**



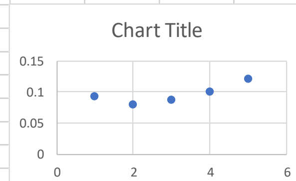
Outlet Area 100%, D1=.5, D2=.35, D3=.35, D2=.3, D5=.25			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.11691344	0.096557	0.000414
Outlet 2	0.08948	0.096557	5.01E-05
Outlet 3	0.10587414	0.096557	8.68E-05
Outlet 4	0.09763547	0.096557	1.16E-06
Outlet 5	0.072883487	0.096557	0.00056
		S index:	**0.154509**



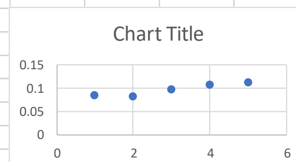
Outlet Area 100%, D1=.5, D2=.38, D3=.37, D2=.36, D5=.35			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.10153287	0.096566	2.47E-05
Outlet 2	0.082230411	0.096566	0.000206
Outlet 3	0.08581046	0.096566	0.000116
Outlet 4	0.098902941	0.096566	5.46E-06
Outlet 5	0.11435517	0.096566	0.000316
		S index:	**0.119675**



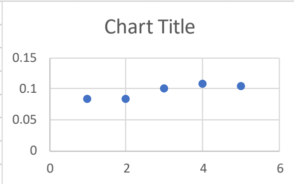
Outlet Area 100%, D1=.5, D2=.40, D3=.38, D2=.36, D5=.33			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0926	0.096565	1.57E-05
Outlet 2	0.0805025	0.096565	0.000258
Outlet 3	0.086871944	0.096565	9.4E-05
Outlet 4	0.10065	0.096565	1.67E-05
Outlet 5	0.1222	0.096565	0.000657
		S index:	**0.149462**



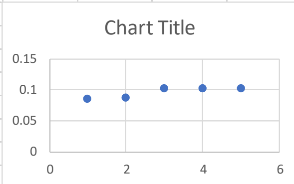
Outlet Area 100%, D1=.5, D2=.42, D3=.4, D2=.36, D5=.33			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.085329	0.09656	0.000126
Outlet 2	0.082697	0.09656	0.000192
Outlet 3	0.096086	0.09656	2.25E-07
Outlet 4	0.10589	0.09656	8.7E-05
Outlet 5	0.1128	0.09656	0.000264
		S index:	**0.119822**



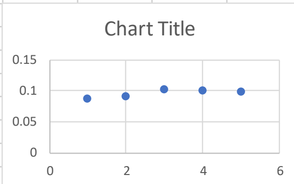
Outlet Area 100%, D1=.5, D2=.42, D3=.4, D2=.35, D5=.31			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.084463567	0.096565	0.000146
Outlet 2	0.083921	0.096565	0.00016
Outlet 3	0.10146	0.096565	2.4E-05
Outlet 4	0.1089295	0.096565	0.000153
Outlet 5	0.10405129	0.096565	5.6E-05
		S index:	**0.10754**



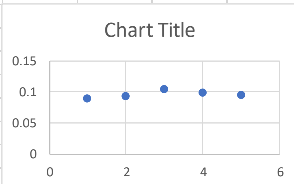
Outlet Area 100%, D1=.5, D2=.42, D3=.39, D2=.33, D5=.3			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0858614	0.096562	0.000115
Outlet 2	0.08868	0.096562	6.21E-05
Outlet 3	0.10287	0.096562	3.98E-05
Outlet 4	0.1024	0.096562	3.41E-05
Outlet 5	0.103	0.096562	4.14E-05
		S index:	**0.079134**



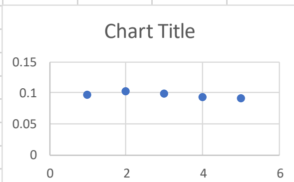
Outlet Area 100%, D1=.5, D2=.42, D3=.38, D2=.32, D5=.29			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0878378	0.096565	7.62E-05
Outlet 2	0.092079669	0.096565	2.01E-05
Outlet 3	0.103165	0.096565	4.36E-05
Outlet 4	0.1013	0.096565	2.24E-05
Outlet 5	0.0984436	0.096565	3.53E-06
		S index:	**0.059631**



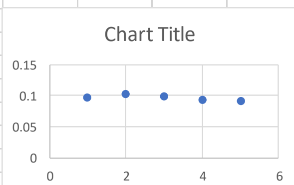
Outlet Area 100%, D1=.5, D2=.42, D3=.37, D2=.31, D5=.28			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.090554	0.096562	3.61E-05
Outlet 2	0.09364	0.096562	8.54E-06
Outlet 3	0.10385	0.096562	5.31E-05
Outlet 4	0.099065	0.096562	6.27E-06
Outlet 5	0.0957	0.096562	7.43E-07
		S index:	**0.047403**



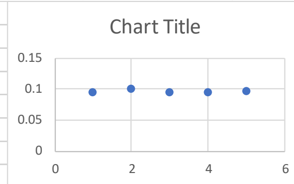
Outlet Area 100%, D1=.5, D2=.42, D3=.35, D2=.3, D5=.28			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0975	0.096534	9.33E-07
Outlet 2	0.1023	0.096534	3.32E-05
Outlet 3	0.0985	0.096534	3.87E-06
Outlet 4	0.09257	0.096534	1.57E-05
Outlet 5	0.0918	0.096534	2.24E-05
		S index:	**0.040432**



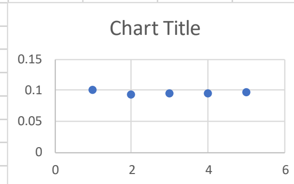
Outlet Area 100%, D1=.5, D2=.42, D3=.35, D2=.3, D5=.28			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0975	0.096534	9.33E-07
Outlet 2	0.1023	0.096534	3.32E-05
Outlet 3	0.0985	0.096534	3.87E-06
Outlet 4	0.09257	0.096534	1.57E-05
Outlet 5	0.0918	0.096534	2.24E-05
		S index:	**0.040432**



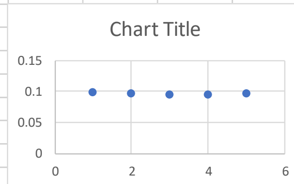
Outlet Area 100%, D1=.5, D2=.42, D3=.35, D2=.31, D5=.29			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.095	0.096559	2.43E-06
Outlet 2	0.1003	0.096559	1.4E-05
Outlet 3	0.095338	0.096559	1.49E-06
Outlet 4	0.09496	0.096559	2.56E-06
Outlet 5	0.097198	0.096559	4.08E-07
		S index:	**0.021164**



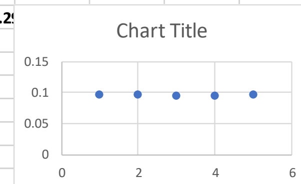
Outlet Area 100%, D1=.5, D2=.4, D3=.35, D2=.31, D5=.29			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.1009583	0.096568	1.93E-05
Outlet 2	0.09356939	0.096568	8.99E-06
Outlet 3	0.095810734	0.096568	5.73E-07
Outlet 4	0.09516	0.096568	1.98E-06
Outlet 5	0.097340271	0.096568	5.97E-07
		S index:	**0.025958**



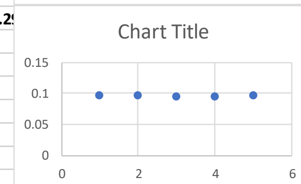
Outlet Area 100%, D1=.5, D2=.41, D3=.35, D2=.31, D5=.29			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.099268	0.096567	7.3E-06
Outlet 2	0.096423	0.096567	2.07E-08
Outlet 3	0.095227	0.096567	1.8E-06
Outlet 4	0.095277	0.096567	1.66E-06
Outlet 5	0.09664	0.096567	5.33E-09
		S index:	**0.015206**



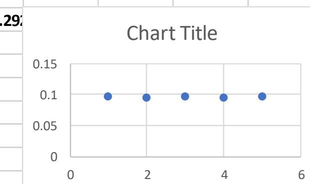
Outlet Area 100%, D1=.5, D2=.412, D3=.352, D2=.312, D5=.2			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.09794	0.096564	1.89E-06
Outlet 2	0.09669	0.096564	1.58E-08
Outlet 3	0.0949	0.096564	2.77E-06
Outlet 4	0.095558	0.096564	1.01E-06
Outlet 5	0.0977338	0.096564	1.37E-06
		S index:	**0.012304**



Outlet Area 100%, D1=.5, D2=.413, D3=.354, D2=.313, D5=.2			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.0974469	0.096539	8.25E-07
Outlet 2	0.097994	0.096539	2.12E-06
Outlet 3	0.094561	0.096539	3.91E-06
Outlet 4	0.095907226	0.096539	3.99E-07
Outlet 5	0.096784756	0.096539	6.05E-08
		S index:	**0.012528**



Outlet Area 100%, D1=.5, D2=.413, D3=.36, D2=.313, D5=.29			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.096576959	0.096568	8.75E-11
Outlet 2	0.096113488	0.096568	2.06E-07
Outlet 3	0.09806101	0.096568	2.23E-06
Outlet 4	0.094979987	0.096568	2.52E-06
Outlet 5	0.097106569	0.096568	2.9E-07
		S index:	**0.010609**



Outlet Area 100%, D1=.5, D2=.413, D3=.359, D2=.314, D5=.2			
	Mass Flow Rate	M	(mk-M)^2
Outlet 1	0.096546993	0.096568	4.3E-10
Outlet 2	0.095967621	0.096568	3.6E-07
Outlet 3	0.0959811	0.096568	3.44E-07
Outlet 4	0.096962	0.096568	1.55E-07
Outlet 5	0.097380988	0.096568	6.61E-07
		S index:	**0.005712**