Isabel Dudlyke

CFD Solidworks Assignment

1 Introduction

The primary objective is to conceive a thrust chamber capable of transporting payloads to Low Earth Orbit (LEO). The design challenge necessitates the creation of a thrust chamber that fits within a confined space of 3m x 1m x 1m, while maintaining a minimum fluid volume of 0.5 m^3. Ground testing under standard atmospheric conditions, mirroring sea level parameters, introduces propane as the propellant under extreme temperature, pressure, and mass flow rate conditions. The design criteria and inlet parameters are shown below in table 1.

Variable	Symbol	Value
Inlet Mass Flow	$\dot{m}_i$	500 kg/s
Inlet Temperature	T_i	3050 K
Inlet Pressure	P_i	5 MPa
Fluid Volume	V_f	< 0.5 m^3
Thrust Force	F	> 1050 kN
Space Requirement	—	3m x 1m x 1m

Table 1: Design Criteria

In order to accomplish this goal, I first researched into the best designs for thrust chambers[1], and then began an iterative design process where I developed a chamber based off of this research and continued to adapt and develop the design as I gained more knowledge about an optimal design. I decided to use Titanium as my material for every iteration, as I found this was the optimal material to use from my research. This is because titanium strong, lightweight, and resistant to corrosion and extreme temperatures[2]. I utilized cut plots of the velocity within the thrust chambers in order to visualize how the fluid will move through the chamber, and thereby understanding how best to move forward with the next iteration.

$$F = \dot{m}_e V_e + (p_e - p_o)A_e$$

After designing each thrust chamber iteration, I used the equation above to calculate the thrust force where P_o is the atmospheric pressure (101325 Pa) and the variables of mass flow, pressure, velocity and area given by the CFD calculation. For the pressure and volume, I used the minimum pressure and maximum velocity given by the CFD.

[1] "A One-Piece Liquid Rocket Thrust Chamber Assembly | T2 Portal." *Technology.nasa.gov*, technology.nasa.gov/patent/MFS-TOPS-93#:~:text=The%20central%20chamber%20is%20being. Accessed 22 Mar. 2024.

[2] "TITANIUM." *FIGHTER JET METALS*, fighterjetmetals.com/titanium/#:~:text=Overall%2C%20titanium%20is%20a%20valuable. Accessed 22 Mar. 2024.

2 Final Thrust Chamber Design

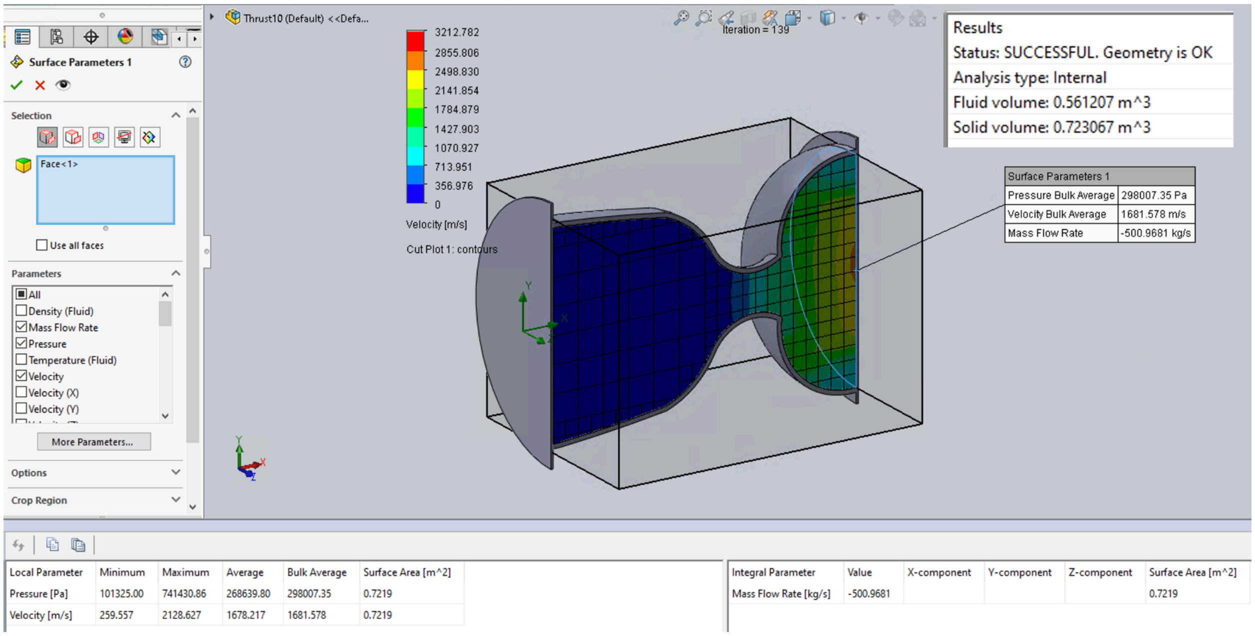
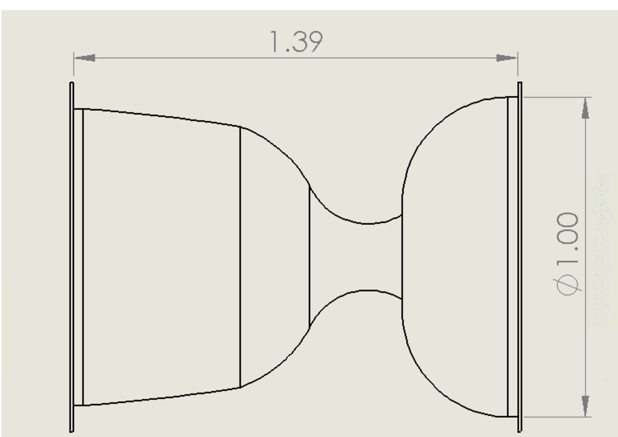


Figure 1: Final Thruster Design Factor of Safety Simulation



My final design had a thrust force of 1066.34 kN which was above the 1050 kN minimum force required. In addition, the design was 1m wide and tall and 1.39 m long and therefore fit within the 1m x 1m x 3m space requirement. In addition the internal volume was 0.56 m^3, which was above the 0.5 m^3. This gave a score of 1900 for this final design. As with all my iterations, was made out of Titanium due to being lightweight and its thermal properties

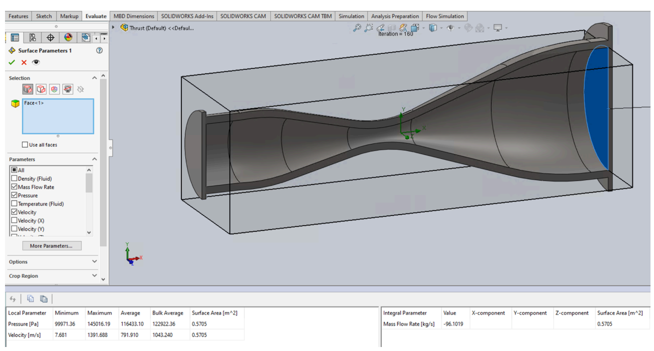
3 Iterative Design Process

Iteration	Fluid Volume (m^3)	Thrust Force	Score	Pass/ Fail
1	0.580646	132.9716094	229.00633	Fail
2	0.253792	272.7609959	1074.74229	Fail
3	1.311218	978.4823953	746.239295	Fail
4	0.843876	1050.208313	1244.50549	Pass
Final	0.561207	1066.374224	1900.1442	Pass

Table 1: Design Iteration Score

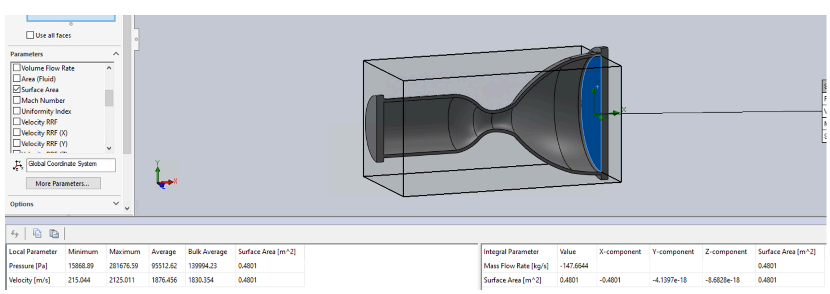
The exact values for the mass flow, outlet pressure, outlet velocity and fluid volume for each of the iterations, as well as the Thrust force calculation can be found in the appendix (Figure A1).

3.1 Iteration 1



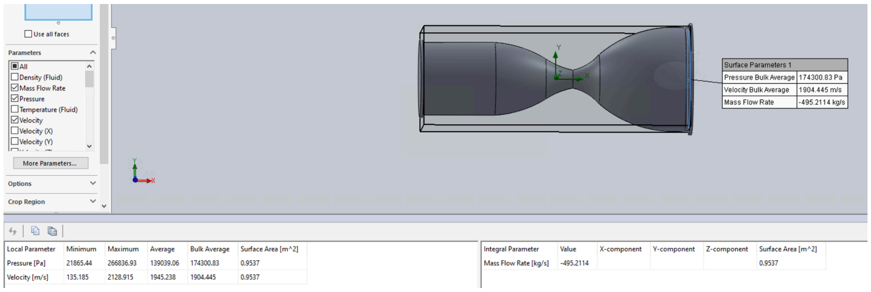
After conducting initial research, I based my initial model off of the shapes I saw. Although this design did reach the minimum volume parameter while fitting within a 3x1x1m space as required, the thrust force output was only 132.97 kN and therefore did not meet the design criteria. After visualizing this design with a cut plot of the velocity of the fluid within the chamber, I noticed that the faster velocities lay close the the neck of the chamber and therefore aimed to shorten the distance between the neck and the outlet face in order to get a higher outlet velocity, and therefore increase thrust.

3.2 Iteration 2



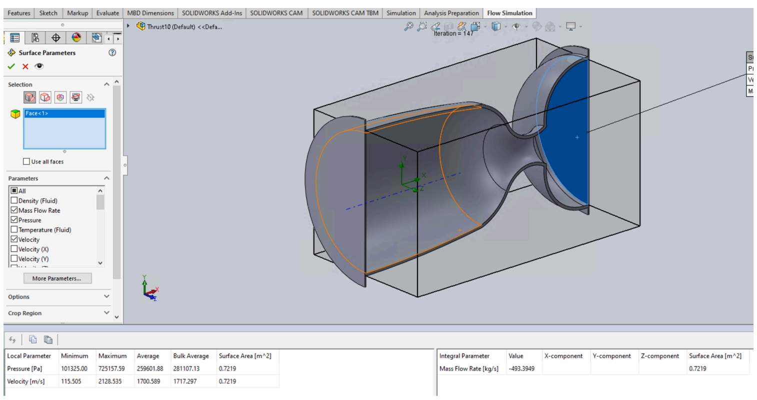
For my second iteration, I shortened the distance between the neck and the outlet mouth of the thrust chamber, and created a wider mouth with a steeper ascent of the walls. This design did approximately double the thrust of iteration 1, this value was still significantly too low. In addition, the fluid volume was now below the 0.5 m^3 threshold. However, from visualizing the cut plot, this iteration did help me to see how the geometry of the thrust chamber affected the outlet velocity, in comparison with the last model. My aim for the next iteration was to work off of this new information while also increasing the fluid volume to above required minimum.

3.3 Iteration 3



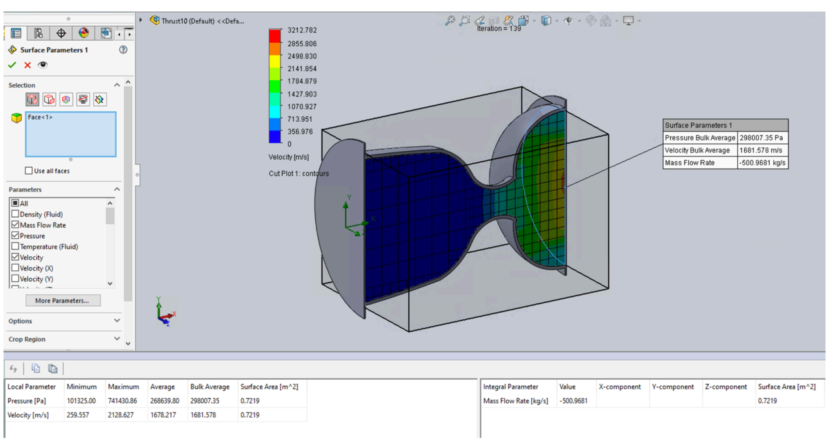
My third iteration had a thrust of 978 kN. This value was extremely near the required minimum of 1059 kN. In addition, it had a fluid volume of 1.31 m^3, which was above the 0.5 m^3 threshold. For my next iteration, my goal was to further decrease the distance between the neck of the thruster and the outlet mouth to increase the mass flow rate and velocity at the outlet. In addition, I also wanted to decrease the fluid volume as this would increase the score of the thruster.

3.4 Iteration 4



For this design, I made a very steep ascent for the outlet wall, and significantly shortened the distance from the neck to the mouth. This design passed all the requirements, with a thrust force of 1050.20 kN, however the volume was 0.84 m^3 and therefore this design was not the most efficient use of space. Therefore, for the next and final iteration I reduced the fluid volume of the thrust chamber by reducing the volume of the inlet chamber of the design.

3.4 Final Design



For my final iteration and the final design, I kept the shape of the outlet chamber the same, however I shortened the length of the inlet area in order to reduce the volume to closer to the 0.5 m^3 minimum. This design gave a thrust force of 1066.37 kN and had a volume of 0.56 m^3, therefore giving a score of 1900.

4 Conclusion

As stated above, the design passes all the design criteria as it has a maximum diameter of 1m, and a length of 1.39m, therefore fits within the 3m x 1m x 1m space requirement. The fluid volume of the chamber is 0.56 m^3, which is greater than the 0.5 m^3 minimum. Finally, it produces a thrust of 1066 kN and therefore is above the 1050 kN thrust force minimum required. This thrust force calculation and fluid volume of my passing design gave a score of 1900.

Each iteration helped me to get to my final design that passed the criteria, as I was able to visualize how the velocity was affected by the changing geometry through the use of the cut plots. Future iterations of this design could be further improved by reducing the fluid volume of the chamber without affecting the geometry of the outlet, by shortening the inlet section of the chamber. In addition, I could try to increase the curvature of the outlet part of the chamber as this may increase the outlet velocity and thereby by the thrust force.

Appendix

Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
m	96.1019	m	147.6644	m	495.2114	m	493.3949	m	500.9681
Ve	1391.688	Ve	2125.011	Ve	2128.915	Ve	2128.535	Ve	2128.627
Pe	99971.36	Pe	15868.89	Pe	21865.44	Pe	101325	Pe	101325
Ae	0.5705	Ae	0.4801	Ae	0.9537	Ae	0.7219	Ae	0.7219
Thrust	132.971609	Thrust	272.760996	Thrust	978.482395	Thrust	1050.20831	Thrust	1066.37422
Fluid Vol	0.580646	Fluid Vol	0.253792	Fluid Vol	1.311218	Fluid Vol	0.843876	Fluid Vol	0.561207
Score	229.00633	Score	1074.74229	Score	746.239295	Score	1244.50549	Score	1900.1442

Figure A1: Iteration Variables and Thrust Force Calculation

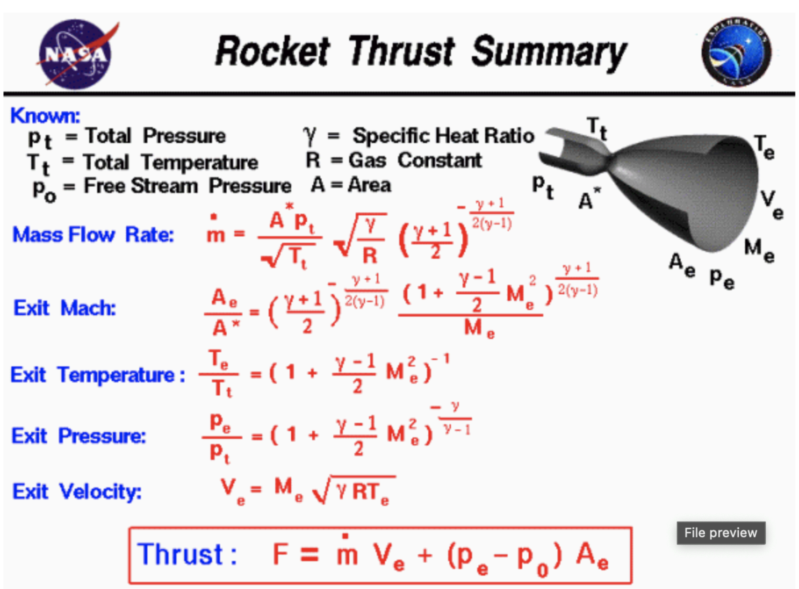


Figure A2: Thrust Force Equation