Electric Pump-Fed Liquid Rocket Engine

Final Design Project

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Engineering at the University of New Brunswick

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ABSTRACT

This report presents the design of an electric pump-fed liquid rocket engine, with the turbopump serving as its primary mechanism. The turbopump's impellers convert rotational mechanical energy supplied by an electric motor into increased fluid pressure and velocity. A motion analysis was conducted on the turbopump assembly using SolidWorks, in which a rotary motor operating at 500 RPM was applied to the shaft. The results indicated that the angular velocity increased linearly from 600 deg/s to 3000 deg/s over a 5-second interval, while the angular acceleration remained steady at 480 deg/s^2. The motor torque was found to hold constant at 1 N·mm throughout the simulation.

TABLE OF CONTENTS

List of Figures

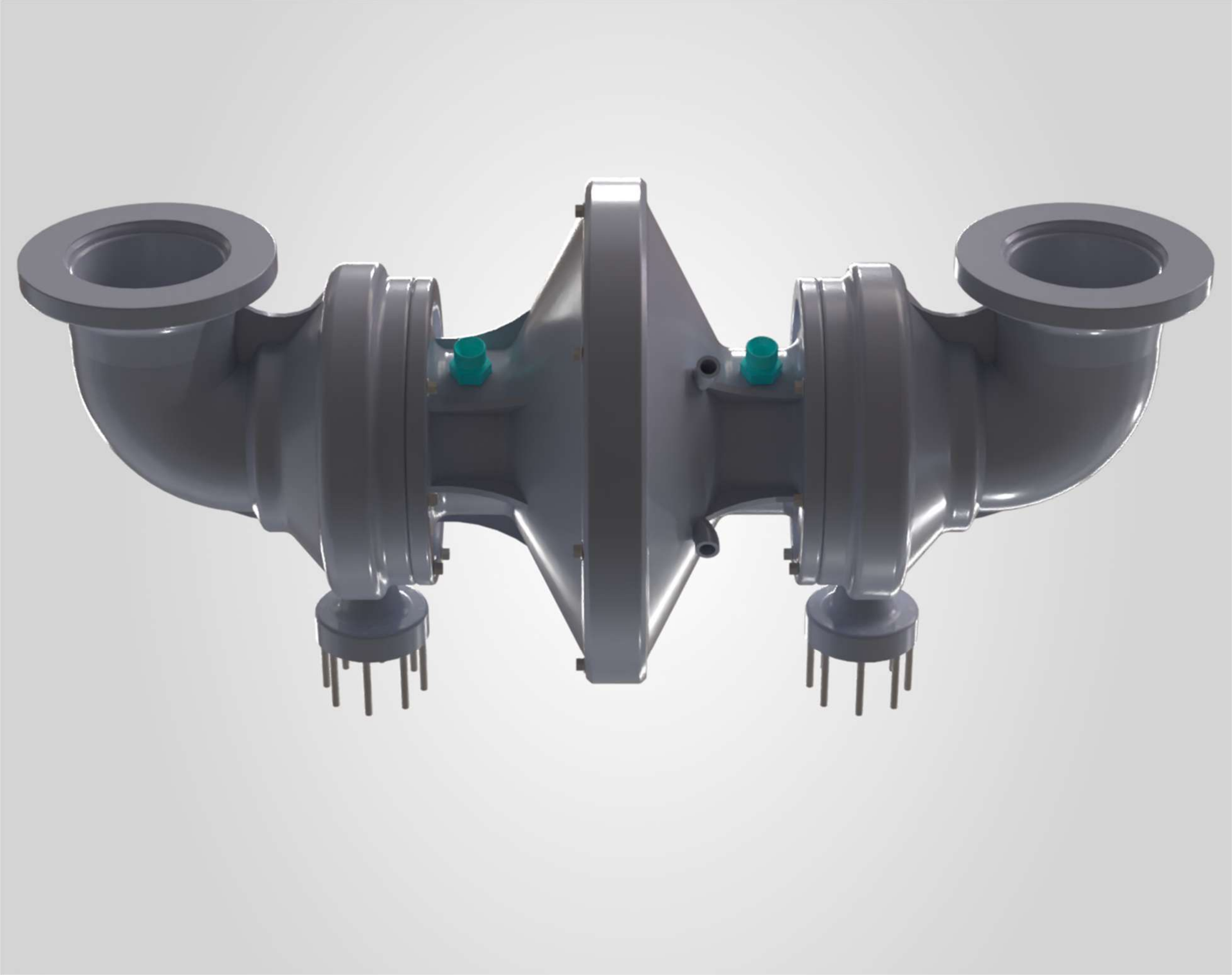


Figure 1: Turbopump Assembly.

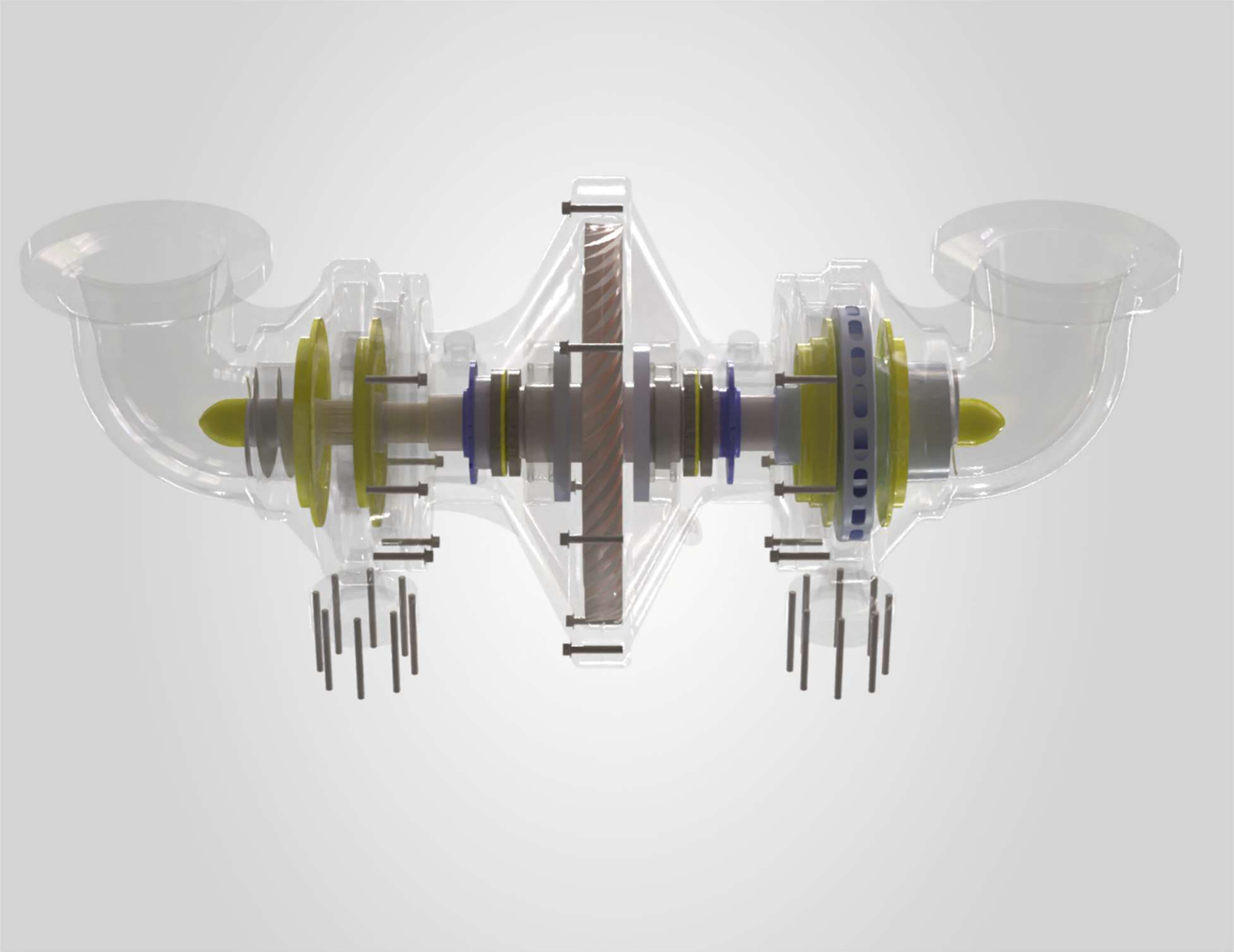


Figure 2: Image showing the internal mechanism driving the turbopump

Figure 3: Combustion Chamber (note that the midsection is hollow, to allow fluid to flow in)

Figure 4: Rocket Nozzle

Figure 5: Injector plate. The array of orifices on the right facilitates the flow of RP-1 (rocket propellant-1), while the remaining section delivers the liquid oxygen (LOX) oxidizer.

Figure 6: Rocket fuel tank. Two orifices are used to adapt to input requirements of the turbopump

Figure 7: Oxidizer fuel tank

Figure 8: L-shaped pipe

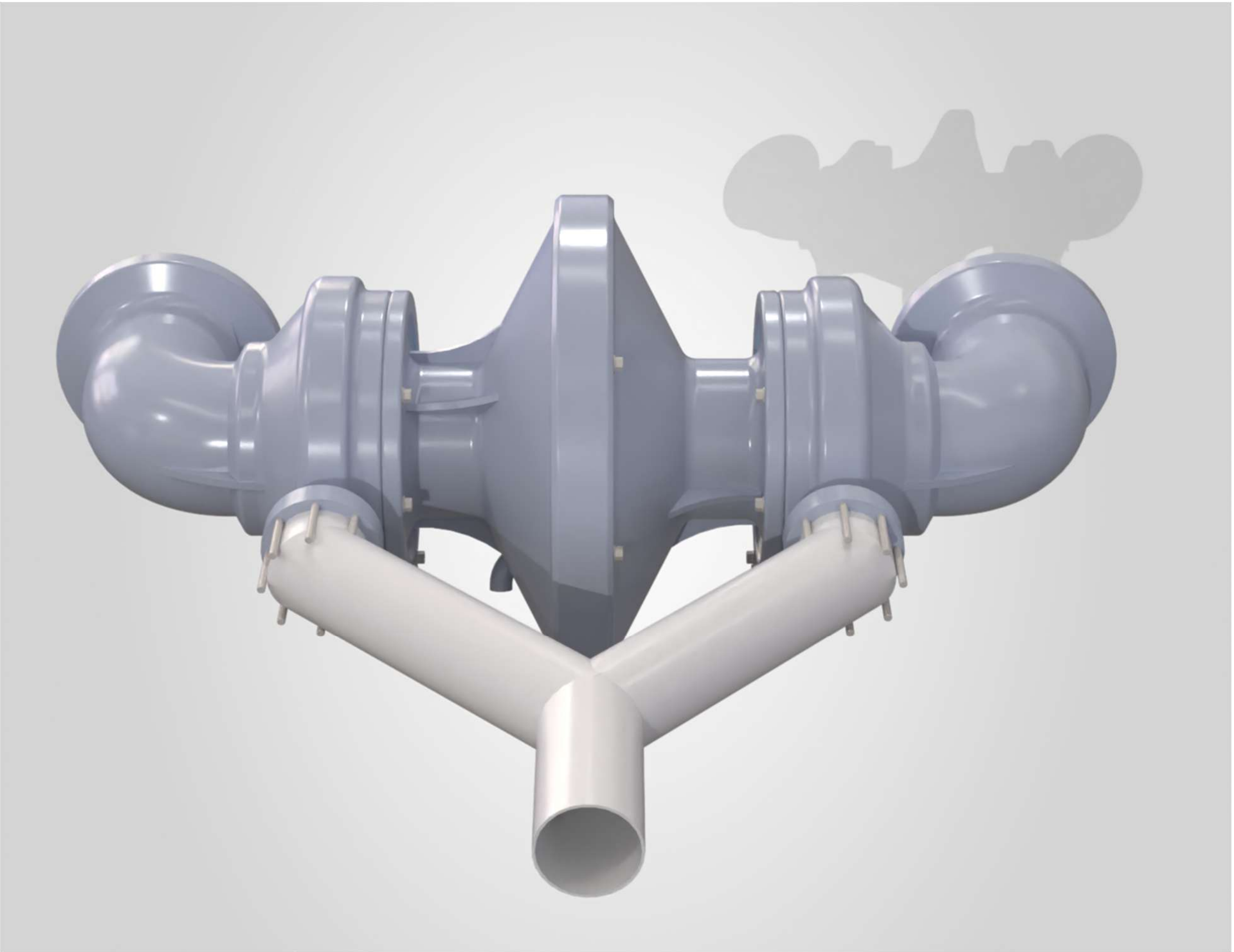


Figure 9: Image of a Y-junction pipe assembled with the turbopump

Figure 10: Isometric view of the electric pump-fed liquid rocket engine assembly

Figure 11: Exploded view of the electric pump-fed liquid rocket engine assembly

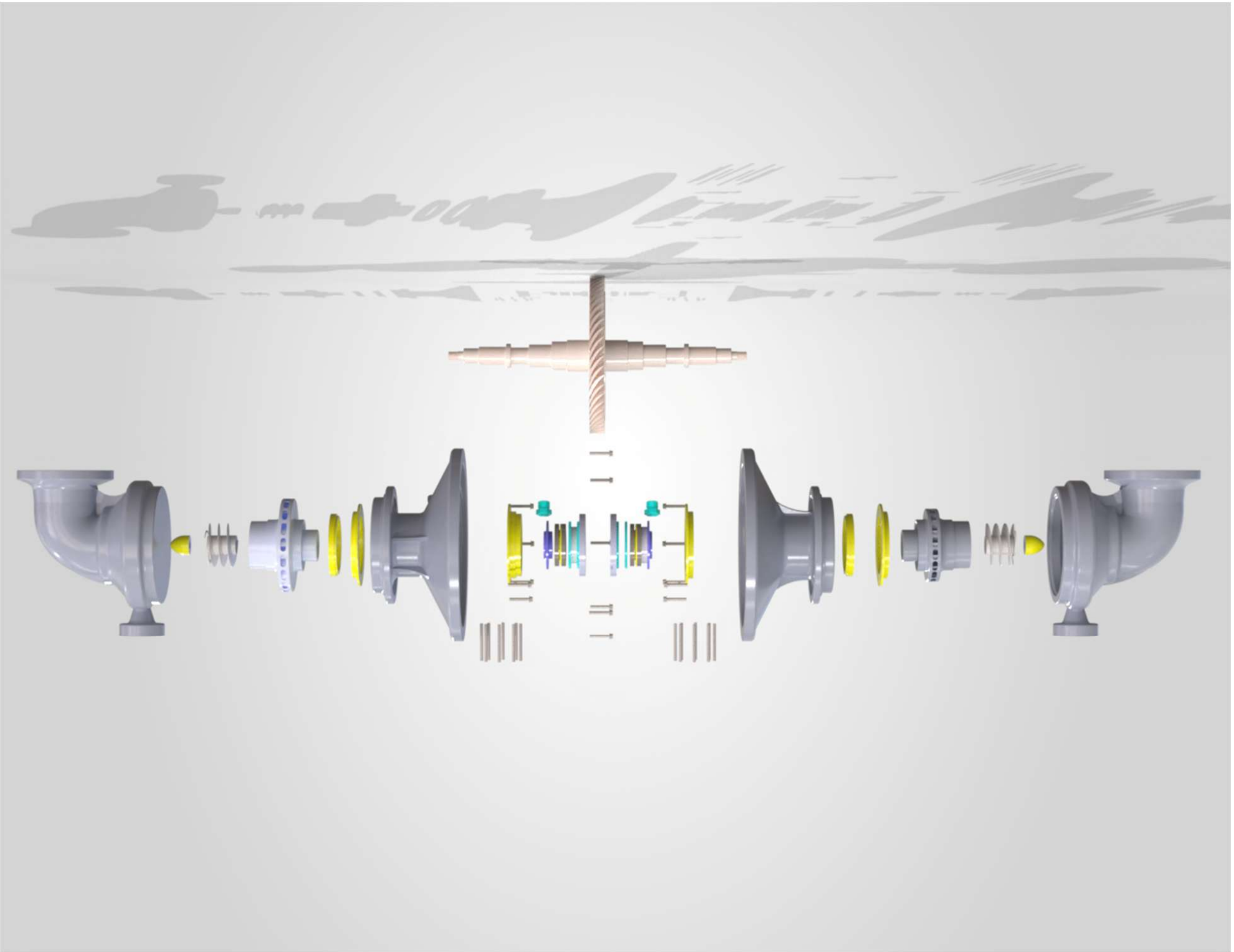


Figure 12: Exploded view of the turbopump

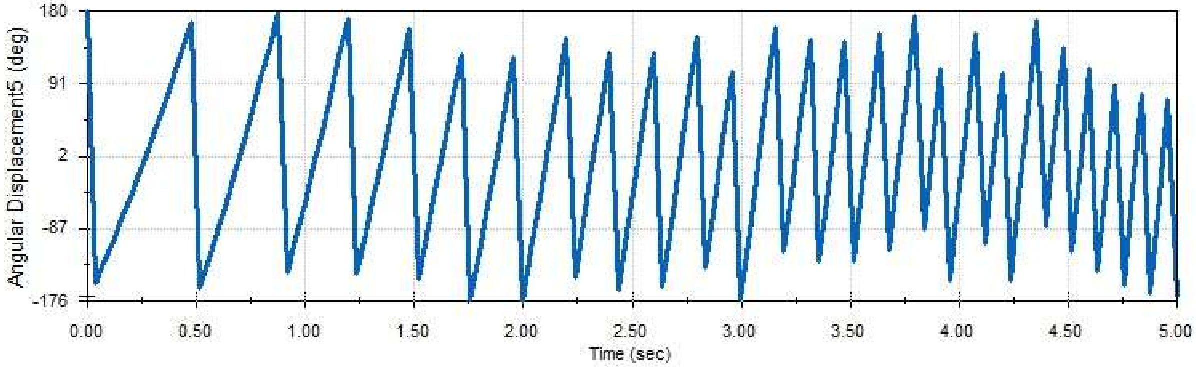


Figure 13: Angular Displacement of the impellers and shaft over time

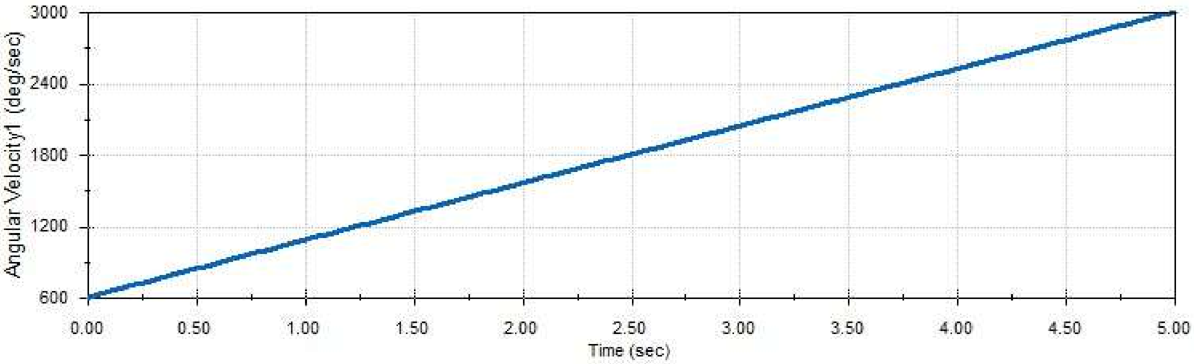


Figure 14: Angular velocity of the impellers and shaft over time

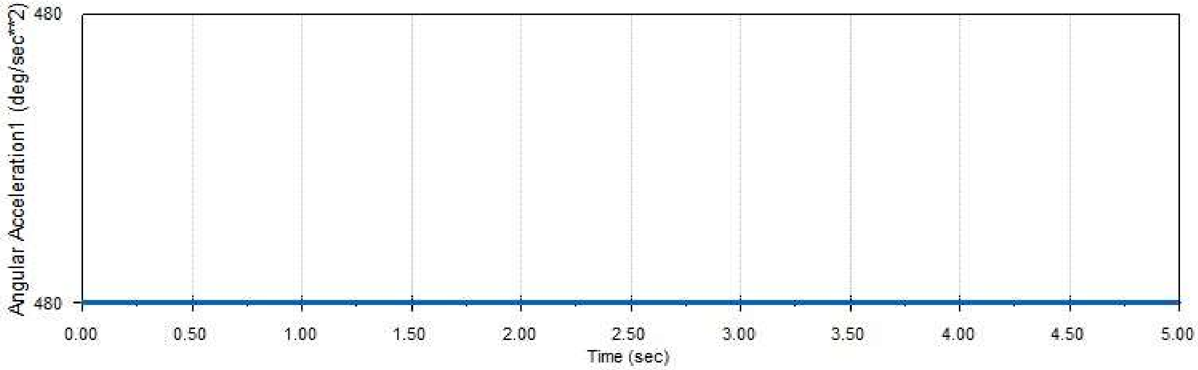


Figure 15: Angular Acceleration of the impellers and shaft over time

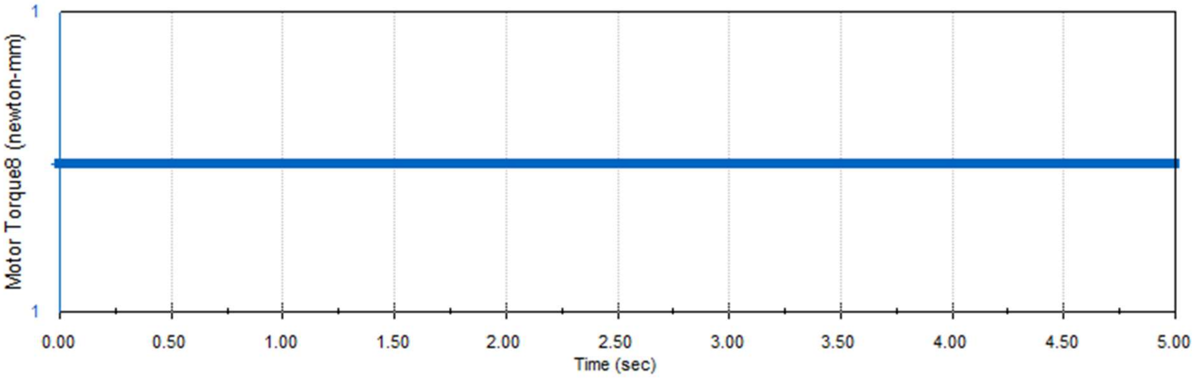
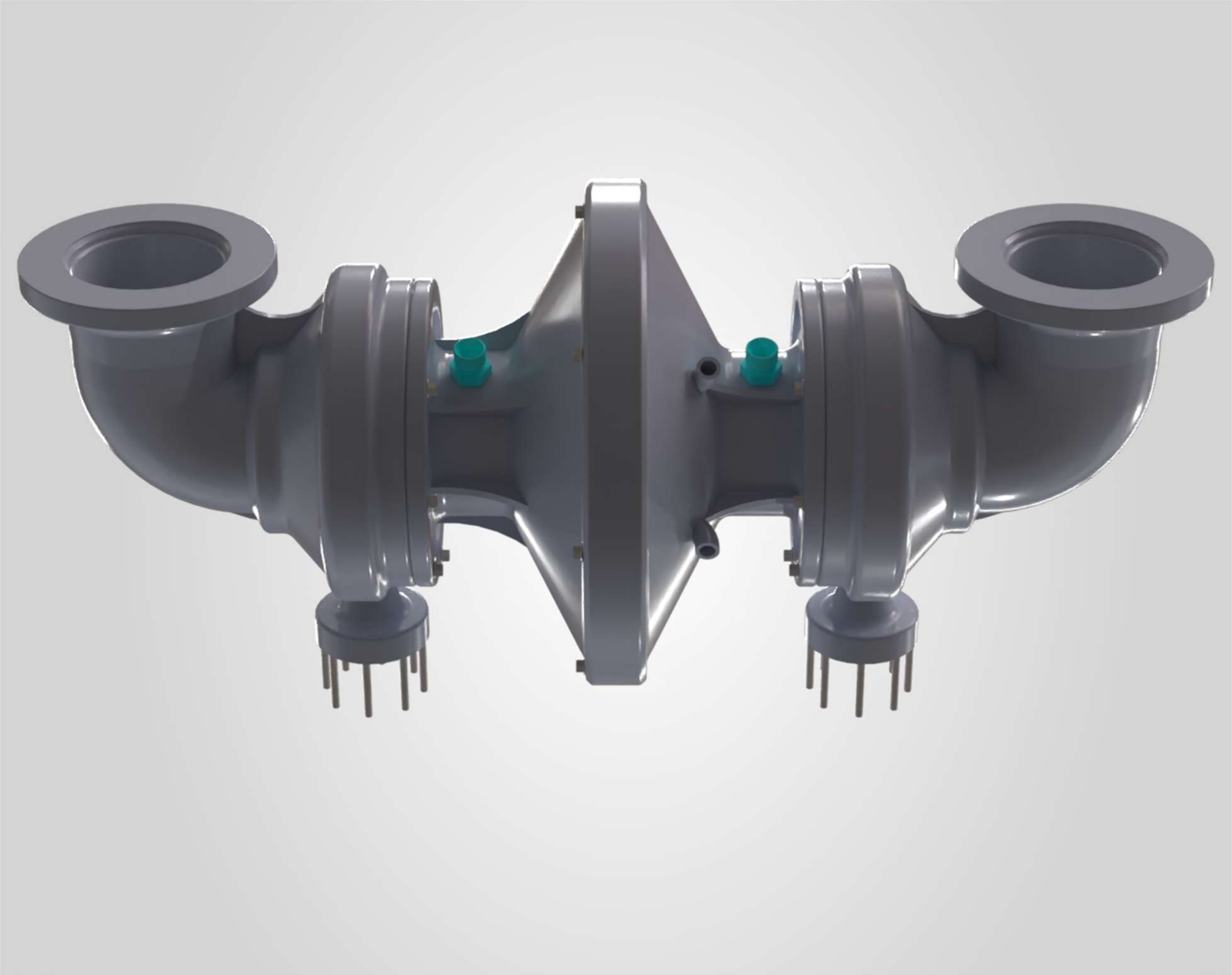


Figure 16: Motor torque experienced by the impeller over time.

INTRODUCTION

This report will outline the design methodology, analysis and reflections for an electric pump-fed liquid rocket engine (LRE). The propellant feed system is driven by a double suction centrifugal turbopump mechanism. The turbopump employs a single central spiral bevel impeller, sided symmetrically by two dedicated inlet ports. Propellant is transported simultaneously from both inlets into the impeller, where it is accelerated and flung radially outward by centrifugal action, before being collected by the volute and released through the two outlet ports at elevated pressure. This type of turbopump was chosen for its intrinsic axial thrust balancing and high flow efficiency. This design ensures that the axial hydraulic forces acting on the impeller are balanced, reducing mechanical stress on the shaft and bearings, and contributing to the overall reliability and longevity of the turbopump assembly.



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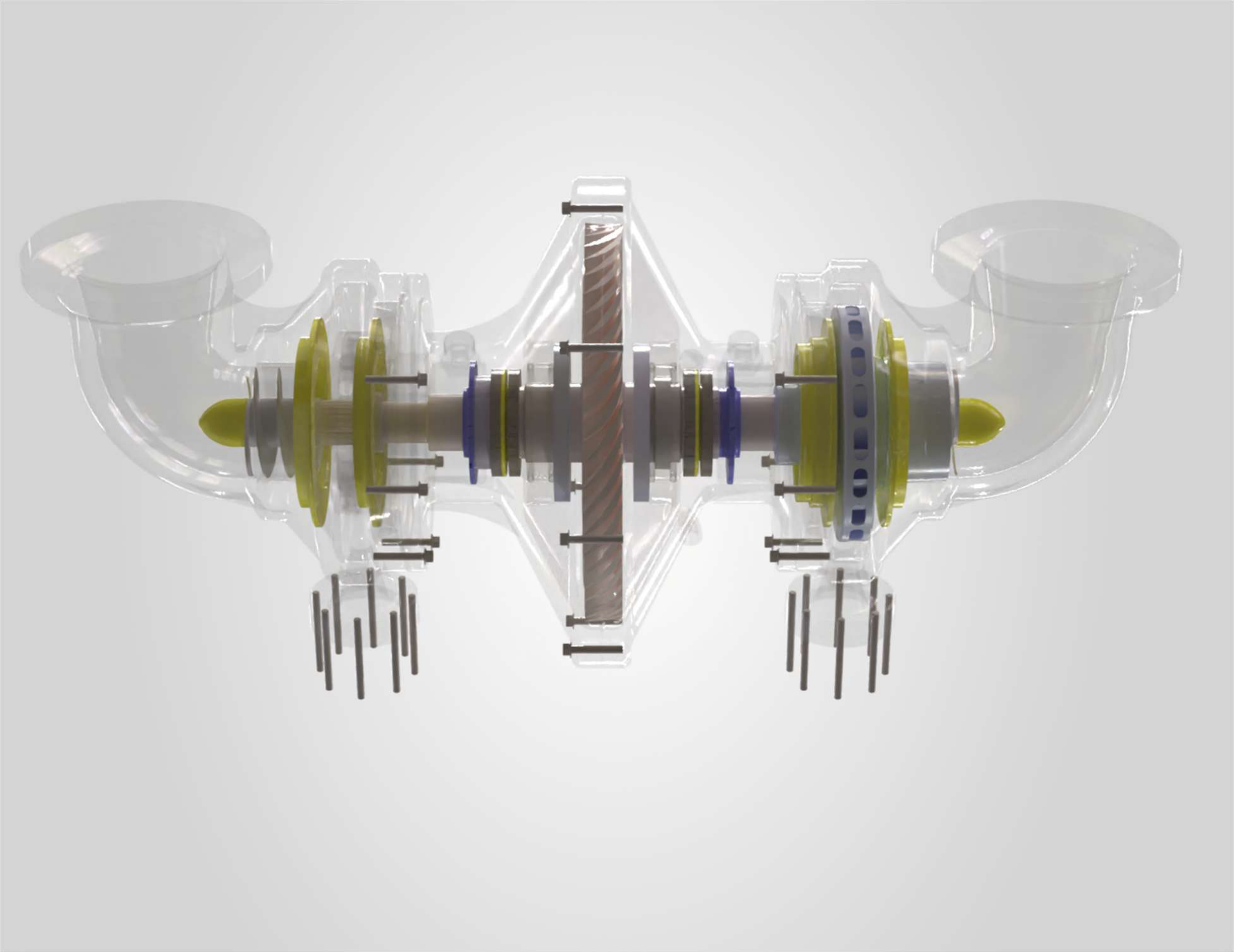


Figure 2: Image showing the internal mechanism driving the turbopump

DESIGN METHODOLOGY

The design process began with the modelling of the combustion chamber and rocket nozzle, developed through a systematic methodology informed by widely cited technical references and design resources, most notably MIT’s Nozzle and Combustion Chamber Design Guide. Prior to determining the chamber dimensions, however, a propellant combination was first established. A LOX/RP-1 (liquid oxygen/rocket propellant-1) configuration was selected for the engine based on its well-documented performance characteristics and widespread use in liquid rocket engine applications.

Following this, the combustion chamber and nozzle geometry were derived by systematically applying the five-step methodology outlined in MIT's Nozzle and Combustion Chamber Design Guide:

1. Derive the chamber volume from the characteristic length (L*)
2. Calculate convergent section parameters
3. Extract cylindrical lengths
4. Define chamber surface area
5. Calculate diverging section length (nozzle)

Figure 3: Combustion Chamber (note that the midsection is hollow, to allow fluid to flow in)

Figure 4: Rocket Nozzle

The design process then progressed to the injector plate and propellant tanks. The injector plate design was relatively straightforward, as several key dimensions had already been established during the combustion chamber design phase. Drawing from MIT's Injector Design Guide, a non-impinging showerhead injector configuration was selected for its simplicity. It is worth noting, however, that this configuration performs optimally only within large combustion chamber volumes and is generally considered less effective than impinging jet designs for liquid rocket engine applications.

The propellant tank design task was more open-ended, as the primary determining factor was the desired propellant mass fraction. The selected tank volumes were sized to carry sufficient LOX/RP-1 propellant to sustain a significant combustion reaction, balancing performance requirements against practical design constraints.

Figure 5: Injector plate. The array of orifices on the right facilitates the flow of RP-1 (rocket propellant-1), while the remaining section delivers the liquid oxygen (LOX) oxidizer

Figure 6: Rocket fuel tank. Two orifices are used to adapt to input requirements of the turbopump

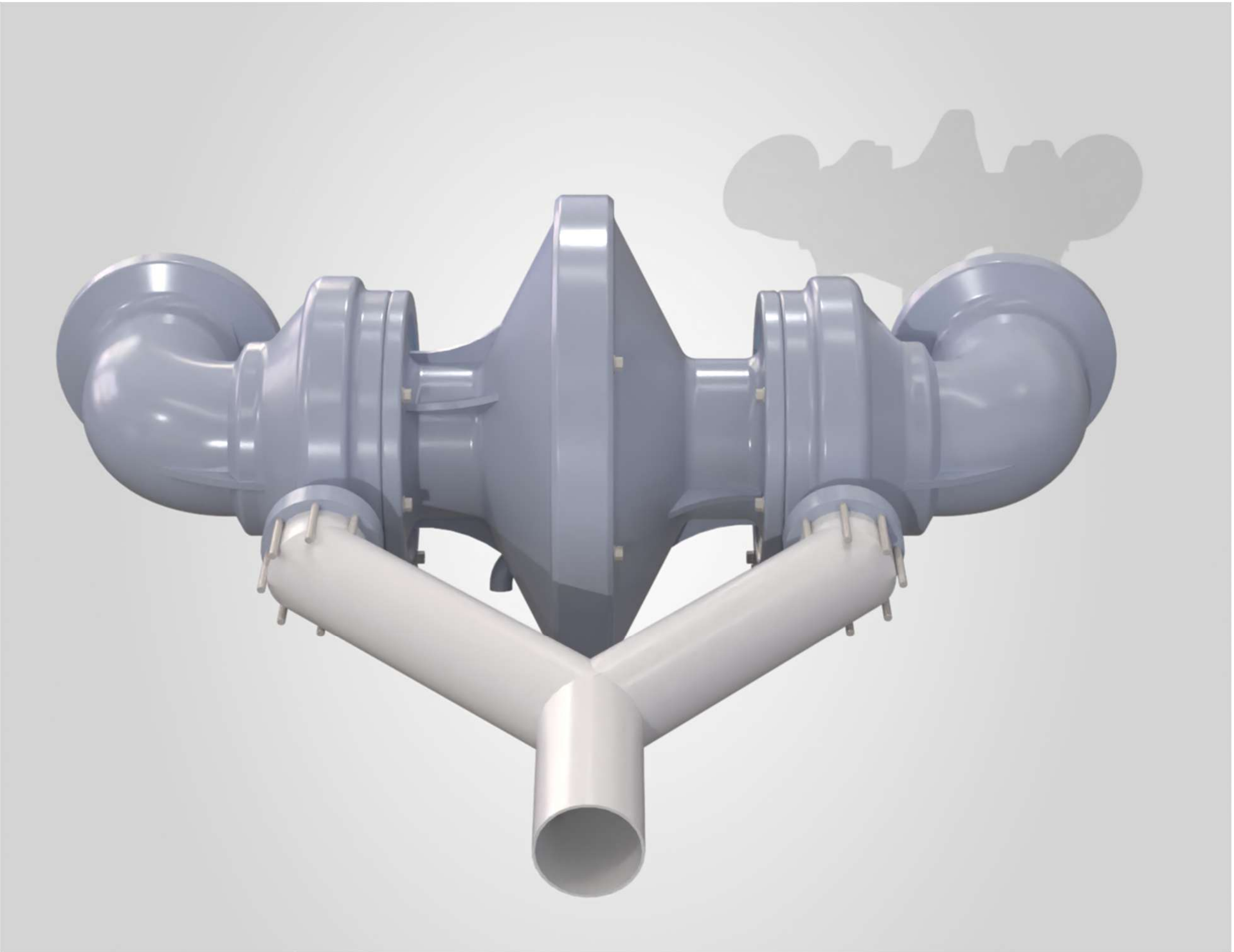
Figure 7: Oxidizer fuel tank

The final modelling phase encompassed the L-shaped pipes, Y-junction pipes, and the turbopump assembly. The turbopump design was heavily inspired by a base CAD model originally created by Max Smoliar, upon which several design elements were incorporated, including a complete casing for the turbopump mechanism and appropriate mates to fully constrain the motion of the shaft and impeller.

The pipe system was initially conceived to be as simple as possible; however, it became apparent that an overly simplified design introduced its own engineering complications. As a result, the design philosophy was shifted toward a more modular approach, allowing individual pipe segments to be linked in virtually any orientation. This decision proved instrumental in facilitating the subsequent assembly of the full liquid rocket engine.

Determining the correct dimensions for the Y-junction pipe required a careful analysis of previously established part dimensions, supplemented by estimates derived under a 45-degree angle constraint, and validated through iterative trial and error. The Y-junction pipe was additionally divided into two unequal segments (comprising two-thirds and one-third of the total body respectively), to simplify the assembly process within SolidWorks. This decision was driven by the practical difficulty of adequately constraining all three ends of the Y-junction as a single part using SolidWorks mates.

Figure 8: L-shaped pipe



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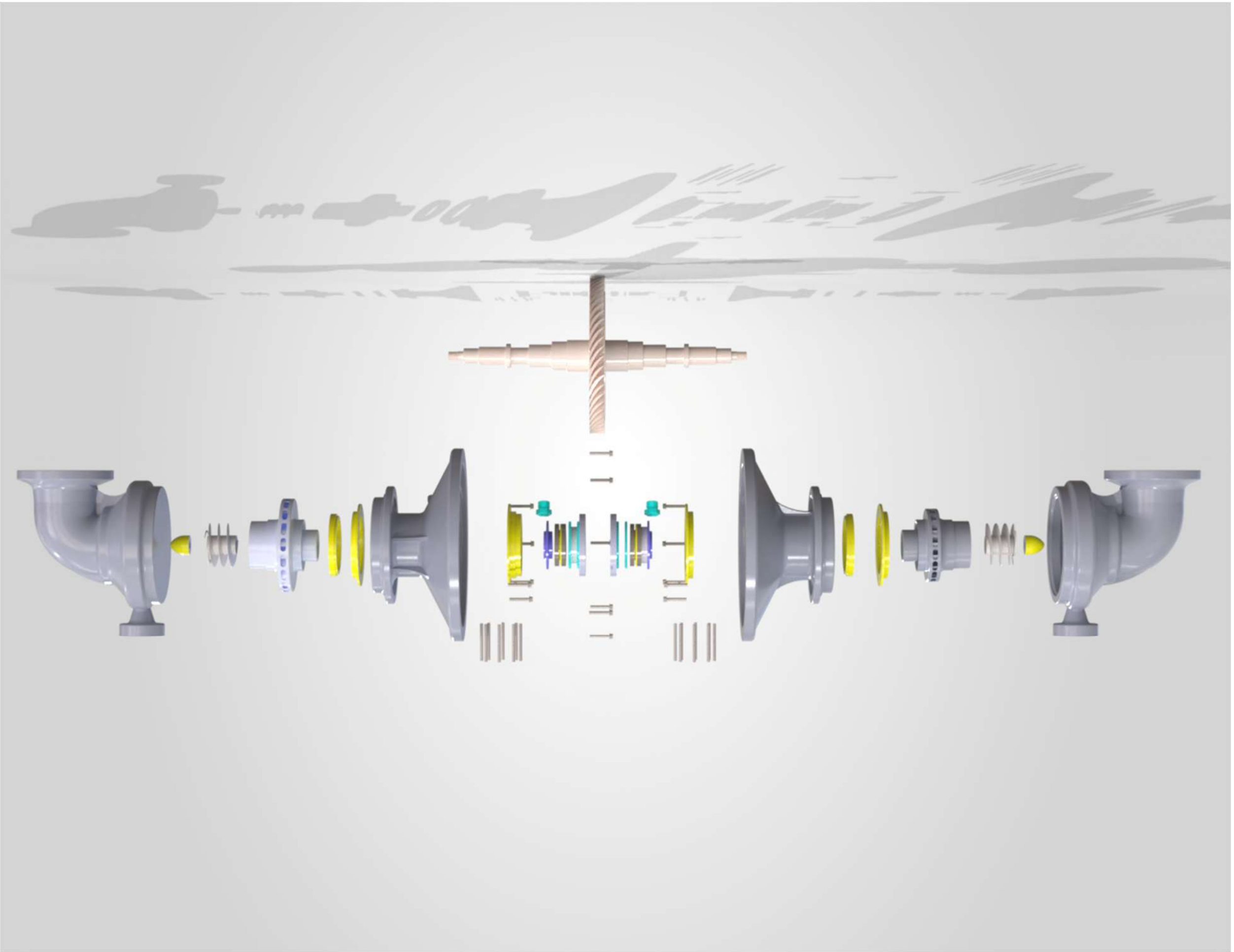


Figure 12: Exploded view of the turbopump

DESIGN ANALYSIS

For the motion analysis of the turbopump assembly, the angular displacement, velocity, and acceleration of the impellers and shafts were analyzed under a rotary motor operating at 500 RPM. A force analysis was also conducted by examining the motor torque acting on the impeller over time.

The angular velocity increased linearly from 600 deg/s to 3000 deg/s over a 5-second interval, while the angular acceleration remained steady at 480 deg/s². Similarly, the motor torque held constant at 1 N·mm throughout the simulation.

Of all the outputs, the angular displacement graphs proved to be the most notable, exhibiting the greatest variance and least predictable behavior compared to the other parameters.

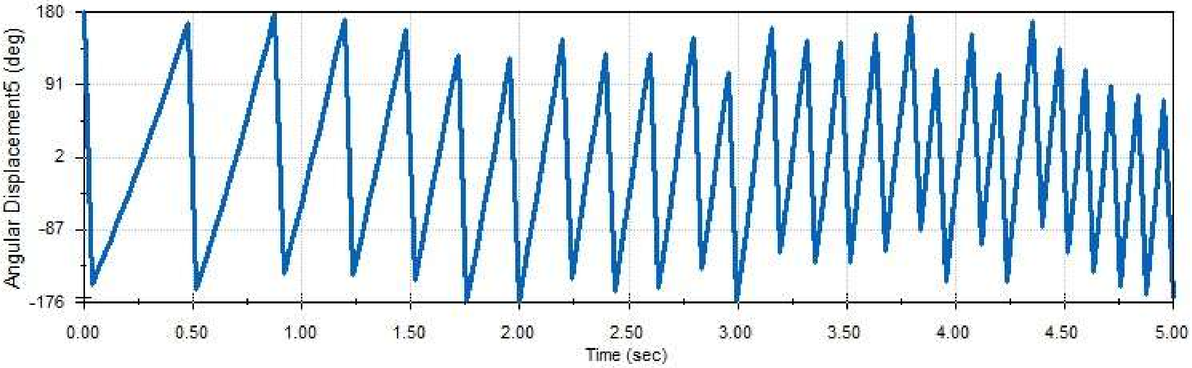


Figure 13: Angular Displacement of the impellers and shaft over time

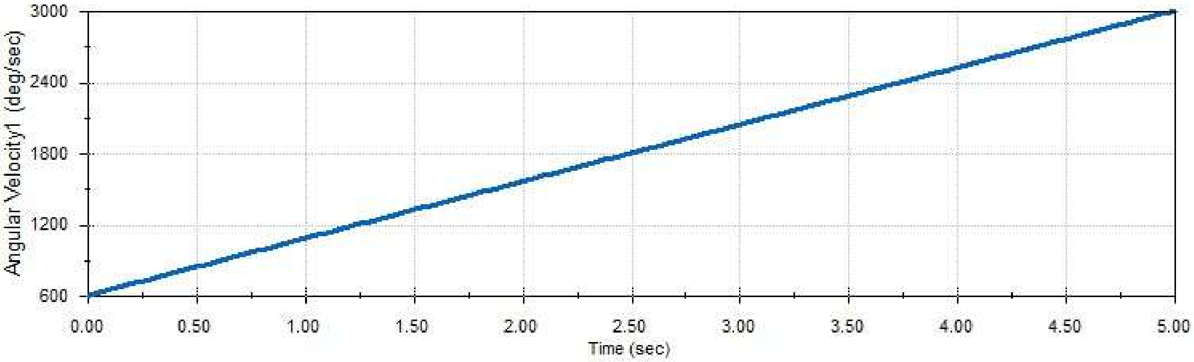


Figure 14: Angular velocity of the impellers and shaft over time

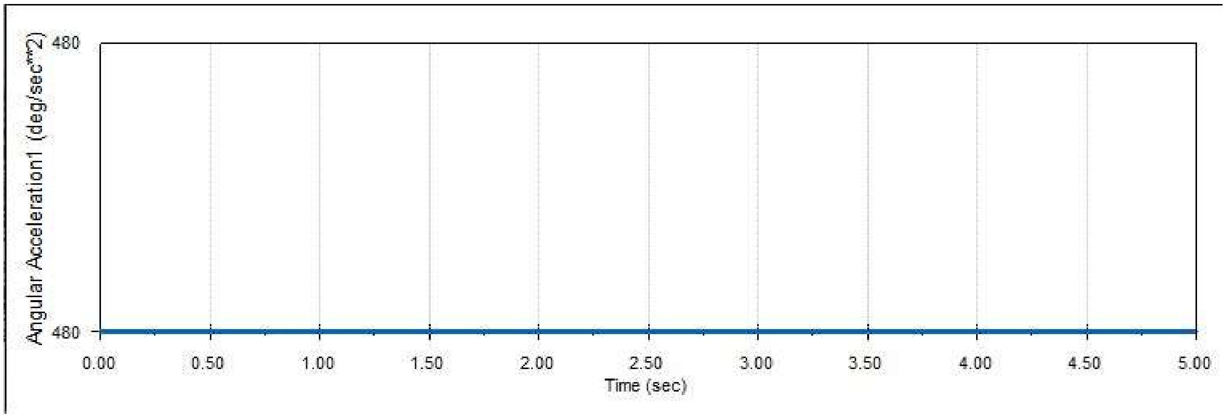


Figure 15: Angular Acceleration of the impellers and shaft over time

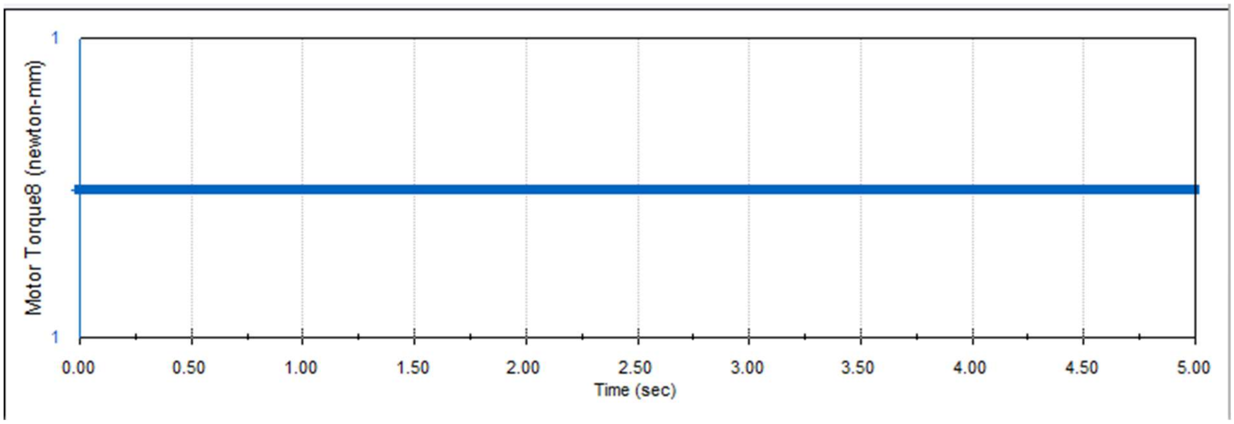


Figure 16: Motor torque experienced by the impeller over time.

Beyond the scope of this study, a wide range of additional analyses could be performed to further evaluate the liquid rocket engine's performance. Flow simulations, for instance, could be employed to assess the effectiveness of the injector in achieving adequate mixing of the propellants, ensuring a stable and efficient combustion reaction within the combustion chamber. Furthermore, structural and thermal analyses could be carried out to evaluate the engine's material response to the extreme temperature conditions generated during combustion, providing insight into its thermal resilience and structural integrity under operational loads. In terms of manufacturing the liquid rocket engine components, I have concluded that a CNC lathe is ideal to manufacture both the combustion chamber and rocket nozzle, as their geometry is rotationally symmetric, allows the thick upper rim to be machined easily, and enables tight tolerances to be achieved. Likewise, a CNC lathe should be used for the injector plate disc body, while for the showerhead hole patterns, a CNC drill press is optimal due to the precise X/Y positioning required for the concentric hole arrays. To manufacture the L-shaped pipes, the most ideal process is CNC mandrel tube bending, as it is the industry standard for precision elbow geometries and prevents wall collapse through the bend. The procedure for manufacturing the propellant tanks requires multiple steps: first, each half is machined individually on a CNC lathe, then the two halves are joined with a precision threaded interface at the cylinder mid-section. A metal seal should also be incorporated at the threaded joint to ensure pressure integrity. Regarding the standard tolerances of the turbopump, the shaft-to-bearing interface represents the most critical fit in the assembly. A locational clearance fit of ISO h6/H7 is ideal, as the bearings must be precisely located on the shaft while remaining assemblable. A fit that is too tight risks bearing damage, while one that is too loose causes vibration at high RPM. In terms of GD&T, a cylindricity of 0.005mm on the bearing journals ensures roundness under radial loads, while a runout below 0.01mm is critical at turbopump speeds to prevent dynamic imbalance.

For the impeller-to-shaft interface, an interference fit of ISO P6/H6 is optimal, since impellers and gears must transmit torque without slipping, and a press fit effectively eliminates relative motion under load. Regarding GD&T, a perpendicularity of less than 0.01mm relative to the shaft axis prevents wobble during rotation, while a circular runout of less than 0.015mm ensures balanced rotation throughout operation.

CONCLUSION

Over the course of this project, the primary objective of demonstrating comprehensive CAD competence was successfully achieved, while simultaneously developing a deeper, hands-on understanding of rocket engineering principles. This project provided a valuable opportunity to integrate concepts from thermodynamics and fluid mechanics into one cohesive system design. Technical proficiency was also expanded through consistent application of SolidWorks, including the use of features such as assembly-level component mirroring and the development of more reliable motion study workflows.

Beyond the technical outcomes, this project significantly developed my ability to manage and sustain progress on a long-term engineering task in a consistent and organised manner. More than a coursework submission, this project represents a foundation to be continually refined and built upon in future engineering endeavours

REFERENCES

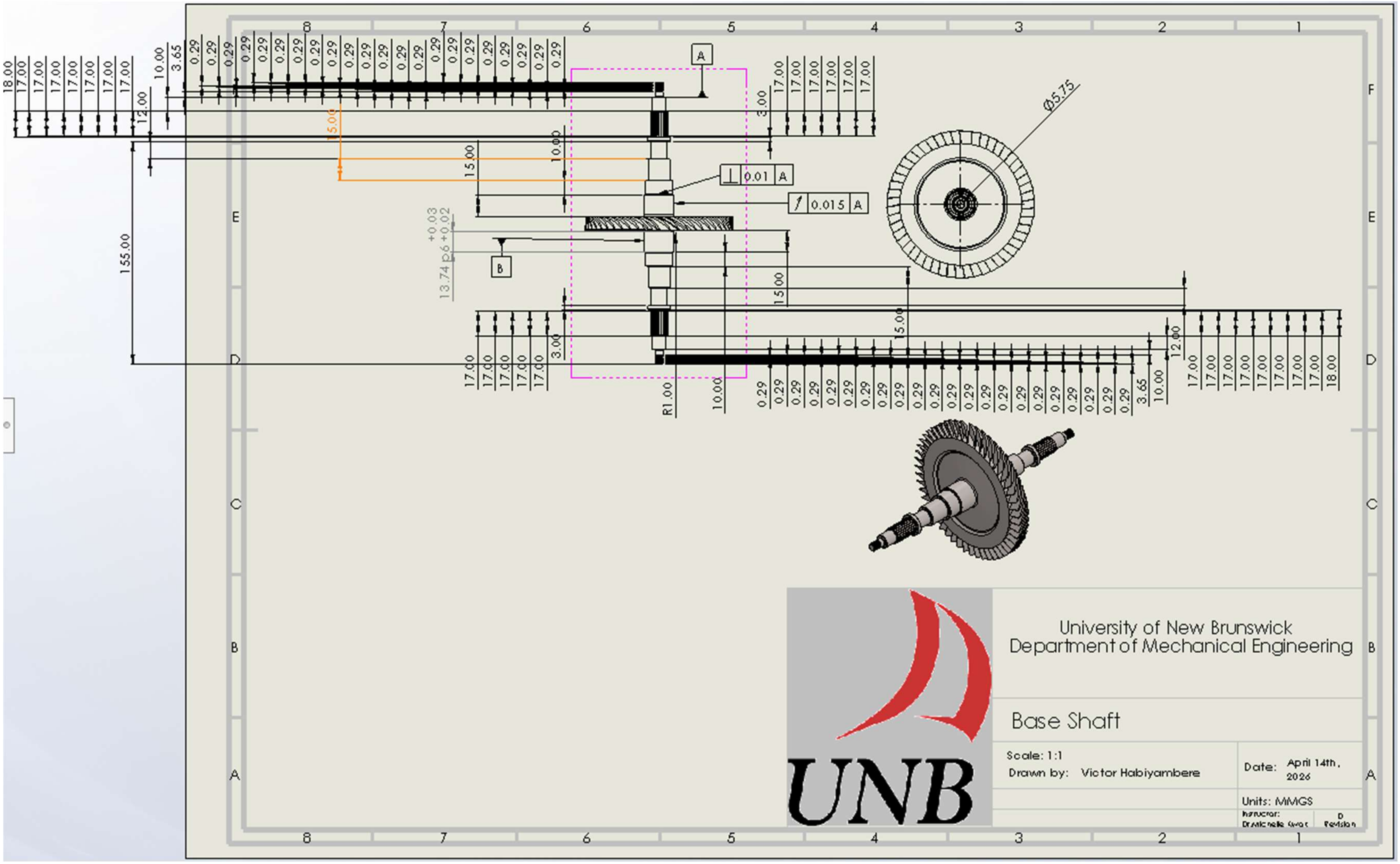
[1] “Topic 6: Injector Design,” Topic 6: Injector Design - MIT Rocket Team - MIT Wiki Service, https://wikis.mit.edu/confluence/display/RocketTeam/Topic+6%3A+Injector+Design (accessed Apr. 13, 2026).

[2] “Nozzle & Combustion Chamber Design Guide,” Nozzle & Combustion Chamber Design Guide - MIT Rocket Team - MIT Wiki Service, https://wikis.mit.edu/confluence/pages/viewpage.action?pageId=153816550 (accessed Apr. 13, 2026).

[3] Turbopump for Liquid Rocket Engine | 3D CAD model library, https://grabcad.com/library/turbopump-for-liquid-rocket-engine-3 (accessed Apr. 13, 2026).

APPENDIX

NOTE: FOR THE TURBOPUMP, SOME PARTS DID NOT IMPORT CORRECTLY FROM THE BASE MODEL, AND THEREFORE HAD NO DIMENSIONS LINKED TO THEM. THEREFORE, BELOW SHOWS ALL THE DRAWINGS FOR THE PARTS WHICH I HAVE DIMENSIONS FOR.



University of New Brunswick
Department of Mechanical Engineering

Base Shaft

Scale: 1:1
Drawn by: Victor Habiyambere

Date: April 14th, 2026

Units: MMGS

Instructor: Dr.Michelle Kwas

D
Revision

Figure 18: Drawing for the primary turbopump mechanism

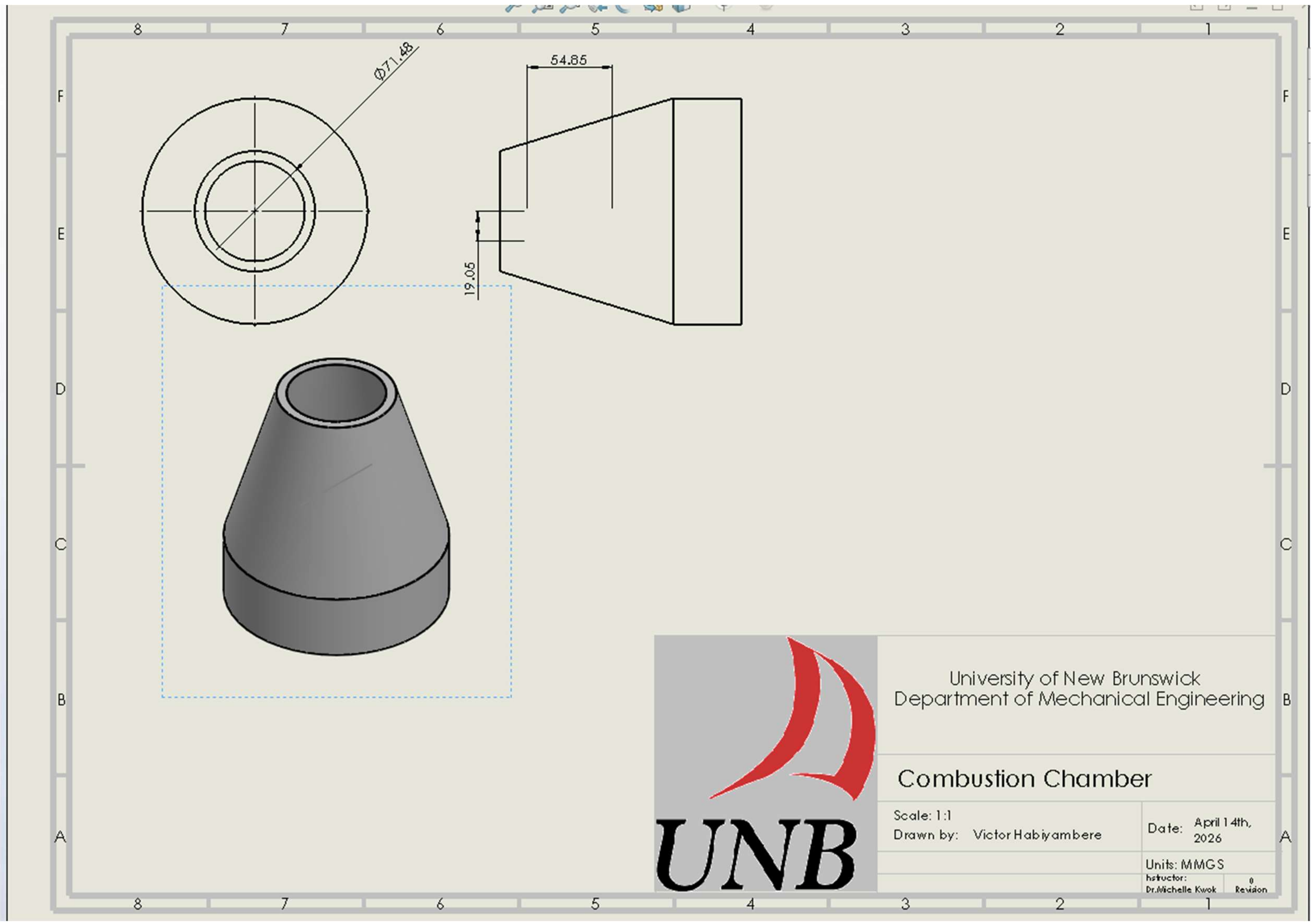
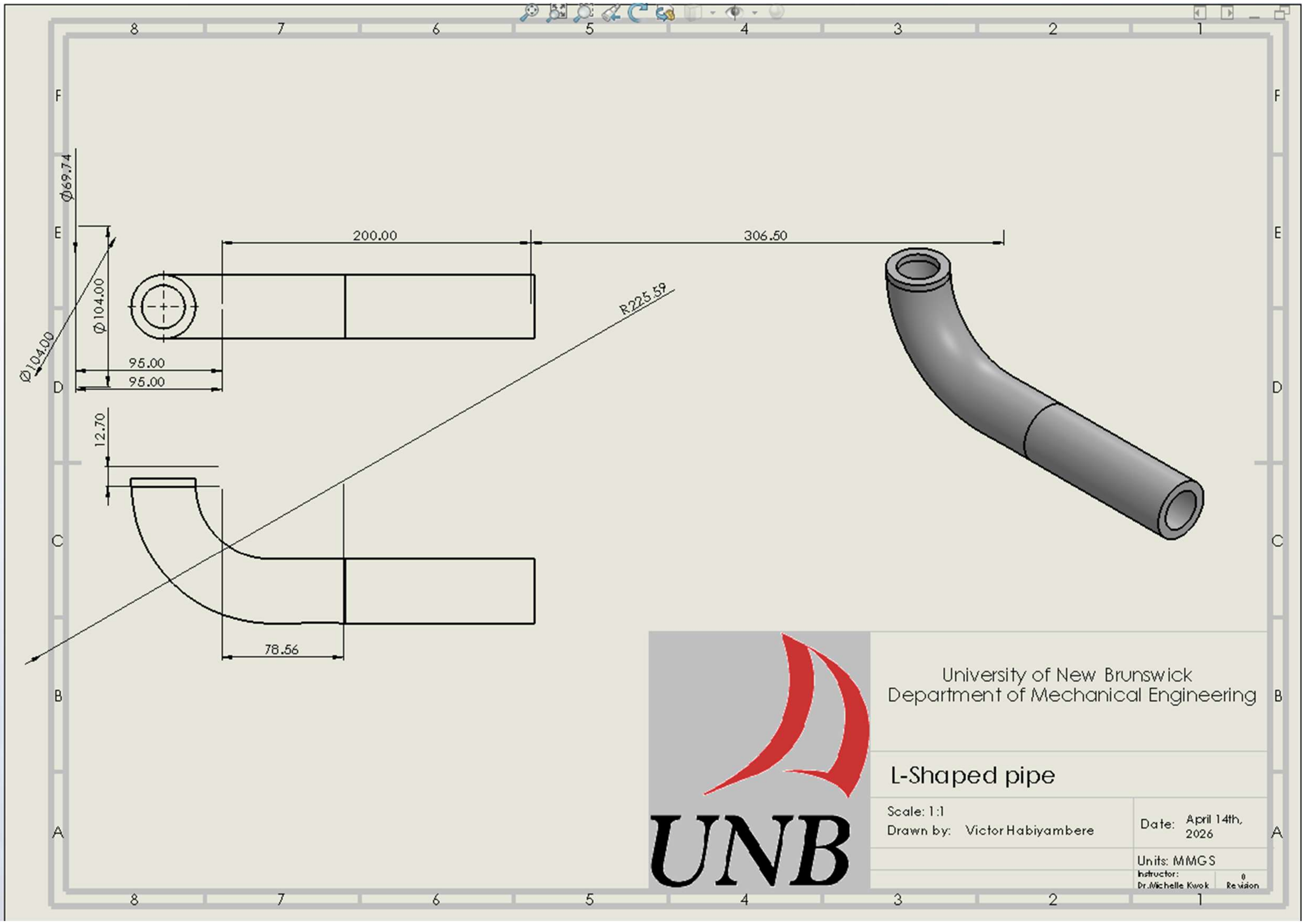


Figure 19: Drawing for the Combustion Chamber



University of New Brunswick
Department of Mechanical Engineering

L-Shaped pipe

Scale: 1:1
Drawn by: Victor Habiyambere
Date: April 14th, 2026
Units: MMGS
Instructor: Dr.Michelle Kwok
0 Revision

Figure 20: Drawing of the L-Shaped pipe

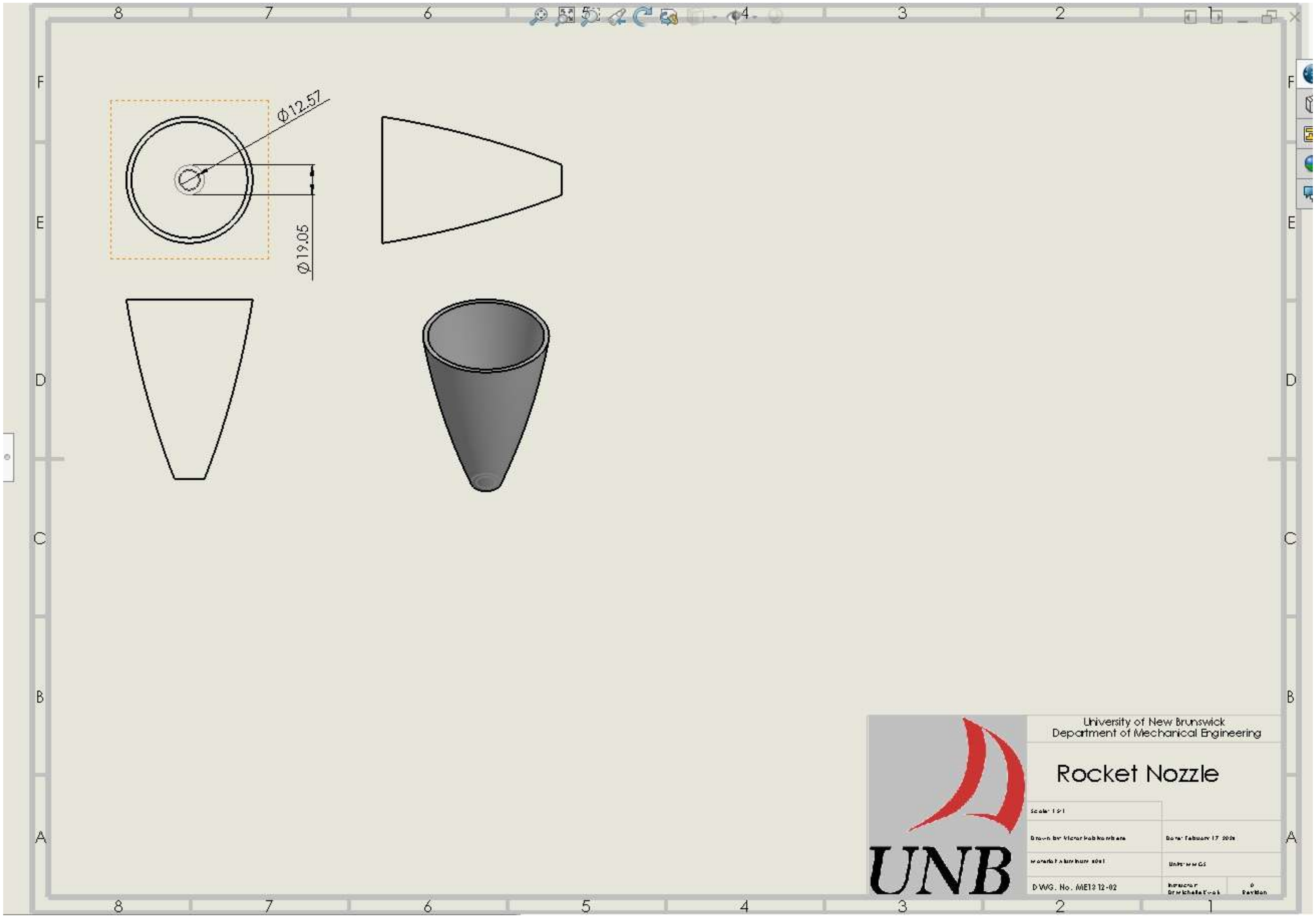


Figure 21: Drawing of the rocket nozzle

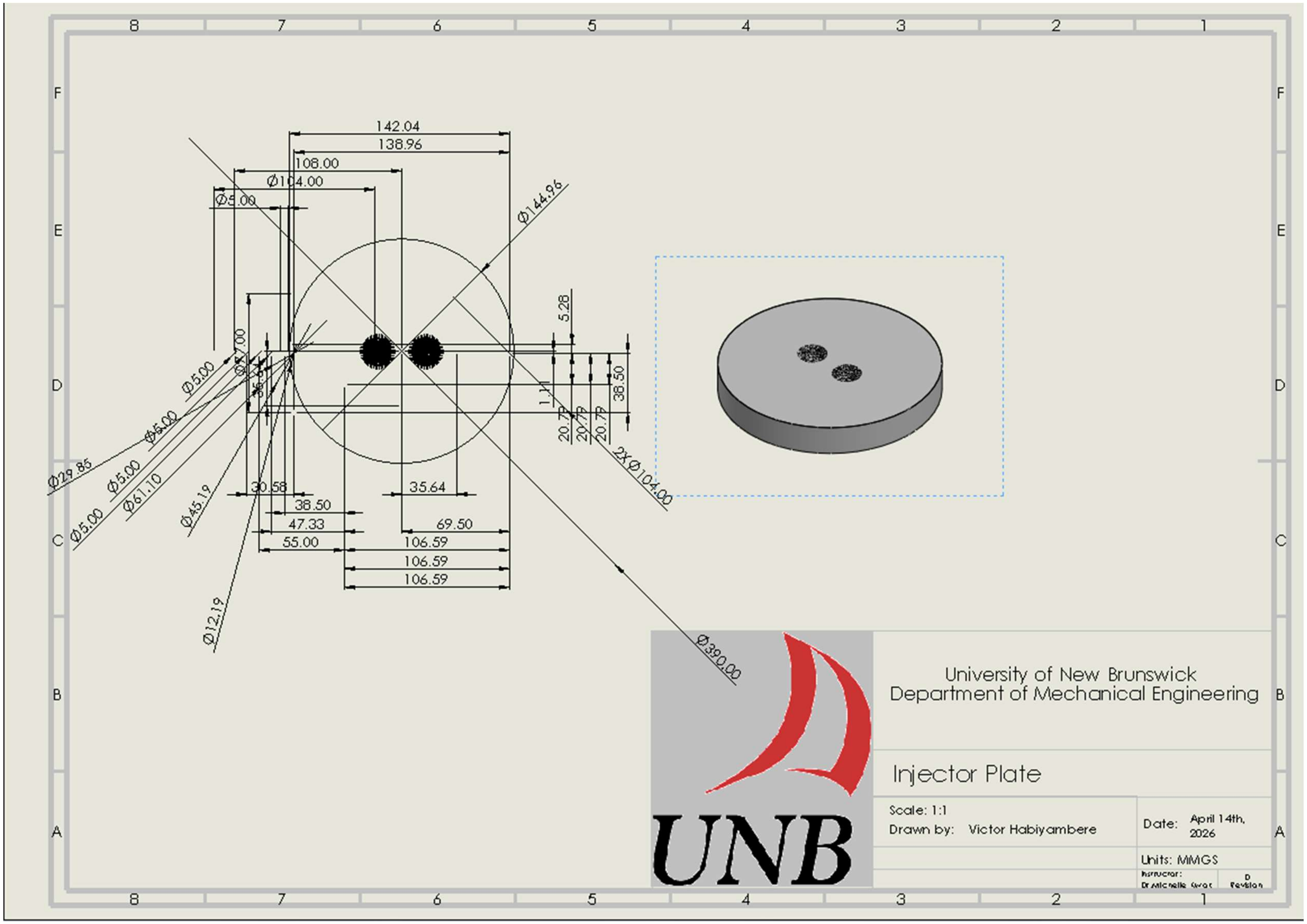
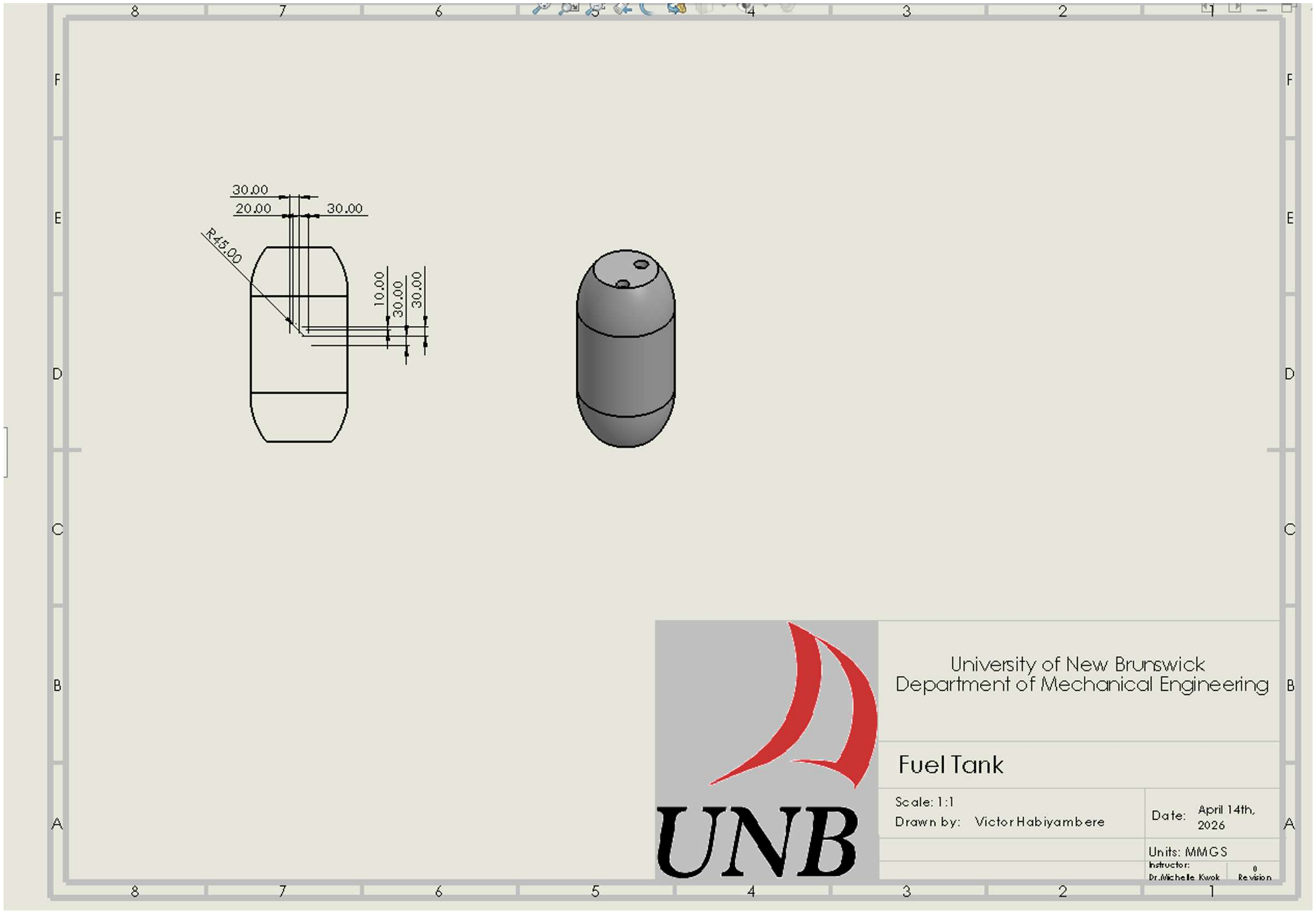


Figure 22: Drawing of the injector plate



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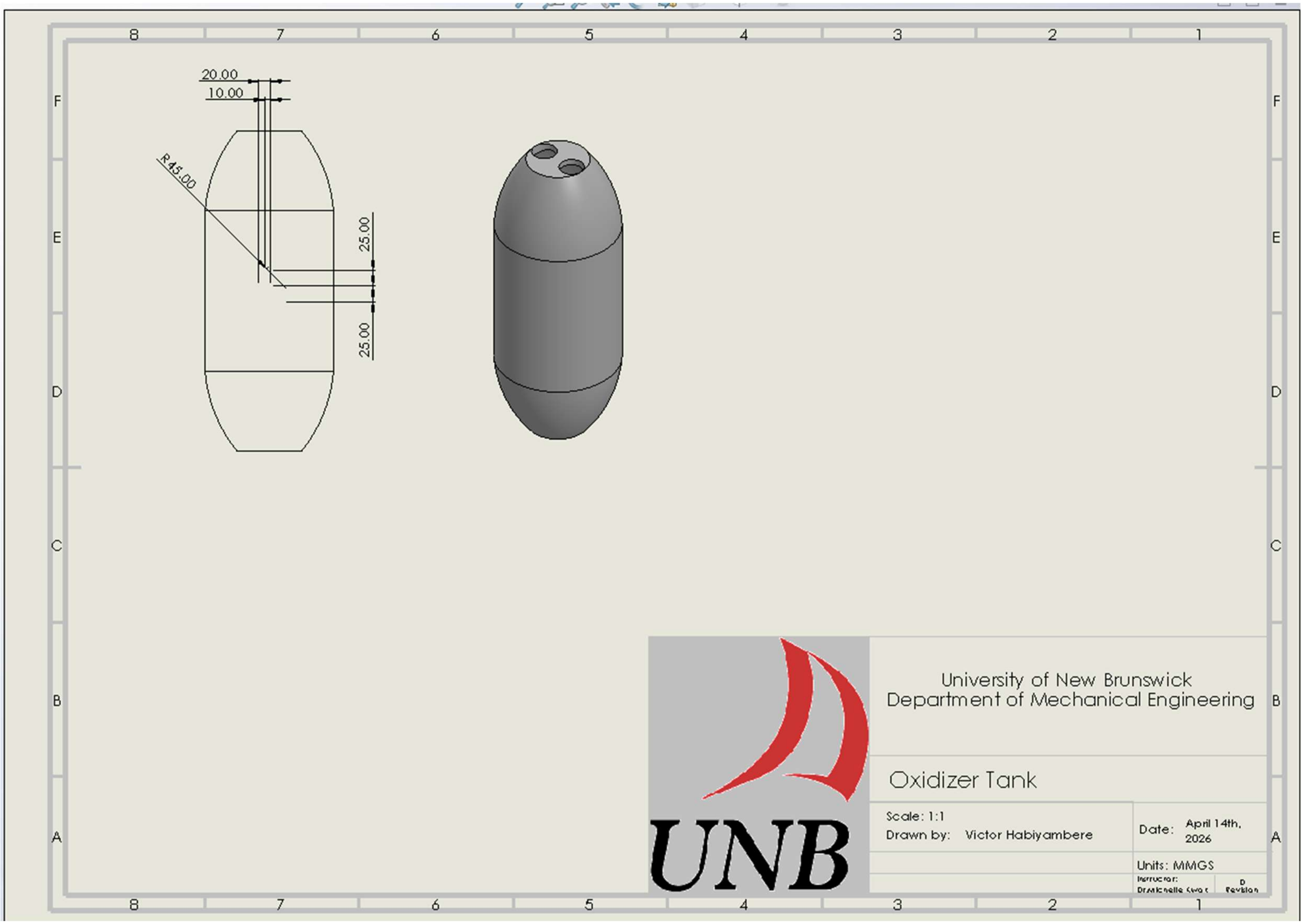
Department of Mechanical Engineering

Fuel Tank

Scale: 1:1
Drawn by: Victor Habiyambere
Date: April 14th, 2026
Units: MMGS
Instructor: Dr.Michelle Kwok
0
Revision

Figure 23: Drawing of the Fuel Tank



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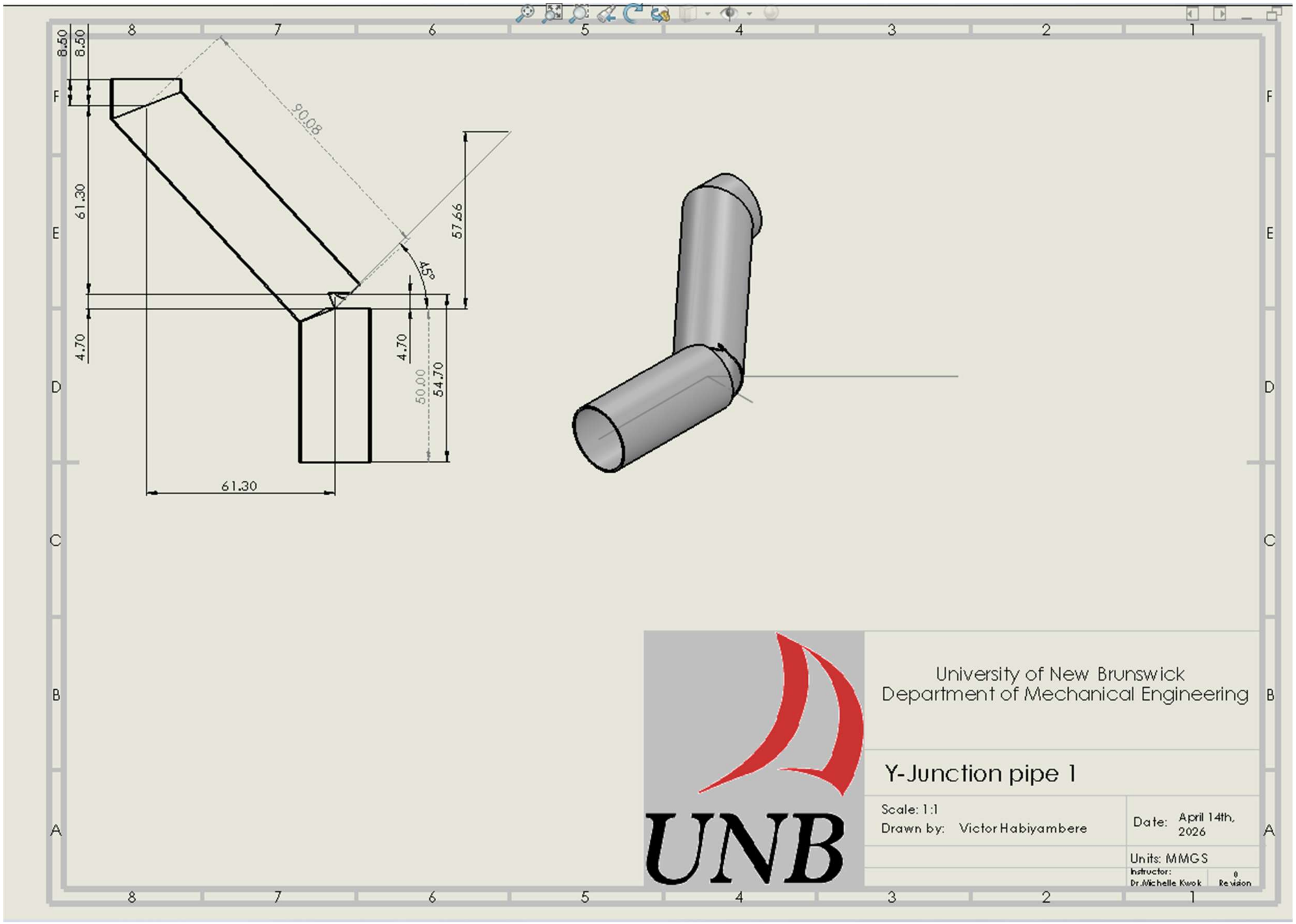
Oxidizer Tank

Scale: 1:1
Drawn by: Victor Habiyambere
Date: April 14th, 2026
Units: MMGS
Instructor:
D
Revision

Figure 24: Drawing of the oxidizer tank



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Department of Mechanical Engineering

Y-Junction pipe 1

Scale: 1:1
Drawn by: Victor Habiyambere
Date: April 14th, 2026
Units: MMGS
Instructor: Dr.Michelle Kwok
Revision: 0

Figure 25: Drawing of the Y-junction pipe #1

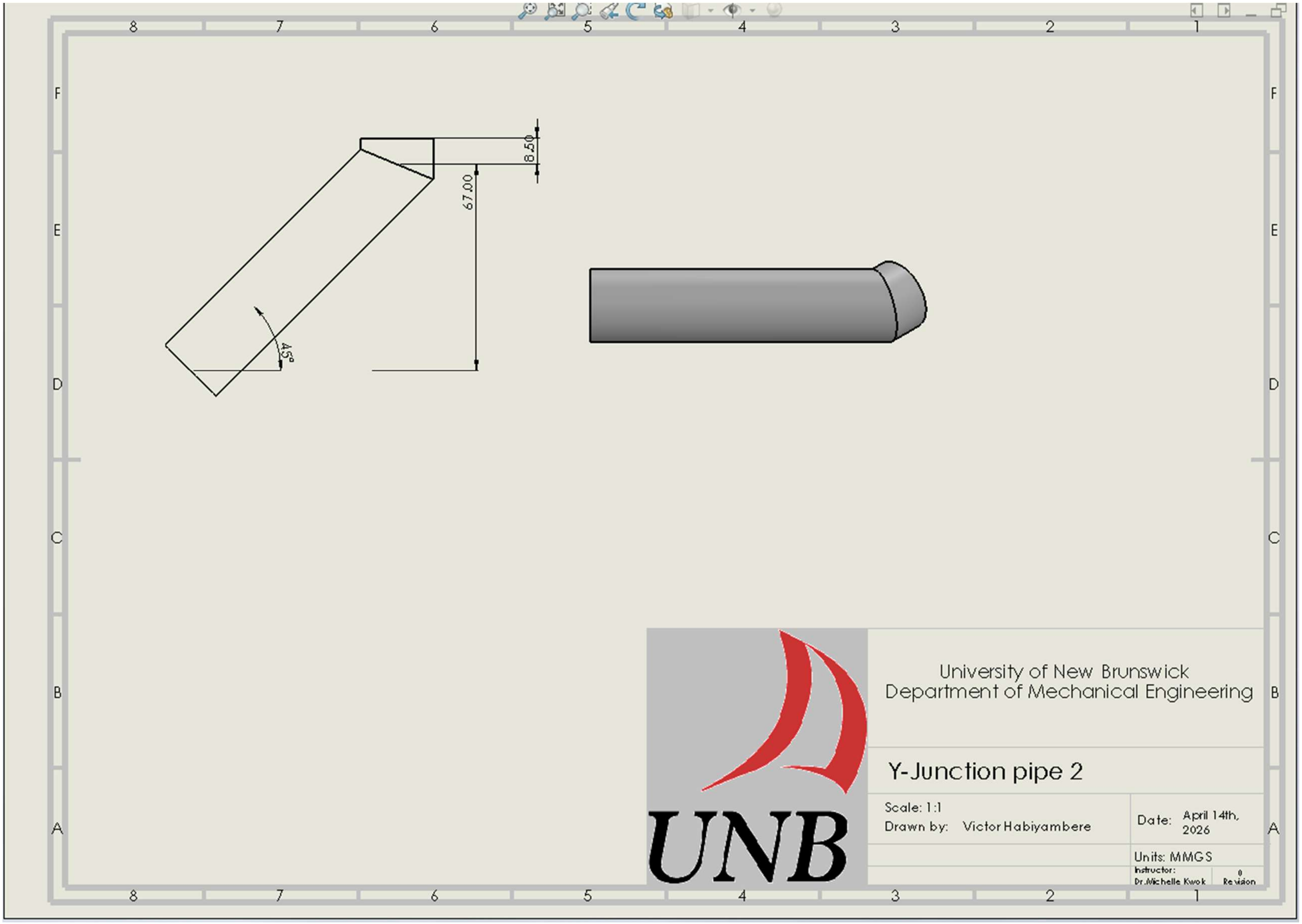

Figure 26: Drawing of the Y-junction pipe #2