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Hydroturbines: A Capstone Design Project

Mr. Alexander Robert Pomesky, Ohio Northern University
Miranda Nienaber, Ohio Northern University
Mr. Thomas James Stickney, Ohio Northern University

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Alex Pomesky Ohio Northern University Department of Mechanical Engineering Ada, Ohio 45810 a-pomesky@onu,edu
Miranda Nienaber Ohio Northern University Department of Mechanical Engineering Ada, Ohio 45810 m-nienaber@onu.edu
Colton Wasserbeck Ohio Northern University Department of Mechanical Engineering Ada,Ohio 45810 c-wasserbeck@onu.edu
Thomas Stickeny Ohio Northern University Department of Mechanical Engineering Ada, Ohio 45810 t-stickney@onu.edu

Abstract

Hydroturbines provide a valuable source of renewable energy when flowing water is available, offering an efficient way to harness the natural movement of water for power generation. To support hands-on learning in renewable energy and fluid dynamics, a mechanical engineering professor teaching a Renewable Energy course has requested the development of experimental equipment that will allow students to evaluate the performance of various types of turbines under different hydraulic conditions.

This capstone project involves the design, fabrication, and testing of turbine modules representing the three main types of hydroturbines: radial, axial, and impulse. Specifically, the modules include a Francis turbine (radial flow, combining impulse and reaction forces), a Kaplan turbine (axial flow, relying on reaction forces), and a Pelton turbine (impulse-driven). These turbines will be interchangeable, allowing students to easily switch between turbine types, record lab data, and directly compare the performance.

The water will be supplied by an existing hydraulics test bench produced by Edibon, Inc., which includes a reservoir, pump, and control valve. An Arduino will be used for system control and data acquisition, with instrumentation sufficient to measure pressure drop, flow rate, shaft RPM, and power output, enabling students to calculate the efficiency of each turbine. This interface will enable students to conduct in-depth efficiency analyses, comparing the mechanical power output of each turbine type to the fluid power supplied by the hydraulic test bench, thus deepening their understanding of turbine performance in renewable energy applications.

Background

Upon receiving the problem statement from the customer, a professor at Ohio Northern University wishing to incorporate such turbines into civil and mechanical engineering labs, the team met with the client to further understand the constraints and metrics. For example, how important was it that all three types of suggested turbines be included? From talks with the customer, it was determined that being able to demonstrate the Pelton, Francis, and Kaplan turbines were indeed constraints. Similarly, the team determined where the budget would come from and what kind of functions the modules should have– i.e. able to be operated by an underclassmen engineering student, ideally without help from a teacher assistant or professor. The team also obtained specification sheets for the current hydraulic bench, which will help determine what flow rates will be available, and thus help appropriately size the system components

The team also conducted research on the current market solutions. It was found that there are few available modules that would be compatible with the current bench, a constraint of the project. Of the available alternatives, they are expensive compared to the predicted cost of building one, ranging between $10-15k each. Thus, the pricing metric had to be adjusted, as simply being lower than the competition was not an acceptable budget request. From preliminary research, the team calculated an initial amount of $1,600 for the budget request.

Another component the team determined was the flowrate of the bench. While the specification did list the maximum flow rate listed, an experimental value would allow the team to more accurately determine our sizing from the maximum flow rate. Doing this helped narrow down how the piping systems would work and make preliminary design decisions about pressurized vessels and high storage basins as a pressure source for the turbines.

Proposed Solution

The solution our team proposed consists of three separate modules, each able to mount on the existing hydraulic bench. Figure 1 shown below depicts the general layout of the solution.

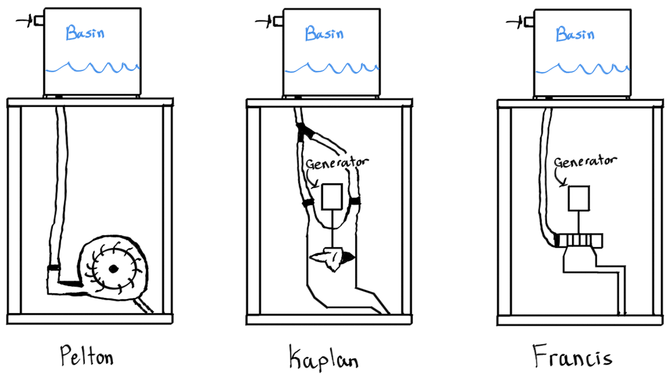

Figure 1: Three separate modules

This design meets the need and creates value for the customer by providing a way for students to learn about the different types of hydroturbines and compare their efficiencies. It is designed so that students can interchange modules by themselves, and each turbine can easily be accessed. Additionally, the most expensive part of the project is the data collection system, allowing for cost efficient maintenance.

The data acquisition system will utilize an Arduino that will be contained within a box on the module used at the hydraulics bench. This is to prevent an accident induced by moving either the bench or the table where the data acquisition system would have resided. This box will also have connections externally where the sensor pigtail from the turbine module can plug into it to be ready to use.

Design

When designing the turbines, a variety of factors such as blade size, desired speed, and flow rate were important variables that were determined using the turbine specific speed. Figure 2 shows a graph used that shows the specific speed, N, as a function of efficiency for each turbine.

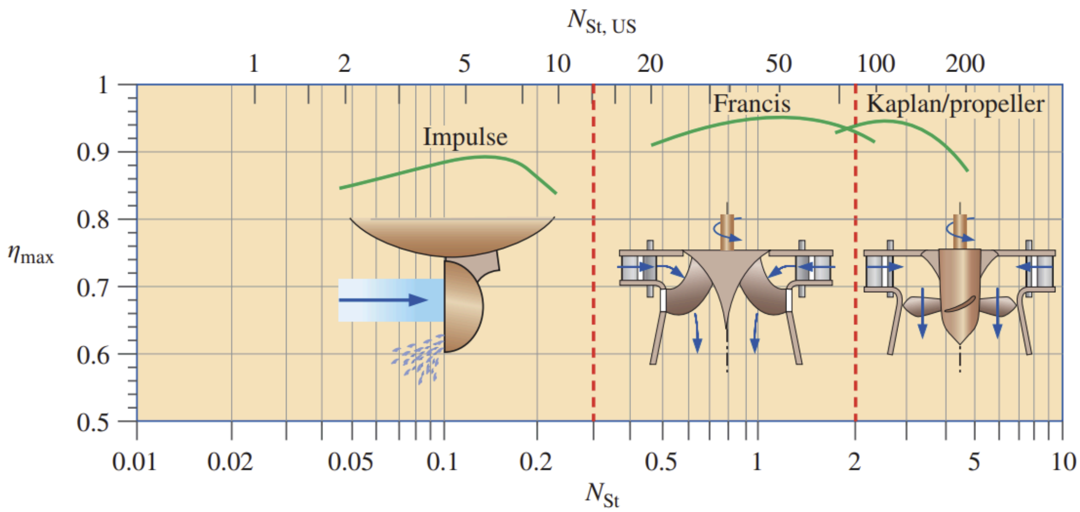

Figure 2: Specific Speed as a function of efficiency[5]

Then, equations that relate the specific speed to sizing parameters were used in order to maximize the efficiency of each turbine. Appendix A shows the technical drawings with the resulting dimensions.

Manufacturing

The design will be machined in-house by members of the team. The Kaplan and Francis turbines will be 3D printed using Polycarbonate. For the Pelton, the body will be milled or cut out of aluminum with the cups being printed out of polycarbonate. The main bodies of the turbine casings will be made out of aluminum and sections will be clear acrylic tubing or clear polycarbonate sheeting for view panes so that flow and turbine movement can be seen.
The frame will be made from steel square tube and will have mounting bracketry for the turbine housing, data acquisition sensors, and the data acquisition module as well.

Material Selection

Early in the design process, the team had recognized that manufacturing the turbines out of aluminum or steel would present a challenge. Due to the complex geometry, we wanted to review the possibility of 3D printing the turbines. Initial concerns were raised surrounding the strength of plastic and degradation while in contact with water. A member of the team experienced with 3D printing created a test plan to determine what filament would perform best after being soaked in water. Figure 3 shows the results of the experiment, which included tensile testing on 6 specimens, 3 of which were soaked in water.

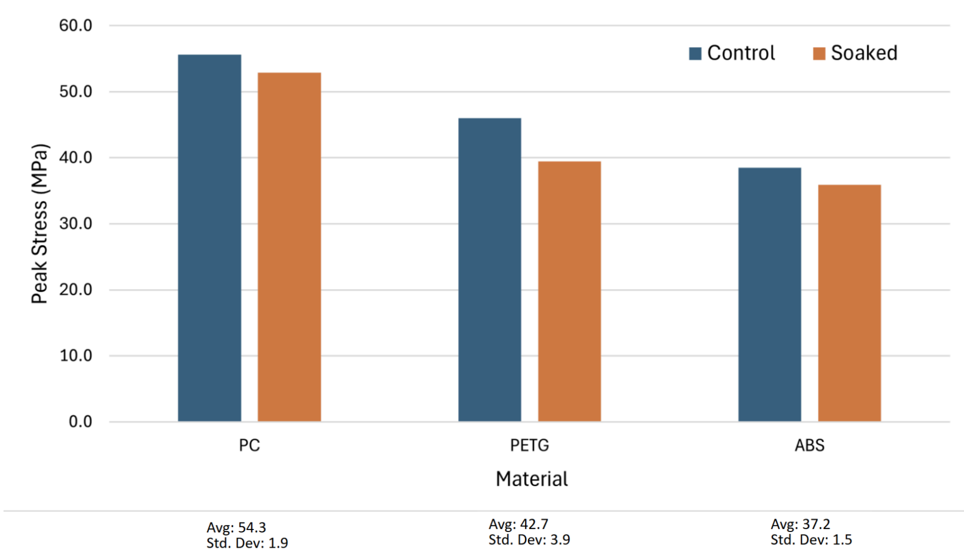

Figure 3: Filament Test Results

The results show that polycarbonate was the strongest filament available to the team. While making note that ABS showed potential use for parts that need to be rigid and consistent. Additionally, Pugh's method was applied to the available filament, shown below in Table 3.

Table 3: Pugh's Method on Filament chosen

			Scoring/Weighted Scoring					
Metric	*Quantity (units)*	*Weight*	*PETG*		*ABS*		*PC*	
Peak Stress (PS)	MPa	25	1	25	0	0	2	50
Dimensional Accuracy (Dim)	mm	15	-1	-15	0	0	1	15
Water Resistance (Dim)	mm	35	0	0	1	35	2	70
Water Resistance (PS)	MPa	25	0	0	2	50	1	25
	Total:	100		10		85		160

The chosen 3D printing filament is Polycarbonate. Results from testing had shown that the resulting print was very dimensionally accurate, capable of withstanding high stress, is very tough (based on stress/strain graph), and is resistant to the effects of water submersion.

Testing

In order to test the functionality of the system, each turbine will be run over a range of flow values to confirm that the efficiencies of each turbine fluctuate with the flow rate. While the turbines were designed to optimize efficiency, the project will be considered successful as long as meaningful data can be produced. This means efficiencies with low uncertainties that match the function of the turbine, i.e. Pelton having a higher efficiency at lower flow rates.

Leak tests will also be performed at the maximum flow rates to ensure that the turbines will not spray water at high pressures. Visibility and ease of use will also be evaluated to make sure the turbines can be interchanged by students, and that the process is a valuable visual to their understanding of hydroturbines.

Conclusion

The objective of this project is to provide a hands-on experience for student use in various engineering classes. The overall success will depend on how clearly the turbines are able to demonstrate the process of converting the kinetic energy from the water to mechanical power transmitted by the turbine shafts. Additionally, the system must give the students the outputs they need to calculate the efficiency, and this efficiency should be consistent with the flow rate, which is controlled by the student. If this process is visible and produces meaningful results, then it will be considered a success

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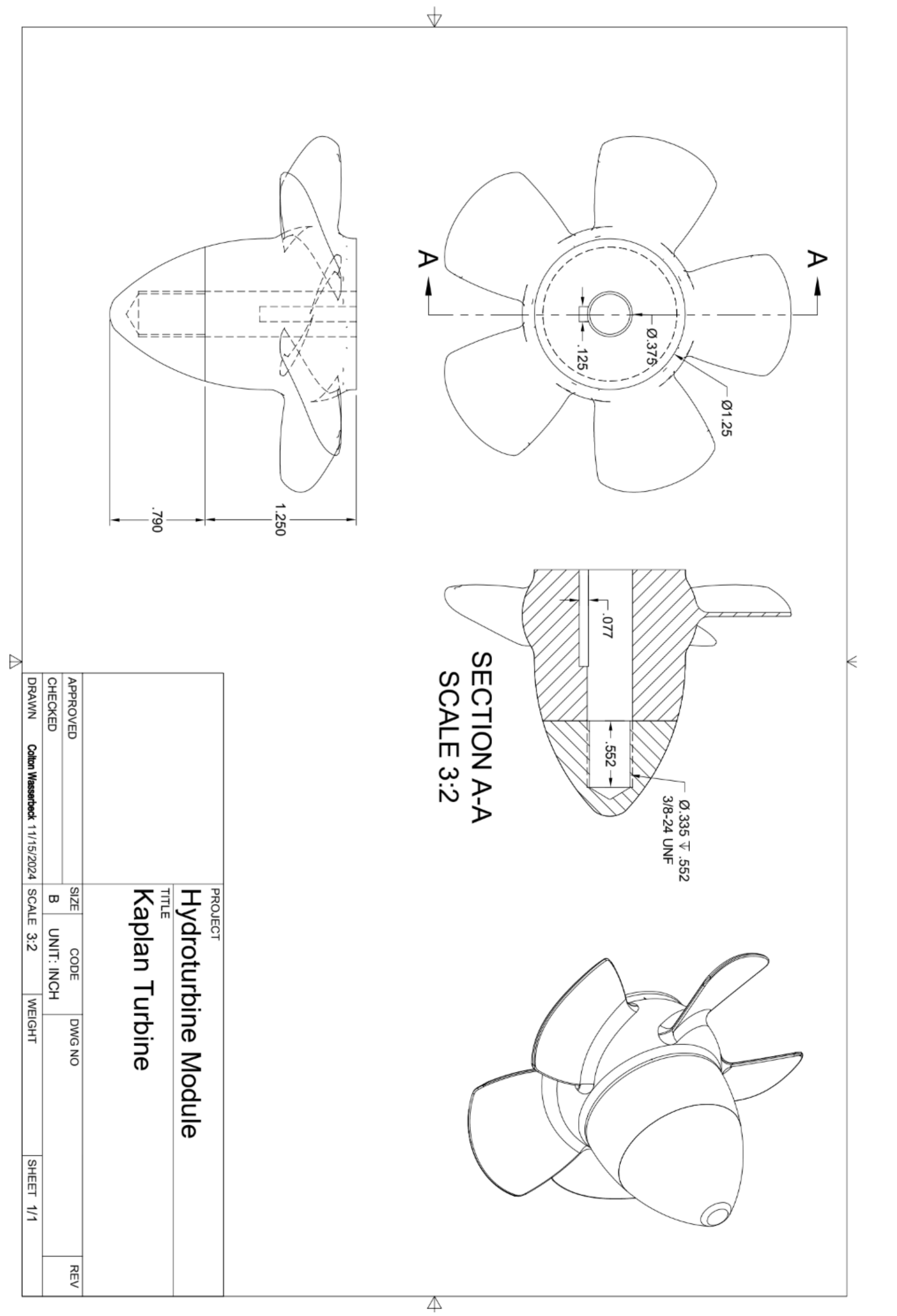
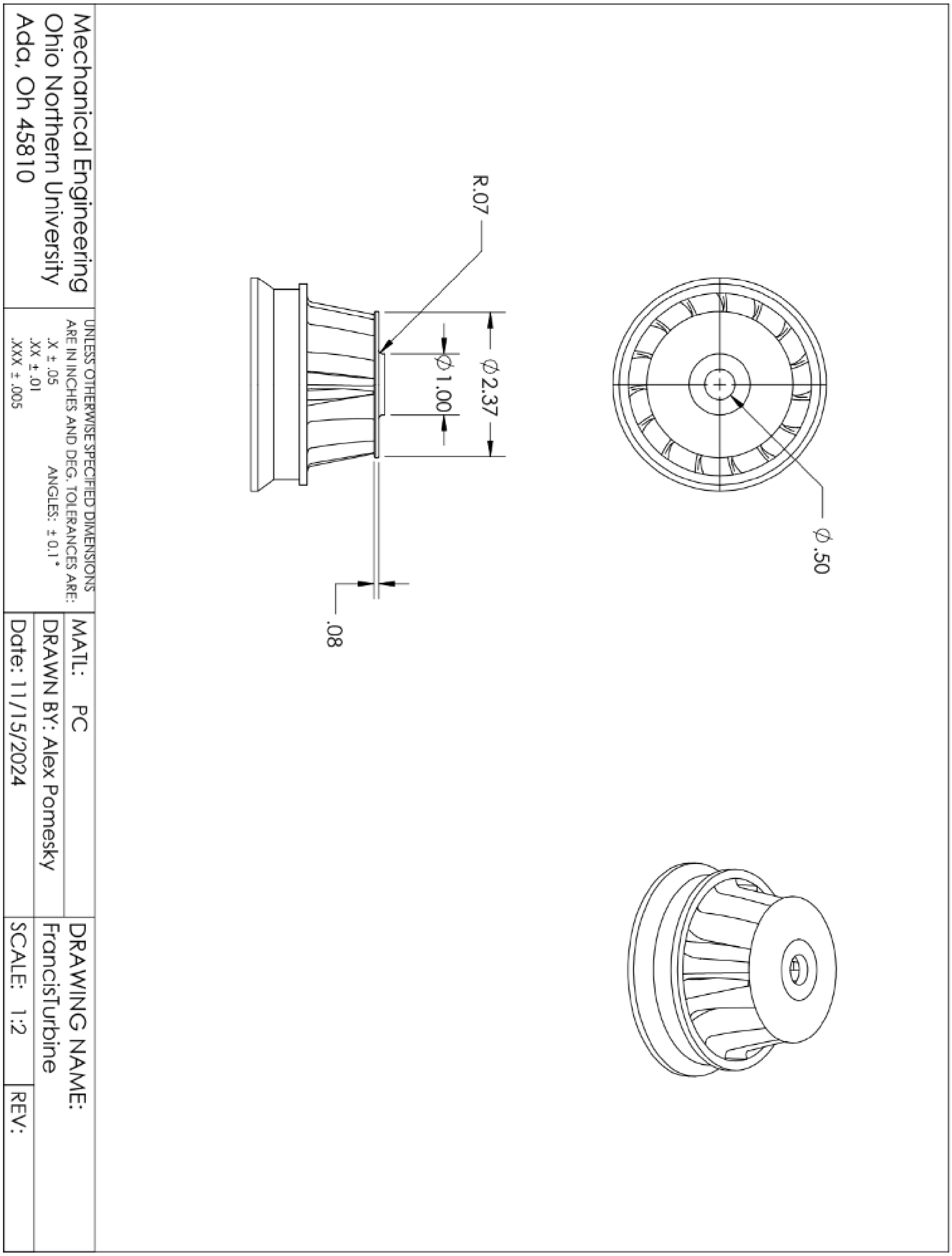
Appendix A: Technical Drawings and Equations




Mechanical Engineering
Ohio Northern University
Ada, Oh 45810
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Date: 11/15/2024
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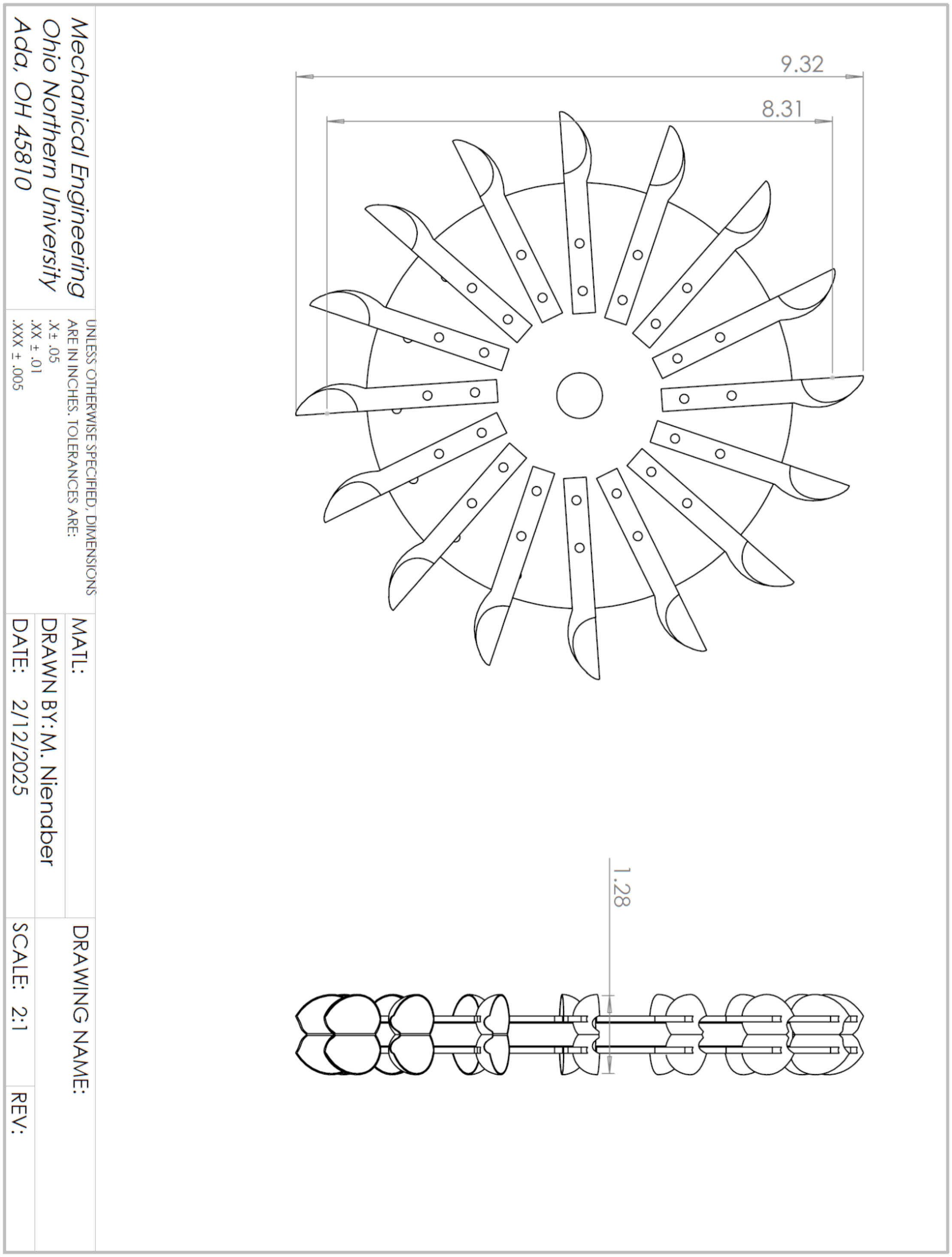
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